The IAQ Investigator's Guide

3rd edition

A Guide to the Principles, Techniques, and Resources Available for Professional Indoor Air Quality Investigations

Edited by Ellen C. Gunderson, CIH, CSP

AIHA
Protecting Worker Health

A Publication by
American Industrial
Hygiene Association

The IAQ Investigator's Guide

3rd edition

A Guide to the Principles, Techniques, and Resources Available for Professional Indoor Air Quality Investigations

by
The American Industrial Hygiene Association
Indoor Environmental Quality Committee

Edited by
Ellen C. Gunderson, CIH, CSP

AIHA
Protecting Worker Health

Published by the American Industrial Hygiene Association
Falls Church, Virginia

Disclaimer Page

This publication was developed by experts with background, training, and experience in various aspects of industrial hygiene and occupational and environmental health and safety, working with information that was available at the time of publication. The American Industrial Hygiene Association (AIHA®), as publisher, and the authors have been diligent in ensuring that the material and methods addressed in this book reflect prevailing industrial hygiene and OEHS practices. It is possible, however, that certain policies or procedures discussed will require modification because of changing federal, state, local, or international regulations.

AIHA® and the authors disclaim any liability, loss, or risk resulting directly or indirectly from the use of the practices and/or theories discussed in this publication. Moreover, it is the user's responsibility to stay informed of any changing federal, state, local, or international regulations that might affect the material contained herein, and of the policies adopted specifically in the user's workplace.

Any specific mention of manufacturers and products in this book does not represent an endorsement by AIHA® or the authors.

ISBN-13: 978-1-935082-51-4

Stock Number: IAQG16-144

AIHA®
3141 Fairview Park Drive, Suite 777
Falls Church, VA 22042
Tel: (703) 849-8888
Fax: (703) 207-3561
Email: Infonet@aiha.org
http://www.aiha.org
Printed in the United States of America

Contributors

Ellen C. Gunderson, CIH, CSP
University of Washington

Wane A. Baker, PE, CIH
Trane/Ingersoll Rand

Catherine C. Bobenhausen, CIH, CSP, LEED AP BD+C
Vidaris, Inc.

John M. Dobby, CIH, CSP
Carnow, Conibear & Assoc., Ltd.

James W. Lewis, CIH, CSP
Maryland Department of Environment

Ralph A. Froehlich, CIH, CSP, QEP, FAIHA
Helix Environmental, Inc.

Michael McGuinness, CIH, CET
RK Occupational & Environmental Analysis

Patrick J. Rafferty, CIH
Rafferty & James, Inc.

Lisa J. Rogers
Mycometer, Inc.

John P. Springston, CIH, CSP, FAIHA
TRC Environmental Corp.

Technical Reviewers

Jeffrey Hicks, CIH, QEP, FAIHA
Exponent, Inc.

William P. Hoychuk, CIH, CSP
The Boeing Company

Ben Kollmeyer, MPH, CIH
Forensic Analytical Consulting Services

Ed Light, CIH, FAIHA
Building Dynamics, LLC

Cheryl L. Marcham, PhD, CIH, CSP, CHMM, FAIHA
The University of Oklahoma

Michael E. Russell, CIH, CSP, CHMM, CPEA
AECOM Technical Services, Inc.

This work constitutes a revision of the 2006 edition which was co-authored by the following contributors:

Catherine C. Bobenhausen, CIH, CSP, LEED AP BD+C
John M. Dobby, CIH, CSP
Ralph A. Froehlich, CIH, CSP, QEP, FAIHA
Ellen C. Gunderson, CIH, CSP
Melissa Ling Cheszek, CIH, CEM, LEED-AP
Patrick J. Rafferty, CIH
Timothy J. Ryan, PhD, CIH, CSP

Contents

Chapter 1: Introduction

What makes a good IAQ investigator?

The attributes of a prepared, informed detective: calm, observant, thorough, and discerning. Additional attributes include skill in knowing which questions to ask, knowledge about building systems, how buildings are run, evidence-based health risks, potential sources of indoor air contaminants, how to put together a strategy to diagnose a problem, and how to connect the dots between personal accounts, investigator observations, and test results. Willingness to engage promptly and the ability to communicate truthfully, clearly and without undue speculation with respect to all parties are also invaluable assets.

In this context, the American Industrial Hygiene Association's Indoor Environmental Quality Committee offers this practical guide. It is intended as a roadmap so that others may profit from lessons learned, and become educated in techniques and strategies for resolving IAQ issues quickly and cost-effectively.

The indoor environment has emerged as an area of specialty for industrial hygienists. Building owners, property managers, employers, mechanical engineers, architects, and medical professionals have also been called on to resolve IAQ complaints. Regardless of expertise or background, it is helpful for the IAQ investigator to:

- Understand all that is involved in identifying the root cause(s) of the initial complaints, or, in some cases, resolving the situation without absolute certainty about the cause(s), and
- Be willing to enlist the help of professionals with expertise in diverse specialties, as the need arises.

The focus of this guide is office environments. However, many of the principles apply to other building types including schools, laboratories, health care facilities, and to some extent, residences.

This newest, 3rd edition represents a major update to incorporate current information and has new material on:

- Risk communication and report writing;
- Trend setting drivers such as green building certifications and low- and zero-energy initiatives;
- Lighting and noise;
- Layout of typical heating, ventilating and air conditioning (HVAC) systems;
- Radon assessment, and
- Guidelines for interpreting volatile organic compound (VOC) data.

Other topics are introduced in sidebars and breakout boxes, including: polychlorinated biphenyls (PCBs), corrosive drywall, spray polyurethane foam (SPF) insulation, and semi-volatile organic compounds (SVOCs). Asbestos and lead issues are not covered; the reader should refer to appropriate regulatory requirements and current technical guidance on those issues.

The contributing authors share case studies from what they've experienced. These can be found in sidebars depicted by a magnifying glass.

This guide should not be followed unthinkingly, like a "cookbook" nor should it be viewed as providing an encyclopedic treatment of the field. It does not eliminate the need for an IAQ investigator to pursue continuous professional development. The authors aspire for it to serve as a solid foundation for life-long learning in this continuously evolving area of practice.

Chapter 2: Background

There have been fundamental changes in commercial building construction, towards using lighter, synthetic construction materials; technologically advanced heating, ventilating, and air-conditioning (HVAC) systems with sophisticated control sequences, and more energy-efficient building envelopes, including permanently sealed windows. This has altered the indoor environment as compared to older buildings, both in terms of the perception of it and in the actual environmental conditions.

The furnishings, finishes, and other materials used in buildings – carpeting, paints, workstations, electronic equipment, furniture, personal products, pesticides, cleaning agents, and deodorizers – contribute, to a greater or lesser extent, to the chemical makeup of indoor air. At the same time, buildings are often operated with the principal goal of keeping them running efficiently and economically, rather than of maintaining optimal conditions for the people inside. As a result, people may experience uneven temperatures, stale air, or odd odors, and it may require them to raise questions and initiate the need for a response.

The U.S. Environmental Protection Agency (EPA) reports that levels of volatile organic compounds (VOC) are almost always higher indoors compared to outdoors.[1] The levels are variable, suggesting that they're influenced by individual sources and the effectiveness of the ventilation near those sources. These chemicals are often the sources of odors, especially in newer or recently remodeled buildings.

Mold has captured public attention, to the extent that one might think all IAQ problems are caused by mold. This is not true! The IAQ investigator must be attentive to other causes of IAQ complaints as well. Many IAQ problems result from improper design, installation, retrofit, operation, or maintenance of HVAC systems.[2,3]

Sometimes, what appears to be an IAQ problem turns out to be caused by other stressors, such as work-related stress, personnel issues, poor ergonomic design of office equipment or furniture, inadequate lighting, excessive noise or vibration. IAQ is one aspect of "indoor environmental quality" which encompasses a broader assessment of agents and stressors affecting people in the built environment.

Interactions between chemical substances, temperature, humidity, lighting, noise and other indoor environmental factors may contribute to occupant complaints in ways not completely understood. The current American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) *Guideline 10 – Interactions Affecting the Achievement of Acceptable Indoor Environments*, reviews the interactions between these environmental conditions as they affect the acceptability of the indoor environment. The guideline acknowledges limitations in the ability to achieve acceptability for the entire building population.[4]

Contributing to IAQ complaints is the fact that people live much of their lives indoors, typically over 90%. Office workers in modern, developed societies today expect a clean, comfortable working environment, often better than conditions in their own homes. Any deviation from this may trigger some form of complaint. This is compounded by ever rising concerns about human exposures to chemicals and other agents that could have a negative impact on health.

Health Effects Related to IAQ

The health effects experienced by building occupants with IAQ complaints can range from mild discomfort to (in rare cases) serious disease. Sore throat, stuffy nose, tearing eyes, headaches and common respiratory allergic reactions are commonly reported IAQ symptoms. Odors may cause concern, or result in discomfort and annoyance. As an investigator, one must be aware of how reported symptoms might relate to conditions in the building and be prepared to enlist the help of medical professionals early on in the process if medical concerns arise.

Individual sensitivities to chemicals and other agents vary. For example, one person may not notice an odor, while others may find it intolerable, or become seriously ill. Conditions of extreme sensitivity (and medically controversial) have been termed as Multiple Chemical Sensitivity (MCS), Environmental Illness (EI), Chemical Sensitivity, Chemical Injury, Toxic Injury, Toxic Induced Loss of Tolerance (TILT) and Idiopathic Environmental Intolerance (IEI). These extreme sensitivities manifest as an unusually severe sensitivity or allergy-like reaction. These reactions occur when the affected person is exposed to chemicals at levels well tolerated by most people. A person with unusually acute sensitivity to even trace amounts of chemicals, or one diagnosed as such, may be very difficult to accommodate in modern buildings. Satisfactory resolution of such a situation may be extremely challenging.

Psychosocial stresses may lead to the perception that the building's air quality is causing a variety of health effects. Underlying distress may actually be generated by job and personal stress, and added to by "sick building" rumors. Under these circumstances, coincidental conditions, such as contagious illness or chronic disease, are often thought to be linked to and caused by the building. A highly charged psychological atmosphere may result, which can escalate if there is failure, hesitation or delay in fully dealing with the situation. Conducting a practical investigation of concerns, and being appropriately sensitive towards individuals with complaints using open, impartial communication, and collaboration on solutions are all keystones to success in resolving these often complex situations.

Mass psychogenic illness (MPI) is an extreme example of what may result from inattention to psychosocial stressors. Serious symptoms, such as headaches, nausea, and fainting, can occur suddenly with few or even no identifiable cause, possibly triggered by an intermittent odor. Symptoms can spread throughout a facility, resulting in abnormal absenteeism and even mobilization of an emergency response.[5-7] Instances of apparent MPI must be carefully and methodically evaluated to determine whether the reactions are based on indoor air problems or simply the result of a "scare." A multi-disciplinary team is often necessary to resolve the medical, psychological, and building-related aspects of the event. A well-designed building IAQ management program can help avoid "sick building" controversies by

- Ensuring that there is prompt investigation and timely response to reported IAQ complaints, and
- Detailing how communications will be handled to respond in a timely and fully transparent manner to address occupant concerns.

The reader should refer to Table 2.1 for a listing of common IAQ terms related to occupant health, as well as the Glossary and Acronyms section.

TABLE 2.1 – IAQ Terminology

- **Sick Building Syndrome (SBS)** is a general term used when a complex set of symptoms affects a number of building occupants and is rarely associated with a medical diagnosis. Symptoms characteristic of SBS usually include mucosal irritation (eyes, nose, or throat), skin irritation and/or general complaints (headache, fatigue, lethargy, and difficulty in concentrating) which disappear shortly after leaving the building. SBS outbreaks have been attributed to VOCs, low relative humidity, settled dust, temperatures too warm, and inadequate outdoor air ventilation. It is also common that no specific cause can be identified. Some IAQ professionals choose not to use this term because buildings do not get sick, occupants do. Some investigators feel that these situations may be related to psychological manifestations in addition to, or aside from, physiological responses to agents within the building.
- **Building-Related Illness (BRI)**, or building-related disease, in contrast to SBS, is an IAQ condition with an established etiology. BRI is characterized by a distinguishable set of symptoms, often accompanied by physical signs and clinical abnormalities, and might affect only one or a few building occupants. These include hypersensitivity diseases, infectious diseases and toxicoses. BRI can be confirmed by a physician's diagnosis. Examples include:

Hypersensitivity Diseases	*Infections*	*Toxicoses*
Hypersensitivity pneumonitis	Legionnaires' disease	Carbon monoxide (CO) poisoning
Allergic rhinitis	Pontiac fever	Pesticide poisoning
Allergic asthma	Histoplasmosis	Lead poisoning
Humidifier fever	Tuberculosis	
	Aspergillosis	

TABLE 2.1 – IAQ Terminology (cont.)

- **Mass Psychogenic Illness (MPI**) refers to an apparent epidemic or cluster, impacting individuals with similar symptoms at the same time and place, for which the probable source is social/psychological and not the environment. Reported health complaints might include headaches, fatigue, nausea, vomiting, hyperventilation, and fainting. MPI is characterized by a sudden onset of symptoms, frequently coinciding with an unusual odor, and seems to spread by sight or direct contact like a contagious disease. The course of such incidents can be studied with the same tools that infectious disease epidemiologists use, since it mimics person-to-person "transmission." However, what is transmitted are often rumors and fears about the building. Such outbreaks are difficult to diagnose since often the source of the odor that triggers the initial complaints is fleeting or intermittent, and the composition and source of the odor is unknown.

Buildings and the Building Environment

IAQ concerns have been expressed by occupants in a wide range of building types —offices, schools, apartments, medical centers, hotels, retail establishments, sports and entertainment venues, government buildings, and manufacturing facilities. The primary objective in resolving IAQ issues is to prevent health effects and to ensure comfortable conditions for people in the building, whether they are employees, children, immunocompromised patients, or the public at large.

Ventilation

The building HVAC system is critical to the quality of air in the building, due to its design, its condition and its operation. As an IAQ investigator, your continuing education on this subject will be fundamental to your ability to successfully resolve many IAQ problems. This guide offers a primer on the topic, including HVAC system descriptions and tips about field inspections and observations.

Consensus design standards and guidelines developed by ASHRAE are primary resources for the IAQ investigator, including the current versions of:

- ASHRAE 62.1 Ventilation for Acceptable Indoor Air Quality[8]
- ASHRAE 62.2 Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings[9]

When referenced as mandatory provisions in State and local building codes, ASHRAE standards are legally enforceable. Even when not enforceable, ASHRAE standards are often referenced as good practice by engineers, architects and government agencies.

An additional valuable resource for the IAQ investigator is "The Indoor Air Quality Guide: Best Practices for Design, Construction and Commissioning"[10] developed by ASHRAE and several partners and funded by the EPA. It's designed for architects, mechanical engineers, contractors, commissioning agents, and all other professionals concerned with IAQ.

Thermal Comfort Complaints

Employees in an office building complained of various IAQ symptoms. Thermal discomfort was found to be the major complaint in individual, private interviews. Using a data-logging meter, measuring temperature and relative humidity, it was determined that temperature "swings" exceeded ASHRAE Std. 55 of less than 4°F over a one-hour period. Also, air velocity measured at work stations was approximately 50 fpm, which exceeded the ASHRAE Std. 113 recommended value of no more than 30 fpm for heating during the winter season. Adjustments were made to the HVAC system and thermal discomfort complaints stopped.

Thermal Comfort and Relative Humidity (RH)

Most complaints about IAQ in offices are about the air temperature. While it's well recognized that thermal comfort is highly subjective, the complaints are usually based on individual preferences. Levels of activity (whether sedentary, typical of the office worker, or active, typical of cleaning staff or maintenance personnel), clothing, fitness level, air temperature, air movement, temperature of surrounding surfaces, and relative humidity (RH), as well as cultural norms, all influence the perception of thermal comfort. A small swing in temperature (on the order of 1 to 2°F) can be perceived as a change from comfortable to uncomfortable by some individuals. ASHRAE *Standard 55 Thermal Environmental Conditions for Human Occupancy* has recommended limits on temperature swings as well as air velocity from mechanical ventilation that can cause uncomfortable drafts.[11] Allowing personal control over the thermostat in buildings with such controls can sometimes be a solution, but may also result in disagreements among the occupants.

Aside from thermal comfort, higher temperatures (as well as higher RH) have been shown to heighten perceptions of poor IAQ and increase emissions of volatile chemicals such as solvents and formaldehyde from building materials. The use of personal cooling fans may help provide additional cooling for some occupants.

Symptoms associated with low RH (< 20%) include dry and sore nose and throat, nose bleeds, sinus and tracheal irritation, dry scratchy eyes, inability to wear contact lenses, and dry flaking skin. Low RH may also contribute to an increase in respiratory illness, by weakening the defenses generally provided by moist mucous membranes. During the winter, low RH is typical indoors.

County Courthouse Emergency Evacuation

A number of employees who occupied the basement of a newly opened courthouse were taken by ambulance to a nearby hospital with reports of illnesses and odor complaints. It was determined a leak of glycol occurred when it was added to the heating system causing a fog and odor. Employees were not informed of the odor source or the nature of the chemical, which contributed to stress. Further investigation determined widespread complaints and dissatisfaction with IAQ. Over a year, more than $1M was spent to correct ventilation problems including changes to eliminate re-entrainment of building exhaust air into the outdoor air intake on the roof and increasing the amount of outdoor air per person. After the corrections, there were no further reported complaints.

With respect to mold, damp materials are of greater concern than RH, since microorganisms grow on surfaces, not in the air. However, the proliferation of microorganisms and dust mites, a source for potent asthma-inducing allergens, is facilitated by high RH (> 65%). Even at lower RH, cool surfaces may lead to condensation that can support fungal growth, especially in poorly ventilated areas of a structure.

Building Dampness and Mold

The presence of dampness and mold in buildings has been conclusively linked to respiratory symptoms in building occupants in authoritative studies.(12) Water damage, damp materials, visible signs of what appears to be mold and evidence of musty odors are all indications of a problem requiring action. Known health risks include exacerbation of asthma, respiratory allergies, in some circumstances, respiratory infections; and increased wheeze, cough, difficulty breathing, and other symptoms.(13) No specific agent has been linked to these symptoms in damp buildings. Before addressing microbial growth, the cause for water intrusion or unusual moisture into or within the building must be determined and corrected, otherwise health symptoms may continue or recur.

Odors and Air Contaminants

Odors and air contaminants may originate from outside the building, or from indoor activities, equipment, or materials. Most building occupants are not tolerant of bad odors within a modern building, and perception of offensive odors will often elicit concerns about what is in the air. For example, an almost imperceptible paint odor that would be tolerated at home may be perceived as disturbing in a work environment, especially where mental stressors complicate the situation.

Low or no delivery of outdoor air into an occupied space can cause a variety of common complaints, even in the absence of any perceptible odor or identification of a chemical cause. For many common indoor chemicals (e.g., formaldehyde, acetic acid) the concentration at which the chemical can be perceived, known as the odor threshold, is not a good indicator of exposure, since the combined exposures may trigger irritation in the absence of a detected odor. The actual perception of a chemical odor is a clear indication of the need to investigate and control the odor.

Lighting, Noise and Other Physical Factors

Lighting, noise and other physical parameters related to the building may have little to do with the quality of indoor air, but the effects created by the absence of good lighting or excessive noise may not be trivial and could have significant impacts on occupant comfort, health and productivity. Studies have linked excessive noise and vibration in office environments to similar health effects associated with poor IAQ, such as headaches, dizziness, irritability and stress. Noise and vibration in offices may originate from or be exacerbated by:

- An HVAC system that is functioning poorly or is badly maintained or designed;
- Office equipment;
- Temporary construction activities;
- Outdoor sources;
- Poor acoustics in the workplace, and
- Conversion to open plan office arrangements.

The most common complaints resulting from poor lighting are difficulty seeing documents or computer displays, eyestrain, eye irritation, blurred vision, dry burning eyes, and headaches. Poor lighting problems include:

- Insufficient light – too little light for the task;
- Glare – too much light for the task or reflected light that interferes with reading or working;
- Improper contrast;
- Poorly distributed light, and
- Flickering.

As an IAQ investigator, be mindful of solutions to these stressors, such as the ready availability of ergonomic workstations, as part of a broad strategy, and keep in mind that multiple issues may be the cause of IAQ concerns. During an IAQ investigation, it's important to consider these factors.

Trends in Building Design, Materials and Furnishings

ASHRAE, EPA and other organizations have developed standards, guidelines and certification programs for design and operation of high performance buildings. Compared to standard buildings, a high performance building is designed to be highly energy efficient, durable and sustainable, as well as enhance occupant productivity and have low impact on the natural environment. These standards and programs often include measures that seek to "design out" IAQ problems. An excellent example of multidisciplinary collaboration on proactive design is the 2009, "Indoor Air Quality Guide: Best Practices for Design, Construction and Commissioning," jointly developed by ASHRAE, the American Institute of Architects, Building Owners and Managers Association International, the Sheet Metal and Air-Conditioning Contractors' National Association, the U.S. EPA and the U.S. Green Building Council.[10]

Significant reductions in the VOC content of wet-applied products such as paints and sealants have resulted from Clean Air Act regulations at the federal, state and local level. Beyond VOC content regulation, voluntary VOC emissions testing is becoming more common in the building product industry. The California Department of Health's "Standard Method for the Testing and Evaluation of Volatile Organic Chemical Emissions from Indoor Sources Using Environmental

Chambers" is a widely-referenced method for testing and evaluating building products for vapor phase organic chemical emissions.[14] It describes procedures for sample collection, emissions testing, indoor concentration modeling and calculation of emissions factors and estimated concentrations in completed buildings. It applies to paints, architectural coatings and finishes, sealants, adhesives, wall and floor coverings, acoustical ceiling, wood paneling and wall and ceiling insulation. Acceptance criteria are based on California's chronic reference exposure levels. Many certifications are based on standardized testing methods, including those established by SCS Global (www.scsglobalservices.com), UL Environment (www.ul.com), the Business and Institution Furniture Manufacturers Association (www.bifma.org), the Carpet and Rug Institute (www.carpet-rug.org), and the Resilient Floor Covering Institute (www.rfci.com), among others.

As an IAQ investigator, one may need to review product literature including VOC content, VOC emissions data, Health Product Declarations, Safety Data Sheets and documents such as installation instructions to help screen potential sources of indoor air contaminants.

Concerns about climate change may result in radical changes in the way buildings are designed and operate – and thus also impact IAQ in the future. Since buildings consume approximately 40% of the total energy consumed in the U.S.[15], there is a major focus on reducing their carbon footprint, through modifications in design, working towards net zero energy consumption, and promoting remodeling and retrofits with significant energy conservation techniques. IAQ challenges related to these initiatives are expected to arise. Natural ventilation and mixed mode systems are strategies that are gaining popularity.

A building designed or renovated to meet high performance standards does not eliminate the potential for IAQ issues over time; as with all buildings, ongoing maintenance and prompt resolution of potential problems are key. Refer to Appendix A, New Buildings, Green Buildings and IAQ, for more information on how new buildings may impact IAQ.

IAQ Investigation Strategies

Fortunately, some IAQ problems are rather straightforward to diagnose and resolve. Many relate to comfort issues, typified by comments such as "it's too hot," "it's freezing in here," "it's too drafty," or "it's stuffy and there's no fresh air." These can generally be corrected by minor adjustment of set points in the cooling and heating system. In some situations, modifications to the existing HVAC system (e.g. relocating supply air diffusers, installing diffuser air flow diverters, opening economizers or fixed louvers to increase outdoor air intake) may be necessary. These approaches can be implemented without the involvement of an independent investigator. Even in these situations, it's wise to keep everyone informed about what is being done to remedy the problem and reduce the stress level.

Interpreting the findings of an initial investigation requires considerable professional judgment. Many times the problem can be resolved quickly on the basis of an initial investigation. At other times, a more detailed in-depth investigation is needed. However, in some instances, the relationship among specific stressors and the health and comfort experience of the occupants may never be understood completely.

In a number of instances, IAQ problems are much more complex and difficult to diagnose and resolve. There may be multiple contributing factors that when combined under specific circumstances trigger complaints, and deciphering these may be impossible or very difficult to identify and resolve. In such circumstances, a more involved integrated technical approach may be required – one that requires management input plus that of one or more outside professionals. Identifying the major causes will usually reduce symptoms for most individuals, but possibly not all. A general approach to an IAQ Investigation is presented in Figure 2.1. Details of the steps involved are given in later chapters designated on the

911 Call Center Evacuation

A 911 call center was evacuated when employees fell ill with reports of odors and a metallic taste in the mouth. Some were seen in the emergency department. Fire department responders could not determine a source of the problem. The center was abandoned due to employee fears and relocated for three months while IAQ investigations were performed and an occupational physician investigated the employee health conditions. It was concluded that a likely source of the odor was from a painting project that had been conducted several days earlier. Paint overspray contacted perimeter radiant heating system parts causing off-gassing of paint odors when the heating system was activated. The physician concluded that underlying job-related stress factors contributed to the symptoms. Recommendations were made to improve ventilation in the call center, reduce workplace stress factors, and to improve specifications and oversight of future painting projects. The call center was reopened with no subsequent issues.

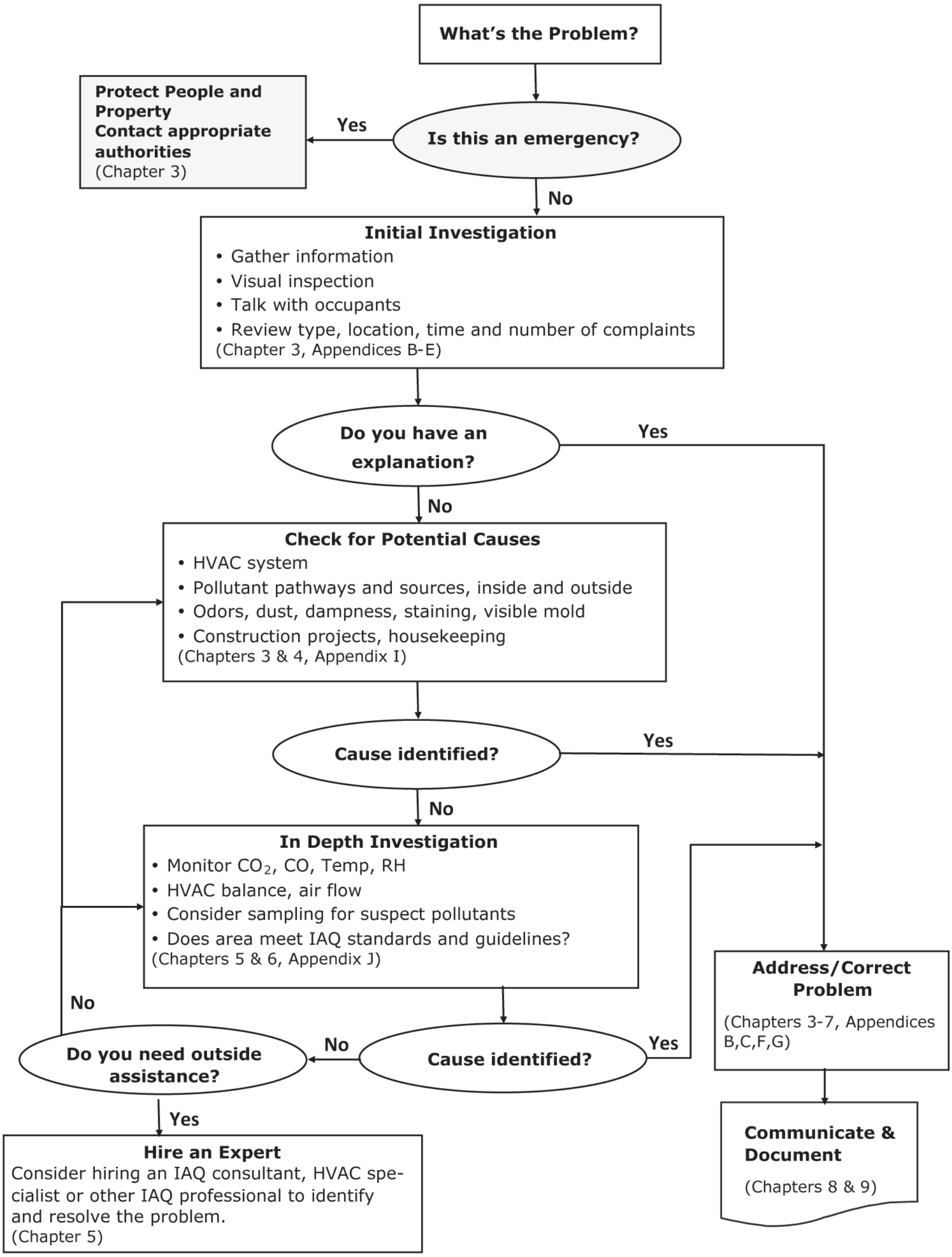
diagram. Appendix B and C list common IAQ problems with possible causes and solutions.

Table 2.2 lists a number of factors that can also affect IAQ.

TABLE 2.2 – Common Factors Affecting Indoor Air Quality and Building Occupant Health

Chemical Contaminants
• VOCs from building materials, furnishings, or maintenance/cleaning products • Ozone from outdoor air, laser printers, or office equipment • Particulate matter from indoor and outdoor sources, including inadequate housekeeping • Odors • Pesticide use, both indoor and outdoor • Combustion sources, both indoor and outdoor • Fiberglass and other types of insulation • Environmental tobacco smoke (ETS) and electronic cigarette emissions
Biological Factors
• Microbiological growth in ventilation systems • Microbial growth on building materials • Water leaks, damp indoor environments • Allergens in occupied areas • Odors from biological sources, including sewage • Communicable infectious diseases or illnesses (flu, common cold, etc.)
Physical Stressors
• Temperature control problems • Air flow problems • Insufficient amounts of outside air supplied to occupants • Relative humidity extremes • High noise levels • Unusual vibrations • Lighting or glare issues • Stressful postures due to non-ergonomic workstations
Psychosocial Factors
• Crowded working conditions/privacy issues • Management/worker issues • Extreme levels of psychological stress in the workplace • Interpersonal difficulties • Office politics • Property manager-occupant issues • Conflicts between organizations in multi-tenant commercial buildings • External stressful events • Personal health • Work/family conflicts • Poor communication with occupants regarding changes in the environment

Figure 2.1 – General Approach to IAQ Investigation



Chapter 3: Initial Investigation

During the initial stages, an IAQ investigation should be broad in scope. There could be multiple causes, requiring a flexible diagnostic approach. These four aspects should be considered:

1. Pollutant source: indoor and/or outdoor contaminant(s)
2. The HVAC system: its design, condition and operation
3. Contaminant pathway(s): driving force(s), such as airflow patterns, pressure differentials (which force airborne contaminants from areas of relatively higher pressure to areas of relatively lower pressure through any available opening, stack effect, transient wind-driven effects)
4. Building occupants, including visitors: with a variety of activities and different tolerances, expectations and susceptibilities

It is useful to think of the entire building – the rooms and the connections between them (e.g., chases, corridors, stairways, elevator shafts) – as part of the building's air distribution system, and also to consider the active role of the building occupants in contributing to potential sources. Often, the pollutant source can be identified by finding the pathway through which it is reaching the affected occupants.

The first goal is to identify IAQ problems that can be resolved by immediate corrective measures. If the cause is unclear, a more in-depth investigation is necessary. The following information should be obtained at the onset of the initial investigation:

- Reports of specific IAQ-related health and comfort complaints, including the number of individuals with such complaints;
- The severity of the complaints (e.g. ranging from triggering occupants to leave and seek medical assistance, to nuisance complaints that are noticeable but do not require any form of medical treatment);
- Time patterns (hour, day, and season) of the onset of health and comfort complaints, and when relief from the reported symptoms occurs;
- Patterns within the building (i.e., where affected individuals are located – normal work station, etc.);
- The relationship between predominant health and comfort complaints and potential source materials, equipment, odors or other factors;
- General cleanliness and housekeeping of the area where individuals with complaints spend time;
- A history of any incidents that may affect IAQ, such as water intrusion or renovation activities, episodes of short-term noticeable odors, other upset conditions;
- Any potential deficiencies in the distribution of adequately conditioned air, including the amount of outdoor air distributed to occupied areas;
- The design, installation, operation, and maintenance of the HVAC system, and
- Available medical opinions about the cause of any adverse health conditions attributed to the building environment.

Determine if this is an Emergency

If this is an emergency, take immediate action to protect the occupants. Emergencies are situations with limited time before serious health problems or property damage results. EPA's I-BEAM[16] program provides examples including:

- The sudden onset of headaches, dizziness, drowsiness, nausea and/or combustion odors (concern of carbon monoxide poisoning);
- Diagnosed Legionnaires' disease (especially with multiple cases);
- Diagnosed tuberculosis (especially with multiple cases);
- Widespread and pronounced breathing difficulties, chest tightness, or respiratory irritation (potentially serious infectious or allergenic agent);
- A natural gas or propane leak;
- Sewage backup and "black water" (sewage) or "gray water" (other non-potable water) flooding impacting occupied spaces, and
- Hazardous material spill or release.

The EPA advises that the situation creating the emergency condition should be dealt with first, including getting people out of harm's way. The EPA recommends taking the following steps in an IAQ emergency.

- Immediately notify, and seek assistance from, an appropriate authority (e.g., health department, hazardous waste office, fire department/haz mat response, gas utility, etc.).
- Evacuate the area, if warranted, and thoroughly walk through the area to verify that evacuation is complete (with appropriate gear).
- Obtain medical assistance.
- Ventilate affected areas with large quantities of outdoor air using temporary fans, if necessary (judgment will be needed to determine if this action is appropriate – some caution is advised since high volume ventilation could disperse certain contaminants (e.g. sewage organisms once surfaces are dry, fungi, etc.)).

A child visiting her mother at work became lethargic, and her lips turned bright red. Shortly thereafter, some adults also exhibited the same symptoms. The fire department responded and found high CO levels, which were traced to an adjacent tenant conducting combustion-related research without venting. The research was suspended immediately.

- Keep the evacuated building occupants informed.
- Begin corrective actions and remediation procedures.

Steps in Investigation (Non-Emergency)

In most cases, IAQ investigations do not involve an emergency situation; however, prompt and deliberate action is still required. A set of hypotheses should be developed to provide focus for a walk-through survey. For example, if allergic-type reactions are reported, the investigator might pay attention initially to chemical or microbiological stressors, whereas if complaints relate primarily to stale air (stuffiness), the adequacy of the HVAC system and operations may need to be addressed.

The success of IAQ problem resolution depends largely on the diagnostic prowess of the investigator. Diagnostic skills can be learned and, with experience, an investigator can minimize frustrating and costly "dead ends." This stage of the investigation should result in an understanding of the specific complaints and physical conditions of the IAQ problem area before significant numbers of samples are collected or other measurements made.

The initial investigation generally is accomplished in three steps: 1) a review of historical information, including occupant observations, symptoms and complaints; 2) an initial walk-through survey; and 3) a review of HVAC design, operation, and maintenance. Many common problems can be identified, and recommendations made, just on the basis of the initial investigation and further investigation(s) should be performed only after identified problems have been corrected and feedback from occupants has been received. Only after these steps are completed should an in-depth sampling strategy be considered.

Historical Information Review

An investigator's first step should be to develop sufficient background on the building. In many cases, information gathering may begin before arrival on-site by discussing the problem over the phone or by reviewing historical documents pertinent to the case (e.g., building plans and specifications, floor plans, prior studies, photographs, and medical documents). Once on-site, the investigator may identify and interview individuals with specific health and comfort issues, and individuals familiar with the history of the building's construction, renovation, operation, maintenance of building systems, and patterns of past and current occupancy. Caution should be used when evaluating secondhand reports. It is important to interview occupants individually, rather than in a group, to obtain the most unbiased information. The checklist provided in Appendix D and the Occupant Interview Form in Appendix E are useful in guiding this process.

> An office area was evacuated because of strong solvent odors and headaches. Heavy use of white board markers in a meeting room was the cause.

Copies of previous engineering reports, environmental audits, or IAQ studies also should be reviewed for clues that might help explain the problem's source.

Information on the history of the building, including any recent renovations, should be reviewed. This would include new furniture, carpeting, casework, paint, wall coverings or similar changes. Such changes have been associated with VOCs and airborne dust, as well as occupant health and comfort complaints. In renovations in which partitions or dividing walls have been installed or rearranged, information or observations should be made to determine the extent to which the HVAC system (i.e., thermostats, supply and return diffusers) and lighting were altered to meet the requirements of the new configuration.

Information about on-site chemical use should be obtained and reviewed, including:

- Cleaners, disinfectants, deodorizers, waxes, and static-reducers used by cleaning crews;
- Pesticides and herbicides used for pest control, landscape care, and maintenance of indoor plants;
- Chemicals used inside the HVAC systems, such as disinfectants, microbial growth inhibitors, scale inhibitors and cleaners;
- Materials used in photocopiers, printers, plotters, and blueprint copiers;
- Specialty chemicals used in graphic arts, building maintenance and mail rooms, and

- Chemicals used in unusual operations in the building such as pottery kilns, printing operations, dry cleaning, nail polishing, 3D printers, or other semi-industrial processes.

The spatial distribution of the complaints should be examined to identify potential migration pathways such as connecting stairwells, elevator shafts, hallways or service by the same air handling unit. Consider pathways related to the HVAC system and pressure differentials within the building (e.g., recirculation within zones, zone overlap, and positively vs. negatively pressurized areas).

> The tenants in a recently renovated office building were complaining about odors that they thought were from mold growing underneath the raised floor. The odor was actually coming from newly installed vinyl-clad computer cables.

The investigator should examine the relationship between reports of intermittent odors and the time and location of any chemical use. The SDS for any chemical should be reviewed. If a specific chemical seems to be the cause, measures should be taken to limit emissions into the affected area, including covering open containers and using limited quantities after hours. ASHRAE recommends local exhaust ventilation for chemical use in offices.[8]

All sources of combustion in the facility should be identified and characterized for the type of fuel burned, the location of exhaust flues, and the frequency and schedule of operation. Other potential CO sources, such as idling motor vehicles or gas or propane-fueled lift trucks, should also be investigated. The smoking and electronic cigarette use policies of the facility should be noted, including the location of any smoking areas and their impact on other areas of the building.

The history of water leaks, flooding, or other conditions suggestive of unusual moisture or high humidity, dampness, and microbial growth should be reviewed, including the extent to which any water damage has been repaired.

The investigator should also be aware of possible sources of contaminants that may enter the building from outside. Neighboring industries, construction projects, heavy traffic, combustion stacks on the roof, loading docks with idling vehicles, agricultural or landscape maintenance operations, and even restaurants are examples of potential sources of emissions that could migrate indoors.

If there is sufficient time before the site visit, occupants may be asked to document changes over time, noting symptoms, reports of unusual events within the building such as odor episodes, and other observations. If it appears there is a relationship between an event and health complaints, or some other pattern emerges, the site visit should be scheduled to coincide with an anticipated recurrence of the IAQ problem. Symptoms that match the effects of specific air pollutants should lead to a search for sources of those pollutants.

Initial Walk-through Survey

The first walk-through survey should include an inspection of the building's immediate outdoor environment, the problem or complaint area(s), a control (non-problem) area, and the major HVAC system components. Many investigators choose to conduct an initial walk-through without being encumbered by measuring devices or instruments of any type. Eyes, ears, nose, and an inquiring mind might be all that are required at this point. Others may perform the walk-through inspection while conducting occupant interviews and taking basic diagnostic readings with direct reading air quality instruments.

The general condition of the complaint area should be assessed. Are temperature, ventilation and relative humidity within acceptable comfort levels? Are there areas of stuffiness or drafts, or hot or cold spots? Are surfaces relatively clean? Are there unusual odors?

> An individual was sneezing all the time at his desk. Deep cleaning his chair and shampooing the carpet resolved the problem.

Particulates

Complaints of eye, skin and upper respiratory irritation may be related to dust or fibers. Sources of particles in a typical office include tracked-in dirt, carpet and textile fibers, paper dust, fine dust from equipment such as printers and copy machines, skin cells, pet dander, and accumulated dust from general occupancy. Noting the color and type of particle or fiber may be a clue to the source. Areas with a high level of activity tend to generate more particles and collect more dirt and dust. The HVAC system may also be a source of particles, suggesting filter problems, insulation erosion, or fan belt wear – soiling of areas near supply air diffusers should be noted.

Air Contaminants

There are many potential sources of air contaminants in modern buildings. These range from building materials, contents such as furnishings and finishes, to office related equipment and sources brought in by occupants.

Offices may include copy centers, photo labs, art rooms, chemical laboratories, and kitchens that contribute to the presence of indoor air pollutants. The inspection should assess whether dedicated local exhaust ventilation may be needed for large copiers or copy rooms, which emit heat and particulates. Combustion sources, such as furnaces, water heaters, and ovens, should be noted for servicing by the owner, to ensure that there are no obvious problems with exhaust ventilation, including dangerous backdraft or corroded flues. Consider the location of exhaust vents and the potential for re-entrainment of exhausted air into outdoor air intakes or other openings.

> A laboratory hallway smelled like pizza, and a combustible gas detector gave elevated % Lower Explosive Limit (LEL) readings over the floor drain adjacent to the emergency deluge shower. Placing a thin tissue over the drain cover confirmed the water seal in the trap within was completely dry, as the tissue was visibly blown off the drain grate. Pouring a quart of water down the drain resolved the complaint.

In newly remodeled or newly furnished buildings, significant chemical sources may be the furnishings, cubical partitions, floor and window finishes, and related new materials. These items often release VOCs, contributing to the presence of a wide variety of VOCs, and often to perceived odors. Consider inquiring about changes in furnishings or remodeling activities and specifics on the materials used.

Are any odors noticed when first entering an area? An investigator with a poor sense of smell may need associates with better olfactory abilities to accurately assess odors in a building. Odor may be an important indicator for many airborne contaminants.

Sink and floor traps should be inspected to see whether they have become dry, especially if the complaints are about rotten-egg or sewer-type odors. Plumbing vents located near outdoor air intakes may also be responsible for sewer odors entering the building.

Inquiries should be made concerning chemical agents used within the building. These would include cleaning chemicals, pesticides, and any special chemicals used in equipment. Information should be gathered to determine if cleaning chemicals present unusual hazards or contain odorants that may trigger complaints by some occupants. Review chemicals stored in janitor closets. If insecticides are used indoors, and there are complaints that may be consistent with exposure to these agents, further evaluation steps should be taken. Insecticides may result in offensive odors that can persist for hours to days. For this reason, insecticide use indoors should be avoided. Consultation with a skilled and experienced pest control operator is recommended if there is a need for pest control.

Water Intrusion and Mold

Are there any signs of excessive moisture including standing water, wet surfaces, water damage, suspect staining or odors? Water-damaged or stained porous furnishings, such as carpet, drywall, or ceiling tiles, should be noted since they could act as reservoirs for microbial growth and potential sources of bioaerosols. Condensation on windows or glass doors, as well as obvious fungal stains, should also be noted.

The American Conference of Governmental Industrial Hygienists (ACGIH®) *Guidelines for Assessing Fungal Problems in Non-industrial Environments* give a number of conditions that may be evidence of fungal growth or lead to fungal growth. These include the presence of visible fungal growth, moldy or earthy odors, the persistent presence of moisture or standing water, or the accumulation of organic debris, especially bird or animal droppings.(17) The location of any of these conditions should be noted for appropriate corrective action.

Some examples of water damaged materials in buildings are given in Figures 3.1 to 3.5.

Fig. 3.1 – Mold growth in closet caused by condensation from room air (www.epa.gov)

Fig. 3.2 – Front side of wall-board looks fine, but surfaces within the wall cavity are covered with mold (www.epa.gov)

Fig. 3.3 – Water stains on wall and ceiling (www.epa.gov)

Fig. 3.4 – Acoustic ceiling tiles with water damage (www.epa.gov)

Fig. 3.5 – Efflorescence on Basement Cinder Block Walls

Efflorescence

Efflorescence (which means "to flower out" in French) is the migration of mineral salts that can be found on the surface of concrete, plaster or masonry as a result of moisture in the wall. It is often whitish in appearance and sometimes referred to as "whiskers" or scum. Portland cement used in mortar and grout can be the cause, as can be natural clays used in brick.

While efflorescence is not microbial growth, it does suggest a moisture condition that may need to be addressed from a structural perspective.

Other Indoor Environmental Issues

Features of the indoor environment should be considered and noted as these may present nuisance or related conditions that can contribute to health complaints in buildings:

- Is lighting sufficient, without glare or reflection? See Appendix F for OSHA Guidelines for Computer Workstation Lighting Problems and Solutions.
- Is there noticeable background noise or vibration from the HVAC system or other sources? See Appendix G for Noise Sources in Offices and Possible Corrective Actions.
- Is there poor ergonomic design of workstations or office furniture? It may be mistaken as an IAQ concern.
- Are there signs of poor housekeeping? It may contribute to poor IAQ.

A homeowner complained about mold growth on the walls of her bathroom. An inspection of the bathroom revealed efflorescence on the plaster walls of the bathroom, as well as on the ceiling above the entrance to the kitchen. The cause of the problem was a leak in a steam pipe behind the walls. The pipe was repaired and the damaged plaster was scraped off. The areas were then re-plastered.

Preliminary Measurements

During initial investigations, several preliminary, semi-quantitative air quality and environmental measurements may be taken. Appropriate instruments and measurements should be selected for the specific issues identified.

Collect measurements in the problem area, in a non-complaint area, and outdoors. Typical measurements might consist of temperature and relative humidity (RH) as indicators of comfort, carbon monoxide (CO) as an indicator of combustion gases, and carbon dioxide (CO_2) which may be informative about outdoor air ventilation supply. Other measurements may include airflow, total VOCs, and airborne particulates.

To identify any changes occurring between early morning and end of day, measurements can be collected over the course of the workday, beginning recording or data-logging before the work force has arrived, for example. Figure 3.6 shows a plot of CO_2, CO, temperature and RH levels over three days in a normal non-complaint office building.

When moisture problems are suspected, a hand held moisture meter may be used to test the relative moisture content of building materials. Given normal variations in moisture content of common materials, it is usually helpful to determine normal moisture levels in unaffected materials for comparison with those in locations suspected of containing unusual moisture. Such measurements may not tell the whole story, since building materials can dry out relatively quickly (in hours to days) following a wetting event.

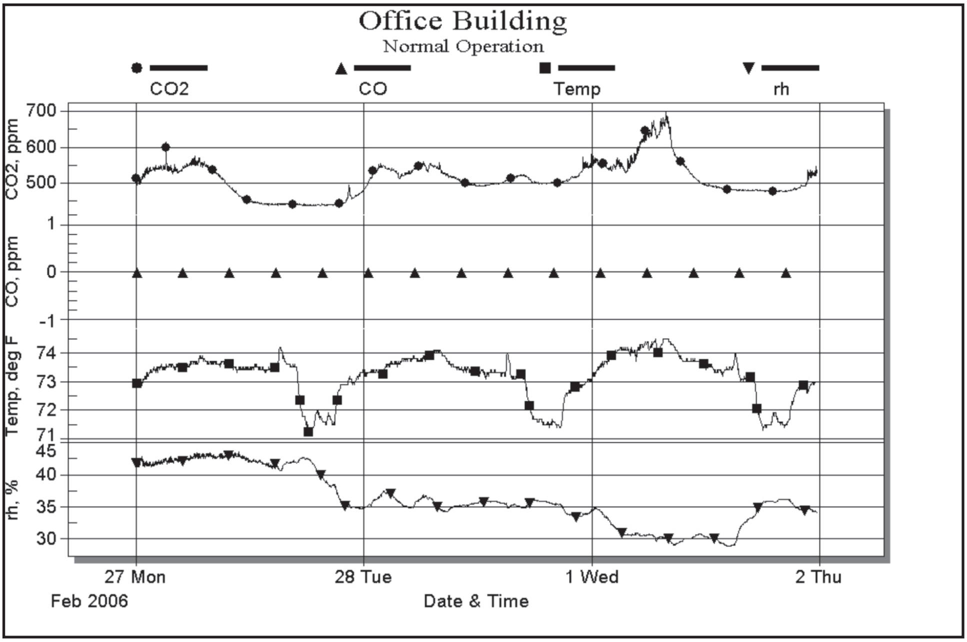


Figure 3.6 – Results from Continuous Monitoring of IAQ Parameters

Table 3.1 lists instruments that are commonly used in initial evaluations; as well as the preferred measurement range for IAQ instruments, and "guidelines" outside of which further investigation normally is warranted.

TABLE 3.1 – Common IAQ Measurement Techniques

Parameter	*Instrument*	*Range Of Measurement*	*Guidelines*
Temperature	Thermometer Thermocouple	30° to 120°F	73° to 79°F (summer) (See Note 1)
			68° to 75°F (winter) (See Note 1)
Relative Humidity	Capacitive Detector Psychrometer	0 to 100% R.H.	20 to 65% R.H. (See Note 1)
Carbon Monoxide	Electro-chemical sensor Colorimetric tube	1 to 50 ppm	0 to 2 ppm above ambient, <9 ppm avg. (See Note 2)
Carbon Dioxide	Infrared Detector Colorimetric Tube	200 to 4000 ppm	<700 ppm above the outdoor level (See Note 3)
Airflow/Air Speed	Smoke tube Thermal Anemometer Flow hood	Qualitative Only 10 to 2000 fpm 10 to 2000 cfm	not to exceed 40 fpm (at the occupant level)[11]
Moisture Content of Materials	Moisture Meter	5 to 30% (wood) (See Note 4) 0–100 (comparative scale)	comparative

Note 1. General guidelines based on ASHRAE Standard 55 assuming typical conditions for type of clothing, air movement, radiant heat, and other complex factors

Note 2. General consensus

Note 3. Guideline based on ASHRAE Standard 62.1 assuming outdoor air supply rate of 15 cfm/person

Note 4. Response factors of moisture meters vary for different types of materials including wood, wallboard, etc.

Measurement of CO_2, (from exhaled breath and outdoor air), may be used as an indicator of ventilation adequacy, given certain conditions are met. It may be an indicator of outdoor air ventilation supply, and the potential for the accumulation of indoor pollutants and odors. Since it is based on both the CO_2 concentration from outdoor air, and from occupant load, there must be a sufficient number of individuals present within the occupied spaces and there must be adequate time duration given to achieve steady-state concentration values. Elevated levels of CO_2 do not directly correlate with airborne pollutant concentrations. Indoor CO_2 levels typically peak in the late afternoon and data-logging throughout the day is often useful. If there are fewer than five to seven persons per 1,000 square feet, CO_2 measurements will not be useful in assessing the adequacy of ventilation, since steady-state concentration values will not be reached within the typical work day (e.g. 8 hours). While in some situations CO_2 concentration measurements can be very useful, there are many circumstances where they are useless or misleading. Knowledge of the limitations of this technique, and caution in interpreting the results, is important.

Figure 3.7 – Measuring Airflow with a Flow Hood

Airflow and air speed can be checked in several ways, including observing the direction of airflow with smoke tubes, measuring air speed using an air velocity meter, or measuring airflow rate emanating from a supply air diffuser using a flow hood. The most accurate method for measuring airflow rate from a supply diffuser is the flow hood, where airflow through an opening (e.g., supply air diffusers) is measured by placing the face of the flow hood over the opening and reading the computed airflow volume in cubic feet per minute (cfm) (see Figure 3.7). Less preferred are air velocity meters (thermal anemometer or pitot tube), where multiple velocity measurements are made across the opening, and the average air velocity, in linear feet per minute (fpm), is multiplied by the size of the opening, in square feet (ft^2), to obtain the airflow rate (cfm).[16] Knowing this amount, and the relative proportion of outdoor air to total supply air, can be used to determine the quantity of outdoor air provided to the occupied space.

To evaluate drafts at a specific location, air velocity measurements are made using a non-directional thermal anemometer. Values exceeding 40 fpm may indicate uncomfortable drafty conditions.[11] According to ASHRAE *Standard 113, Method of Testing for Room Air Diffusion*, the measured velocity in the occupied area in all directions should not exceed 30 fpm for heating in winter and 50 fpm for cooling in the summer period. If these conditions are not met, it is suggested that draft problems be resolved by modifying the air diffusion grilles using standard accepted procedures.[18]

The current ASHRAE Standard 62.1 (Ventilation for Acceptable Indoor Air Quality) gives three procedures for determining ventilation rates for different types of facilities:

- Ventilation Rate Procedure
- IAQ Procedure
- Natural Ventilation Procedure

The Ventilation Rate and Natural Ventilation Procedures give specific design requirements, where the IAQ Procedure is based on analysis of contaminant sources for achieving minimum contaminant concentrations. In the Ventilation Rate Procedure the standard calls for the calculation of outdoor air requirements based on both the occupancy and the square footage of the space. For example, for typical office spaces the outdoor air requirement is 5 cfm per person, plus 0.06 cfm per square foot of space. In an office space that is 1,000 ft^2 and occupied by five people, the minimum outdoor air requirement is 85 cfm of outdoor air (e.g. 5 cfm/person x 5 persons + 0.06 cfm/ft^2 x 1000 ft^2), which is equivalent to a minimum ventilation rate of 17 cfm outdoor air/person. This assumes that outdoor air quality meets certain acceptability criteria.[8] Note that higher outdoor air supply rates may be stipulated by state or local regulations or codes.

The current ASHRAE Standard 55 (Thermal Environmental Conditions for Human Occupancy) includes a chart showing acceptable comfort conditions based on the interaction of temperature and RH. This translates into an acceptable temperature range of 68° to 75°F in winter, and 73° to 79°F in summer, with the RH level being kept below 65%.[11] However, ASHRAE recommendations for temperature and humidity take into consideration type of clothing, air movement, radiant heat, and other complex factors which are not usually assessed in most IAQ investigations. Thus, the recommended range values should be used only as general guidelines.

Thermal discomfort is a very common source of dissatisfaction with IAQ. Data logging temperature and RH over a period of days or weeks is often useful in highlighting the need to adjust HVAC operations for the benefit of occupant comfort.

Low humidity—common in buildings without humidification during winter months in cold climates, desert areas, or at high altitudes—frequently results in dry skin, lips, eyes, and nasal mucosa, as well as sore throats and nose bleeds. This can trigger occupant complaints and, in some cases, might lead to secondary infections. In general, it is recommended that RH indoors not be lower than 20%. Increasing RH within a building can be challenging and consultation with a licensed mechanical engineer with experience in designing appropriate systems may be necessary.

RH in excess of 65% may provide conditions suitable for biological growth on surfaces, including molds and yeasts, and also promote the proliferation of dust mites.[19] High humidity within a building is indicative of an HVAC system that is not capable of removing a sufficient quantity of moisture from incoming air, or the system is faulty and requires repair or maintenance.

CO levels that are measurably above outdoor ambient levels indicate that combustion air is entering the building or is not being properly controlled. Because of the potential for this to become a serious health hazard, it must be investigated quickly and thoroughly. The investigation team must consider safeguards to protect their own health and avoid exposure to hazardous levels of CO during their work.

Office employees of a food distribution company who relocated to a temporary, rental warehouse were experiencing fatigue and headaches. The plant manager, who for a period of weeks attributed the symptoms to stress, called an industrial hygiene consultant and expressed concern that chlorine used as a disinfectant was a cause for the symptoms. Sampling was planned for chlorine; however, the absence of odor and irritant symptoms did not suggest chlorine was the likely source. The carbon monoxide (CO) sensor in a 4-gas meter immediately alarmed when the meter was turned on in the office during the opening conference with the plant manager, indicating 50–100 ppm CO. Levels in the distribution warehouse adjacent to the office were 400–700 ppm with higher levels measured near the exhaust of propane fork lift trucks. Recommendations were made to immediately stop operation of the fork lift trucks until they could be properly serviced, and to ventilate the facility. After the fork lift trucks were serviced and ventilation was restored to the warehouse, the symptoms disappeared.

Smoking and Vaping

Where smoking is allowed in buildings, environmental tobacco smoke (ETS) has been one of the most frequent causes of complaints for building occupants. In addition to CO and respirable particles, nitrogen oxides, hydrogen cyanide, and formaldehyde are produced along with a wide variety of other gases, vapors, and odors. If separately ventilated smoking areas are not properly designed for complete isolation or outside smoking areas are too close to openings into the building, non-smokers may still be exposed to ETS. If possible, indoor smoking should not be allowed, or at a minimum, should be restricted in a manner that results in minimizing exposures to non-smokers. Many municipalities in the U.S. now ban smoking in public buildings and areas, and smoking in workplaces is increasingly prohibited.

The use of electronic cigarettes has increased in recent years and regulation of the products and their use is evolving. Although e-cigarettes may be "safer" for the user than tobacco cigarettes, they emit airborne agents that may result in exposures to non-users. Research indicates that emissions from users "vaping" e-cigarettes may contain nicotine, other organic compounds and particulates whose health effects have not been thoroughly studied.[20]

The current ASHRAE Standard 62.1 defines ETS to include emissions from electronic smoking devices, as well as cannabis smoke. The existing requirements include separation of ETS-free spaces from ETS spaces.[8] Also, the National Institute for Occupational Safety and Health (NIOSH) recommends that employers establish and maintain smoke-free workplaces that protect those in workplaces from involuntary, secondhand exposures to tobacco smoke and airborne emissions from e-cigarettes and other electronic nicotine delivery systems.[21] As an IAQ investigator, determine where any smoking or vaping occurs and how it might affect building occupants.

Findings and Recommended Corrective Actions

All key observations need to be recorded, and shared with the building owner's representative with suggestions for possible corrective actions. Emergency situations (e.g., those involving CO, Legionella, or some other situation requiring prompt action) must be addressed immediately. Where the problem has not been resolved, the need for further work should be considered and discussed. The investigator can work with the building owner's representative to keep building occupants informed. It is important that all parties involved (management, medical personnel, human resources, legal, facilities and the key occupants in the area under study) be informed of the status of the investigation, if the problem has been resolved, and what, if any, further work will be done.

Some building owners or managers will require assistance with budgeting, and cost estimates may be needed. Where costs cannot be firmly established, specifications can be prepared and opened to competitive bidding or obtaining cost quotations. Recommended improvements can be coordinated with any upcoming renovation work, to minimize costs.

A schedule should be set. During the course of corrective actions, other issues, including those previously inaccessible, may surface. Contingency plans can be developed as additional safeguards, as deemed appropriate.

Chapter 4: HVAC Overview and Inspection

HVAC Overview

Understanding the HVAC system is a critical aspect to most IAQ evaluations. These systems provide comfort control to the built environment, and they serve as the main or only source of outdoor air into the occupied spaces. Outdoor air drawn into a building dilutes normal odors created by occupants and their activities, and also dilutes airborne chemicals that may be coming from furnishings, building materials, equipment, occupant activities and other sources. In some situations, the HVAC system is not only the source of solving a variety of IAQ problems, these systems may also be the source of biological or chemical agents causing complaints in the building. Understanding their basic designs, operations, maintenance and problems or failure points, is obviously important to the IAQ investigator. During a typical IAQ evaluation, three basic questions should be answered concerning the HVAC system:

- Is the system maintaining comfort within the space?
- Does the system provide sufficient quantities of outdoor air to the occupied spaces?
- Is the system serving as a source of indoor air pollutants to a degree that may be causing occupant complaints?

The HVAC system functions, in a sense, as the "breathing system" of the building. It provides the building with outdoor air, cools and heats the air (i.e. conditions it), removes moisture, and exhausts and/or reconditions re-circulated air. The assessment of the HVAC system can be one of the most complex and least understood parts of the investigation, especially for someone with limited training or experience. Many of the important components of the HVAC system are hidden, out of sight, and the way they operate is often not intuitive. Many of the surfaces within an HVAC system cannot be visually examined without making destructive openings or by use of remote visualization equipment. An investigator is likely to encounter a wide range of system types, as well as generational differences in equipment and control technology. Many systems, especially in larger buildings, are electronically controlled, and require specific expertise for diagnosis and repair. Even older systems can be complex. Figure 4.1 shows the general relationship between several HVAC components; however, many variations are possible. The numbers on the illustration correspond to the components discussed below.

In many instances, it is the role of the IAQ investigator to identify obvious deficiencies by asking the right questions and by probing methodically into how the system works. Successful resolution may then require more specialized HVAC technical or mechanical engineering services, or the investigator may work in tandem with a member of that profession.

While this guide can serve as a "primer" – investigators must understand their limits. In some situations, an individual who is investigating health complaints within a building will need to team up with an experienced mechanical engineer or HVAC technician. Having the knowledge of professionals who know the history and current status of the building and its systems is essential. What will they add? Their experience and knowledge will help everyone understand how the HVAC system is actually being operated, maintained, the history of any significant changes, and how all of this may relate to the problem. They then may be able to pinpoint how the air quality in the building is being compromised because of other priorities, such as energy savings and cost, and how mid-course corrections can be made. Table 4.1 summarizes a number of common problems and solutions to HVAC issues that can affect IAQ.

Terminology

Mechanical ventilation systems have a number of specialized terms and units of measure. The most common terms that the IAQ investigator may encounter are presented below.

Air handling unit (AHU): A system equipped with a supply air fan, and air cooling and heating capability

ASHRAE: The American Society of Heating, Refrigerating and Air Conditioning Engineers, a professional association that develops standards and guidelines related to ventilation systems used for comfort and ventilation that are often adopted by building code officials. ASHRAE Standard 62.1 is the standard for commercial and institutional buildings. This standard is modified and updated on a regular basis.

Chiller: Equipment that cools water. Often this water will be circulated to cooling coils within air handling units.

Condensate drip pan: A pan or trough that captures and drains water that condenses on cooling coils. This is located under the cooling coils.

Constant air volume (CAV): An air handling system that provides constant airflow to the occupiable spaces, and the temperature of the supply air is heated or cooled by passing the air stream through heating or cooling exchange coils. This results in constant ventilation, and requires considerable fan energy.

Diffuser: A ventilation system component that distributes air to an occupied space. Diffusers often have directional fins that aid in mixing the supply air with room air.

Economizer: A series of automated air dampers that regulate the quantity of outdoor and return air that make up the supply air delivered by air handling systems to occupied spaces in modern buildings. These systems take advantage of cool outdoor air for indoor cooling, and restrict outdoor air supply to minimize cooling demand when warm outdoor conditions exist.

Filters: Specially designed porous materials used to remove particulate matter from the air stream. These are typically located downstream of the mixing chamber, and upstream of the coils and fan.

Induction units: Air handling units that draw room air into a heat exchanger where the air stream is cooled or heated, and then the air stream is re-introduced into the space. These systems are commonly found along the perimeter of office spaces with large window areas. It is common that no outdoor air is provided to the space by these systems (i.e. recirculated air only). These systems aid in providing supplemental cooling and heating, and work in conjunction with central air handling systems.

Mixing chamber: The space within the air handling system where return air from the occupiable space is mixed with outdoor air.

Sound liner: Insulation located inside air handling units, and also inside other surfaces (e.g. VAV boxes, ducting) that serves as thermal insulation and sound adsorbing material. A common type is fiberglass batting treated with neoprene, resulting in a black matting material.

Thermostat: A device that senses temperature, and directs the air handling unit to provide heated or cool air. The device will also control the fan within the air handling unit.

Variable air volume (VAV): An air handling system that conditions air to a constant temperature and then varies the supply air flow to maintain thermal comfort.

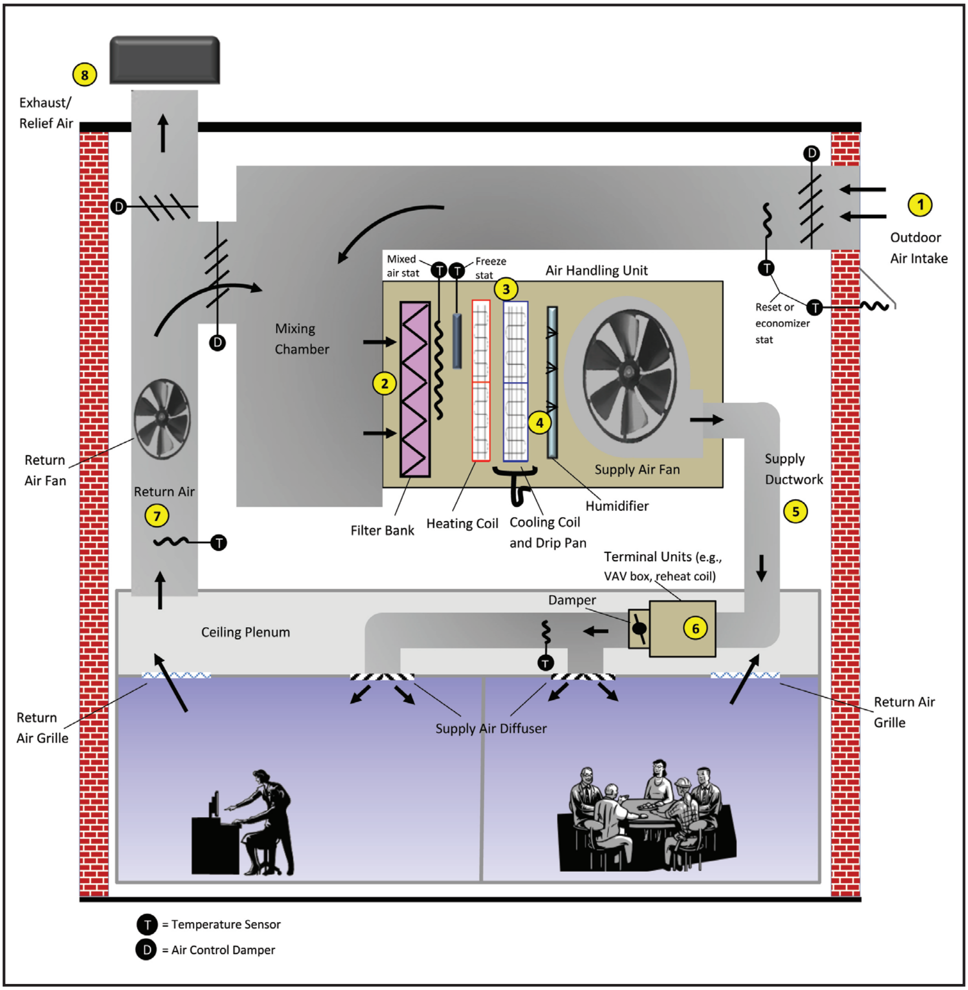


Figure 4.1 – Typical HVAC System Components (source: E. Gunderson)

HVAC System Basics and Types

As an investigator, identify and inspect the three major components of the HVAC system:

- Heating and Cooling Generation Equipment
  - Heating: warm air furnace, steam or hot water boiler, or radiant panels for heat
  - Cooling: chillers, cooling towers, and air-cooled compressors in packaged equipment for cooling

- Distribution System
  - Heat exchangers or coils: In large buildings, heating and cooling occurs by the use of heat exchange coils that receive hot or cold water from boilers or chillers. The air supplied to the occupied spaces is cooled or heated when the air stream passes through the coils. The water in the coils does not contact the air stream, since it is within an enclosed plumbing system. The HVAC system within large buildings may be complex, with several systems working in tandem to maintain comfort and to ventilate the building. An air handling system consists of one or more fan sections for supply and return air, a cooling section for chilled water or refrigerant cooling coils, a heating section for hot water or steam coils, a gas heat exchanger or an electrical coil, and a humidification section (if required). Particulate filters are normally located immediately upstream of the fan and coils, and just after the point where outdoor air is drawn into the system and mixed with return air. The filters aid in keeping the equipment and ducting within the air handling system clean, and prevent dust stains around supply air diffusers within the occupied spaces. The air handling unit requires regular maintenance to replace filters and belts, and repair fans, motors, and coils.
  - Ductwork: Air is the most common delivery medium for conditioning buildings, through insulated ductwork. Supply air from the HVAC system enters the occupied spaces through diffusers. The diffusers aid in mixing the air within the space. The air is then exhausted from the occupied space through the return air system, which may or may not be ducted. In large buildings, it is common that the return air is drawn through the open space above the ceiling (the ceiling plenum) – there is no ductwork within the plenum other than for the supply air.
- HVAC Terminal Equipment
  - Three types of air distribution outlets include ceiling diffusers (the most common type), linear slots, and

grilles (on walls or in floors; a grille with a volume control damper is also called a register).

- Window air conditioners or fan coil units, or, above the ceiling variable air volume (VAV) boxes or reheat coils, to control the amount of tempered air supplied through ceiling diffusers.

VAV systems are widely used in many applications. They are designed to supply only the amount of air needed to satisfy the thermal load requirements within the zone (a space or group of similar spaces). In this system, a central supply fan sends air through ductwork to terminal units (VAV boxes) throughout the building. The airflow to each zone is controlled by the VAV box (a "smart damper"), which varies the airflow in response to the space temperature. Most VAV systems provide cool air (e.g. 55°F) after the building is warmed up in the morning. Heating of the space relies on thermal loads that include the occupants, lighting, computers and other sources of heat. A temperature sensor located in the room provides information to an automated control system that controls the dampers within the VAV boxes. As cooling requirements drop, the damper continues to close, restricting the quantity of cool supply air to the space. Ideally, the minimum position should be set to provide a continuous level of ventilation air to the space, while not over-cooling. Some VAV boxes in perimeter zones contain a reheat coil for times when supplemental heating is needed to maintain comfort.

Diagrams and descriptions of some of the basic types of HVAC systems are given in Appendix H, along with the building types where they may be found. Figures 4.2 to 4.4 below illustrate the airflow pathways for three types of ventilation approaches. For example, Figure 4.2 shows a single-zone self-contained HVAC unit which contains the air circulating fan, refrigerating compressor/condenser/cooling coil and heating coil in one box (often called a "packaged" unit), which can be configured as a "unit ventilator" for a single zone such as a school classroom; a "rooftop unit" in a low-rise office building; and a "through-wall air conditioner" in a hotel. A central air handling unit is depicted in Figure 4.3, serving multiple rooms while a unit ventilator serves a single room or zone. Some buildings (commonly, multi-family residential buildings and schools) are mostly naturally ventilated, relying on exhaust airflow through kitchen and bath fans to induce outdoor air to enter the space by the negative pressure provided by the fan (Figure 4.4).

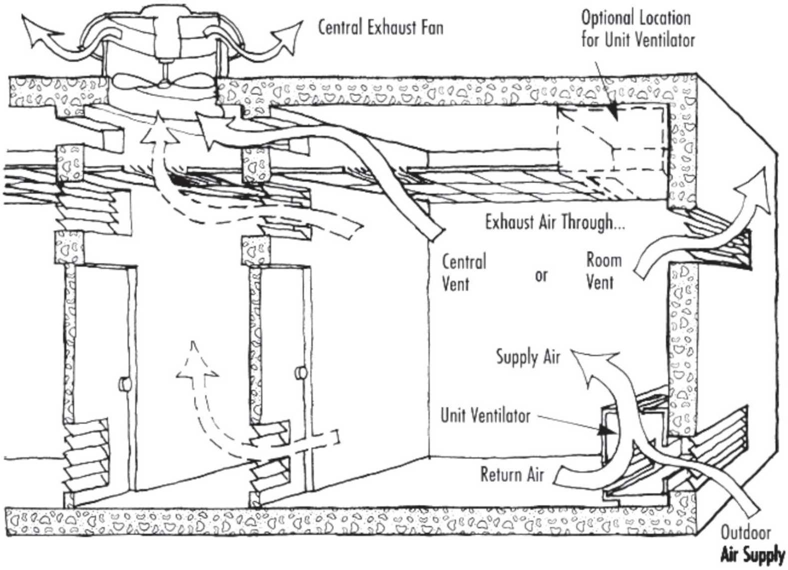


Figure 4.2 – Unit Ventilator (source: EPA Tools for Schools)

The building's HVAC system receives air from its surroundings, and when the ambient air does not meet the National Ambient Air Quality Standards (NAAQS) for a given pollutant, the investigator needs to determine the extent to which the HVAC system might filter or otherwise treat incoming air (See Chapter 6, Table 6.3). Some outdoor air pollutants, such as suspended particulate matter, can be easily treated (e.g. with mechanical filters), while others, such as carbon monoxide, cannot be easily dealt with.

An HVAC inspection should begin with observation of the building's surroundings and what could impact the outdoor air intake. What other conditions external to the building might account for the indoor air complaints? Examples may include construction activities, nearby industries that are emitting chemicals or dusts, the location of cooling towers that release mists that may contain chemicals or microorganisms, peeling or deteriorating paint that may contain lead, nearby exhausts or flues for combustion gases, and bathroom exhausts or laboratory fume hood vents. Is the building situated on "contaminated" soil or groundwater that could result in chemicals entering the building? Are the building's outside air intakes located near traffic or near a parking garage, trash containers, exhaust vents or loading docks?

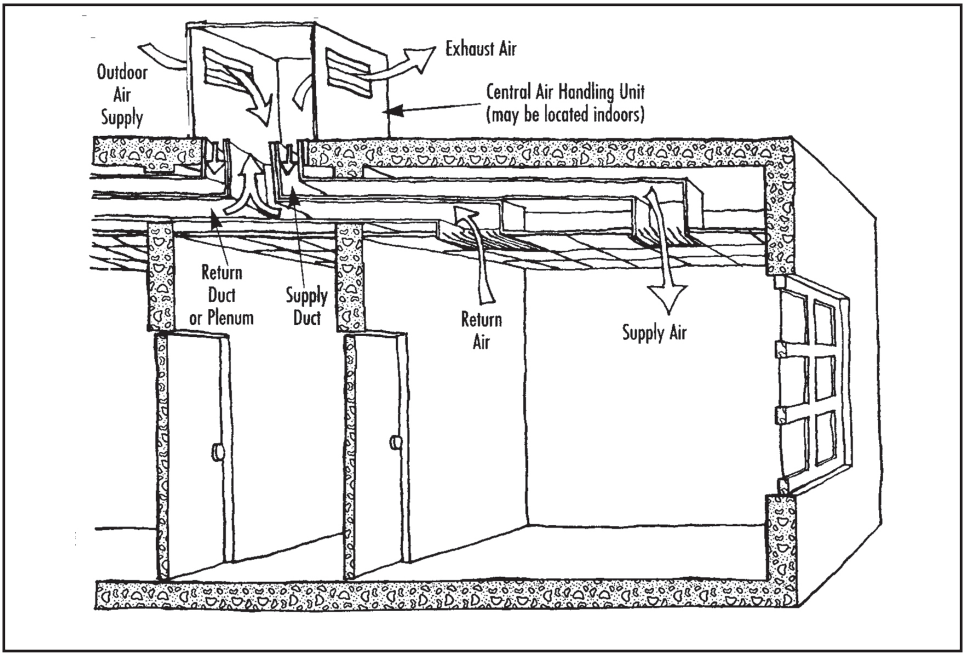


Figure 4.3 – Central Air Handling Unit (source: EPA Tools for Schools)

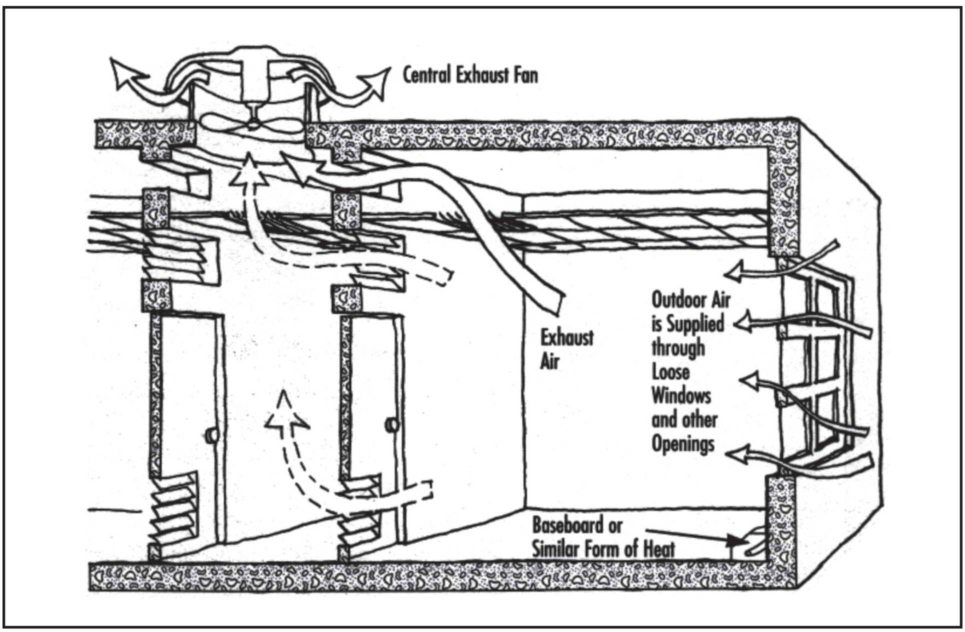


Figure 4.4 – Exhaust-only System (source: EPA Tools for Schools)

HVAC Inspection

Before an inspection, if possible, review available mechanical plans, HVAC control schematics, and balancing reports. Talk to building engineers regarding operating and maintenance procedures, schedules of operation, and potential problems noted about the system. When this type of information is available, it is often helpful to gain an understanding of the layout of the building. Identify the location of important air handling equipment within the building, locate the outdoor air intakes, and look for suspect outdoor air contaminant sources near the intakes.

Request that building maintenance supervisors or HVAC technicians who know the building and the ventilation systems lead a tour of the building to examine the HVAC system. They may provide valuable insight into the system's deficiencies, operational problems, redesign, and idiosyncrasies. They can describe the configuration and operation of the system; how, where, and the extent to which outdoor air is introduced into the building; and preventative maintenance procedures and schedule, including information about when the system components were last cleaned. The checklist in Appendix I can be a guide when conducting such a tour.

Investigators are likely to have their own version of an inspection protocol. However, it is critical that investigators follow the full pathway the air travels, from entering the outdoor air intakes to its exhaust back outdoors. Other critical aspects are to verify that the systems are operating, outdoor air is being drawn into the system and being distributed to the building occupants, and that interior surfaces of the air handling equipment are reasonably clean and the system is not acting as a significant source of indoor air contaminants.
The following paragraphs are keyed to general HVAC components shown in Figure 4.1. Tips on what to note and important aspects of each location within an air handling system are provided for each major component.

① Outdoor Air

The quality of the outdoor air that enters the HVAC system will impact the quality of the air indoors. In some situations, outdoor air may serve as a source of significant contaminants to the indoor environment. Identify the outdoor air intake location and note if there

> General IAQ complaints were received one winter at a Michigan office building. It was discovered that the outside air intake louver actuator motor was disconnected, and the louvers were wired shut with a coat hanger. This restricted outdoor air intake into the building. The system was restored to the original design configuration and the complaints ceased.

are obvious pollutant sources. Examples include nearby construction or agricultural activities, loading docks with idling vehicles and major traffic routes, cooling towers or evaporative condensers near outdoor air intakes, and building exhausts located near outdoor air intakes.

Outdoor air intakes should be located some distance away from other building components or equipment, such as cooling towers, exhaust outlets, combustion stacks, plumbing vent pipes, dumpsters, loading docks and smoking areas so the emissions from these components do not become entrained into the building. The current ASHRAE 62.1 standard recommends a separation distance of at least 15 to 30 feet, depending on the contaminant source.[8] Note prevailing wind direction and building configuration; this minimum distance may not always be sufficient to protect the air intake.

Unfortunately, outdoor air intakes sometimes are positioned near a loading dock or at ground level. Idling vehicles at the dock can result in exhaust being drawn into the building. One way of controlling this is to prohibit vehicles from idling when at the loading dock. In situations where the outdoor air intake is too close to a pollutant source, it may be necessary to move the intake.

Most outdoor air intakes should be fitted with a bird screen to prevent birds and other small animals from entering the air handling system. Inspect to determine if the bird screen is present and is clean. Bird nests and bird droppings can be a source of allergens and biting insects (e.g. mites), as well as opportunistic pathogens such as *Cryptococcus neoformans* and *Histoplasma capsulatum*.

The dampers of the outdoor air intake should be carefully examined. Are they closed? On days of extreme heat or cold, they should be expected to be at their minimum set point, restricting the quantity of outdoor air entering the system. Even though they may appear closed, there should be enough leakage through the dampers to achieve the minimum outdoor air intake requirements. If the louvers appear to be closed, it may be necessary to measure the volumetric flow of air entering the system using a velometer. If smoke tubes are used to aid in documenting flow conditions, use them with caution since some tubes generate irritant smoke, and the fine particulates released may cause in-duct smoke sensors to set off fire suppression systems. If the temperature outside is mild (e.g. between 50 and 70°F), and the outdoor air dampers are closed, it is worthwhile to find out why. Many modern air handling units will be equipped with economizer systems that regulate the outdoor air louvers. These systems may fail, or if the minimum set points have changed, it may result in chronically reduced or insufficient outdoor air supply. Sometimes, the dampers are manually closed by building personnel during extreme weather events, and then never re-opened. Damper controls may also break over their lifespan.

② Filters

All HVAC systems need to be equipped with particulate filters. Their purpose is primarily to help keep surfaces within the air handling system clean, since accumulated dust will interfere with the proper operation of the equipment, and many surfaces within the system are not readily cleanable. Filters also help to provide clean air for building occupants, to prevent dust staining on finished surfaces near supply air diffusers, and aid in keeping the interior of the building clean. Note the type, efficiency and condition of the filter media of the filter bank section. Low efficiency (e.g. less than a numerical value of "40" or a MERV rating of 6) filters do little to filter out small particles that may affect the mechanical equipment and the building occupants. Filters actually become more efficient as particles load on their surface. Higher efficiency, pleated media filters only work if they are securely fitted into the filter bank and properly sealed. Small gaps between individual filters allow unfiltered air to bypass the filters. Excessively loaded filters can also reduce airflow and force air to bypass the filter.

Figure 4.5 – Inspecting Filter Bank (pre-filter is removed here to inspect secondary bag filters)

Determine if the filters are changed at regular intervals, based on visual condition or by pressure drop. The most effective way is to change filters at regular intervals, or when the pressure drop across the filters meets the criterion recommended by the manufacturer. Filters should also be changed after heavy construction activities in or outside the building. A common change schedule is quarterly for standard pleated filters, and annually for extended life and higher efficiency bag filters.

The current ASHRAE 52.2, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*, establishes a performance standard that sets a Minimum Efficiency Reporting Value (MERV) for filtration media based on removal efficiency by particle size.[22] To maintain the filter efficiency, significant air leakage between or around the filters must be avoided. An example of a MERV 8 filter is a disposable extended surface pleated filter, 1 to 5 in. thick with cotton-polyester blend media in a cardboard frame. An example of a MERV 13 filter is a rigid style cartridge box filter 6 to 12 in. deep which uses lofted (air laid) or paper (wet laid) media. MERV 13 filters are typically used in high performance commercial buildings, and they are designed to control particles in the range of 0.30 to 1.0 micron size. For optimum IAQ, the most efficient filters should be used based on the HVAC system design.

③ Heating and Cooling Coils

Air handling units may contain both heating and cooling coils. Some systems may contain only cooling coils. The effectiveness of the filters can be quickly determined by the condition of the upstream face of the coils. Particulate build-up on the face of the coils reduces their heating or cooling capacity and also can be a nutrient source for biological growth. This accumulated particulate matter can also result in clogging the condensate drain.

It is also necessary to examine surfaces downstream of the cooling coils. This is often overlooked by maintenance personnel. Note the condition of the condensate pan. Is the water flowing quickly from the pan or is there standing water?

> Extensive mold growth was observed in many individual fan coil units in a hotel facility. The chilled water lines were insulated up to the unit, but were not insulated within the unit. Heavy condensation due to the tropical climate resulted in mold growth on the wetted fiberglass lining of the units.

This area is expected to be wet during the cooling season. However, there should not be standing water or evidence of water not draining properly. This condition leads to biological growth that can further restrict proper drainage.

Figure 4.6 – Neglected Cooling Coil with Biological Growth. ©2006 Timothy J. Ryan, PhD, CIH.

There are many reasons why water may not drain properly in a condensate pan. The drain point may be too high, or the pan may not be sloped properly towards the drain. In draw-through units, where the fan is located after the cooling coils, a p-trap must be designed for proper drainage of the water. If the trap becomes dry, air can be pulled in through the p-trap, causing sewer gases to enter the system. High negative pressure at the condensate drain may hinder proper drainage. This can occur if the filters become clogged because of a buildup of particulate matter. A smoke tube can be used to determine whether the trap is dry (smoke is pulled into unit through the p-trap).

If there is insulation near the heating or cooling coils, the condition of the insulation should be examined. Is it deteriorating? Is it soiled? Is it wet and/or supporting microbial growth? It is common in some older systems or poorly maintained units that cleaning or replacement of insulation within the air handling system is indicated.

There may be situations in which liquid water droplets are released from condensate on cooling coils due to high air velocity through the coils. This may occur due to soiling of the coils that can restrict air flow through portions of the coils, or simply because air velocity is high enough to cause a mist to be released from the coils. This can wet surfaces of the interior HVAC system downstream from the coils, and may support microbial growth.

④ Humidifiers

Some air handling units are equipped with humidifiers. This equipment is more commonly found in climates that have cold, dry winters, and where electronic equipment that is sensitive to static electrical discharge is present. Humidifiers require an additional degree of maintenance. Humidifiers can provide conditions conducive to microbial growth in sump water, duct interiors, and within occupiable spaces. Humidifiers can also introduce water-conditioning chemicals into the indoor air if process steam is used for humidification. It is important to understand the source of the water used in the humidification system, and to inspect the reservoir and surfaces downstream of the system.

⑤ Supply Ductwork

Note whether the supply ductwork has internal insulation. Although lined ducts provide superb noise attenuation, they may also provide ideal conditions for dust accumulation and in some circumstances, microbial growth. Non-rigid interior duct liner may be impossible to clean. Older fiberglass insulation itself may become an issue over time, as fibers can erode from the interior surfaces of the air handling unit and ducting, and migrate into the occupied spaces.

Are there supply diffusers that are covered with tape or cardboard as you observe the interior space? These are tell-tale signs that the occupants are experiencing discomfort and are attempting to deal with drafts. Do furniture, walls, or partitions block supply air diffusers? Renovations or remodeling activities may have been done without taking the HVAC system into consideration. Measurement of airflows, through the use of airflow hoods or velocity meters, can help determine if the flows are consistent with design parameters. Is the ductwork intact? Leaks and breaks may cause reduced airflows.

Investigators may notice particulate dust stains around supply diffusers. This may indicate inadequate filtration at the HVAC unit. Other times, however, particles that are generated within the space itself are attracted to the thermal and electrostatic differences near the diffusers, and stick there. A good way to figure out which is the source of particles is to remove the diffuser face. If there is particulate buildup on the duct-side of the diffuser, then it is most likely a filtration and cleanliness issue from the interior of the air handling system. However, if that area is relatively clean, then it is an indication of particulate build-

> Black fibers kept reappearing on an individual's desk after she repeatedly cleaned it. She was convinced it was coming from the ventilation system. Based on visual examination, it turned out her sweater was shedding.

up within the interior space itself, and may suggest a need to improve housekeeping activities.

If corrective actions include duct cleaning, this should be done cautiously, since this activity can release dust and worsen the problem. Duct cleaning may require that access holes be created so that cleaning in difficult to access areas can be performed. Large duct cleaning projects should be conducted by contractors who are well experienced and have a demonstrated track record of conducting thorough cleaning, without releasing dust into the occupied spaces. A carefully planned protocol for cleaning may be helpful to ensure the work is thorough and does not worsen the situation. Duct cleaning should only be conducted if absolutely necessary. Due to the cost and difficulty of duct cleaning, the use of higher efficiency and well-fitting filters to prevent the need for this cleaning is the better approach.

⑥ Terminal Units

Terminal units, such as variable air volume (VAV) boxes, fan coil systems, heat pumps, or induction units, especially those serving the areas where complaints or concerns are stemming from, should be evaluated. Again, dampers may be functioning improperly or shut; filters may be missing or clogged, and interior surfaces may be soiled. In heat pump units, it is important to examine the condensate pan for proper drainage, cleanliness and absence of microbial growth. Often, the coils and condensate pans may be difficult to access. This may also mean that they seldom, if ever, are inspected and cleaned. Perimeter induction units sometimes are used as bookshelves, plant holders, or are completely blocked by furniture. The condensate pans in these units may not be properly drained. Terminal units may not receive the same periodic maintenance as the larger air handlers do. It is important to have the mechanical blueprints or have a knowledgeable building engineer locate the units in a complaint area and inspect them as a possible contributor to poor IAQ.

⑦ Return Air

It is useful to understand how the air from the occupied spaces is returned to the HVAC unit. Is it an open-plenum return located in the ceiling space (or under the floor), where the air makes its way back to the air handlers based on negative pressurization? How clean is the ceiling or floor plenum? Are there plumbing or sprinkler lines

> Pouring a mixture of hot water with peppermint oil extract down a drain vent on the roof of a 4 story building helped conclusively track down a cracked plumbing vent pipe in the basement of the facility. Since the cracked pipe was located in a vertical pipe chase, the entire building had been experiencing occasional foul sewer odors. The cracked pipe was repaired and odors ceased.

that run through the plenum that can be a source of water leaks for microbial growth, such as "sweating" on uninsulated pipes? Do several air handlers use the same plenum return, in that contaminants from one area can then be dispersed throughout the building through the other air handlers? Missing ceiling tiles can cause short-circuiting if the space above the ceiling is used as the return air plenum, resulting in unusual pressure differentials and causing poor distribution of supplied air.

The return-air may be ducted back to the air handler. In this case, the space above the ceiling plenum is not conditioned, and condensation on cold duct surfaces or cold water plumbing may be an issue. Since the return air flow is not filtered, if there is unusual dust within the occupied spaces, dust may accumulate within the return air ducts and in severe situations, may require cleaning or duct replacement.

⑧ Exhaust Air

Special use areas, such as bathrooms, kitchens, and parking garages are normally equipped with fans that exhaust air directly to the outdoors. These areas should be running under negative pressure relative to adjacent spaces. This can be confirmed with the use of a smoke tube. It is important to confirm that the air is being directly exhausted to the outdoors, and not returned to the air handler to redistribute contaminants. This is especially true for chemical source areas within the building, such as dedicated smoking lounges or copy centers.

The building should be designed with more outdoor air supplied than exhausted. This results in the building running under a slight positive pressure in relation to the outdoors. This reduces the amount of unconditioned, unfiltered outdoor air that infiltrates through openings, such as doors and windows, or small penetrations, such as cracks and gaps in the building envelope. A smoke tube can be used to visualize the flow of air through entrances and windows.

Mechanical Rooms

If the air handlers are located in a mechanical room, it is important to note the condition of the room. Some mechanical rooms serve as a mixing plenum. That is, outdoor air and return air flow into the room to mix, and this mixed air is then drawn into the air handling unit for distribution to the building. In these cases, it is very important that the mechanical room be kept clean and free of chemicals (i.e., disinfectants, solvents, or cleaners) and other materials that can affect the air that is being distributed to the occupants. In some situations, combustible materials may not be stored within these systems because of fire hazard concerns.

Building Automation Systems/Environmental Monitoring and Thermostats

Building Automation Systems (BAS), or Building Management Systems (BMS), are centralized, interlinked, computer networks of electronic devices designed to monitor and control the environment in commercial, industrial, and institutional facilities. The basic function of a BAS is to keep the building climate within a specified range, control systems such as lighting, security, fire and flood safety, monitor performance and device failures in all systems and provide malfunction alarms. A BAS may control HVAC components such as chillers, boilers, air handling units, roof-top units, fan coil units, heat pump units, and VAV boxes. A BAS should help ensure occupant comfort and IAQ, as well as reduce building energy and maintenance costs, compared to a non-centralized controlled building. HVAC systems may be centrally programmed to shut off (e.g., nights and weekends) or modify operation (e.g., set back thermostat or reduce outside air).

As an IAQ investigator, it is important to understand the operation of the BAS and environmental monitoring systems. Is the control of temperature, airflows, and outdoor air quantities based on thermal set-points, or also by humidity and/or carbon dioxide levels? Where are the sensors for temperature or other parameters located? Are they calibrated on a regular basis? Often, an interior sensor that also serves a zone with exterior offices will generate complaints about thermal comfort. If sensors are placed in the supply air stream, they will not respond correctly to changing temperatures in the

After conducting an internet search on the health effects of mold exposures, employees in a small municipal complex believed that elevated mold levels were to blame for their symptoms, reported to include headaches, cough, eye irritation and more frequent respiratory infections. In response, the facility manager issued a request for proposals to conduct a mold assessment including specified air sampling. The township, however, chose to retain an experienced qualified firm to perform a broader assessment, beyond just mold sampling, which considered other potential issues that can adversely impact IAQ. The investigation found a few stained ceiling tiles, small roof leaks and limited condensation on uninsulated segments of ductwork, but the extent of mold growth was inconsistent with the prevalence and severity of symptoms reported by the occupants. Upon inspection of a pair of rooftop air handling units, it was discovered there were no filters or outdoor air intakes of any type within these systems. Similar findings were noted at the forced-air furnaces serving other portions of the facility: low-efficiency panel filters, neglected humidifiers, and a complete lack of outdoor air supplied to the occupied space. Subsequent retrofit of appropriate filters and provisions for outdoor air supply (with energy recovery) resulted in a marked decrease in occupant symptoms. Occupants reported that the entire facility smelled cleaner and fresher.

served area, and if sensors are exposed directly to a heat load (e.g., direct or reflected sunlight, office equipment, etc.), the remainder of the area might be cooled excessively. The BAS will also sense and control the temperature of the supply air, as well as the chilled and hot water used to provide cooling and heating in the building. All these elements may be of importance, especially if you are dealing with humidity issues within a building.

Table 4.1 provides a list of issues with ventilation systems that can be factors affecting IAQ.

TABLE 4.1 – HVAC Deficiencies and Solutions that may affect IAQ

Description	*Observation*	*Possible Solution*
Nonexistent or minimal outdoor air supplied by air handling equipment	Insufficient dilution ventilation, odor complaints, health complaints	Ensure outdoor air provided to occupied spaces by HVAC equipment are in accordance with current ASHRAE 62.1 recommended outdoor air supply rates
Tightly closed outdoor air dampers or economizer systems	Insufficient outdoor air ventilation	Modify minimum set points or open outdoor air damper to achieve outdoor air rates recommended by ASHRAE 62.1
HVAC automated start and stop times out of sync with occupancy	Reduced ventilation, odor and health complaints, thermal discomfort	Adjust HVAC automation to start system well before daily occupancy to provide comfort during occupied periods
Excessive cycling of heating and cooling	Thermal discomfort, elevated humidity in humid climates, reduced ventilation	Trouble-shoot temperature control system and verify proper operation
Insufficient air filtration	Increased airborne particulate concentrations, increased dust in HVAC system and occupied areas, dust staining or surfaces near supply air diffusers	Upgrade filters with more efficient styles that the air handling unit can handle; check system specifications for ability to handle increased static pressure load
Soiled air filters	Reduced airflow, filters may be deformed due to pressure, reduced ventilation, odor	Provide regularly scheduled air filter changes; if necessary, increase servicing frequency
Standing water and soiling of cooling coil, drain pan, and internal surfaces	Dust accumulation, possible microbial growth on surfaces and likely shedding of biological material into supply air, odors	Routinely inspect and clean surfaces; ensure that drain pan drains properly
Chilled water provided to cooling coils, temperature too high	Supply air temperature too warm, thermal comfort complaints, excessive airflow	Lower chilled water temperature
Chilled water provided to cooling coils, temperature too low	Supply air temperature too low, thermal comfort complaints	Raise chilled water temperature
Use of steam from boiler system for humidification	Chemical additives and by-products in supply air, odors, irritation of eyes and respiratory system	Use a potable water source for humidification

TABLE 4.1 – HVAC Deficiencies and Solutions that may affect IAQ (cont.)

Description	*Observation*	*Possible Solution*
Poor placement of thermostats or sensors	Thermal discomfort complaints	Relocate thermostats to representative areas or subdivide zone
Closed VAV boxes	Thermal discomfort, health complaints, reduced ventilation, reduced air movement, possibility of increased negative pressurization of building	Set minimum VAV box flows to ensure minimum ventilation rate recommended by current ASHRAE 62.1, adjust supply air temperature as needed to achieve thermal comfort and outdoor air supply
Poor location of supply diffusers and returns	Short circuiting of ventilation air within the occupied spaces, resulting in poor ventilation	Relocate diffusers or returns to improve air distribution
Distributed heat pump system, with makeup air discharged far from heat pump	Increased recirculation of air, reduced ventilation	Extend makeup air branch discharges to the heat pump air intakes
Building at negative pressure	Doors are difficult to open or close; air infiltrates without being conditioned	Add make-up air by adjusting or adding outdoor air or reduce exhaust
Special-use areas under positive pressure	Odors coming from areas that should be exhausted	Rebalance affected parts of air handling system

Figure 4.7 – Condensate Pan with Good Drainage

Atmospheric Moisture Issues

When a building is maintained under a negative pressure relative to the outdoors, warm humid air will be drawn into the building through open doors and windows, or small openings within the building envelope. When the warm, moist air contacts a cool, air-conditioned surface, condensation and the formation of liquid water may occur, which may result in microorganism growth.

A key issue for moisture management is the operation and maintenance of the HVAC system. Often, cooling equipment is oversized with respect to the cooling capacity required to effectively cool the space. On days that are not extremely hot, the oversized coil can cool the outside air very quickly, and may only cycle on for 10-15 minutes every hour to meet the cooling requirements of the occupants and other heat-sources in a building. During the other 45 minutes, outdoor air enters the air handler without being cooled sufficiently to remove the moisture, thereby leading to an increased moisture load in the building.

In addition, the temperature of the chilled water that serves the cooling coils may be raised to save on energy costs. Again, this may cool the air sufficiently to meet occupants' comfort needs. However, if the temperature of the cooling coils is above the dew point temperature of the air, the moisture in the outside air is not removed, and can increase the moisture load in the occupied space.

Excessive outside air entering the building may cause high humidity indoors under certain conditions. For example, if the chiller is off at night while the blower continues to operate, the cooling capacity may not be adequate for the outside air volume. Also, when HVAC systems have economizer systems, moist air can be introduced when outdoor RH levels are high and moisture levels are not monitored. When fog occurs, the outside air temperature may be within the operating parameters of the economizer, but the moisture content of the air may cause a problem.

In many cases, the expertise of a mechanical engineer or experienced HVAC technician is required to determine the best course of action to resolve moisture problems related to HVAC equipment.

Chapter 5: Additional Investigations and Studies

Many IAQ issues are resolved during the initial investigation, often without any sophisticated testing being required. In some cases, however, initial causation hypotheses are not supported by observations, and their proposed solutions do not resolve the problems. In these cases, additional study becomes necessary.

A methodical approach can be used, consisting of observation, identification of likely correlations, followed by testing related to a specific hypothesis – e.g. if the complaints are nasal congestion and sneezing, with individuals reporting that symptoms occur in the building and not anywhere else – differential causes may be common allergens (fungi, certain insects, pet allergens, grasses and pollens), and then mucus membrane irritants (e.g. aldehydes). The most logical tests would be for common allergens and aldehydes.

Others have initiated specialty studies based from a new working hypothesis that is developed from all of the information obtained in the initial investigation, including the accepted null hypothesis (see callout box below on hypothesis formulation and testing).

Application of the Scientific Method in IAQ

Any complaint-driven IAQ investigation begins with a statement of the problem. For the majority of IAQ investigations, the initial statement may be as simple as "The XYZ facility has an IAQ problem, because of the nature and number of health complaints expressed by occupants". In order to scientifically test this assertion, the investigator will continue the process of inquiry through adopting the null hypothesis, H_o, and the collection of data. For example, the null hypothesis may be "There is no discrete cause of IAQ problems in the XYZ facility." Next, one or more possible explanations for the cause of the IAQ problem are stated in the form of alternative hypotheses, Ha_1, Ha_2, … Ha_n, such as "the health complaints include symptoms consistent with mild respiratory allergy, and this is commonly caused by fungi (mold) and other common allergens", or "health complaints include chemical odors and headache, and this is commonly caused by VOCs." Often, these alternatives are suggested by building occupants during the initial stages of an investigation.

The goal of the specialty studies and testing is to try and refute, or nullify, the null hypothesis. The investigator must assume that the alternate hypothesis is wrong until they find evidence to the contrary. For example, suppose you believe that VOCs are the root cause for IAQ complaints at XYZ facility. Testing is performed not to prove that VOCs are the cause, but rather to reject the null hypothesis that there is no discrete cause of IAQ problems at the facility. Beware, though, often IAQ problems can be caused by multiple different issues and not just one single problem or contaminant. Once the problem is identified, the resolution may be a simple or complex, technically easy or quite difficult, and either a modest or very expensive undertaking. In any event, though, by carefully attributing the problem's root cause to a specific factor, decision making related to the solution will be both enhanced and defensible.

In simpler terms, before drawing conclusions with hypotheses and sampling data, the IAQ investigator needs to answer the question:

Does the data show that there is no significant difference in results from samples collected in a complaint area compared to a non-complaint area, other "control" area, or what might be expected normally?

- If no significant difference is seen, then the parameter tested may not be a factor in the complaint.
- If the data from samples taken in the complaint area are significantly higher than the non-complaint/control/normal data, then the parameter tested may be a factor in the complaint. However, it may not prove the parameter tested is the root cause of the complaint since there may be other contributing factors.

When is Sampling Needed?

Additional study may include sampling for specific VOCs, formaldehyde and other aldehydes, ozone, combustion gases, specific chemical agents, particles, and/or bioaerosols in the air and—in some cases—on surfaces. Such in-depth studies may also entail detailed evaluations of HVAC systems, lighting and noise measurements, tracer gas studies to identify air pathways or precise measurements of outdoor air supply, epidemiological studies, including questionnaires, and medical evaluations of affected building occupants.

In a case of suspected radon contamination of a building, or suspected carbon monoxide or other specific agent exposures, conducting testing within the building is the only way to determine if these agents are present and at harmful levels.

Before conducting extensive sampling, the investigator must have a well thought out plan and be able to answer some key questions:

- Is sampling really necessary?
- Will the sampling help the investigation or not?
- Is it plausible for the agent you believe responsible for the complaints to actually be in the area?
- Is the sampling and analytical method generally accepted and validated?
- Are the methods capable of detecting the agent at levels consistent with what you expect to find?
- What will be done with the data?
- What levels are considered normal or typical?
- Are there accepted standards or guidelines for the contaminants being sampled for, or parameters being measured?

- How will the data be interpreted and what will it be compared to?
- What will you do if the results suggest there is widespread contamination?

IAQ investigators need to carefully consider the agents that they test for, limiting the testing to agents that could be present and those that could cause the health complaints expressed by the occupants. Sampling and analysis for chemical agents, microorganisms and dusts can be a costly undertaking. Money may be better spent on timely remediation of an obvious IAQ problem rather than, for example, trying to characterize an unknown odor or determining the species of fungi. However, even when sampling may not be technically needed, it can be useful for helping to reassure occupants that a problem does not exist. Negative results can also help rule out suspected problems and help narrow the focus of an investigation. Negative results cannot be used to rule out any possible contaminant, because it is impossible to test for every possible contaminant. Importantly, negative results can be used to rule out probable contaminants.

It may be useful to conduct sampling for suspected contaminants in multiple locations within a building, such as the area where individuals with health complaints report that they experience symptoms, and locations where they report they do not experience symptoms. Sometimes, outdoor air testing for comparison purposes is useful (e.g. especially for fungi). One of the fundamental problems with contaminant sampling at the very low levels typically encountered indoors is variability. Background contaminant levels can vary considerably both temporally and spatially, which may result in arbitrary classification of data. IAQ standards and guidelines are discussed in Chapter 6 (What is Normal?), along with resources and factors to consider when interpreting sample results. Sampling methods and equipment are discussed in this chapter and in Appendix J, IAQ Sampling Equipment and Monitors.

SVOCs and EDCs

Semivolatile organic compounds (SVOCs) are a subgroup of VOCs that have higher molecular weights and higher boiling points than other VOCs. Indoors, they may be found as airborne vapors, absorbed in airborne and settled particles, and adsorbed on indoor surfaces. SVOCs are ubiquitous in indoor environments and include pesticides, certain plasticizers, flame retardants, and some components of soot from combustion. They are active ingredients in cleaning agents, pesticides, and personal care products, as well as additives in floor coverings, furnishings, and electronic components. Even foods may contain SVOCs. They may persist indoors for weeks or years when surfaces become contaminated.

At present, the extent of health risks from exposures to many SVOCs in the indoor environment, like VOCs, is uncertain. There is evidence that they can cause a variety of adverse health effects, if the exposures are sufficiently high. Associations include allergies, asthma, respiratory symptoms, endocrine activity, and reproductive effects. Some SVOCs are known to be toxic, such as PCBs, dioxins and pentachlorophenol; some are no longer used because of demonstrated or suspected health effects, such as polybrominated biphenyls (PBBs); and concerns are emerging about potential health effects of others.

Less is known about SVOCs than VOCs in general, because they are challenging to measure and their occurrence indoors is complex. When research studies have shown strong indications of health risks, some SVOCs have been phased out by manufacturers, only to be replaced with new SVOCs with unknown and undefined health risks. There is growing concern about SVOCs with chemical structures that may mimic human hormones and increase or decrease endocrine activity, which can cause a wide range of developmental and reproductive effects. These SVOCs, called endocrine disrupting chemicals (EDCs), may include polybrominated flame retardants, phthalates, pesticides, antimicrobials and polycyclic aromatic hydrocarbons (PAHs).

It should also be noted that some IAQ sampling results for work environments are considered exposure records by OSHA, and are subject to recordkeeping requirements. Additionally, the potential for future litigation involving alleged exposures and health effects should be considered. Therefore, proper written documentation and record retention are important for sampling data, details of the investigation, actions undertaken and final results.

Chemical and Particulate Contaminants

Volatile Organic Compounds/Microbial Volatile Organic Compounds

Significant indoor VOC sources may include new carpeting, carpet adhesives, paint, caulking, window coverings, furnishings, foam cushions, fabric coverings and office furniture made with pressed wood products. User-specific VOC sources can include solvents present in art supplies, cleaning products, disinfectants, air fresheners, dry erase markers, and even the occupants themselves (e.g., perfumes, aftershave, or deodorants).

Microbial VOCs, often referred to as MVOCs, are a variety of low molecular weight organic compounds formed by metabolic actions of bacteria and fungi. They may range from ethanol and butanol to 8 and 9 carbon alcohols, aldehydes and ketones, and are responsible for earthy or "fungus-like" odors.(23) Many MVOCs have extremely low odor thresholds, often in the parts per billion (ppb) range. Although none of them can be regarded as exclusively from microbial growth, or from any particular microbial species, they are of particular interest to the IAQ investigator since they may indicate the presence of active microbial growth. The ability of MVOCs to diffuse from enclosed spaces, from behind presumably impermeable vinyl wallpaper and vapor barriers, or off HVAC filters free of visible contamination, has been of growing interest to investigators seeking to use MVOCs as indicators of mold contamination.

As a general rule, the sampling method for VOCs or MVOCs should have been validated for the low levels typically found in non-industrial environments. Studies using traditional industrial hygiene methods for hydrocarbons or solvents (i.e., charcoal tubes followed by carbon disulfide desorption and analysis by gas chromatography) cannot achieve the parts-per-billion sensitivity usually needed, so alternate methods are required. EPA and National Institute for Occupational Safety and Health (NIOSH) methods to measure VOCs at such lower levels are summarized in Table 5.1.

VOC levels in buildings can be reported either as total VOCs (TVOC), from integrating all the individual responses on a gas chromatogram, or as individual chemicals identified by separate responses. For integrated reports, the TVOC concentration is usually referenced to toluene or hexane response factors. Portable photoionization detectors (PIDs) with high sensitivity (e.g. 1 ppb detection limit) are also used as a measure of TVOC Even though TVOC determinations are used frequently in product emission testing and building certification programs, studies have shown that TVOC measurements have questionable and minimal value when trying to determine the cause of occupant health complaints. The composition of the individual VOCs within the TVOC mixture varies widely among buildings, and the odor thresholds and potencies of the individual VOCs causing sensory irritation also varies greatly.[24]

TABLE 5.1 – Parts-Per-Billion Level VOC Sampling and Analytical Methods

Method	*Description*	*Reference*
EPA TO-1 and TO-17	Tenax® sorbent tube or multi-sorbent tube, thermal desorption, gas chromatography/mass spectrometry (GC/MS) analysis	Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air – 2nd ed. (EPA/625/R-96/010b, January, 1999)[25]
EPA IP-1B	Tenax® sorbent tube or multi-sorbent tube, thermal desorption, GC/MS analysis	Compendium of Methods for the Determination of Air Pollutants in Indoor Air (EPA/600/4-90/010, April, 1990)[26]
EPA TO-14A and IP-1A	Summa® canister, cryogenically-cooled trapping, GC and GC/MS analysis	See above[27,28]
EPA TO-15	Summa® canister, multisorbent tube trapping, thermal desorption, GC/MS analysis	Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, See above[29]
NIOSH 2549	Multisorbent tube, thermal desorption, GC/MS analysis	NIOSH Manual of Analytical Methods, 4th ed., 1996[30]
ISO 16000-6	Tenax® TA sorbent tube, thermal desorption, GC/MS or GC/MS-FID analysis	Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax® TA sorbent, thermal desorption and gas chromatography using MS or MS-FID (ISO, 2011)[31]
Hand-held Photoionization (PID) Instrument	ppb range PID, calibrated to isobutylene	Manufacturer's recommendation, provides measure of TVOC on real-time basis

Where a standard EPA or NIOSH method is not available, practical, or otherwise useable, several alternatives have been successfully tested and employed. One such approach involves the collection of samples on selective sorbents (i.e., Tenax® TA and Anasorb® GCBI), with analysis via thermal desorption using GC/MS in select ion monitoring (SIM) mode. This method can detect levels of VOCs in the low ppb range and is routinely used to sample MVOCs. Many VOCs can also now be surveyed at ppb levels with direct reading instruments, such as a photoionization detector (PID).

Regardless of the technique used, careful consideration should be given to the sampling locations. For example, collecting samples in complaint and non-complaint control areas may be useful. In some situations sampling in outdoor locations is a common approach that may be useful to determine relative differences and the contributions of specific VOCs to indoor sources. Given the imprecision associated with sampling for contaminants in the ppb range, special attention should be paid to collecting an adequate, statistically sound number of samples. Additionally, the investigator must determine what concentrations of which VOCs will be considered as either acceptable or indicative of being unusual and possibly triggering complaints. Comparisons between indoor and outdoor VOCs is particularly relevant when looking at specific chemicals typically associated with gasoline powered vehicles, such as benzene, toluene and xylenes, which may be entrained into the building via the HVAC system or pressure differentials.

Another approach to interpreting VOC data is to rank the individual contaminants identified at each sample location by decreasing order of concentration. A comparison of the rank order of contaminants in complaint area samples, with those of control and outdoor samples, might

VOCs and Odor from Carpeting

Occupants of a renovated office space complained of chemical odors. Interviews and a visual inspection were conducted. Carpet tiles emitted a strong vinyl like odor and a white residue was found on the backing of the carpet tiles when they were peeled back. Concrete moisture was not elevated compared to the carpet tile manufacturer's recommendations for moisture content. However, pH was elevated (pH>10) at some locations beneath the carpet tile. It was concluded that the elevated pH may have contributed to degradation of the carpet tile backing, resulting in the odor. The investigator recommended removal of the carpet tile and adhesive, scarifying of the concrete surface, and then installing new carpet tile. Subsequently, occupants reported that the odor had disappeared.

(For more information see "Contaminant emission rates from PVC backed carpet tiles on damp concrete" available at: http://www.iee-sf.com/resources/pdf/PVCCarpetEmissions.pdf) suggest specific VOCs at higher levels in the problem area. Owing to a lack of conclusive health data for exposures to very low VOC concentrations, the practitioner is cautioned against drawing cause-and-effect relationships based on VOC measurement data alone.

There are other ways of interpreting VOC data. Aside from workplace occupational exposure limits (e.g. Permissible Exposure Limits, Threshold Limit Values and Recommended Exposure Limits) which are not relevant in non-industrial environments, there are published values related to normal, non-complaint buildings. These include the U.S. EPA VOC data gathered from the Building Assessment and Study Evaluation (BASE) study, in which approximately 100 office buildings were evaluated, including measurement of selected VOCs. These and other data are presented and discussed in Chapter 6 (What is Normal?).

Formaldehyde in FEMA Trailers and Laminate Flooring Products

Many of the temporary housing trailers supplied by the Federal Emergency Management Agency (FEMA) following Hurricanes Katrina and Rita were found to contain elevated levels of formaldehyde, allegedly due to faulty construction practices and the use of substandard building materials. Occupants reported suffering from breathing difficulties, flu-like symptoms, eye irritation and nosebleeds and filed a class-action suit against the trailer manufacturers.

More recently, media reports and pending litigation regarding formaldehyde emissions from Chinese-made laminate flooring have caused concerns among many homeowners, builders, and suppliers.

In response to public concerns about potential formaldehyde exposures, AIHA created an online Formaldehyde Resource Center (https://www.aiha.org/publications-and-resources/Pages/AIHA-Formaldehyde-Resource-Center.aspx), including FAQs, a fact sheet, and technical guidance on laminate flooring outgassing.

Formaldehyde

Many modern office furnishings, building materials and finish surfaces contain formaldehyde that can be slowly released into the indoor environment. These include fabrics, foam cushions, adhesives, pressed wood products, laminate flooring, manufactured wood (laminated beams), insulation and other sources. Formaldehyde has historically been an issue in new or remodeled construction, where numerous and multiple formaldehyde sources are present and the vapor can accumulate. For many individuals, the first symptom of exposure is eye irritation, which is a common complaint of some building occupants. Airborne formaldehyde may be measured to determine whether concentrations are elevated in the problem area when compared with control areas or IAQ guidelines.

The sampling method used for formaldehyde should be one that has been validated for the low concentrations (e.g., detection limit of 10 ppb or lower). The methods generally used for these levels include: EPA TO-11A, EPA IP-6A or ASTM D5197 using a DNPH (2,4-dinitrophenylhydrazine) coated sorbent tube for active sampling and high performance liquid chromatography (HPLC)/UV analysis; or EPA IP-6C using a DNPH passive sampler and HPLC/UV analysis.[32-36] There are also several commercially available, portable real-time formaldehyde instruments for readings at the ppb level. These methods are summarized in Table 5.2.

As with sampling for other VOCs, testing locations for formaldehyde typically include both complaint and control areas. One possible approach to interpreting the data is to compare concentrations at each sample location versus the intensity of complaints in those locations. If this approach identifies higher levels in the problem areas, the investigator can evaluate the extent to which off-gassing of particular products, and/or inadequacies in ventilation, may be contributing to the problem. With the tentative identification of a source, the investigator may wish to consider off-site controlled testing (i.e., chamber testing) of the suspected article(s) by a competent third-party laboratory. Select an ISO 17025 accredited laboratory whose accreditation covers the requested test methods.

Ozone

Sources of ozone in office environments may include photocopy machines, printers, electric motors, blue-line drawing machines, certain types of portable air cleaners, and outdoor air. Exposure to ozone can cause eye irritation, chest pain, coughing, throat irritation and congestion, and can worsen symptoms of bronchitis, emphysema and asthma in persons with such pre-existing respiratory disorders. Typical ozone monitors are based on ultraviolet absorption and electrochemical technologies. Colorimetric tubes specific for ozone may also be used near specific source locations. It is important to measure outdoor ozone levels for comparison, since it is a common outdoor air pollutant. Formaldehyde and ozone measurement techniques are summarized in Table 5.2.

TABLE 5.2 – Parts-Per-Billion Level Formaldehyde and Ozone Sampling and Analytical Methods

Parameter	*Method*	*Description*	*Reference*
Formaldehyde (and other aldehydes/ carbonyls)	EPA TO-11A	DNPH* sorbent tube, high performance liquid chromatography (HPLC)/UV analysis	Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air – 2nd ed.[32]
	EPA IP-6A	DNPH sorbent tube, HPLC/UV analysis	Compendium of Methods for the Determination of Air Pollutants in Indoor Air[33]
	EPA IP-6C	DNPH passive sampler, HPLC/UV analysis	See above[34]
	ASTM D5197	DNPH sorbent tube, HPLC/UV analysis	Standard Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Air[35]
	ISO 16000-3	DNPH sorbent tube, HPLC/UV analysis	Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air -- Active sampling method[36]
	Real-time instruments	Various detection methods, specify at least 10 ppb detection limit	Manufacturer's recommendation
Ozone	ISO 13964	Real-time UV photometric analyzer	Determination of ozone in ambient air -- Ultraviolet photometric method[37]
	ASTM D5149-02	Real-time ethylene chemiluminescence analyzer	Standard Test Method for Ozone in the Atmosphere: Continuous Measurement by Ethylene Chemiluminescence[38]
	Real-time instruments, ozone detector tubes, ozone test strips	Various detection methods, specify at least 10 ppb detection limit	Manufacturer's recommendation

DNPH = 2,4-dinitrophenylhydrazine*

Carbon Monoxide and other Combustion Products

IAQ inspections should include an estimate of the occupants' exposure to CO, unless it can be confirmed that no combustion sources are contained within, or are immediately adjacent to, the facility. This is especially important in situations where occupants report persistent headaches. Other combustion products (e.g. oxides of nitrogen) may be measured in the indoor environment when the nature of the complaints or the findings of the initial investigation point to either a specific type of combustion products, or to suspected combustion

Corrosive Drywall in Buildings

In 2001, some homes and larger buildings built or renovated in the U.S. were found to contain drywall that emitted sulfur gases, such as hydrogen sulfide, mercaptans, and others; this was termed corrosive drywall (CDW), because it attacked certain metals such as copper. The majority of complaints regarding CDW have been from Florida, Louisiana, Mississippi, Alabama and Virginia. The CDW appears to have originated from a certain Chinese mine where gypsum that contained sulfur compounds was mixed with oil shale and then made into gypsum board. That material was found to emit sulfur gases in the low parts per billion (ppb) levels, adversely impacting the air quality in the affected homes and other buildings. Odors (e.g., smell resembling a burnt match or sewage), visible corrosion of copper (in AC cooling coils, piping and uninsulated wiring) and silver (in electrical circuit boards) items have all been associated with the installation of this product. Occupants have also reported various health concerns, such as irritated and itchy eyes and skin, difficulty in breathing, persistent cough, bloody noses, runny noses, recurrent headaches, sinus infection, and asthma attacks. As of late 2014, the Consumer Product Safety Commission (CPSC) had received over 4,000 complaints alleging damage caused by CDW. It is likely that CDW is present in tens of thousands of single and multi-family residences constructed or renovated in or after 2001, along with an unknown number of commercial and public buildings. Efforts to eliminate CDW emissions while leaving the drywall in place generally have not been successful. When CDW is widespread through a home or other building (i.e., detected in the majority of rooms), complete removal of all drywall and adjacent insulation is a prudent approach to facilitate dust and odor elimination.

(For more information, see AIHA White Paper on Corrosive Drywall, 2010, and Assessment and Remediation of Corrosive Drywall: An AIHA Guidance Document, 2013. Both available at http://www.aiha.org.)

sources. Notable combustion sources include natural gas-fired furnaces, boilers, water heaters, cooking stoves or unvented heaters (regardless of any “ventless” labeling claims), as well as vehicular traffic, including all types of fossil-fueled industrial trucks.

Typical natural gas combustion by-products may include nitrogen oxides (NOx), CO, CO_2 and methane. Emissions from combustion of other fossil fuels (i.e., diesel fuel) can also contain sulfur dioxide (SO_2), VOCs, polynuclear aromatic hydrocarbons (PNAs or PAHs) and soot (including ultrafine particulate matter). Sampling methods will depend on the specific compound and detection limit desired and may include colorimetric detector tubes, direct-reading instruments, and active or passive sampling devices. Real-time instruments are available for a variety of different combustion products, including CO and oxides of nitrogen and sulfur. Experience has shown that such devices operated in a data-logging mode can be very useful in identifying concentration peaks throughout the day. When peak concentrations are correlated to logged health complaints from occupants, it may be possible to identify cause and effect relationships, and pollutant source locations.

The generation of combustion by-products often shows a definite time pattern, and the investigator must ensure that sampling takes place when and where sources are most likely to be found. Sampling sites might include the complaint area, a control area, and areas between the complaint area and suspected combustion sources. These intermediate locations may help to identify pathways for the combustion products to travel from the source to the complaint area.

Real-time ultrafine particle counters and other direct reading instruments are very useful in helping to identify such pathways. The outdoor air must also be sampled, either upwind of the building or by the HVAC outdoor air intakes, and at several different times during the course of the day, in order to determine ambient concentrations and their potential influence on the testing.

The interpretation of combustion product sampling results usually consists of a relatively straightforward comparison of concentrations in problem areas with those of control and outdoor areas, and exposure limits. CO, for example, may routinely be detected indoors in single-digit ppm concentrations, particularly in urban environments, because of ambient air pollution. Such concentrations are unlikely to be the cause of any IAQ complaints or concerns. However, when outdoor CO concentrations exceed ambient air quality limits, they might contribute to discomfort in some individuals indoors. If the concentrations of combustion products indoors significantly exceed outdoor levels, the building should be examined carefully to locate the sources of combustion products, regardless of their relationship to the reported symptoms.

Occupants in an office building were complaining about being bitten by dust mites. Samples collected of settled dust in the space indicated that there were numerous small fiberglass fibers present. An inspection of the roof mounted HVAC package unit revealed that the internal fiberglass insulation was damaged and eroding. The fiberglass sound liner insulation was removed and replaced with closed-cell foam insulation. In addition, the supply air ducting and entire office space was professionally cleaned to remove residual fiberglass particles. These actions resolved the complaints.

Particulate Matter and Fibers

Air and surface dust sampling for particles and fibers may be performed when the initial investigation indicates visual evidence of excessive dust, when complaints consist of skin and/or respiratory irritation and possible allergic reactions, or when the facility is located near sources of possible particulate emissions (e.g., buildings located adjacent to a construction site, or a dust emitting industry such as a quarry or similar source). In such instances, sampling may be warranted to show suspected pathways of particulate, such as from mechanical equipment or construction activities. Fiberglass, which is widely used in building materials, insulations and furnishings, can be an IAQ concern if it becomes airborne. Similarly, other fibers (both natural and synthetic) from furnishings and other sources may be a concern.

A variety of sampling and analytical techniques are available to the IAQ investigator. Air sampling may be performed using filter cassettes or with direct reading (optical light-scattering) instrumentation. Cyclones can be used with the filter cassettes to differentiate between total and respirable dust. Multi-stage impactors can be utilized to differentiate and distinguish particle size ranges. Handheld dust monitors are also available which can simultaneously measure aerosol concentrations corresponding to PM_1, $PM_{2.5}$, respirable and PM_{10} fractions. Generally, the respirable fraction of dust (rather than total airborne dust) is the most useful measure in IAQ studies.

Particles designated “respirable” are less than 10 micrometers (µm) in diameter and typically fall into two general categories: those larger than 2.5 µm, and those smaller than 2.5 µm. Ultrafine particles are generally described as particles less than 0.1 µm in diameter (i.e., 100 nanometers).

Surface wipe, micro-vacuum or tape-lift samples may be taken to identify the constituents of settled dust, and analyzed to relate to specific sources and determine if settled dust is a reflection of suspended particulate matter exposures. ASTM Method E1216 gives a procedure for taking tape-lift samples.[39]

Analysis of airborne dust samples may consist of gravimetric determination of total or respirable particulate, or particulate and fiber characterization using polarized light microscopy (PLM), scanning electron microscopy (SEM), transmission electron microscopy (TEM) and/or X-ray diffraction (XRD). Where contamination from

PCBs in Buildings

Polychlorinated biphenyls (PCBs) are a group of man-made chemicals associated with a potential risk to human health and the environment. PCBs have been demonstrated to cause cancer in laboratory animals, as well as a variety of other adverse health effects involving the immune system, reproductive system, nervous system and endocrine system. They were first manufactured in the 1920s and used in a variety of industrial and commercial applications including electrical equipment, hydraulic fluids and insulating materials. PCBs were also used in many building materials, particularly caulking, grout, expansion joint material and paint, from approximately 1950 to 1978. The manufacture of PCBs was banned in the U.S. in 1979. There is growing evidence that PCB exposures, in both vapor and particulate matter form, arise from PCB-containing products in the building environment. Additionally, secondary sources of PCBs can contribute to the overall exposure. The sources include materials that have become contaminated due to absorption from direct contact with PCB sources, or through adsorption of airborne PCBs emitted by primary sources, such as caulk or light ballasts. In most cases, the building owners and occupants are not even aware of the existence of these chemicals. PCBs have not been associated with common IAQ complaints, like eye and respiratory irritation, but there are other concerns. While testing for PCBs in building materials is not required by the EPA at this time, building owners should be aware of their possible presence. Assessment of suspect building materials should be made prior to any significant disturbance of the materials to help ensure the safety of both building occupants and maintenance/construction workers. (For more information see AIHA White Paper on PCBs in the Built Environment, 2013. Available at http://www.aiha.org.)

diesel exhaust is suspected, such as from fresh air intakes located by loading docks, the use of a diesel particulate matter sampler via NIOSH Method 5040 may be warranted.[40] Anaysis for other agents, such as lead, may be useful in some situations (e.g. where lead hazards are suspected). Chemicals including certain pesticides can be analyzed from wipe samples.

Biological Contaminants

Microorganisms and Allergens

Investigation for microorganisms is often called for when there has been a water intrusion problem in a building, be it an internal (e.g., plumbing leak) or external (e.g., flood of water intrusion through the building envelope) event. Such investigations may include a visual examination, and in some situations, be coupled with sampling and analysis. Sampling may include surface and air sampling.

Sampling should be considered when there is evidence that Building Related Illness (BRI) may be present (e.g., Legionnaires' disease, Pontiac Fever, hypersensitivity pneumonitis, or pronounced respiratory allergies). Air, water, bulk, and/or surface samples may be collected. Sampling sites for potential sources of water-borne bioaerosols, such as *Legionella* bacteria, may include cooling towers, hot and cold domestic water systems, and decorative fountains. Specific information on inspecting and evaluating building water systems for *Legionella* is available in the AIHA® guideline, *Recognition, Evaluation and Control of Legionella in Building Water Systems*.[41]

Sampling for airborne fungi may be warranted in some cases, but it must be performed in conjunction with a detailed visual inspection. Endotoxin, MVOCs, protozoa, and other agents may also be sampled, although this is not common in most IAQ evaluations.

The National Institute for Occupational Safety and Health (NIOSH) and other agencies give the following general position and recommendations, which is consistent with the current consensus among scientists and medical experts.[12,42]

- Visible water damage, chronic damp materials, visible mold, and mold odor indicate an increased risk of respiratory symptoms.

- NIOSH does not recommend routine air sampling for mold in damp building evaluations because air concentrations of molds or spores cannot be interpreted with regard to health risk and they are highly variable over time.
- Instead, NIOSH encourages detection by thorough visual inspections and detection via musty or moldy odors. Building consultants can sometimes identify sources of dampness with visual observations, moisture meters and infrared cameras.
- In cases where there is no visible sign of dampness, but musty or moldy odors are still present, strategies for detection of hidden mold (e.g., the use of a borescope, destructive opening and inspection of cavity or hidden areas) should be considered.
- The most important steps in dealing with indoor dampness or mold are to identify the source of moisture and to take the necessary steps to make repairs to stop them.

Inspections for hidden mold are discussed further in Chapters 6 and 10 of the AIHA® publication, *Recognition, Evaluation, and Control of Indoor Mold*.[43]

Bioaerosol and microbial sampling, analysis, and data interpretation can be very complex. The investigator must develop a clear sampling strategy, and a plan on how to evaluate that data, before collecting any samples. The investigator must realize that sampling data (particularly air sampling data) represents only a "snapshot" in time and interpretation of that data must take this into account. How representative is the sample if only a small volume of air or surface area is sampled, as compared to the total area of concern? The possibility for false negative and false positive results can be quite high because of the wide variability in bioaerosol concentrations (both spatially and temporally), as well as in the sampling and analytical methods used. Some of the factors that can adversely affect sampling results are given in Table 5.3.

When the decision has been made to sample for microorganisms or allergens, resources such as the ACGIH® *Bioaerosols: Assessment and Control*[17] and the AIHA® publications, *Recognition, Evaluation, and Control of Indoor Mold*[43] and *Field Guide for the Determination of Biological Contaminants in Environmental Samples*, 2nd edition[44] can be consulted in evaluating the facility, the design and execution of the sampling strategy, and interpretation of microbial and allergen data, including bioaerosol concentrations and the results of surface sampling.

TABLE 5.3 – Factors Known to Affect Bioaerosol Sampling Results

Factor	*Issue*
Environmental or Geographic	Snow cover or vegetation; prevailing temperature and humidity; flooding frequency and patterns; rainfall; time of day; construction and landscaping activities; rural versus urban; season; geographic region
Sampler	Sampling duration; sampler type and performance (impactor versus impinger versus filter versus spore trap); flow rate; height of sample collected
Sampling Media (culturable samples)	Nutrient agar type used; presence of antibiotics; water quality used for agar prep; media expiration date; temperature
Analysis	Temperature and relative humidity in incubator; light versus dark conditions; time allowed for growth; percent trace analyzed (for spore traps); analyst experience and training
Other	Bioaerosol concentration; activity of sampler prior to and while collecting samples; sample storage and handling conditions

Dust samples from carpet or surfaces within the occupied spaces may also be collected and analyzed for fungi and bacteria, or allergens from fungi, cat, dog, mice, dust mites, and cockroaches. Samples are typically collected by vacuuming dust from a pre-measured area using a filter cassette or other dust collection device attached to a vacuum pump. The results are typically compared to published data (see Chapter 6, What is Normal?). Generally, a minimum of 100 mg of dust is needed for allergen and fungi analysis.

Radon

Although not a cause of typical IAQ complaints, radon gas and radon decay products may be a concern within the built environment. Radon concerns usually are related to specific geographic areas, since the primary source is from the gases underlying a building or house. The general emphasis of radon problems is concentrated around residential and school buildings, but the IAQ investigator should be aware that commercial and office buildings may also be affected. The EPA states that radon is the largest source of radiation exposure and risk to the general public, and is the second-leading cause of lung cancer after smoking. They publish guidelines and recommendations for testing and remediation of radon problems[45,46], as well as detailed maps showing geographical areas with the potential for radon emissions.[47] EPA recommends all homes (and apartments below the 3rd floor) and schools be tested for radon regardless of geographic location. Appendix K gives details about radon occurrence, sampling methods, standards and guidelines, and mitigation methods.

> An elementary school in the Chicago area tested for radon using short term passive measurement devices. Levels exceeded the EPA action level in several classrooms that were built on slab on grade. Follow-up longer term testing confirmed the levels. Parents called for the students to be relocated. The local health department stated evacuation wasn't needed until levels reached 100 pCi/L, which was in agreement with EPA recommendations. However, due to parental pressure, the school district temporarily relocated the students and installed a radon mitigation system. Ongoing radon testing indicated levels below the EPA action level in the classrooms.

HVAC Studies

When the results of the initial HVAC evaluation indicate a need for further evaluation of all or part of the system, the investigator is encouraged to collaborate with a qualified and experienced mechanical engineer or HVAC technician. Specialized studies of any HVAC system are likely to require a review of the original facility commissioning data and design specifications (if available), and/or the recollection of similar information. An HVAC investigation may need to be performed to determine if the original design was adequate. Furthermore, changes in the building or the HVAC over the years since the facility was commissioned should be understood and evaluated to determine what effect they may have had on the operation of the HVAC system.

> A chimney sweep was called in to clean the ductwork because of grit coming from the HVAC system. The work caused more particulate matter to enter the occupied areas, creating a very unclean environment and stressful situation. The solution included a thorough cleaning of the air handler and replacement of the ductwork.

Spray Polyurethane Foam (SPF) Insulation (see Figure 5.1)

Spray polyurethane foam (SPF) is an energy-efficient type of insulation and air sealant material. However, exposures to one of its ingredients, isocyanates, and other SPF chemicals in vapors, aerosols, and dust during and after installation can cause health complaints. For example, airborne isocyanates are linked to asthma, sensitization, lung damage, other respiratory and breathing problems, and skin and eye irritation.

Building occupants may be exposed to SPF chemicals during SPF installation if the work area is not properly isolated and ventilated. After application, vapors may linger in a building until properly ventilated. Typical wait time following application is 24 hours before re-occupancy. Cutting or trimming the foam as it hardens may generate dust that may contain unreacted isocyanates and other chemicals. After application, dust may linger in a building until properly ventilated and thoroughly cleaned. Any heat-generating processes such as drilling, welding, soldering, grinding, sawing, or sanding on or near SPF may generate airborne chemicals, including, isocyanates, amines, carbon dioxide, carbon monoxide, hydrogen cyanide, or nitrogen oxides.

After applied and cured, SPF is considered relatively inert; however, there are situations where the cured foam may pose potential risks. These include heating or grinding of SPF by maintenance workers, and disturbance of SPF or hot work done on or near it in building renovation, demolition or disassembly.

If building occupants have concerns that they may be exposed to residual SPF chemicals, potential off-gassing, or continue to smell odors, the U.S. EPA advises:

- Immediate medical attention for breathing problems or other adverse health effects.
- Contact contractor and/or product manufacturer for help in solving the problem if SPF is shown to be the source.
- If concerns not resolved, contact local or state consumer protection office or contractors' licensing board.
- Consumers should file an online Consumer Product Incident Report with the U.S. Consumer Product Safety Commission on SaferProducts.gov website if SPF is considered to be the problem.
- Work with the contractor to identify the problem or consider hiring an IAQ consultant. If you are consulted to investigate such a problem, use the most current sampling/analytical protocols. For example, ASTM Subcommittee D 22.05 Indoor Air Quality is developing test methods to determine VOCs, diisocyanates, oligomeric isocyanates, and amine catalysts emitted from SPF insulation products in buildings (ASTM WK30960).

Note: Removal may not resolve the problem and may create other problems. If SPF was not applied properly, chemicals may have migrated to surfaces elsewhere in the building and may cause residual odors. Also, disturbing SPF material might generate dust or hazardous materials if done improperly, especially if heating SPF. (For more information see EPA Design for the Environment, Steps to Control Exposure. Available at http://www.epa.gov/dfe/pubs/projects/spf/steps_to_control_exposure.html.)

A specialized HVAC study may include an engineering evaluation of central systems to verify the system's capacity for heating, cooling, providing outdoor air, and distributing conditioned air. An updated air balance study might be required to verify whether air distribution is appropriate and adequate for the thermal load (occupants and equipment), distributed according to design, and whether pressure differentials between areas and/or zones is correct. Whereas basic functionality of the system should have been determined in the initial HVAC evaluation, at this time a calibration check on controls such as thermostats, actuators, and control motors may be warranted.

Specialized studies also may include precise determination of outdoor air supply to the occupiable spaces. One method of doing this is a tracer gas study to verify outdoor air supply and the pathway of a suspected pollutant.[48,49] Tracer gases such as introduced carbon dioxide, nitrous oxide, or low levels of easily detected halocarbons may be employed for these studies. Measurement of carbon dioxide concentrations over time can be a useful indicator of outdoor air supply in buildings, if the concentrations are allowed to reach steady-state or equilibrium levels. This requires a relatively high occupancy load for a period of time. For example, at an occupancy load of 5 occupants for each 1000 square feet of area, equilibrium of CO_2 may be reached within 5 to 6 hours after occupancy begins. Measurements taken in buildings with lower occupancy loads or before equilibrium is reached may result in incorrect conclusions.

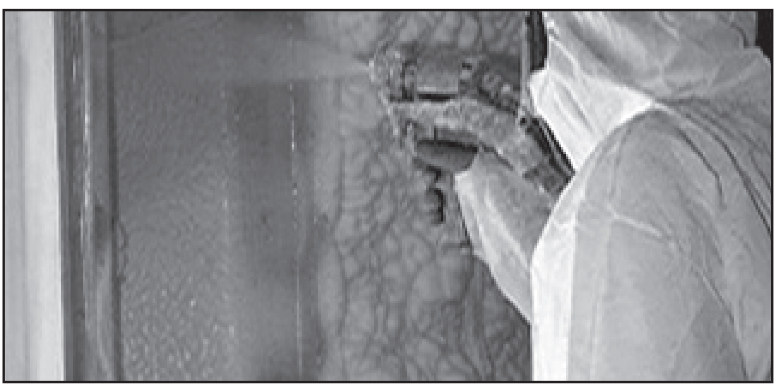


Figure 5.1 – Open-Cell SPF Two-component "Professional" High-Pressure Application System (www.epa.gov)

Lighting and Noise

When lighting issues cannot be corrected with commonly recommended solutions (see Appendix F), more information may be needed. Measuring lighting levels with a light meter to assess lighting problems and comparing to standard guidelines may help. A calibrated light meter specifically designed for measuring workplace lighting should be used. Ideally, it should display in both foot candles (fc) and lux (lx) units, and have a range of at least 1 to 2000 fc or 1 to 20,000 lx. The amount of light falling on a surface is defined as "illuminance", and is measured in lx (metric unit = lumen/square meter) or fc (English unit = lumen/square ft.). One fc equals 10.8 lx. Measure lighting at workstations and for various tasks that are performed according to standard methods. Lighting survey guidance is given in the current Illumination Engineering Society of North America (IES) Handbook[(50)] and online through the Canadian Center for Occupational Health and Safety[(51)] and the OSHA Computer Workstations eTool.[(52)]

Individual preferences and needs in lighting should be considered; individual task lighting that is adjustable in light intensity and position can be a solution. If lighting problems appear to be widespread, a lighting professional with knowledge and experience in the specific workplace type or setting may need to be consulted to assess the problems and recommend corrective actions.

Noise in an office environment usually never exceeds occupational noise standards that apply in a manufacturing facility to protect workers from hearing loss. Sound levels in most offices are in the 45–60 decibel (dB) range, well below the range for possible hearing damage.

Office Noise Complaint

The Chair of the Physics Department in a Midwestern university complained of noise in his office space. The university requested an investigation and noise survey. Results of noise levels and octave band frequency measurements were compared to recommended ANSI Standard S12.2 Noise Criterion (NC) levels established for different types of rooms and occupancies. For offices, a NC level should range from 30 to 35. Results indicated a NC of 40 to 55 depending on whether the office windows were open and window air conditioner was operating. An exhaust fan under the window outside the office was the primary noise source and the window air conditioner was a secondary source. The university removed the exhaust fan, which was exhausting air from a steam tunnel, and replaced it with an inline fan inside the tunnel that substantially quieted the noise.

However, background or other sounds in an office, especially in an open office environment, can affect a person's comfort and productivity, and potentially their health with increased stress. Sound levels can be measured with a sound level meter and compared to recommended noise level guidelines for office environments. A qualified person should conduct a noise survey using standard procedures such as those described on the OSHA eTools website.[53] The sound level meter can also be used to evaluate equipment that may be causing excessive noise, and to determine the effectiveness of corrective actions taken, such as repairs to the HVAC system or improving acoustics in the area. The current ANSI Standard S12.2, *Criteria for Evaluating Room Noise describes the Noise Criteria* (NC) method of evaluating room noise, which usually pertains to the impact of HVAC or mechanical noise, and is commonly used by acoustical professionals.[54,55] An NC level describes the relative loudness of a space, examining a range of frequencies (rather than simply measuring the decibel level). This level illustrates the extent to which noise interferes with speech intelligibility. Recommended ANSI NC levels for some areas in office buildings are given in Chapter 6 (Table 6.2). Common noise sources in offices and possible corrective actions are given in Appendix G.

Questionnaires

Administration of questionnaires to gather information about building occupants' health and comfort complaints associated with occupancy within the built environment is rarely done. There are some circumstances in which this may be useful. The most common way of gathering this information is to interview those with complaints. Suggested questions to ask are given in Appendix E. However, if a large population needs to be surveyed, a computer based surveying questionnaire may be appropriate. The survey method will need to be carefully designed to collect pertinent information, speed data processing, and ensure confidentiality. Some investigators are concerned that using a questionnaire may result in excessive false positive responses. Questionnaires are generally skewed in favor of complainants (non-complainants are not similarly motivated). Also, questionnaires do not provide the opportunity for follow-up clarification. Examples of questionnaires used successfully in NIOSH and other studies are referenced.[56-58] A questionnaire might typically be distributed to building occupants in complaint and control areas, as it is important that both complaint and control populations are surveyed to determine differences in both environmental conditions as well as in questionnaire response rates.

Completed questionnaires can be reviewed by the investigator to identify patterns of health and comfort complaints in the further development of alternative causation hypotheses. In larger surveys, an epidemiologist may be consulted to identify appropriate study criteria (such as sample sizes, significance of findings, and other statistical considerations).

Medical Evaluation

In some specialized investigations, the use of a thorough medical evaluation of persons reporting health complaints may be appropriate to identify signs and symptoms associated with the environment and the presence of disease conditions. In contentious situations, having occupants evaluated by a physician may not be possible.

When employed, the most effective approach to medical evaluations is to administer them via a third-party physician or healthcare provider who can look for commonalities in symptoms, diagnoses, and potential causes. A primary care physician may find it necessary to refer patients to an allergist, occupational medicine physician, or other specialist (e.g. dermatologist) for further evaluation. In some situations, a physician who is an American Board of Preventive Medicine (ABPM)-certified occupational medicine physician may be helpful. For more information about occupational medicine physicians and their practices, see the American Conference of Occupational and Environmental Medicine (ACOEM) website (www.acoem.org).

An IAQ investigator should provide the physician with information regarding the building and IAQ issues that may be related to the symptoms

> A number of employees thought recent cancers in occupants of a particular area of a building were related to IAQ in the building. Extensive sampling data showed no unusual agents or conditions. The physician's evaluation, personal interviews, and participation in group meetings reassured the employees that the building environment was not related to the recent cancers. The occupational physician's role in the investigation was critical.

reported so the physician can make more informed evaluations of each subject. Because of patient-physician confidentiality, it must be understood that the investigator cannot be privy to the specific, individual findings of the medical evaluations. However, the medical provider should be selected on the basis of his or her ability and willingness to provide the investigator feedback about the signs and symptoms prevalent in the building population the extent to which they may relate to the building environment.

Chapter 6: What is Normal?

Interpreting the results from sampling indoor environments can be challenging. There are few, if any, clear legal limits specifically designated for contaminants found in non-industrial indoor areas, other than the OSHA (or State OSHA) occupational permissible exposure limits. However, there are a number of ambient (outdoor) and occupational air quality standards, and consensus standards and guidelines available to help the IAQ investigator. There is also a growing body of published data from studies of many types of buildings that attempts to characterize what contaminant levels have been measured in "normal" buildings—those that have no IAQ complaints or problems. The EPA's BASE study(59) is one example. Typically, the investigator may need to use several different resources to determine what is considered acceptable or "normal" for chemical and biological contaminants within the modern built environment.

Standards and Guidelines

Table 6.1 lists several agencies and organizations that have standards or guidelines that may be useful for interpreting IAQ data. It should also be noted that available guidelines do not adequately take into account exposure to multiple contaminants at low levels, which is recognized as a common problem in interpreting IAQ data.

TABLE 6.1 – IAQ Standards and Guidelines Resources

Parameter	*Agency Standards/Guidelines*
Regulatory Standards and Guidelines	
Ambient air	U. S. Environmental Protection Agency (EPA): National Ambient Air Quality Standards (NAAQS)[60]
	California Air Resources Board: Ambient Air Quality Standards[61]
Indoor Air	Canada Environmental Health Directorate: Exposure Guidelines for Residential Indoor Air Quality[62]
	California Office of Environmental Health Hazard Assessment (OEHHA): Chronic Reference Exposure Levels[63]
	Texas Department of Health: Texas Voluntary Indoor Air Quality Guidelines for Government Buildings[64]
Occupational	Occupational Safety and Health Agency (OSHA): Permissible Exposure Limits (PELs)[65]
	National Institute for Occupational Safety and Health (NIOSH): Recommended Exposure Levels (RELs)[66]
Consensus Standards and Guidelines	
Indoor Air	American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE): ANSI/ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality[8]
Occupational	American Conference of Governmental Industrial Hygienists (ACGIH®): Threshold Limit Values (TLVs®)[67]
	American Industrial Hygiene Association (AIHA®): Workplace Environmental Exposure Levels (WEELs®)[68]
Other Guidelines	
Indoor Air	World Health Organization (WHO): Air quality and indoor air quality guidelines[69,70]
	ASTM International (ASTM): ASTM Standards on Indoor Air Quality[71]

Indoor Environmental Conditions

The physical parameters that contribute to the quality of the indoor environment may play a large part in an IAQ investigation. Individual preference and sensitivity should be considered in assessing the area. The guidelines presented in Table 6.2 reflect levels or ranges where the majority of building occupants are generally comfortable and able to work productively. Creative solutions may be needed to address concerns of an individual who needs environmental conditions outside the norm.

Chemical and Particulate Contaminants

The workplace exposure levels established by OSHA, NIOSH, ACGIH®, and AIHA® are normally considered inappropriate for use in non-industrial settings. The expectation of occupants within the built environment is for reasonably clean conditions, with no significant accumulations of dust, and generally free of chemical odors. Although this presents a dilemma of creating a double standard, in which industrial workers are expected to tolerate greater exposures to dusts and chemicals as compared to office workers, it is commonly considered that more suitable guidelines for indoor air contaminants include those published by the EPA (NAAQS), Health Canada, California OEHHA, WHO, ASHRAE, and ASTM. Note that public health standards from the EPA and WHO cover only 60 substances, and generally are two orders of magnitude or more lower in concentration when compared to most occupational exposure limits (PELs, TLVs®, RELs, WEELs®), which cover more than 600 substances.

Some of the more restrictive standards and guidelines from the above resources and others are summarized in Table 6.3. The effects of outdoor contaminant levels on indoor levels must always be taken into account when evaluating data. Also, averaging times for the standards and guidelines may be very different from the duration of time office workers are present within a particular indoor environment, so a direct comparison of the data may not be possible.

TABLE 6.2 – Guidelines for Physical Parameters

Parameter	*Guideline Levels*	*Source*
Temperature	Winter: 68° to 75°F Summer: 73° to 79°F	ASHRAE Standard 55 (see Note 1)
Relative humidity	20% to 65% RH	ASHRAE Standard 55 (see Note 1)
Air movement	Basic guideline: Not to exceed 40 fpm at occupant level	ASHRAE Standard 55
	Velocity in occupied area in all directions: Not to exceed 30 fpm for heating Not to exceed 50 fpm for cooling	ASHRAE Standard 113
	Not to exceed 48 fpm	WHO
Ventilation (using carbon dioxide (CO_2) as indicator)	Less than 700 ppm CO_2 over outdoor ambient air (typically around 400 ppm)	ASHRAE Standard 62.1 (see Note 2)
Lighting (measured at work surface)	Visual tasks: High contrast or large size: 30 fc Medium contrast or small size: 50 fc Low contrast or very small size: 100 fc Computer work: Ambient lighting: 30 fc Supplemental individual task lighting: max total at surface of 50 fc	ANSI/IES RP-1
Noise	Not to exceed average of 45 dBA (in open plan offices)	Canadian Research Council
	45 dBA (averaged over 8 or 24 hrs) To prevent activity interference and annoyance in indoor residential areas, hospitals and schools.	EPA
	Office buildings: Private offices 30–35 NC Open-plan areas 35–40 NC	ANSI S12.2

Note 1. General guidelines based on ASHRAE Standard 55 assuming typical conditions for type of clothing, air movement, radiant heat, and other complex factors

Note 2. Guideline based on ASHRAE Standard 62.1 assuming outdoor air supply rate of 15 cfm/person

fc = foot-candles

dBA = decibels (A weighted)

NC = noise criteria

TABLE 6.3 – Selected Standards and Guidelines for Common Indoor Air Pollutants

Pollutant	*Standard (S) or Guideline (G)*	*Source*	*Remarks*	*Levels Commonly found Indoors**
Carbon Monoxide	9 ppm (S)	EPA	8 hr avg outdoor	ND to 4 ppm**
	9 ppm (G)	LEED	and not > 2 ppm above outdoor levels; indoor preoccupancy limit	
	10 ppm (G) 25 ppm (G)	Health Canada	24 hr avg indoor residential 1 hr avg indoor residential	
	6 ppm (G) 9 ppm (G) 31 ppm (G)	WHO	24 hr avg indoor 8 hr avg indoor 1 hr avg indoor	
Formaldehyde	0.027 ppm (G)	LEED and CA	Indoor preoccupancy limit	< 0.03 ppm
	0.04 ppm (G) 0.1 ppm (G)	Health Canada	8 hr avg indoor residential 1 hr avg indoor residential	
	0.08 ppm	WHO	30 min avg, non-occupational settings	
	0.016 ppm (G)	NIOSH	8 hr avg occupational	
	0.016 ppm (S)	FEMA	8 hr avg indoor trailer	
	0.002 ppm (G)	CA-r	No significant health risk with indefinite exposure	
Nitrogen Dioxide	0.053 ppm (S) 0.1 ppm (S)	EPA	Annual avg outdoor 1 hr avg outdoor	ND to 0.3 ppm**
	0.18 ppm (S)	CA	1 hr avg outdoor	
	0.05 ppm (G) 0.25 ppm (G)	Health Canada	24 hr avg indoor residential 1 hr avg indoor residential	
	0.1 ppm (G)	WHO	1 hr avg indoor	
Ozone	0.075 ppm (S)	EPA	8 hr avg outdoor	ND to 0.03 ppm
	0.07 ppm (S)	CA	8 hr avg outdoor	
	0.05 ppm (S)	CA-ac	Limit on output of air cleaners	
	0.05 ppm (S)	FDA	Limit on output of indoor medical devices	
	0.02 ppm (G)	Health Canada	8 hr avg indoor residential	
Respirable Particulates (PM_{10})	150 $\mu g/m^3$ (S)	EPA	24 hr avg outdoor	3 to 35 $\mu g/m^3$
	50 $\mu g/m^3$ (S)	CA	24 hr avg outdoor	
	50 ug/m^3 (G)	LEED	Indoor preoccupancy limit	

TABLE 6.3 – Selected Standards and Guidelines for Common Indoor Air Pollutants (cont.)

Pollutant	*Standard (S) or Guideline (G)*	*Source*	*Remarks*	*Levels Commonly found Indoors**
Fine Particulates ($PM_{2.5}$)	35 µg/m³ (S)	EPA	24 hr avg outdoor	1 to 25 µg/m³
	12 µg/m³ (S)	EPA	Annual avg outdoor	
	12 µg/m³ (S)	CA	Annual avg outdoor	
Lead	0.15 µg/ m³ (S)	EPA	3 mo rolling avg	-
Radon	4 pCi/L (G)	EPA	Annual avg indoor	0.7 to 1.3 pCi/L (homes); avg outdoor 0.4 pCi/L
Sulfur Dioxide	0.075 ppm (S)	EPA	1 hr avg outdoor	**
	0.04 ppm (S)	CA	24 hr avg outdoor	
	0.25 ppm (S)	CA	1 hr avg outdoor	
Hydrogen Sulfide	0.03 ppm (S)	CA	1 hr avg outdoor	-

ND – none detected using standard sampling methods
EPA – EPA National Ambient Air Quality Standard
CA – California Ambient Air Quality Standard
CA-r – California Chronic Reference Exposure Level
CA-ac – California standard for non-industrial air cleaners
FEMA – Federal Emergency Management Administration
FDA – U.S. Food and Drug Administration
LEED – U.S. Green Building Council LEED certification IAQ preoccupancy limits for new construction
PM_{10} – particles with diameters of 10 µm or less
$PM_{2.5}$ – particles with diameters of 2.5 µm or less
pCi/L – pico-curies/liter
** outside levels may affect indoor levels*
*** depending on fuel sources used indoors; levels are normally less than outdoors, unless a significant indoor source exists*

Volatile Organic Compounds/ Microbial Volatile Organic Compounds

Typical total VOC concentrations found indoors range from 50 to 500 to even 1000 µg/m³. In the LEED green building rating system, the target threshold for TVOC in a newly-constructed, pre-occupied building is 500 µg/m³. There are often dozens, sometimes hundreds, of individual compounds present at concentrations of approximately 1 µg/m^3 or more.[(24)] Table 6.4 summarizes VOCs most frequently found in the EPA BASE study of 56 normal public and private office buildings. Twenty-four VOCs with the highest median concentrations are presented. Overall, indoor VOC concentrations ranged from below the limit of detection to 450 µg/m^3. All detectable VOCs had median indoor/outdoor concentration ratios greater than one, suggesting that all detectable VOCs had indoor sources. Five of the VOCs (d-limonene, 2-butoxyethanol, n-undecane, n-dodecane, and hexanal) had median indoor/outdoor concentration ratios near or greater than ten.[(72)]

TABLE 6.4 – VOCs Commonly Found in Normal Indoor Air of Office Buildings[(72)]

VOC	*Concentration Range (µg/m^3)*	*VOC*	*Concentration Range (µg/m^3)*
Acetone	7.1–220	Ethylbenzene	0.3–30
Toluene	1.6–360	Ethyl acetate	0.22–65
m- & p-Xylenes	0.8–96	2-Butanone	0.7–18
n-Undecane	0.6–58	Styrene	0.2–6.7
n-Dodecane	0.5–72	2-Butoxyethanol	0.7–78
Nonanal	1.2–7.9	2-Ethyl-1-hexanol	0.3–48
n-Decane	0.3–50	Octane	0.2–280
o-Xylene	0.3–38	Butyl acetate	0.3–51
d-Limonene	0.3–140	n-Hexane	0.6–21
Benzene	0.6–17	a-Pinene	0.3–8.4
1,1,1-Trichloroethane	0.6–450	Naphthalene	0.3–9.7
Hexanal	0.8-12	1-Butanol	0.8-15

Table 6.5 lists a number of VOCs that have been reported in published, peer-reviewed surveys conducted in office buildings and in new and existing residences in North America.[(73-75)] Listed exposure guidelines for the general population for these VOCs were developed by the California Office of Environmental Health Hazard Assessment (CA OEHHA)[(76)] and the Agency for Toxic Substances and Disease Registry (ATSDR).[(77)] These guidelines represent concentration levels at or below which no adverse health effects are anticipated over the specified exposure duration.

TABLE 6.5 – VOC Guidelines of Interest (CA OEHHA REL update as of June 2014[76] and ATSDR MRL update as of December 2014[77])

	CA OEHHA REL (μg/m³)			ATSDR MRL (μg/m³)		
Compound	Acute	8-hr	Chronic	Acute	Intermediate	Chronic
Acetaldehyde	470	300	140			
Acrolein	2.5	0.7	0.35	7	0.1	
Acrylonitrile			5	217		
Benzene	27	3	3	29	19	10
Bromomethane (Methyl bromide)				194	194	19
1,3-Butadiene	660	9	2			
2-Butanone	13,000					
2-Butoxyethanol				29,000	14,000	966
t-Butyl methyl ether (Methyl-t-butyl ether)			8000	7000	2500	2500
Carbon disulfide	6200		800			935
Carbon tetrachloride	1900		40		190	190
Chlorobenzene			1000			
Chloroform	150		300	490	240	98
1,4-Dichlorobenzene			800	12,000	1200	60
1,2-Dichloroethane (Ethylene dichloride)						2400
Dichloromethane (Methylene chloride)	14,000		400	2000	1000	1000
1,4-Dioxane	3000		3000	7200	720	100
Ethylbenzene			2000	22,000	8700	260
Ethylene glycol			400	2000		
Formaldehyde	55	9	9	49	37	10
n-Hexane			7000	2000		
Naphthalene			9			4
Phenol	5800		200			
2-Propanol (Isopropanol)	3200		7000			
2-Propanone (Acetone)				62,000	31,000	31,000
Styrene	21,000		900	21,000		850
Tetrachloroethene (Tetrachloroethylene, Perchloroethylene)	20,000		35	40	40	40

TABLE 6.5 – VOC Guidelines of Interest (CA OEHHA REL update as of June 2014[76] and ATSDR MRL update as of December 2014[77]) (cont.)

	CA OEHHA REL (µg/m³)			*ATSDR MRL (µg/m³)*		
Compound	*Acute*	*8-hr*	*Chronic*	*Acute*	*Intermediate*	*Chronic*
Toluene	37,000		300	3800		300
1,1,1-Trichloroethane (Methyl chloroform)	68,000		1000	11,000	3800	
Trichloroethene (Trichloro-ethylene)			600		2	2
Vinyl chloride	180,000			1300	77	
Xylene isomers	22,000		700	9000	2600	200

CA OEHHA REL = California Office of Environmental Health Hazard Assessment Reference Exposure Level

ATSDR MRL = Agency for Toxic Substances and Disease Registry Minimal Risk Level

REL = concentration level at or below which no adverse health effects are anticipated for specified exposure duration

MRL = estimate of daily human exposure to hazardous substance with little risk of adverse non-cancer health effects over specified exposure duration

Data from a limited number of MVOC studies show that levels of MVOCs found indoors are typically lower than VOC levels. Table 6.6 compares MVOC levels found in "non-complaint buildings" to those found outdoors and in "complaint buildings." MVOC levels in non-complaint buildings were essentially representative of outdoor air. In complaint buildings, where odor and eye, nose, and throat irritation complaints were common, MVOC levels were approximately seven times higher than typical outdoor levels.[78-80]

TABLE 6.6 – MVOCs from Comparative Field Studies

Location	*MVOC*	*Concentration Avg. and/or Range Found (µg/m³)*
Non-Complaint Buildings		
23 Homes[80]	1-Octen-3-ol	4.1
	2-Pentylfuran	3.7
132 Homes[79]	1-Octen-3-ol	1.8
	Pentan-2-ol	0.2
	3-Methyl-1-butanol	0.7
30 Buildings[78]	Total	2.2–8.8
Complaint Buildings		
30 Buildings[78]	Total	10.1–85.7 (average 29.2)
Outdoors		
27 Samples[78]	Total	1.1–9.5 (average 4.5)

Biological Contaminants

The interpretation of microbiological sampling results is more complex than assessing chemical data. Not only is there a natural background of airborne biological materials outdoors and indoors, but both are highly variable on a daily or even hourly basis. Again, there are no regulatory standards for exposure levels to microbial contamination indoors. The following well recognized resources can assist the investigator:

- ACGIH®: Bioaerosols: Assessment and Control[17]
- AIHA®: Field Guide for the Determination of Biological Contaminants in Environmental Samples, 2nd edition[44]
- AIHA®: Recognition, Evaluation and Control of Indoor Mold[43]

As discussed in the previous chapter, many factors can affect the sampling results. A useful method for interpreting microbiological results is to compare the kinds, or taxa, ranked occurrence, and concentrations of organisms detected in different environments. Usual comparisons are indoors to outdoors or complaint areas to non-complaint areas. For example, in a building without mold problems, the qualitative diversity (taxa) of airborne fungi indoors and outdoors should be similar. Conversely, the dominating presence of one or two fungal taxa indoors and the absence of the same taxa outdoors may indicate indoor mold growth.[81]

The consistent presence of certain fungi indoors, such as *Stachybotrys chartarum*, *Chaetomium spp.*, *Fusarium* or *Ulocladium*, above background concentrations may indicate the occurrence of a persistent moisture problem and a potential atypical fungal exposure. Analytical results from bulk material or dust samples may also be compared to results of similar samples collected from reasonable comparison areas.[81]

The indoor to outdoor comparison must be done with care since some conditions can prevent such a comparison. In addition to statistical limitations, poor weather conditions can suppress outdoor fungal spore concentrations, leading to the false conclusion of amplification indoors. It may be useful for the investigator to obtain airborne microbial concentration ranges by season or month in the geographic region of concern. Some microbiological labs provide this information to their clients.

When assessing allergen data, detailed pollen and mold count data reports, which are regularly available to the public through the National Allergy Bureau of the American Academy of Allergy, Asthma and Immunology (www.aaaai.org/nab/) from counting stations throughout the U.S. and Canada, may be useful. Outdoor airborne fungal concentrations (total culturable or countable fungi) are reported to exceed 1000 cfu/m^3 routinely, and concentrations near 10,000 cfu/m^3 are not uncommon in summer months.[23]

For indoor air, some governmental agencies and groups have proposed guideline upper limit levels that range from 50 to 2000 total cfu/m^3 for fungi in non-contaminated environments. However, these guidelines are not based on health effects, nor are they consistent with findings that average levels in normal non-air-conditioned homes during the growing season often exceed 2000 cfu/m^3.[82,83] In addition, a literature review reported an average culturable fungal concentration of 1252 cfu/m^3 (range 17 to 9100 cfu/m^3) in 820 non-complaint residential structures. This review also noted that fungal concentrations found in residential buildings were consistently higher than those in commercial

> Bioaerosol sampling indicated slightly elevated fungi levels indoors compared to outdoors, but a source was not found. The original investigators did not evaluate the HVAC system. It was determined that filters were missing from the air handlers, which explained why bioaerosol counts indoors were similar to outdoor counts, and in the normal range of variability.

buildings.[84] Thus, using numerical criteria for interpreting airborne fungal results is problematic because of the wide variations and the lack of consensus. The comparative approaches discussed above (e.g. indoor/outdoor, complaint/non-complaint) are the most common methods used when interpreting these data.

Comparisons of total bacteria levels indoors versus outdoors has not been found to be as useful as for fungi, since natural bacteria reservoirs exist in both settings. Comparisons of the specific types of bacteria present, excluding those of known human origin, can help determine building-related sources.[81] Table 6.7 lists the most common fungi and bacteria found indoors in normal buildings, although sampling results may typically report numerous additional genera for any given sample.

TABLE 6.7 – Common Indoor Fungi and Bacteria in Normal Indoor Settings

Fungi	Bacteria
Alternaria	*Staphylococcus*
Aspergillus	*Micrococcus*
Cladosporium	*Flavobacterium*
Penicillium	Gram-negative types

Employees in an office building reported complaints of watery eyes, runny nose, and sneezing. Interviews determined that some of the employees reported allergies to cats, dogs, and dust mites. Many of the employees were mobile workers so work stations were shared. Results from bulk micro-vacuuming of upholstered chairs and carpeting indicated elevated levels of cat allergen in one of the chairs, and lower levels of cat, dog and dust mite allergens in the other chairs. Cat allergens were detected in air samples also. It was concluded that employees who had allergies to cats and who shared work stations with cat owners were potentially exposed to cat allergens. Recommendations were made to replace the upholstered chairs with non-porous mesh style chairs and to conduct a thorough cleaning with HEPA vacuums.

Interpretation of results from settled dust samples collected from carpet and other surfaces is equally challenging. Measurements of total culturable fungi exceeding 10^5 cfu/g of dust collected from carpet or furniture surfaces have been correlated with prior water and mold damage.[85] Another study found levels at 10^6 cfu/g in undamaged residences.[86]

It has been reported that levels of arthropod and mammalian allergens, such as cat, dust mite, and cockroach, in residences range from essentially undetectable to in excess of 10,000 µg/g of dust.[23] In the EPA BASE study, settled dust samples were collected for allergen analysis from 93 normal (non-complaint) office buildings. Table 6.8 shows the percentage of BASE samples by allergen concentration ranges proposed as relative risk thresholds for sensitization to cat and dust mite allergen.[87] A risk threshold for cockroach is listed based on published studies.[88,89]

TABLE 6.8 – Proposed Risk Thresholds for Allergens in Dust Samples[87-89]

	Low	*Moderate*	*High*
Cat *Fel d*1	< 1 µg/g	1–8 µg/g	> 8 µg/g
	77.7%	21.5%	0.8%
Dust mite *Der f*1, *Der p*1	< 2 µg/g	2–10 µg/g	> 10 µg/g
	98%, 99.2%	1.2%, 0.4%	0.8%, 0.4%
Cockroach		2 U*/g	

** U – unit of allergen*

Summary

The measurable contaminants found in indoor environments are rarely at levels known to be harmful, even when occupants complain of discomfort and adverse health effects. Testing may not detect any chemical or biological contaminants above background levels, or exceeding the limit of detection of the sampling method. Alternately, results may appear to show a wide variety of chemicals or biological species present that are actually quite normal. Such equivocal results may prompt the need for the investigator to consider other IAQ complaint causes. Improvements to optimize the environment can always be made, even if only for one very sensitive (or vocal) individual. Although there is an absence of well recognized IAQ contaminant exposure limits for many chemical and biological agents at this time, indoor air can still meet a reasonable standard of quality for the health and comfort of building occupants.

Chapter 7: Considerations for Special Indoor Environments

The IAQ investigation approach detailed in this guide is most applicable to a standard office building with mechanical HVAC systems. However, the investigator should be aware of special IAQ concerns in other types of facilities and environments they may encounter that may require a modified approach. While the approach and methodologies presented earlier may still apply, the investigator may be challenged further with high-risk populations, unusual living and work spaces, spaces that are not meant to be occupied, or other conditions that require the development of more creative investigation and solution strategies. Some of these environments are special because of their occupant populations, which may require special building design and operation, as well as high levels of maintenance and housekeeping to provide good IAQ for the occupants. Some of these include health care facilities, schools and correctional and custodial care facilities. Teaming with appropriate mechanical engineers, technicians and other professionals that know the facility well may be necessary to complete a successful investigation. The following issues are offered for consideration by IAQ investigators when working in these special indoor environments.

Hospitals and Health Care Facilities

The standard of care for IAQ in hospitals and health care facilities is at a higher level than in the office environment. Patients or residents may be more susceptible to contaminants, and immunocompromised patients may be unable to resist infection, even from natural levels of microorganisms. While rare in normal office buildings, Building Related Illness (BRI) may be more common in these environments.

Of primary concern in hospitals and health care facilities is the prevention of outbreaks of serious infections from building sources, especially aspergillosis, legionellosis (Legionnaires' disease), histoplasmosis, tuberculosis and other respiratory infections. Aspergillosis is a concern both for operations and maintenance activities and for construction activities, where dusts and soils containing *Aspergillus* may be disturbed. Although dozens of *Aspergillus* species have been identified in the environment, the number associated with aspergillosis is much smaller, and appears to be limited to *A. flavus, A. fumigatus, A. nidulans, A. niger and A. terreus*.[90]

Legionellosis is typically caused by aerosol mist generation from water systems containing elevated levels of the legionella bacteria, such as from cooling towers, decorative fountains, and domestic water systems (e.g. from showers and sink faucets). Preventative maintenance, pro-active risk management programs and corrective action programs are recommended to prevent the amplification of *Legionella* in water systems.[41,91-94] Histoplasmosis is a serious fungal infection caused by the fungus *Histoplasma capsulatum*, which is found in soils and nesting materials associated with bird or bat droppings. Bird and bat infestations of existing buildings or the disturbance of soil containing droppings may disperse spores and infect susceptible individuals, especially immunocompromised patients. Tuberculosis, flu and other respiratory infections that are transmitted from patient-to-patient and patient-to-staff are special concerns in some health care settings, and special safeguards such as personal protective equipment, isolation rooms, engineered pressure differentials and ultraviolet disinfection may be employed to minimize the transmission of disease.

Many new hospitals are being designed and operated to greatly reduce the risk of infections, including HEPA filtration in HVAC systems for surgical suites and sensitive patient areas.[95-98] However, the impact of renovation or demolition of existing health care buildings on IAQ is in some cases not considered until problems surface during construction. Before beginning a construction project at a medical facility, IAQ concerns should be addressed to minimize potential health impacts.

Because hospitals and some health care facilities operate on a 24-hour, 7-day per week basis, investigations and corrective actions are often difficult to schedule. They must be carefully planned to accommodate the normal operations, since some investigation/remediation activities can adversely affect the delivery of health care services. If not properly controlled, the correction of minor IAQ problems may result in greater potential hazards than the original concerns.

Hospitals handle a variety of hazardous chemicals in laboratories (formaldehyde, organic solvents, phenol, mercury), sterilizers (ethylene oxide, glutaraldehyde), surgeries (anesthetic gases), pharmacies (antineoplastic agents), and morgues (formaldehyde). Emissions from these areas should be controlled by dedicated exhaust ventilation systems. Health care facilities can also contain a number of unique sensitizers and allergens, such as latex, psyllium laxatives, medications, and methyl methacrylate in bone cement. If these well-recognized air contaminant sources are not properly controlled, they may impact occupied areas.

Thermal comfort requirements typically differ for staff and patients. Staff may require lower temperatures since they are moderately active compared to bed-ridden or sedentary patients or residents who may require higher air temperatures for comfort.

Control of odors, especially human bioeffluents, is a continuing problem in many health care facilities, especially long-term care facilities. General ventilation rates may need to be increased to dilute odors to acceptable levels, even at the expense of increased energy use.

Schools

Schools are well-known high-occupancy structures that often are affected by budgetary restrictions that limit preventative maintenance, which may result in IAQ problems. Temporary solutions may be needed until funding is available to fully address identified IAQ problems. Asbestos-containing building materials, lead-based paint, lead pipes and PCB-containing caulks and electrical equipment are frequent concerns in older school buildings, and may be an occupant exposure issue that needs to be addressed to improve IAQ.

Classroom occupant density may exceed design criteria and that of similar spaces in office areas. Classroom occupant density is often two to four times greater than an office area. Because of the higher occupant density, inadequate outdoor air supply is a common issue in school classrooms. Increasing school-age populations often result in the use of prefabricated classroom structures, with their attendant IAQ problems related to formaldehyde in building materials, inadequate ventilation, and mold growth in wall and ventilation systems.

Many schools rely on natural ventilation (e.g. through openable windows and doors), which can introduce high humidity in buildings during humid periods; or no ventilation during time periods when doors and windows are kept closed. Ventilation systems may not be well maintained, which occurs more frequently in schools due to budget constraints. When ventilation systems are turned off for extended periods of time, such as during hot and humid summer months and on weekends, unconditioned humid air will migrate into buildings. This may result in condensation on cool surfaces and cause fungal growth.

Classrooms, including laboratories, arts workrooms and shops contain diverse activities, and a wide range of potential air pollutant sources. Potential asthma triggers, such as animals, may be found in some classrooms. Local exhaust ventilation systems may be missing or inadequate. Some children are more sensitive to contaminants or allergens compared to adults. Carpeting can become problematic in schools, especially when younger children or animals are present, and if carpeting becomes wetted (e.g. from many wet feet entering the space) and is not properly cleaned.

Arts and crafts activities may also release air contaminants indoors, and local exhaust ventilation may be needed to control air

Staff in a large high school reported IAQ complaints for several years. The school was evacuated mid-year and closed by the regional superintendent when hidden mold was uncovered in one area of the school. Students and staff were relocated to another school and mobile classrooms. Investigations were conducted by several consultants and NIOSH. A consulting firm coordinated mold remediation activities as well as HVAC and architectural corrections. The school re-opened the next school year and IAQ complaints declined significantly.

contaminants at the sources. Ceramics classes in particular may need extensive regular housekeeping to minimize contamination on surfaces and resuspension of contaminants into the air during occupied periods.

Schools should be encouraged to set up their own IAQ program with practical approaches to preventing and solving problems, as outlined in the EPA "Tools for Schools" Guidance documents.[99] The "CHPS Best Practices Manual" can help in the design and renovation of schools using IAQ, energy and sustainable building practices.[100]

Recreational Buildings

Recreational facilities must consider the humidity levels from swimming pools, locker rooms, saunas or steam rooms, and human respiration and perspiration. These sources must also be adequately and properly ventilated to control humidity levels and pressurization throughout the building. Indoor swimming pools and saunas are significant sources of humidity, and if not maintained under negative pressure may distribute moisture through wall and ceiling systems and cause mold damage. Ice rinks present potential CO issues from the use of ice resurfacing vehicles (e.g. Zamboni® machines). Food service areas may be a source of odors or preventative pesticide use.

Building maintenance and construction activities may be difficult to schedule while allowing continued use of the facility.

Transportation Facilities

Transportation facilities, such as airport terminals, train stations, and bus terminals, are used by travelers and the staff members who operate and service them. While poor IAQ may not be noticed or problematic to travelers, who are present for short periods of time, they may be the source of complaints by staff who occupy the

Workers in a computer center complained about fine greyish-white dust deposits which kept appearing on their monitors and other horizontal surfaces. The investigation revealed that they were using ultrasonic humidifiers to maintain humidity levels in the center. It was determined that the dust was calcium and other water mineral deposits left behind by the evaporating water droplets from the humidifier.

buildings for longer time periods. The concerns of both groups must be considered to ensure that IAQ issues do not affect the use of the facilities.

Transportation facilities often house food service and other commercial uses that may be a source of odors or other air contaminants. Building maintenance and construction activities may be difficult due to security issues and the need to schedule during periods of low occupancy. Combustion products from vehicle exhaust and cigarette smoking can be problematic if they have not been adequately controlled.

Transportation Vehicles – Land, Sea, Air

Transportation vehicles have widely varying levels of ventilation and IAQ issues. Trains and buses typically have simple pass-through ventilation with heating and cooling. Usually these vehicles do not have humidity controls or exhaust ventilation except perhaps in cooking areas or restrooms. Diesel buses and trains may release diesel exhaust emissions, and studies have documented higher levels of these emissions inside buses compared to outside.[101] EPA advises schools and school districts to replace older diesel buses and to limit school bus idling time to reduce inside as well as outside levels of diesel emissions.[102] Newer hybrid diesel-electric buses produce lower emissions and may stop idling automatically when the bus stops, improving IAQ in the vehicle and in nearby buildings.

Passenger cruise ships are usually well-equipped with supply ventilation systems for engine exhaust, thermal comfort, and special air quality areas. Smaller vessels have more rudimentary systems, and carbon monoxide from engine and generator exhaust has been recognized as a potential IAQ issue for houseboats with gasoline engines. In addition, hot tubs and pools may also present biological and chemical air quality issues due to the elevated water temperature and sanitation schedule (e.g. concerns of Legionnaires' disease and other infectious diseases). The CDC conducts unannounced cruise ship inspections twice per year under the CDC Vessel Sanitation Program (VSP). The objective is to prevent and control the introduction, transmission, and spread of gastrointestinal (GI) illnesses on cruise ships, but improved IAQ may also benefit. Similar programs are in place for cruise lines based in other countries. Ships inspected under CDC jurisdiction include those that carry 13 or more passengers, and have a foreign itinerary with U.S. ports. The inspection includes HVAC systems maintenance and cleanliness, swimming pool and whirlpool spa maintenance and disinfection, pest management practices, potable water systems and food services.[103]

Aircraft flying above 10,000 feet (3000 meters) use cabin pressurization to safeguard passenger and crew. As a result, there may be limited outdoor air ventilation of the cabin space, allowing air contaminants generated within the cabin to increase over time. This may be of greater concern for crew members who may be exposed repeatedly to IAQ problems in aircraft cabins. NIOSH has measured indoor air contaminants, airborne infectious agents, and even ionizing radiation on commercial airline flights to address these issues. CDC's Flight Crew Research Program includes results from various studies.[104] Air contaminants of particular concern included carbon dioxide (as an indicator of poor outdoor air ventilation), CO, odors and ozone, which may be brought into the airplane at certain altitudes. Control strategies include HEPA filtration, CO monitoring, use of ozone converters, and setting minimum outdoor air ventilation levels can help control air contaminants. Low humidity may be an issue to some individuals on long flights, but it is usually not controlled.

Residential Buildings

Particular attention should be paid to combustion sources to ensure that they are properly ventilated. This would include cooking, space heating and hot water appliances. CO emissions can pose a life-threatening hazard, and are frequently caused by failures in the exhaust ducting (e.g. combustion appliance flues or chimneys) and improper pressurization (e.g. negative pressure from exhaust fans or other sources drawing combustion gases into the occupied spaces). In addition to oil- and gas-fired appliances, this concern includes fireplaces and wood burning stoves, which can also be a source of smoke and suspended particulate matter. Houses with attached garages and apartments with underground parking areas pose the potential for CO and combustion gas problems. CO alarm sensors should be installed and operational when any combustion appliance or device is present in a building.

Smoking and vaping in a residential environment can be a significant source of pollutants and odor complaints, especially in multi-family buildings. Allergen levels may be increased by pets (dander) and poor housekeeping (cockroach and other insect allergens). Rooms where moisture can accumulate (e.g., basements, bathrooms, kitchens, and laundry areas) should be inspected thoroughly for microbial growth. Chemicals (cleaning agents, pesticides, and air fresheners) used in homes can be a source of IAQ problems. Products used for crafts or hobbies can also be of concern. The use of a residential space for the illegal manufacturing of methamphetamine or other drugs can result in dangerous chemical residues on finished surfaces. When such activity is known or suspected, surface sampling should be used to confirm or refute the need for chemical decontamination.

Migration of contaminants from spaces such as attached garages (CO), crawlspaces or basements (radon, microbials), or attics (fibers from insulation, microbials) can also affect IAQ.

Resources for the investigator addressing residential settings include the EPA website (http://www.epa.gov/iaq/homes/) and the current ASHRAE Standard 62.2 "Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings," which defines minimum requirements for mechanical and natural ventilation systems and the building envelope to provide acceptable IAQ in residences.[9]

Basic Environments

Dramatic differences in IAQ problems are seen when comparing developed countries and developing countries around the world. One particular issue for developing countries is indoor exposure to emissions from unvented cooking and heating devices that burn liquid petroleum products, such as kerosene, or solid fuels, such as wood, coal, charcoal, crop residues or animal waste. Studies have shown that combustion emissions, combined with inadequate ventilation, may cause high levels of respirable particulate matter, CO, VOCs, and polycyclic aromatic hydrocarbons (PAHs).[69,70,105]

Building materials, construction methods and building codes vary widely around the world. Natural ventilation is more common in basic structures, and can cause air contaminants to accumulate if windows or roof vents are not opened or provided. The use of indigenous building materials can also contribute to problems due to decay, off-gassing, moisture accumulation, or poor performance. In developing countries, outdoor air pollution may significantly degrade indoor air quality.

Fatal CO exposures have been reported in poorly ventilated dwellings, such as vacation cabins and trailers, because of unvented indoor heating or cooking with kerosene, coal, propane and charcoal.

Correctional and Custodial Care Facilities

An obvious concern for operators of correctional facilities is safety and security. Security concerns must be addressed in advance of conducting an IAQ evaluation and recommended corrective measures. Prior to the site visit, the investigation team should meet with the facility operator regarding special procedures to follow at the facility, and review of the tools and equipment that will be used during the investigation. Written procedures for conducting the investigation and an action plan for security emergencies can help in planning and clearly communicating what needs to be accomplished.

During the investigation, communication with occupants or staff may be limited. Security staff may be interviewed to determine specific occupant concerns. The potential that inaccurate information is given due to conflicts between parties (e.g. between staff, inmates, management, etc.) should be recognized.

Some custodial care facilities have less than optimum sanitary conditions due to limited resources. Odors from human bioeffluents can be significant, as well as odors from cleaning and disinfecting products and air fresheners. Ventilation systems should be evaluated to verify proper operation and maintenance and to ensure that adequate outdoor air is supplied to occupied spaces.

Moisture control is essential to minimize microbial growth in institutional buildings. Restrooms, kitchen facilities and similar areas with water service need to be evaluated to ensure that visible fungal growth or malodors are not occurring.

A significant concern in these facilities is control of tuberculosis transmission and other infectious airborne diseases, which may affect occupants, staff, visitors, and the community. The high density and turnover of occupants, along with poor ventilation and sanitary conditions, are contributing factors.

The confined nature of these buildings makes preventative maintenance, renovation, and corrective actions difficult and expensive to accomplish. Extensive planning may be necessary to minimize delays for corrective actions.

The rare books collection staff at a university library was concerned about recent elevated humidity levels. Upon external investigation of the air handler, very limited drainage was noted. Inspection doors were installed in the unit, at which time over a foot of standing water was observed under the cooling coil, and microbial growth the size of marbles was covering the coil. Pressure washing the coil and cleaning the drain trap solved the problem.

Libraries and Museums

Since the primary goal of libraries and museums is to preserve their collections for use by patrons, ventilation systems may have been designed to minimize damage to the collections rather than optimize IAQ conditions for the staff and patrons. Due to common funding constraints, some of these institutions are located in sub-standard structures that can further complicate air quality issues.

Libraries, for example, need to control humidity levels to prevent fungal growth on paper, leather and adhesives in books. Where irreplaceable manuscripts or volumes are being maintained, separate rooms within the library may exist that are equipped with fire detection and suppression systems that prevent wetting of the materials. Dedicated ventilation systems with precise control of temperature and humidity may also be used in these areas.

Museums have additional IAQ concerns in areas where restoration, preservation or research is conducted, or where chemical and biological agents are present in the items being held (e.g. historical items, plant and insect collections). Chemical releases indoors must be controlled by using limited quantities of hazardous materials, closed containers, laboratory hoods or other local exhaust ventilation systems, or increased outdoor air supplied to these areas. Publications including *Health & Safety for Museum Professionals* and *Hidden Hazards within Art & Museum Collections* give additional guidance for the IAQ investigator.[106-108]

Some museums may also have additional chemical hazards from the materials in the collections. For example, restoration of paintings may release pigments containing lead, arsenic, cadmium or other hazardous materials in addition to the cleaning solvents. Natural history museums may have preserved biological specimens using formaldehyde solutions, mercury compounds or arsenic salts, which may be maintained in ventilated cabinets. Historical museums may receive explosive materials or military equipment containing flammable, explosive or possibly even radioactive materials.

Chapter 8: Risk Communication

Given the fact that performing IAQ investigations involves assessment of environmental health stressors in the built environment and their potential risks to occupants, elements of risk communication will almost certainly be involved in the process if risks are identified in the assessment process. Therefore it is imperative that not only must IAQ practitioners be grounded in risk assessment and risk management principles but they must also be able to effectively communicate risk if they are to be considered competent professionals. The importance of being able to effectively and honestly communicate and discuss risk cannot be overstated. Diverse groups may be considered "interested parties" that are vested in the results of a given IAQ investigation. These parties may include building occupants or their representatives, parents or relatives of occupants, building owners or managers, insurers, allied investigators or medical personnel, regulators, the public and in some cases, the media.

Building investigations may involve responding to "IAQ emergencies" where occupants either evacuate a "problem" facility or refuse to enter a building until and unless the causes of their health issues are discovered and addressed. Poor or lack of response on the part of building owners/managers to occupant concerns may elicit feelings of distrust, disrespect or disgust in occupants, parents or the media. A skillful risk communicator has the ability to reduce tensions, relieve anxiety and effect appropriate changes in not only how a building is operated and maintained but also in forming an effective program of conflict resolution and a proactive, on-going program of complaint response and decision-making involving all concerned parties. The practices given in this chapter can apply to very large serious IAQ problems, such as a *Legionella* outbreak affecting a whole building; but they can also apply and be useful in responding to and resolving smaller less serious problems.

According to the EPA report, *Effective Risk and Crisis Communication during Water Security Emergencies, Summary Report of EPA Sponsored Message Mapping Workshops*[(109)], "Risk communication is a science-based approach for communicating effectively and accurately to diverse audiences in situations that are high-concern, high-stress, emotionally charged, and/or highly controversial. Its purpose is to enhance knowledge and understanding, build trust and credibility, encourage constructive dialogue, produce appropriate levels of concern, and provide guidance on appropriate protective behavior and actions following a crisis incident. Although much about risk communication involves elements of common sense, its principles are supported by a considerable body of scientific research as reflected in more than 8,000 articles in peer-reviewed scientific journals, 2,000 published books, and a number of published literature reviews by major scientific organizations such as the National Academy of Sciences."

"As with many other activities, good risk communication requires anticipation, preparation, and practice. This involves anticipating scenarios requiring risk communication, preparing key messages, and practicing delivery in advance of crisis events. Preparing for effective risk communication is an ongoing process that should be an integral component of overall crisis response planning."

Seven General Rules of Risk Communication[109]

The following are examples of best practices for effective risk communications:

1. **Accept and involve stakeholders as legitimate partners**
   - Demonstrate respect for those affected by risk management decisions by involving people early, before important decisions are made.
   - Include in the decision-making process the broad range of factors involved in determining perceptions of risk, concern, and outrage.
   - Involve all parties that have an interest or a stake in the risk in question.
   - Use a wide range of communication channels to engage and involve people.
   - Adhere to highest ethical standards: recognize that people hold you professionally and ethically accountable.
   - Strive for win-win outcomes.
2. **Listen to people**
   - Do not make assumptions about what people know, think or want done about risks.
   - Take the time before taking action to find out what people are thinking: use techniques such as interviews, facilitated discussion groups, information exchanges, availability sessions, advisory groups, toll-free numbers, and surveys.
   - Let all parties who have an interest or a stake in the issue be heard.
   - Let people know that what they said has been understood and what actions will follow.
   - Identify with your audience and try empathetically to put yourself in their place.
   - Acknowledge the validity of people's emotions.
   - Emphasize communication channels that encourage listening, feedback, participation, and dialogue.
   - Recognize that competing agendas, symbolic

meanings, and broader social, cultural, economic, or political considerations often exist and complicate the task of risk communication.

3. **Be truthful, honest, frank, and open**
    - If an answer is unknown or uncertain, express willingness to respond to the questioner within an agreed-upon deadline.
    - Disclose risk information as soon as possible (emphasizing appropriate reservations about reliability); fill information vacuums.
    - Do not minimize or exaggerate the level of risk; do not over reassure.
    - Make corrections quickly if errors are made.
    - If in doubt, lean toward sharing more information, not less – or people may think something significant is being hidden or withheld.
    - Discuss data and information uncertainties, strengths and weaknesses – including the ones identified by other credible sources.
    - Identify worst-case estimates as such, and cite ranges of risk estimates when appropriate.
    - Do not speculate, especially about worst cases.
4. **Coordinate, collaborate, and partner with other credible sources**
    - Take the time to coordinate all inter-organizational and intra-organizational communications.
    - Devote effort and resources to the slow, hard work of building bridges, partnerships, and alliances with other organizations.
    - Use credible and authoritative intermediaries between you and your target audience.
    - Consult with others to determine who is best able to take the lead in responding to questions or concerns about risks: establish and document agreements.
    - Do not attack those with higher perceived credibility.
    - Cite credible sources, issue communications together with, or through, other trustworthy sources.

5. **Meet the needs of the media (if relevant; this is uncommon)**
   - Be accessible to reporters; respect their deadlines.
   - Prepare a limited number of key messages in advance of media interactions; take control of the interview and repeat or bridge to your key messages several times.
   - Provide information tailored to the needs of each type of media, such as sound bites and visuals for television.
   - Provide background materials on complex risk issues.
   - Say only those things that you are willing to have repeated by the media: everything you say is on the record.
   - Keep interviews short: agree with the reporter in advance about the specific topic of the interview and stick to this topic during the interview.
   - Always tell the truth.
   - If you do not know the answer to a question, focus on what you do know and tell the reporter what actions you will take to get an answer.
   - Stay on message; bridge to important messages.
   - Be aware of, and respond effectively to media pitfalls and trap questions.
   - Avoid saying “no comment.”
   - Follow up on stories with praise or criticism, as warranted.
   - Work to establish long-term relationships of trust with specific editors and reporters.
6. **Speak clearly and with compassion**
   - Use clear, non-technical language appropriate to the target audience.
   - Use graphics and other pictorial material to clarify messages.
   - Avoid embarrassing people.
   - Respect the unique communication needs of special and diverse audiences.

- Understand that trust is earned – do not ask or expect to be trusted by the public.
- Express genuine empathy; acknowledge, and say, that any illness, injury, or death is a tragedy and to be avoided.
- Personalize risk data: use stories, narratives, examples, and anecdotes that make technical data come alive.
- Avoid distant, abstract, unfeeling language about harm, deaths, injuries, and illnesses.
- Acknowledge and respond (in words, gestures, and actions) to emotions that people express, such as anxiety, fear, anger, outrage, and helplessness.
- Acknowledge and respond to the distinctions that the public views as important in evaluating risks.
- Use risk comparisons to help put risks in perspective; avoid comparisons that ignore distinctions people consider important.
- Identify specific actions that people can take to protect themselves and to maintain control of the situation at hand.
- Be sensitive to local norms, such as speech and dress.
- Strive for brevity, but respect a person's desire for information and offer to provide needed information within a specified period of time.
- Always try to include a discussion of actions that are underway or can be taken.
- Promise only that which can be delivered, then follow through.

7. **Plan thoroughly and carefully**
    - Begin with clear, explicit objectives – such as providing information, establishing trust, encouraging appropriate actions, stimulating emergency response, or involving stakeholders in dialogue, partnerships, and joint problem solving.
    - Identify important stakeholders and subgroups within the audience – respect diversity and design communications for specific stakeholders.

- Recruit spokespersons with effective presentation and personal interaction skills.
- Train staff – including technical staff – in basic, intermediate, and advanced risk and crisis communication skills: recognize and reward outstanding performance.
- Anticipate questions and issues.
- Prepare and pretest messages.
- Carefully evaluate risk communication efforts and learn from mistakes.
- Share what you have learned with others.

Chapter 9: Report Preparation

One of the most important skills that an IAQ investigator can have is the ability to write a clear and concise report detailing the findings of their investigation and the actions required to resolve the problem(s). It is important to note, however, that a report is only as good as the work and data that it is presenting. If the investigative work was poorly done and incomplete, then the report detailing that work will be equally inferior. Conversely, thorough and comprehensive investigative work must be presented in a quality report in order for it to be used effectively. The following guidance is based upon documents produced by the Australian Institute of Occupational Hygienists (AIOH)[110] and the British Occupational Hygiene Society (BOHS).[111]

ABCs of Writing

When preparing any report, it is important to remember the ABCs of writing:

Accuracy: The report must present technical content and data that is accurate, consistent, and grammatically correct.

Brevity: The report should be brief and to the point. Do not include irrelevant information.

Clarity: Keep the report simple, avoid using technical jargon as much as possible and emphasize what actions need to be taken to correct the problem.

It is also essential that the author consider who will read the report, the level of their knowledge and expertise, and what information they expect to see in the report. In some situations, it is appropriate to prepare a comprehensive and detailed technical report, and a brief synopsis memorandum designed for a non-technical audience. The report should be timely, a report that arrives months after the investigation may be of little or no value to the reader.

Written English

As previously noted, the quality of the writing in a report is essential to clearly convey the findings of an investigation to the reader. The author should keep in mind the following general points when preparing a report:

- **Punctuation:** Technical reports tend to rely heavily on punctuation, which many people tend to either overuse or use incorrectly. The author needs to understand and be knowledgeable in the correct usage of commas, colons, semicolons, etc.
- **Grammar:** Reports should generally be written in the past tense using the third-person passive voice (e.g. "samples were collected" rather than "I took samples").
- **Jargon:** The author should avoid the use of technical jargon wherever possible, unless it is absolutely necessary to accurately and precisely describe certain aspects of the work performed.

- **Sentences:** Sentences should be kept as short as possible. No more than 25 words in length is a good rule of thumb.
- **Paragraphs:** Paragraphs should also be kept short and focused on a single topic. Several short paragraphs, rather than a single, long and rambling paragraph, are much easier for the reader to follow and understand. It also helps to ensure that the information contained in each short paragraph is relevant to the subject being discussed. Paragraphs, and the information they contain, should flow consistently into each other from beginning to end.
- **Word Choice:** The author needs to choose words carefully to avoid ambiguity which may cause the reader to draw incorrect conclusions. This is particularly important when drawing conclusions and making recommendations.
- **Acronyms:** Acronyms and other abbreviations must be defined the first time that they are used within the text.
- **Units:** Units must be used consistently throughout the report. (e.g., when discussing a specific contaminant, for example, use either mg/m^3 or ppm, but not both.)

Quality Assurance/Quality Control

Reviewing both the structure and content of a report is an essential part of the report writing process. The review process should include checking not only the technical aspects of the report, but also looking for typing and grammatical errors. All reports should be checked by at least one person other than the author and should also be peer reviewed. Having a technical editor review the report with focus on readability, grammar, punctuation, and spelling may be helpful. Following are some basic items that should be included in any QA/QC report review:

- Make sure that the font type and size(s) is consistent throughout the report.
- Do a spell check on the report, but do not let the program automatically make corrections as it can introduce errors by incorrectly substituting words.

- Check for common transpositions that spell checking will miss (e.g., "form" instead of "from").
- Check all laboratory reports for accuracy of data and text.
- Check that data presented in the text is consistent with data in any tables and charts.

Presentation of Numerical Data

There are a variety of ways numerical data can be presented in a report, including the use of tables, graphs and charts. Often, a graph or table can provide as much, if not more, information to the reader than trying to explain it in one or more paragraphs. However, the author must make sure that whatever format is used to present data is appropriate and that it accurately conveys that information. For reports that contain a lot of numerical data, the results are usually best presented in a table. Comparison of data collected from different locations is often best presented in bar chart form (see Figure 9.1), while data looking at general trends is normally presented in graph form. When presenting data when there is an appropriate standard or guideline value, it is helpful to scale that data to the value that it is being compared to. Whatever format is used, it should be visually attractive, easy to follow and readily understandable.

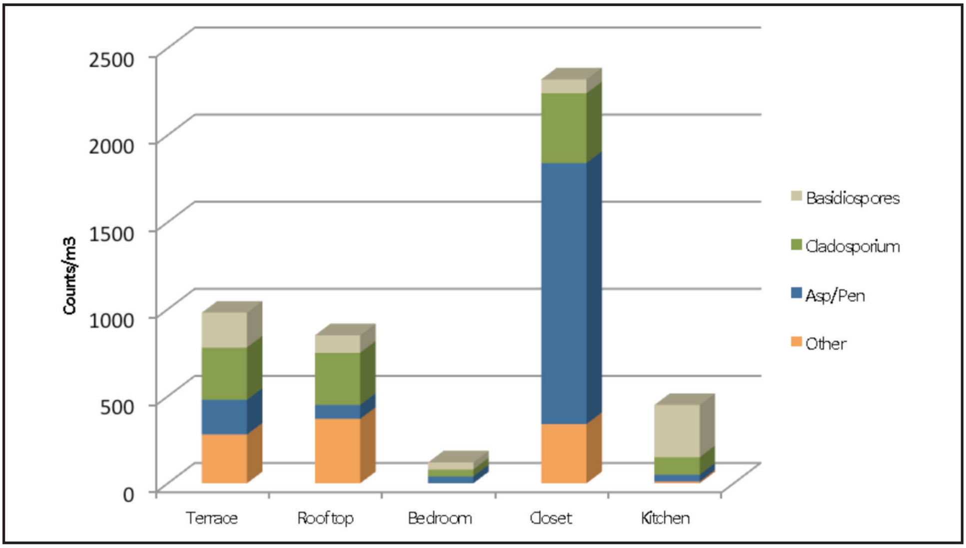


Figure 9.1 – Example Graphical Depiction of Microbiological Air Sampling Data

Photographs

Photographs can greatly enhance a report and make it much easier for the reader to understand the conditions that were observed by the IAQ investigator. However, when taking and choosing photographs for a report it must be ensured they accurately depict the conditions observed and illustrate the intended points. Additionally, overuse of photographs in a report can reduce their overall effectiveness.

Diagrams and Maps

In certain instances, the use of a diagram or map to convey information can be more effective than using a photograph. Simple floor plans or maps can be an easy, yet accurate, way of presenting information such as moisture readings, air flow directions, etc. Maps are also an excellent way to accurately depict sampling locations, which can be essential when interpreting results.

Typical Layout of an IAQ Report

The report should satisfy the reader that 1) the work was thoroughly and properly conducted and 2) appropriate conclusions and recommendations were drawn. The exact content of a report will vary depending upon the scope, objectives, length and nature of the investigation. A short, one hour survey of a single office may only require a three or four page report to describe the findings, while a detailed investigation of an entire building will likely require that a comprehensive report be prepared. A typical IAQ report should be broken down into, at a minimum, the following sections:

- Cover Page
- Executive Summary
- Introduction
- Background
- Description of the Facility
- Sampling Methods and Measurements
- Results
- Discussion and Observations
- Conclusions and Recommendations
- References
- Appendices

COVER PAGE

The cover page should include the following:

- A title summarizing the nature of survey (e.g., "*Limited IAQ Assessment of XYZ…*")
- Date of the report
- Name and address of the client
- Name and address of the consultant performing the work
- Name and signature of the person preparing the report
- Name and signature of the person who reviewed and approved the report (if applicable)

EXECUTIVE SUMMARY

The executive summary provides the reader with an overview of the report contents. The executive summary should be no more than one page in length and should include both the problems that initiated the IAQ survey, as well as the overall findings of the investigation, and an outline of the recommendations.

INTRODUCTION

The introduction should explain why the investigation and report was needed and the agreed upon terms under which the survey was performed and what information was provided by the occupants or client (e.g. "*XYZ company requested that a limited IAQ assessment be performed due to employee concerns regarding musty odors*...". The date(s) of visit(s), site(s) visited and individual(s) performing the survey(s) should also be clearly identified.

BACKGROUND

This section should include background information on the nature of the problem(s), including when they were first reported and the nature of the complaints. Also included should be a clear description of the aims and objectives of the investigation and report.

FACILITY DESCRIPTION

The clear description of the facility and areas investigated should be provided, which typically includes:

- Year constructed and any renovation dates
- Building construction type (i.e., brick and mortar, steel and glass, etc.)

- Description of the immediately surrounding neighborhood and any potential external pollution sources that could impact the subject facility
- Building furnishings and construction materials
- A description of the heating and ventilation systems

SAMPLING METHODS AND MEASUREMENTS

Where sampling and analytical work or measurements are performed, specific information needs to be included. Provide enough detail so that the sampling or measurements may be independently repeated. Examples include:

- Details on the specific sampling and analytical procedures used, including information regarding sampling flow rates, equipment, media and analytical methods. If a published and validated method was used for sampling (i.e., OSHA, NIOSH or EPA methods), it should be clearly identified.
- Sampling or measurement locations, times and duration.
- Types of instruments used, including calibration information.

RESULTS AND DISCUSSION

Results may be presented in the body of the report and/or as appendices. The level of information provided should satisfy the technical reader, but not complicate the report for the lay person. Results should be compared to any relevant exposure standards or guideline values. In the event that no relevant standards or guideline values exist, comparison to published, peer-reviewed data collected from similar environments (i.e., EPA BASE study data) may be an acceptable alternative. Provide sufficient detail concerning significant observations. For example, simply stating that fungal growth was observed in an area is not especially helpful to the reader. Often, the magnitude of the observation is important. If fungal growth is observed, describe where and how big the stains appear. Providing a range if an estimate is given is a common approach. For example, if one is reporting observing stains that appear to be consistent with fungal growth, mentioning that it is between 5 and 10 square feet in size can eliminate the imagination of the reader who may believe that the visible staining was 100 square feet, or 10 square inches.

Any limitations and disclaimers regarding the samples collected or interpretation of the results may be reported. For example, "x, y, z were not sampled because…," or "x location was not evaluated because…" Also, disclaimers may be included about the limitations of the sampling and analysis process, and that results may vary depending on time, temperature, activities, changes in ventilation, changes in operation, etc. The results may indicate only what was sampled under the conditions at the time of sampling.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations section will likely be the one that is most closely read by interested parties. The section should present the key information gathered from the investigation in a clear and concise manner. The information presented must address the questions or concerns that initiated the survey, and should be easily understandable without having to reference the rest of the report. Wherever possible, conclusions as to the probable root cause of the problem should also be drawn and stated, along with the scientific basis that supports these conclusions. Similarly, if no problem was identified, then that should be clearly stated.

Recommendations should be listed by priority, along with guidance on an appropriate implementation time frame (e.g., "*Immediately vacate the space and remove all fungal contaminated materials as soon as possible*.") It is important to make clear which recommendations are essential to address or solve the problem, and which are desirable in terms of good practice. Any recommendations arising for regulatory requirements or applicable guidelines should reference the specific source document(s) (e.g., "*As per ASHRAE 62.1-2013, the minimum acceptable ventilation rates should be...*"). For recommendations involving structural remediation that may expose remediation workers to potential hazards, appropriate safeguards and personal protective equipment for these workers should be specified.

Chapter 10: Concluding Remarks

The goal of most IAQ investigations is to help identify the source of complaints and to correct the condition that caused the complaint. One should avoid the temptation to get lost in scientific study and research! Work will not be finished until the investigator can propose a rational strategy for resolving the IAQ problem. Consider people, equipment, maintenance, and costs in your recommendations.

One may be a very competent investigator – but how are their people skills? An open manner – explaining what they are doing, why they are doing it, what their schedule is, and when results will be available – can yield benefits including increasing trust and the realization that the investigator is honestly committed to working on the problem. The building owner can benefit from coaching, too.

The investigator should avoid unnecessary comments and judgements about health complaints, comfort issues, odors, and stuffiness – all carry the risk of being misconstrued as conclusions, rather than hypotheses, or blown out of proportion.

They should make sure to check with building managers, before going into occupied areas and interviewing occupants, or responding to questions that may come up from occupants. They should also avoid offering conclusions about their findings before they have completed the investigation. More than one investigator has been embarrassed when they find and point out what they believe is the smoking gun cause of an indoor air quality complaint, only to find out later that the issue did not in fact come about until only recently, well after the complaints had begun.

In general, building managers need accurate and defensible oral and written reports that will identify problems and solutions, limit liability exposure and justify expenditures. However, one should keep in mind that they may not understand all technical terms. Occupants generally need assurance that their problem has received a sound, impartial scientific investigation in which their concerns were heard and considered, and that the identified problems will be corrected as quickly as possible. The report should be complete so that a follow-up study can be done at a later date, if needed.

What is appropriate for the building and its staff should be considered. If the solution involves use of equipment that is high maintenance, or requires extensive training, and the building does not have the staff or the manpower to match those requirements, the solution may not be suitable. In addition, the investigator should recognize that changes to building systems must be in compliance with all regulatory requirements and applicable fire, electrical and other building codes.

Above all, this guide should be used to hone detective skills, because, along with years of experience, it should serve an IAQ investigator well.

References

1. **U.S. Environmental Protection Agency (EPA):** *Report to Congress on Indoor Air Quality: Executive Summary and Recommendation*, Vol. 1–3 (EPA- 400/1-89-001 A-D). Washington, D.C.: EPA, 1989. Available at http://www.epa.gov/nscep/index.html. [Accessed January 11, 2016.]
2. **Seitz, T. A.:** “Indoor Air Quality Investigations: 1971 through 1988.” In *The Practitioner’s Approach to IAQ Investigations.* Akron, OH: AIHA, 1990.
3. **National Institute for Occupational Safety and Health (NIOSH):** “Indoor Air Quality: Selected References.” (U.S. Government Printing Office 1990-748-160/00538). Cincinnati, OH: NIOSH, 1989.
4. **American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)**: “ASHRAE Guideline 10- Interactions Affecting the Achievement of Acceptable Indoor Environments.” Atlanta, GA: ASHRAE, 2011.
5. **Jones, T.F., A.S. Allen, et. al.:** Mass Psychogenic Illness Attributed to Toxic Exposure at a High School. *New Engl. J. Med. 342(7)*:96-100 (2000).
6. **Epidemiologic Notes and Reports:** Epidemic Psychogenic Illness in an Industrial Setting. *Morb. Mort. Weekly Rep. 32(22)*:287-288, 294 (1983).
7. **National Institute for Occupational Safety and Health (NIOSH):** *Spectrum Control, Inc. Fairview, PA* (Hazard Evaluation and Technical Assistance Report No. HETA 82-273-1239). Cincinnati, OH: NIOSH, 1982.

8. **American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE):** "ASHRAE Standard 62.1-2013, Ventilation for Acceptable Indoor Air Quality." Atlanta, GA: ASHRAE, 2013. Free viewing available at https://www.ashrae.org/standards-research--technology. [Accessed January 11, 2016.]
9. **American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE):** "ASHRAE Standard 62.2-2013, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings," Atlanta, GA: ASHRAE, 2013. Free viewing available at https://www.ashrae.org/standards-research--technology. [Accessed January 11, 2016.]
10. **American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE):** "Indoor Air Quality Guide: Best Practices for Design, Construction and Commissioning." Atlanta, GA: ASHRAE, 2010. Free download available at https://www.ashrae.org/resources--publications/bookstore/indoor-air-quality-guide. [Accessed January 11, 2016.]
11. **American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE):** "ASHRAE Standard 55-2013, Thermal Environmental Conditions for Human Occupancy." Atlanta, GA: ASHRAE, 2013.
12. **National Institute for Occupational Safety and Health (NIOSH):** NIOSH Alert: Preventing Occupational Respiratory Disease from Exposures Caused by Dampness in Office Buildings, Schools, and Other Nonindustrial Buildings. NIOSH Pub. No. 2013-102. Cincinnati, OH: NIOSH, 2012. Available at http://www.cdc.gov/niosh/docs/2013-102. [Accessed January 11, 2016.]
13. **California Department of Public Health:** "Statement on Building Dampness, Mold and Health, September 2011" Available at http://www.cdph.ca.gov/programs/iaq/pages/indoormold.aspx. [Accessed January 11, 2016.]
14. **California Department of Public Health:** "Standard Method for the Testing and Evaluation of VOC Emissions from Indoor Sources Using Environmental Chambers, Version 1.1 (2010)" Available at http://www.cdph.ca.gov/programs/IAQ/Documents/cdph-iaq_standardmethod_v1_1_2010%20new1110.pdf. [Accessed January 11, 2016.]
15. **International Energy Agency (IEA):** "Transition to Sustainable Buildings, Strategies and Opportunities to 2050 (2013 edition)." Available at http://www.iea.org/publications/freepublications/publication/transition-to-sustainable-buildings.html. [Accessed January 11, 2016.]

16. **U.S. Environmental Protection Agency (EPA):** Indoor Air Quality Building Education and Assessment Model (I-BEAM) Software. Washington, DC: EPA, 2002. Available at http://www.epa.gov/indoor-air-quality-iaq/indoor-air-quality-building-education-and-assessment-model. [Accessed January 11, 2016.]
17. **American Conference of Governmental Industrial Hygienists (ACGIH®):** *Bioaerosols: Assessment and Control.* Macher, J. (ed). Cincinnati, OH, ACGIH®, 1999.
18. **American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE):** *Method of Testing for Room Air Diffusion* (ASHRAE 113-2013). Atlanta, GA: ASHRAE, 2013.
19. **Lundblad, F.P.:** House Dust Mite Allergy in an Office Building. *Appl. Occup. Env. Hyg. 6(2)*:94–96 (1991).
20. **American Industrial Hygiene Association (AIHA®):** "White Paper: Electronic Cigarettes in the Indoor Environment." Falls Church, VA: AIHA, 2014. Available at https://www.aiha.org/government-affairs/Documents/Electronc%20Cig%20Document_Final.pdf. [Accessed January 11, 2016.]
21. **National Institute for Occupational Safety and Health (NIOSH):** *Current Intelligence Bulletin 67: Promoting Health and Preventing Disease and Injury Through Workplace Tobacco Policies*. Morgantown, WV: NIOSH Publication 2015-113 (2015). Available at http://www.cdc.gov/niosh/docs/2015-113/ [Accessed January 11, 2016.]
22. **American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE):** *Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size* (ANSI/ASHRAE Standard 52.2-2012). Atlanta, GA: ASHRAE, 2012.
23. **Gunderson, E.C. and C.C. Bobenhausen:** "Indoor Air Quality." In *The Occupational Environment: Its Evaluation, Control and Management*, 3rd ed. Anna, D.H. (ed.). Falls Church, VA: American Industrial Hygiene Association, 2011. pp 450-500.
24. **Lawrence Berkeley National Laboratory, Indoor Air Quality Scientific Findings Resource Bank:** "Indoor Volatile Organic Compounds (VOCs) and Health." Available at http://www.iaqscience.lbl.gov/voc-summary.html. [Accessed January 11, 2016.]
25. **U.S. Environmental Protection Agency (EPA):** "Method for the Determination of Volatile Organic Compounds in Ambient Air Using Tenax Adsorption and Gas Chromatography/Mass Spectrometry, Method TO-1." In *Compendium of Methods for the Determination of Toxic*

Organic Compounds in Ambient Air, 2nd ed. (EPA-625/R-96/010b). Cincinnati, OH: EPA, 1999. Available at http://www.epa.gov/ttn/amtic/airtox.html. [Accessed January 11, 2016.]

26. **U.S. Environmental Protection Agency (EPA):** "VOCs in Indoor Air, Solid Adsorbent Tubes, Method IP-1B." In *Compendium of Methods for the Determination of Air Pollutants in Indoor Air* (EPA/600/4-90/010). Research Triangle Park, NC: EPA, 1990. Available at http://nepis.epa.gov... [Accessed January 11, 2016.]
27. **U.S. Environmental Protection Agency (EPA):** "Determination of Volatile Organic Compounds in Ambient Air Using Specially Prepared Canisters with Subsequent Analysis by Gas Chromatography, Method TO-14A." In *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, 2nd ed. (EPA/625/R-96/010b). Cincinnati, OH: EPA, 1999. Available at http://www.epa.gov/ttn/amtic/airtox.html. [Accessed January 11, 2016.]
28. **U.S. Environmental Protection Agency (EPA):** "VOCs in Indoor Air, Stainless Steel Canister, Method IP-1A." In *Compendium of Methods for the Determination of Air Pollutants in Indoor Air* (EPA/600/4-90/010). Research Triangle Park, NC: EPA, 1990. Available at http://nepis.epa.gov... [Accessed January 11, 2016.]
29. **U.S. Environmental Protection Agency (EPA):** "Method for the Determination of Volatile Organic Compounds in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry, Method TO-15." In *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, 2nd ed.* (EPA-625/R-96/010b). Cincinnati, OH: EPA, 1999. Available at http://www.epa.gov/ttn/amtic/airtox.html. [Accessed January 11, 2016.]
30. **National Institute for Occupational Safety and Health (NIOSH):** "Volatile Organic Compounds (Screening) Method 2549." In *NIOSH Manual of Analytical Methods, 4th. ed.* (DHHS Publication No. 96-135) Cincinnati, OH: NIOSH, 1996. Available at http://www.cdc.gov/niosh/docs/2003-154/method-cas6.html. [Accessed January 11, 2016.]
31. **International Organization for Standardization (ISO)**: *Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax® TA sorbent, thermal desorption and gas chromatography using MS or MS-FID* (ISO 16000-6:2011). Geneva: ISO, 2011.
32. **U.S. Environmental Protection Agency (EPA):** "Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed

by High Performance Liquid Chromatography, Method TO-11A." In *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, 2nd ed.* (EPA-625/R-96/010b). Cincinnati, OH: EPA, 1999. Available at http://www.epa.gov/ttn/amtic/airtox.html. [Accessed January 11, 2016.]

33. **U.S. Environmental Protection Agency (EPA):** "Formaldehyde & Other Aldehydes in Indoor Air Using a Solid Adsorbent Cartridge, Method IP-6A." In *Compendium of Methods for the Determination of Air Pollutants in Indoor Air* (EPA/600/4-90/010). Research Triangle Park, NC: EPA, 1990. Available at http://nepis.epa.gov... [Accessed January 11, 2016.]
34. **U.S. Environmental Protection Agency (EPA):** "Determination of Formaldehyde and Other Aldehydes in Indoor Air Using Passive Sampling Device, Method IP-6C." In *Compendium of Methods for the Determination of Air Pollutants in Indoor Air* (EPA/600/4-90/010). Research Triangle Park, NC: EPA, 1990. Available at http://nepis.epa.gov... [Accessed January 11, 2016.]
35. **ASTM International (ASTM):** *Standard Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Air (Active Sampler Methodology*) (ASTM D5197-09). West Conshohocken, PA: ASTM, 2009.
36. **International Organization for Standardization (ISO):** *Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air -- Active sampling method* (ISO 16000-3:2011). Geneva: ISO, 2011.
37. **International Organization for Standardization (ISO):** *Determination of ozone in ambient air -- Ultraviolet photometric method* (ISO 13964:1998). Geneva: ISO, 1998.
38. **ASTM International (ASTM):** *Standard Test Method for Ozone in the Atmosphere: Continuous Measurement by Ethylene Chemiluminescence* (ASTM D5149-02(2008). West Conshohocken, PA: ASTM, 2008.
39. **ASTM International (ASTM):** *Standard Practice for Sampling for Particulate Contamination by Tape Lift* (ASTM E1216-11). West Conshohocken, PA: ASTM, 2011.
40. **National Institute for Occupational Safety and Health (NIOSH):** "Elemental Carbon (Diesel Particulate), Method 5040." In *NIOSH Manual of Analytical Methods,* 4th. ed. (DHHS Publication No. 2003-154). Cincinnati, OH: NIOSH, 2003. Available at http://www.cdc.gov/niosh/docs/2003-154/pdfs/5040.pdf. [Accessed January 11, 2016.]

41. **American Industrial Hygiene Association (AIHA®):** *Recognition, Evaluation, and Control of Legionella in Building Water Systems*. Falls Church, VA: AIHA®, 2015.
42. **California Department of Public Health:** "Statement on Building Dampness, Mold, and Health." September 2011. Available at http://www.cdph.ca.gov/programs/IAQ/Documents/statement_on_building_dampness_mold_and%20health2011.pdf. [Accessed January 11, 2016.]
43. **American Industrial Hygiene Association (AIHA®):** *Recognition, Evaluation, and Control of Indoor Mold.* Prezant, B., D.M. Weekes, and J.D. Miller (eds.). Fairfax, VA: AIHA®, 2008
44. **American Industrial Hygiene Association (AIHA®):** *Field Guide for the Determination of Biological Contaminants in Environmental Samples*, 2nd ed. Hung, L.L., J.D. Miller and H.K. Dillon (eds.). Fairfax, VA: AIHA®, 2005.
45. **U.S. Environmental Protection Agency (EPA):** *A Citizen's Guide to Radon* (EPA 402-K-12-002). Washington, DC: EPA, 2012. Available at http://www.epa.gov/radon/pubs/citguide.html . [Accessed January 11, 2016.]
46. **U.S. Environmental Protection Agency (EPA):** *Technical Support Document for the 1992 Citizen's Guide to Radon* (EPA 400-R-92-011). Washington, DC: EPA, 1992. Available at http://nepis.epa.gov.... [Accessed January 11, 2016.]
47. **U.S. Environmental Protection Agency (EPA):** "EPA Map of Radon Zones.". Available at www.epa.gov/radon/zonemap.html. [Accessed January 11, 2016.]
48. **ASTM International (ASTM):** *Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution* (ASTM E741-11). Philadelphia, PA: ASTM, 2011.
49. **ASTM International (ASTM):** *Standard Practices for Air Leakage Site Detection in Building Envelopes* (ASTM E1186-98). Philadelphia, PA: ASTM, 1998.
50. **Illumination Engineering Society of North America (IES):** *The Lighting Handbook, 10th ed.*, DiLaura, D., K. Houser, R. Mistrick, and G. Steffy (eds.). New York: IES, 2011.
51. **Canadian Center for Occupational Health and Safety (CCOHS):** "Lighting Ergonomics – Survey and Solutions." Available at http://www.ccohs.ca/oshanswers/ergonomics/lighting_survey.html. [Accessed January 12, 2016.]
52. **Occupational Safety and Health Administration (OSHA):** "OSHA Computer Workstations eTool." Available at https://www.osha.gov/

SLTC/etools/computerworkstations/wkstation_enviro.html. [Accessed January 12, 2016.]

53. **Occupational Safety and Health Administration (OSHA):** "OSHA Noise and Hearing Conservation eTool." Available at https://www.osha.gov/dts/osta/otm/noise/exposure/index.html. [Accessed January 12, 2016.]
54. **American National Standards Institute (ANSI):** *ANSI Standard S12.2, Criteria for Evaluating Room Noise.* New York: ANSI, 2008.
55. **Acoustics.com**: "Codes and Testing." Available at http://www.acoustics.com/codes_testing.asp. [Accessed January 12, 2016.]
56. **National Institute for Occupational Safety and Health (NIOSH):** "Appendix B, Example of Questionnaire Used in the Health Survey." In *Nassau Community College, Garden City, New York* (NIOSH Health Hazard Evaluation Report: HETA #2000-0168-2871) Cincinnati, OH: NIOSH, 2000. Available at www.cdc.gov/niosh/hhe/reports/pdfs/2000-0168-2871.pdf. [Accessed January 12, 2016.]
57. **U.S. Environmental Protection Agency (EPA): "**Appendix F (Indoor Environmental Quality Questionnaire)." In *A Standardized EPA Protocol for Characterizing Indoor Air Quality in Large Office Buildings.* Research Triangle Park, NC: EPA, 2003. Available at http://www.epa.gov/indoor-air-quality-iaq/standardized-epa-protocol-characterizing-indoor-air-quality-large-office. [Accessed January 12, 2016.]
58. **Griffith, F.D.:** A Simplified IAQ Questionnaire to Obtain Useful Data for Investigating Sick Building Complaints. *Am. Ind. Hyg. Assoc. J. 52(8)*:A-434-A-437 (1991).
59. **U.S. Environmental Protection Agency (EPA):** *Building Assessment, Survey and Evaluation Study (BASE).* Washington, DC: EPA, 2006. Available at http://www.epa.gov/indoor-air-quality-iaq/building-assessment-survey-and-evaluation-study. [Accessed January 12, 2016.]
60. **U.S. Environmental Protection Agency (EPA):** *National Ambient Air Quality Standards (NAAQS)*. Available at http://www.epa.gov/ttn/naaqs/criteria.html. [Accessed January 12, 2016.]
61. **California Air Resources Board:** California *Ambient Air Quality Standards* (CAAQS). Available at www.arb.ca.gov/research/aaqs/caaqs/caaqs.htm. [Accessed January 12, 2016.]
62. **Health Canada:** *Exposure Guidelines for Residential Indoor Air Quality*. Available at http://www.hc-sc.gc.ca/ewh-semt/air/in/res-in/index-eng.php. [Accessed January 12, 2016.]

63. **State of California, Office of Environmental Health Hazard Assessment (OEHHA):** *Chronic Reference Exposure Levels (ChRels)*. Available at www.oehha.ca.gov/air/allrels.html. [Accessed January 12, 2016.]
64. **Texas Department of Health (TDH):** *Texas Voluntary Indoor Air Quality Guidelines for Government Buildings* (Pub. No. 2-10). Austin, Texas: TDH, 2003. Available at https://www.dshs.state.tx.us/iaq/SchoolsGuide.shtm. [Accessed January 12, 2016.]
65. **U.S. Department of Labor, Occupational Safety & Health Administration (OSHA):** *Limits for Air Contaminants* (Standard 1910.1000 Table Z-1). Washington, DC: OSHA, 1997. Available at https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992. [Accessed January 12, 2016.]
66. **National Institute for Occupational Safety and Health (NIOSH):** *NIOSH Pocket Guide to Chemical Hazards*. Available at http://www.cdc.gov/niosh/npg/. [Accessed January 12, 2016.]
67. **American Conference of Governmental Industrial Hygienists (ACGIH®):** *2015 TLVs® and BEIs.* Cincinnati, OH: ACGIH®, 2015.
68. **American Industrial Hygiene Association (AIHA®):** *2011 Workplace Environmental Exposure (WEEL®) Values*. Available at https://www.aiha.org/get-involved/AIHAGuidelineFoundation/WEELs®/Pages/default.aspx. [Accessed January 12, 2016.]
69. **World Health Organization (WHO):** *Air Quality Guidelines. Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide.* Copenhagen, Denmark: WHO, 2005. Available at http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/pre2009/air-quality-guidelines.-global-update-2005.-particulate-matter,-ozone,-nitrogen-dioxide-and-sulfur-dioxide. [Accessed January 12, 2016.]
70. **World Health Organization (WHO):** *WHO Guidelines for Indoor Air Quality: Selected Pollutants.* Copenhagen, Denmark: WHO, 2010. Available at http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2010/who-guidelines-for-indoor-air-quality-selected-pollutants. [Accessed January 12, 2016.]
71. **ASTM International (ASTM):** *ASTM Standards on Indoor Air Quality (various)*. View listing at http://www.astm.org/BOOKSTORE/COMPS/IAQCMP.htm. [Accessed January 12, 2016.]

72. **Girman, J.R., G.E. Hadwen, L.E. Burton, S.E. Womble, and J.F. McCarthy: "**Individual Volatile Organic Compound Prevalence and Concentrations in 56 Buildings of the Building Assessment Survey and Evaluation (BASE) Study." *Proceedings of Indoor Air 1999.* pp. 460–465. Available at http://www.epa.gov/indoor-air-quality-iaq/individual-volatile-organic-compound-prevalence-and-concentrations-56. [Accessed January 12, 2016.]
73. **Levin, H., and A.T. Hodgson:** "VOC Concentrations of Interest in North American Offices and Homes." *Proceedings of Healthy Buildings 2006.* Available at http://www.buildingecology.com/articles/voc-concentrations-of-interest-in-north-american-offices-and-homes/. [Accessed January 12, 2016.]
74. **Maddalena, R.L., N. Li, A.T. Hodgson, F.J. Offermann and B.C. Singer:** "Maximizing Information from Residential Measurements of Volatile Organic Compounds." *Proceedings of Healthy Buildings 2013*. Available at https://indoor.lbl.gov/publications?page=1. [Accessed January 12, 2016.]
75. **Logue, J.M., T.E. McKone, M.H. Sherman and B.C. Singer:** "Hazard assessment of chemical air contaminants measured in residences." *Indoor Air 21*:92-109 (2011). Available at https://indoor.lbl.gov/publications?page=4. [Accessed January 12, 2016.]
76. **California Office of Environmental Health Hazard Assessment (CA OEHHA):** "**OEHHA Acute, 8-hour and Chronic Reference Exposure Level**s **(REL**s**).**" Available at http://oehha.ca.gov/air/allrels.html. [Accessed January 12, 2016.]
77. **Agency for Toxic Substances and Disease Registry (ATSDR):** "Minimal Risk Levels (MRLs)." Available at http://www.atsdr.cdc.gov/mrls/index.asp. [Accessed January 12, 2016.]
78. **Strom, G., J. West, B. Wessen, and U. Palmgren:** Health Implications of Fungi in Indoor Environments: Quantitative Analysis of Microbial Volatiles in Damp Swedish Houses. *Air Qua. Mon. 2*:291–305 (1994).
79. **Elke, K., J. Begerow, H. Oppermann, U. Kramer, E. Jermann and L. Dunemann:** Determination of Selected Microbial Volatile Organic Compounds by Diffusion Sampling and Dual-Column Capillary GC-FID—a New Feasible Approach for the Detection of an Exposure to Indoor Mould Fungi. *J. Environ. Mon. 1*:445–52 (1999).
80. **Ryan, T.J., and C. Beaucham :** Dominant MVOCs in 23 US Homes. *Chemosphere 90(3)*: 977–85 (2013).

81. **American Industrial Hygiene Association (AIHA):** "Facts About Mold." Available at https://www.aiha.org/publications-and-resources/TopicsofInterest/Hazards/Pages/Facts-About-Mold.aspx. [Accessed January 12, 2016.]
82. **Rao, C.Y., H.A. Burge, and J.C. Chang:** Review of Quantitative Standards and Guidelines for Fungi in Indoor Air. *J. Air Waste Manag. Assoc. 46*:899–908 (1996).
83. **Burge, H.A.:** An Update on Pollen and Fungal Spore Aerobiology. *J. Allergy Clin. Immunol. 110*:544–52 (2002).
84. **Gots, R.E., N.J. Layton, and S.W. Pirages:** Indoor Health: Background Levels of Fungi. *Am. Ind. Hyg. Assoc. J. 64*:427–38 (2003).
85. **Hodgson, M. and R.J. Scott:** "Prevalence of Fungi in Carpet Dust Samples." In *Bioaerosols, Fungi and Mycotoxins: Health Effects, Assessment, Prevention and Control,* E. Johanning (ed.). Albany, NY: Boyd Printing Company, 1999. pp. 268–274.
86. **Hicks, J.B., E.T. Lu, R. De Guzman, and M. Weingart:** Fungal Types and Concentrations from Settled Dust in Normal Residences. *J. Occup. Environ. Hyg. 2*:481–92 (2005).
87. **Macher, J.M., F.C. Tsai, L.E. Burton, and K-S Liu:** "Concentrations of Cat and Dust Mite Allergens in 93 U.S. Office Buildings." *Proceedings of Indoor Air 2002*, pp. 359–364.
88. **Rauh, V.A., G.L. Chew, and R.S. Garfinkel:** Deteriorated Housing Contributes to High Cockroach Allergen Levels in Inner-City Households. *Environ. Health Perspect. 110(2)*:323–27 (2002).
89. **Gelber, L.E., L.H. Seltzer, J.K. Bouzokis, S.M. Pollart, M.D. Chapman,and T.A. E. Platts-Mills:** Sensitization and Exposure to Indoor Allergens as Risk Factors for Asthma Among Patients Presenting to Hospital. *Am. Rev. Respir. Dis. 147*:573–78 (1993).
90. **National Disease Surveillance Centre (NDSC):** *National Guidelines for the Prevention of Nosocomial Invasive Aspergillosis During Construction/Renocation Activities*. Dublin, Ireland: NDSC, 2002. Available at www.hpsc.ie/A-Z/Respiratory/Aspergillosis/Guidance/. [Accessed January 12, 2016.]
91. **Occupational Safety and Health Administration (OSHA):** "OSHA Legionnaires' Disease eTool." Available at https://www.osha.gov/dts/osta/otm/legionnaires/index.html. [Accessed January 12, 2016.]
92. **Centers for Disease Control and Prevention (CDC):** "Healthcare-associated Infections (HAIs), Guidelines and Recommendations."

Available at http://www.cdc.gov/HAI/prevent/prevent_pubs.html. [Accessed January 12, 2016.]

93. **American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE):** *ASHRAE Guideline 12-2000, Minimizing the Risk of Legionellosis Associated with Building Water Systems*. Atlanta, GA: ASHRAE, 2000.

94. **American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE):** *ASHRAE Standard 188-2015, Legionellosis: risk Management for Building Water Systems.* Atlanta, GA: ASHRAE, 2015. View at https://www.ashrae.org/standards-research--technology/standards--guidelines/other-ashrae-standards-referenced-in-code#188. [Accessed January 12, 2016.]

95. **Noskin, G.A. and L.R. Peterson:** Engineering Infection Control through Facility Design. *Emerg. Infect. Dis. J. 7(2)*:Mar-April (2001). Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2631721/, [Accessed January 12, 2016.]

96. **Health Canada:** *Construction-Related Nosocomial Infections in Patients in Health Care Facilities – Decreasing the Risk of Aspergillus, Legionella and Other Infections.* Ottawa, Canada: Canadian Medical Association, 2001. Available at www.abatement.com/pdf/canada-construction-guidelines.pdf. [Accessed January 12, 2016.]

97. **Bartley, J.M.:** *APIC State-of-the-Art Report: The Role of Infection Control During Construction of Health Care Facilities.* Washington, DC: Association for Professionals in Infection Control and Epidemiology, Inc., 2000. Available at http://www.apic.org/Resource_/TinyMceFileManager/Practice_Guidance/IC-During-Construction-HC-Fac.pdf. [Accessed January 12, 2016.]

98. **Joint Commission on Accreditation of Healthcare Organizations (JCAHO):** *A Guide to Managing Indoor Air Quality in Health Care Organizations.* Hansen, W. (ed.). Oakbrook Terrace, IL: JCAHO, 1997.

99. **U.S. Environmental Protection Agency (EPA):** "Creating Healthy Indoor Environments in Schools." Available at http://www.epa.gov/iaq/schools/. [Accessed January 12, 2016.]

100. **Collaborative for High Performance Schools (CHPS):** "Best Practices Manual." Available at http://www.chps.net/dev/Drupal/node/288. [Accessed January 12, 2016.]

101. **Sabin, L.D., K. Kozawa, E. Behrentz, A.M. Winer, D.R. Fitz, D.V. Pankratz, S.D. Colome and S.A. Fruin:** "Analysis of real-time variables affecting children's exposure to diesel-related pollutants during

school bus commutes in Los Angeles." *Atmospheric Environment* 39, 5243-5254 (2005). Available at http://cichlid.cert.ucr.edu/research/pubs/8.pdf. [Accessed January 12, 2016.]

102. U.S. Environmental Protection Agency (EPA): "National Clean Diesel Campaign (NCDC), Clean School Bus." Available at http://www.epa.gov/cleanschoolbus/csb-overview.htm. [Accessed January 12, 2016.]

103. Centers for Disease Control and Prevention (CDC): *Vessel Sanitation Program, 2011 Operations Manual.* Atlanta, GA: CDC, 2011. Available at www.cdc.gov/nceh/vsp/operationsmanual/opsmanual2011.pdf. [Accessed January 12, 2016.]

104. Centers for Disease Control and Prevention (CDC): "Aircrew Safety & Health, Cabin Air Quality." Available at http://www.cdc.gov/niosh/topics/aircrew/cabinairquality.html. [Accessed January 12, 2016.]

105. World Health Organization (WHO): *Indoor Air Quality Guidelines: Household Fuel Combustion.* Geneva, Switzerland: WHO, 2014. Available at http://www.who.int/indoorair/guidelines/hhfc/en/. [Accessed January 12, 2016.]

106. Makos, K.A, et. al.: Workshop 5: Hidden Hazards within Art & Museum Collections. Presented at AIHA Fall Conference, November 21, 2014.

107. Hawks, C., M. McCann, K. Makos, L. Goldberg, D. Hinkamp, D. Ertel, P. Silence (eds.): *Health & Safety for Museum Professionals.* New York: Society for the Preservation of Natural History Collections, 2010.

108. Makos, K.A. and M. Skimina: "Hidden Hazards: Health and Safety in Museums and Art Galleries." *The Synergist* 14, 28-31 (2003).

109. U.S. Environmental Protection Agency (EPA): *Effective Risk and Crisis Communication during Water Security Emergencies, Summary Report of EPA Sponsored Message Mapping Workshops*. Cincinnati, OH: EPA, 2007. Available at http://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=461264&ei. [Accessed January 12, 2016.

110. Australian Institute of Occupational Hygienists (AIOH): *Guideline for Writing Occupational Hygiene* Reports. Tullamarine, Vic, Australia: AIOH, 2006. Available at https://www.yumpu.com/en/document/view/34233341/guideline-for-writing-occupational-hygiene-reports-the-aioh. [Accessed January 12, 2016.]

111. British Occupational Hygiene Society (BOHS): *Clear and concise report writing: guidance for occupational hygienists*. Derby, UK: BOHS, 2011. Available at http://www.bohs.org/reportwritingguidance. [Accessed January 12, 2016.]

For More Information

Resources

Standards and Guidelines

Environmental Protection Agency (EPA) National Ambient Air Quality Standards (NAAQS).	http://www.epa.gov/air/criteria.html
ANSI/ASHRAE* Standard 62.1: Ventilation for Acceptable Indoor Air Quality.	http://www.ashrae.org
62.1 User's Manual. ASHRAE*.	http://www.ashrae.org
ANSI/ASHRAE* Standard 62.2: Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. ASHRAE.	http://www.ashrae.org
ANSI/ASHRAE* Standard 55: Thermal Environmental Conditions for Human Occupancy. ASHRAE.	http://www.ashrae.org
ASTM Standards on Indoor Air Quality.	http://www.astm.org
World Health Organization: Guidelines for Air Quality in Europe.	http://www.who.org

Health Canada: Exposure Guidelines for Residential Indoor Air Quality.	http://www.hc-sc.gc.ca
California Department of Public Health: Indoor Air Quality Program.	http://www.cdph.ca.gov/programs/IAQ/Pages/default.aspx
Texas Voluntary Indoor Air Quality Guidelines for Government Buildings.	http://www.dshs.state.tx.us/iaq

**use most current version of ANSI/ASHRAE standards/publications*

Investigation and Diagnosis

Indoor Air Quality Handbook. Spengler, J. D., J. M. Samet and J. F. McCarthy (eds.). New York: McGraw-Hill, 2001.	http://www.books.mcgraw-hill.com
Gunderson, E.C. and C.C. Bobenhausen: "Chapter 18: Indoor Air Quality." In The Occupational Environment: Its Evaluation, Control, and Management, 3rd edition. Anna, D.H. (ed.). Fairfax, VA: AIHA, 2011.	http://www.aiha.org/market
Godish, T.: Sick Buildings: Definition, Diagnosis and Mitigation. Boca Raton, FL: CRC Press, LLC, 1995.	http://www.crcpress.com
Hays, S.M., R.V. Gobbell, and N.R. Ganick: Indoor Air Quality: Solutions and Strategies. New York: McGraw-Hill,1994.	http://www.books.mcgraw-hill.com
Light, E. and J. Sundell: TFII-1996 General Principles for the Investigation of IAQ Complaints, Task Force II Report. Finland: ISIAQ, 1998.	http://www.isiaq.org
Environmental Protection Agency (EPA): Indoor Air Quality Building Education and Assessment Model (I-BEAM) Software, 2002.	http://www.epa.gov/iaq
Environmental Protection Agency (EPA): Building Assessment, Survey and Evaluation Study (BASE), 2006.	http://www.epa.gov/iaq/
The Practitioner's Approach to Indoor Air Quality Investigations: Proceedings of the Indoor Air Quality International Symposium. Fairfax, VA: AIHA, 1990.	http://www.aiha.org/market

Ventilation and HVAC Systems

ASHRAE: The Indoor Air Quality Guide: Best Practices for Design, Construction and Commissioning, 2010 (free download)	http://www.ashrae.org
Burton, D.J.: The IAQ and HVAC Workbook, 4th ed. revised. Itasca, IL: National Safety Council, 2011.	http://www.aiha.org
Bearg, D.W.: Indoor Air Quality and HVAC Systems. Boca Raton, FL: CRC Press, LLC, 1993.	http://www.crcpress.com
Grimm, N. R. and R. C. Rosaler: HVAC Systems and Components Handbook. New York: McGraw-Hill, 1997.	http://www.books.mcgraw-hill.com
Sheet Metal and Air Conditioning Contractors National Association, Inc. (SMACNA): IAQ Guidelines for Occupied Buildings Under Construction, Chantilly, VA: SMACNA, 2007.	http://www.smacna.org

Building Owner's Guides

Environmental Protection Agency (EPA) and National Institute of Occupational Safety and Health (NIOSH): Building Air Quality: A Guide for Building Owners and Facility Managers. Washington, DC: EPA, 1991.	http://www.epa.gov/iaq
Environmental Protection Agency (EPA) and National Institute of Occupational Safety and Health (NIOSH): Building Air Quality - Action Plan, Washington, DC: EPA, 1998.	http://www.epa.gov/iaq
Environmental Protection Agency (EPA): Indoor Air Quality Tools for Schools Action Kit, Washington, DC: EPA, 2009.	http://www.epa.gov/iaq/
Collaborative for High Performance Schools: CHPS Best Practices Manual, 2006.	http://www.chps.net/manual/index.htm
Workers Compensation Board of British Columbia: Indoor Air Quality: A Guide for Building Owners, Managers, and Occupants, British Columbia: WCB, 2005.	http://www.worksafebc.com

Biological Contaminants

American Conference of Governmental Industrial Hygienists (ACGIH®): Bioaerosols: Assessment and Control, Macher, J. (ed.). Cincinnati, OH: ACGIH®, 1999.	http://www.acgih.org
American Industrial Hygiene Association (AIHA®): Field Guide for the Determination of Biological Contaminants in Environmental Samples, 2nd edition. Hung, L.L., J.K. Miller, and H.K. Dillon, (eds.). Fairfax, VA: AIHA®, 2005.	http://www.aiha.org/market
American Industrial Hygiene Association (AIHA®): Recognition, Evaluation and Control of Indoor Mold. Prezant, B., D.M. Weekes, and J.D. Miller, (eds.). Fairfax, VA: AIHA®, 2008.	http://www.aiha.org/market
Fundamentals of Mold Growth in Indoor Environments and Strategies for Healthy Living. Adan, O.C.G. and R.A. Samson (eds.). Utrecht, The Netherlands: Wageningen Academics Publishers, 2011.	http://www.aiha.org/market or http://www.wageningenacademic.com/
Damp Indoor Spaces and Health. Washington, DC: National Academy of Science, 2004.	http://www.nas.edu
Bioaerosols Handbook. Cox, C.S. and C.M. Walthes, (eds.). Boca Raton, FL: CRC Press, LLC, 1995.	http://www.crcpress.com
Bioaerosols: Burge, H.A. (ed.). Boca Raton, FL: CRC Press, LLC, 1995.	http://www.crcpress.com
Aerobiology. Muilenberg, M. and H. Burge (eds.). Boca Raton, FL: CRC Press, LLC, 1996.	http://www.crcpress.com
Indoor Allergens: Assessing and Controlling Adverse Health Effects. Pope, A.M., R. Patterson, and H. Burge, (eds.). Washington, DC: National Academy of Science, 1993.	http://www.nas.edu

Legionnaires' Disease

American Industrial Hygiene Association (AIHA®): Recognition, Evaluation, and Control of Legionella in Building Water Systems. Falls Church, VA: AIHA®, 2015.	http://www.aiha.org
American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE): Legionellosis: Risk Management for Building Water Systems (ASHRAE Standard 188P-2015). Atlanta, GA: ASHRAE, 2015.	http://www.ashrae.org
American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE): Minimizing the Risk of Legionellosis Associated with Building Water Systems (ASHRAE Guideline12-2000). Atlanta, GA: ASHRAE, 2000.	http://www.ashrae.org
ASTM D5952-08. Standard Guide for the Inspection of Water Systems for Legionella and the Investigation of Possible Outbreaks of Legionellosis (Legionnaires' Disease or Pontiac Fever). ASTM International, West Conshohocken, PA: 2008.	http://www.astm.org
Occupational Safety and Health Administration: "Legionnaires' Disease, Section III, Chapter 7." In OSHA Technical Manual. Washington, DC: OSHA, 1999.	http://www.osha.gov
Centers for Disease Control and Prevention (CDC): Guideline for Preventing Health-Care-Associated Pneumonia. Atlanta, GA: CDC, 2003	http://www.cdc.gov/hicpac/pubs.html
U.S. Department of Veterans Affairs: Prevention of healthcare-associated Legionella disease and scald injury from potable water distribution systems. VHA Directive 1061, 2014.	http://www.va.gov

Remediation of Biological Contaminants

New York City Department of Health: Guidelines on Assessment and Remediation of Fungi in Indoor Environments. New York City Department of Health, 2008.	http://www.nyc.gov/html/doh/html/environmental/moldrpt1.shtml
Environmental Protection Agency (EPA): Mold Remediation in Schools and Commercial Buildings. Washington, DC: EPA, 2008.	http://www.epa.gov/iaq/
California Research Bureau: Indoor Mold: A General Guide to Health Effects, Prevention, and Remediation. Umbach, K.W. and Davis, P.J. (eds). Sacramento, CA: CRB, 2006.	http://library.ca.gov
Institute of Inspection, Cleaning and Restoration Certification (IICRC): Standard and Reference Guide for Professional Mold Remediation (S520). Las Vegas, NV: IICRC, 2015.	http://www.iicrc.org
Institute of Inspection, Cleaning and Restoration Certification (IICRC): Standard and Reference Guide for Professional Water Damage Restoration (S500). Las Vegas, NV: IICRC, 2006.	http://www.iicrc.org
Canadian Construction Association: Mould Guidelines for the Canadian Construction Industry. Ottawa, ON: CCA, 2004.	http://www.cca-acc.com

Chemical Sensitivity

The Interagency Workgroup on Multiple Chemical Sensitivity: A Report on Multiple Chemical Sensitivity, 1998. (view online)	http://web.health.gov/environment/MCS/index.htm
Ashford, N.A. and C.S. Miller: Chemical Exposures: Low Levels and High Stakes, 2nd edition. New York: John Wiley and Sons, Inc., 1998.	http://www.wiley.com
Staudenmayer, H.: Environmental Illness Myth and Reality. Boca Raton, FL: CRC Press, LLC, 1998.	http://www.crcpress.com

Black, D.W.: Idiopathic Environmental Intolerance; Multiple Chemical Sensitivity; Environmental Illness, Merck Manual, 2014.	http://www.merckmanuals.com/professional/special-subjects/idiopathic-environmental-intolerance/idiopathic-environmental-intolerance

Green Buildings

EPA Green Building Portal	http://www.epa.gov/greenbuilding/
U.S. Green Building Council (USGBC)	http://www.usgbc.org
ANSI/ASHRAE/USGBC/IES Standard 189.1, Standard for the Design of High-Performance, Green Buildings Except Low-Rise Residential Buildings	http://www.ashrae.org
Green Globes	http://www.greenglobes.com
BREEAM	http://www.breeam.org
Living Building Challenge	http://living-future.org/lbc
International Code Council	http://www.iccsafe.org
Passive House Institute US	http://www.phius.org

Research

Lawrence Berkeley National Laboratory (LBNL) Indoor Air Quality Scientific Findings Resource Bank	http://www.iaqscience.lbl.gov
California EPA Air Resources Board, Indoor Air Quality and Personal Exposure Assessment Program	http://www.arb.ca.gov/research/indoor/indoor.htm
EPA Air and Climate Change Research	http://www.epa.gov/air-research/air-quality-and-climate-change-research

Other Resources

American Industrial Hygiene Association (AIHA®) and Indoor Air Quality Association (IAQA): Body of Knowledge, Indoor Air Quality Practitioner. Falls Church, VA: AIHA®, 2015.	http://www.aiha.org or http://www.iaqa.org

Courses/Conferences/Symposiums

American Industrial Hygiene Association (AIHA): Various professional development courses, continuing education classes, annual conference with IAQ sessions and symposiums	www.aiha.org
NIOSH Educational Resource Centers: Professional development courses offered through regional educational centers across US	www.niosh.gov
International Society of Indoor Air Quality (ISIAQ): International "Indoor Air" conference every three years, staggered with "Healthy Buildings" conferences every three years	www.isiaq.org
ASHRAE: Annual and Winter ASHRAE conferences, and periodic IAQ conferences and other specialty conferences with focus such as buildings and energy	www.ashrae.org
Indoor Air Quality Association: Courses and conferences	www.iaqa.org
Maine Indoor Air Quality Council: Courses and conferences	www.maineindoorair.org

Note: This listing does not constitute an endorsement of any particular organization or educational program.

Laboratories and Consultants

American Industrial Hygiene Association: List of Accredited Laboratories	www.aiha.org
AIHA Consultants Listing	www.aiha.org
American Board of Industrial Hygiene (ABIH) Consultants Listing	www.abih.org
U.S. Centers for Disease Control and Prevention (CDC): Environmental Legionella Isolation Techniques Evaluation (ELITE) Program	www.cdc.gov

Journals

The following journals may contain IAQ-related articles. This is not intended to be a complete list.

- Advances in Building Energy Research
- American Journal of Public Health
- Annals of Occupational Hygiene
- Applied and Environmental Microbiology
- ASHRAE Journal
- Atmospheric Environment
- Building and Environment
- Energy and Buildings
- Environmental Health Perspectives
- Environment International
- Indoor Air
- Indoor and Built Environment
- Journal of the Air and Waste Management Association
- Journal of Environmental Monitoring
- Journal of Environmental and Public Health
- Journal of Exposure Analysis and Environmental Epidemiology
- Journal of Indoor Environmental Quality
- Journal of Occupational and Environmental Hygiene
- Journal of Occupational and Environmental Medicine

Other Publications

- Environmental Reporter
- Healthy Indoors Magazine
- Heating/Piping/Air Conditioning Engineering
- High Performing Buildings
- Morbidity and Mortality Weekly Report (CDC)
- The Synergist

Glossary and Acronyms

ACGIH®: American Conference of Governmental Industrial Hygienists.

AHU: Air handling unit.

AIHA®: American Industrial Hygiene Association.

Allergen: A substance capable of causing an allergic reaction in susceptible individuals.

Allergic rhinitis: Inflammation of the mucous membranes in the nose caused by an allergic reaction.

Anemometer: An instrument that measures air velocity.

Animal dander: Tiny particles of animal skin, fur, or feathers.

Antimicrobial: Property of a chemical or mixture that inhibits microbial growth.

Bioaerosol: Airborne particles originating from microbial matter, including cells, cell fragments, hyphae and spores.

BRI: Building–related illness. An identifiable disease, or illness that can be traced to a specific pollutant or source within a building (e.g., legionellosis).

BTU: British thermal unit. The amount of heat required to raise or lower one pound of water by one degree Fahrenheit. A BTUh is how many BTUs are used per hour.

Building envelope: Elements of the building, including all external building materials, windows, and walls, that enclose the internal space.

CAV: Constant air volume. An air handling system that provides constant air flow, while varying temperature, to meet heating and cooling needs.

CDC: U.S. Centers for Disease Control and Prevention.

CIH: Certified Industrial Hygienist. Certified by the American Board of Industrial Hygiene (http://www/abih.org).

CO: Carbon monoxide. A well-recognized, often lethal, combustion by-product.

CO_2: Carbon dioxide. Human respiration by-product that is typically used as an indicator of general building ventilation efficacy and capacity.

Dampers: Mechanical controls that vary airflow through an air outlet, inlet, or duct. A damper position may be immovable, manually adjustable, or part of an automated control system.

Diffusers and grilles: Components of the ventilation system that distribute and return air to and from an occupied space.

Drain trap: A bend in the drain pipes of sinks, toilets, and floor drains, which is designed to stay filled with water, preventing sewer gases from escaping into the room.

Economizer: A ducting arrangement and automatic control system that allows an HVAC system to supply up to 100% outside air to the building when the outside air is cooler than the return air (economizer cycle).

EDC: Endocrine disrupting chemical.

ETS: Environmental tobacco smoke.

Exhaust air: Air removed from a space and not used therein.

Exhaust ventilation: Mechanical removal of air from a portion of a building (e.g., laboratory, restroom, or general area) directly to the outdoors.

Flow hood: A device that measures airflow quantity through diffusers and grilles. It is also referred to as an air capture hood or Balometer™.

Fungi: Any of a group of saprophytic lower organisms that lack chlorophyll, including macrofungi (mushrooms and puffballs) and microfungi (molds and yeasts).

Green building: The practice of constructing buildings that are healthier, less polluting, and more resource-efficient.

HEPA: High-efficiency particulate arrestance (or air) filters that are designed to remove 99.97% of airborne particles measuring 0.3 micrometers or greater in diameter.

Humidifier fever: A respiratory illness caused by exposure to toxins from certain microorganisms found in wet areas in humidifiers and air conditioners.

HVAC: Heating, ventilating and air-conditioning system.

Hypersensitivity diseases: Diseases characterized by allergic responses to certain pollutants, including asthma, rhinitis, and hypersensitivity pneumonitis.

Hypersensitivity pneumonitis: A rare, but serious disease that involves progressive lung damage as long as there is exposure to the causative agent.

IAQ: Indoor air quality.

IEQ: Indoor environmental quality.

Immune system: All internal structures and processes providing defense against disease-causing organisms such as viruses, bacteria, fungi, and parasites.

Indoor air pollutant: Includes airborne particles, dust, fibers, mists, bioaerosols, and gases or vapors.

IH: Industrial hygienist.

Legionnaires' disease: An acute, sometimes fatal respiratory disease caused by a bacterium of the genus Legionella, especially L. pneumophila, characterized by severe pneumonia, headache, and a dry cough. The bacteria have been found in water delivery systems and can survive for long periods in water systems.

Makeup air: Air brought into a building from outdoors that has not been previously circulated through the system (or outdoor air supply).

MCS: Multiple chemical sensitivity. A condition where a person reports sensitivity or intolerance to a number of chemicals and other irritants at very low concentrations.

Microorganisms: Agents that are, or are derived from, living organisms such as viruses, bacteria, fungi, and mammal and insect allergens.

MPI: Mass psychogenic illness.

MVOC: Microbial volatile organic compound. A volatile organic compound that is given off by microorganisms during active growth that can cause odors or irritation.

Natural ventilation: The movement of outdoor air into a space through intentionally provided openings, such as windows and doors, or through non-powered ventilators or by infiltration

Negative pressure: Condition that occurs when less air is supplied to a space than is exhausted from the space, so the air pressure within that space is less than that in surrounding areas. Under this condition, air will flow from surrounding areas into the negatively pressurized space through available openings.

NIOSH: National Institute for Occupational Safety and Health.

Off-gassing: Usually, a time-dependent process whereby VOCs and formaldehyde contained in new building products or materials diffuses from those materials into the immediate indoor air environment.

OSHA: Occupational Safety and Health Administration.

Outdoor air supply: Air brought into a building from the outdoors (often through the ventilation system) that has not been previously circulated through the system. It is also known as “make-up air.”

PCB: Polychlorinated biphenyl.

PELs: Permissible Exposure Limits. Legally enforceable exposure standards set by the Occupational, Safety and Health Administration (OSHA):

PID: Photoionization detector. Used to detect certain organic chemical air pollutants.

Plenum: Open air spaces that are used as part of a building’s air distribution system.

PM: Particulate matter.

$PM_{2.5}$: Particulate matter with an aerodynamic diameter of 2.5 micrometers or less.

PM_{10}: Particulate matter with an aerodynamic diameter of 10 micrometers or less.

Pollutant pathways: Avenues for the unintentional movement and distribution of pollutants in a building.

Pontiac fever: A flu-like illness caused by the bacterium *Legionella pneumophila* contracted by breathing mist from a water source (such as air conditioning cooling towers, whirlpool spas, and showers) contaminated with the bacteria. It is a milder form of legionellosis than Legionnaires’ disease, which is caused by the same bacterium.

Positive pressure: Condition that occurs when more air is supplied to a space than is exhausted, so the air pressure within that space is greater than that in surrounding areas. Under this condition, if an opening exists, air will flow from the positively pressurized space into surrounding areas.

Pressed wood products: A group of materials used in building and furniture construction that are made from wood veneers, particles, or fibers bonded together with an adhesive under heat and pressure.

Psychogenic illness: Syndrome where symptoms develop in an individual or group of individuals who are under some type of physical or emotional stress.

Psychosocial factors: Psychological, organizational, and personal stressors that could produce symptoms similar to those caused by poor IAQ.

Re-entrainment: Term for when air being exhausted from a building is immediately brought back into the building through an air intake or other opening.

Respirable particles: Particles less than 10 micrometers in aerodynamic diameter that are able to reach the lungs.

Radon and radon decay products: A radioactive gas formed by the decay of uranium in soils and rocks. The radon decay products (also called radon daughters or progeny) can be inhaled and deposited in the lung where they release radiation as they further decay.

RELs: Recommended Exposure Limits. Non-legally enforceable exposure limits recommended by the National Institute for Occupational Safety and Health (NIOSH).

RH: Relative humidity.

SDS: Safety data sheet.

Sewer: A channel or conduit that carries waste water and storm water runoff from the source to a treatment plant or receiving stream.

SBS: Sick building syndrome. Term applied to buildings with uninvestigated or unresolved indoor environmental complaints.

Sensitization: Repeated or single exposure to an allergen that results in the exposed individual becoming hypersensitive to that allergen.

Short-circuiting: Situation that occurs when the supply air flows directly to the return or exhaust grilles before ventilating the occupied space.

Smoke tube: Small tube device that creates smoke to visually observe the flow of air currents.

Soil gases: Gases that may enter a building from the surrounding ground (e.g., radon, volatile organic compounds, pesticides).

SPF: Spray polyurethane foam.

Spore: Single-cell reproductive body of molds and certain bacteria (e.g., *Bacillus anthracis*).

SVOC: Semi-volatile organic compound.

Toxicosis: Health effects caused by exposure to excessive levels of toxic materials (e.g., carbon monoxide).

Ton: Air handling units and air conditioners are sized in tons. Each ton equals 12,000 BTUh (BTU/hr).

Tracer gases: Compounds, such as CO_2, nitrous oxide or sulfur hexafluoride, which are used to identify suspected pollutant pathways and quantify ventilation rates.

TLVs®: Threshold Limit Values. Non-legally enforceable exposure limits recommended by the American Conference of Governmental Industrial Hygienists.

TVOC: Total volatile organic compounds.

Ultrafine particulate: Particulate matter with an aerodynamic diameter of 0.1 micrometers or less.

Unit ventilator: A fan-coil unit package device for applications in which the use of outdoor- and return-air mixing is intended to satisfy tempering requirements and ventilation needs.

VAV: Variable air volume. An air handling system that conditions air to a constant temperature and then varies the supply air flow to maintain thermal comfort.

Ventilation air: Defined as the total air, which is a combination of the air brought inside from outdoors and the air that is being re-circulated within the building.

Ventilation rate: The rate at which indoor air enters and leaves a building. Expressed in one of two ways: the number of changes of outdoor air per unit of time (air changes per hour, or "ach") or the rate at which a volume of outdoor air enters per unit of time (cubic feet per minute, or "cfm").

VOC: Volatile organic compound.

Zone: The occupied space or group of spaces within a building which has its heating or cooling controlled by a single thermostat.

Appendix A:

New Buildings, Green Buildings and IAQ

Building Certification Programs

ASHRAE, along with the U.S. Green Building Council (USGBC), has published ASHRAE Standard 189.1 "Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings." They have also established certifications for design and operation of commercial (and residential) high performance buildings, geared toward building owners, facility managers, architects, contractors and engineers.[A-1]

The EPA has construction guidelines with a primary focus on IAQ in schools. IAQ Design Tools for Schools (DTfS) addresses the design of new schools as well as repair, renovation and maintenance of existing schools.[A-2] "High performance schools" include elements of IAQ, energy efficiency, daylighting, materials efficiency and safety. EPA's Indoor AirPLUS program includes construction specifications developed to recognize new homes equipped with IAQ features.[A-3]

The USGBC's Leadership in Energy and Environmental Design (LEED®) rating systems dominate the current green building certification market. LEEDv4 incorporates options for reduced emissions and enhanced indoor environmental quality, such as increased emphasis on emissions testing of building materials in addition to reduced VOC content and disclosure of chemical formulations.[A-4] Other popular green building certification programs include Green Globes[A-5], and in Europe, the Building Research Establishment Environmental Assessment Methodology (BREEAM).[A-6] The Living Building Challenge is an international certification program that requires projects to meet performance standards over a minimum of 12 months of continuous occupancy.[A-7]

With respect to IAQ, these certification programs share a number of general elements (be aware of individual nuances):

- Compliance with the current ASHRAE 62.1 standard for ventilation air quantity
- Increased ventilation and outdoor air delivery monitoring
- Low-VOC adhesives, sealants, paints, coatings, floor coverings and composite wood
- Mechanical system design, materials selections, and installation locations to reduce potential for mold
- Use of filters with a minimum efficiency rating value (MERV) of 13
- Better layout and access for filter change-out and for HVAC equipment maintenance
- Cooling towers designed to prevent transmission of *Legionella* (drift control)
- Domestic hot water systems designed to prevent amplification of *Legionella*
- Ability to flush out the building with 100 percent outside air, while maintaining reasonable indoor temperature and humidity conditions
- Compliance with ASHRAE 15 Safety Standard for Refrigeration Systems
- Exterior envelope commissioning, to control uncontrolled infiltration of outside air
- Control or eliminate smoking in the new building
- System controls for lighting and thermal comfort
- Address acoustics and noise control

- Ensure access to daylight and views
- IAQ management plans

The International Code Council (ICC), along with sponsors including ASHRAE and USGBC, has developed the *International Green Construction Code (IgCC)*. The IgCC is the first model code to include sustainability measures for the entire construction project and its site — from design through construction, and beyond.[A-8] In addition, the ICC collaborated with the National Association of Home Builders (NAHB) to develop the *ICC 700 National Green Building Standard*. It prescribes practices within a certification program that can be incorporated into new home construction and remodeling projects.[A-9]

Energy Conservation

It will be a challenge to meet the growing demand for lower energy consumption in buildings while protecting IAQ. ASHRAE's 2014 Position Document on IAQ includes this cautionary statement: "…sustainable/net zero energy building efforts will fail if they achieve energy targets but cause significant health or comfort problems for occupants or impede occupant performance…" and suggests that "…an integrated design can lead to high performing buildings that are both energy efficient and have good IAQ. Passive design features (i.e. the architectural and envelope aspects) can be optimized before active design strategies (HVAC systems) are designed for thermal conditioning..." The Position Document reiterates the need to control sources first, before considering ventilation and air cleaning.[A-10]

ASHRAE Standards 90.1 "Energy Standard for Buildings Except Low-Rise Residential Buildings" and 90.2 "Energy-Efficient Design of Low-Rise Residential Buildings," with each update, establish more stringent energy targets.[A-11,A-12] ASHRAE's Advanced Energy Design Guide series of publications[A-13] offer contractors and designers practical tools and recommendations for achieving 30% and 50% energy savings compared to code minimum. This is the first step in the process toward achieving a net-zero energy building, which is defined as a building that, on an annual basis, draws from outside resources equal or less energy than it provides using on-site renewable energy sources.

Natural Ventilation

Natural ventilation systems have seen increased use in European commercial buildings, and design and installation of these systems in U.S. commercial buildings (low to midrise) is growing. Hybrid (or mixed-mode) ventilation systems may offer energy savings, IAQ and climate control through the combination of natural ventilation systems with mechanical equipment.

Passive House (known in Germany, where it originated, as Passivhaus) is a concept for designing buildings with minimal heating and cooling loads, which reduces or eliminates the need for mechanical heating and cooling. The goal of Passive House is to significantly reduce energy consumption and peak energy demand. The key components are a super-insulated, air-tight building envelope and strategic use of solar loads and shading. Unlike a typical building that relies on natural infiltration to replenish indoor air, an air-tight Passive House is designed with mechanically supplied ventilation distributed evenly throughout the structure to prevent condensation in exterior walls, while exhausting air (but capturing heat) to eliminate odors and other indoor contaminants. By combining mechanical ventilation with energy recovery, a Passive House delivers a steady supply of filtered, tempered outside air.[A-14] There are ancillary benefits to a building designed to the Passive House standard, such as thermal comfort (even temperatures throughout), substantial soundproofing, and significantly smaller mechanical equipment and space requirements. In the U.S., the Passive House Institute U.S. (PHIUS) is gaining traction, with many single-family and small commercial buildings becoming certified.[A-15]

Lighting

Trends in lighting of buildings are also being affected by evolving energy saving requirements. The current ASHRAE Standard 90.1[A-11] includes a significant section on lighting that describes daylighting options and controls, space-by-space lighting power density limits, and thresholds for natural lighting coming into a building. LEED performance standards for new construction include credits for defined high quality lighting that improves occupants' comfort and productivity, as well as meeting energy efficiency requirements.

References

A-1. **American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE):** *ASHRAE Standard 189.1–2014, Standard for the Design of High-Performance Green Buildings, Except Low Rise Residential Buildings*. Atlanta, GA: ASHRAE, 2014. Free viewing available at https://www.ashrae.org/standards-research__technology. [Accessed January 12, 2016.]

A-2. **U.S. Environmental Protection Agency (EPA):** IAQ Design Tools for Schools (DTfS). Available at http://www.epa.gov/iaq/schools/indoor_air_quality_design-tools-schools. [Accessed January 12, 2016.]

A-3. **U.S. Environmental Protection Agency (EPA):** EPA Indoor AirPLUS Program. Available at http://www.epa.gov/indoorairplus/. [Accessed January 12, 2016.]

A-4. **United States Green Building Council (USGBC):** "LEED V4 User Guide." Available at http://www.usgbc.org/leed/v4. [Accessed January 12, 2016.]

A-5. **Green Building Initiative-Green Globes Certification:** "Green Globes for New Construction Tool." Available at http://www.thegbi.org/green-globes-certification/how-to-certify/new-construction/. [Accessed January 12, 2016.]

A-6. **Building Research Establishment Environmental Assessment Methodology (BREEAM):** "BREEAM International Certification New Construction." Available at http://www.breeam.org. [Accessed January 12, 2016.]

A-7. **Living Building Challenge:** "Living Building Challenge 3.0 Certification." Available at http://living-future.org/lbc. [Accessed January 12, 2016.]

A-8. **International Code Council (ICC):** "2012 International Green Construction Code (IgCC)." Available at http://www.iccsafe.org/codes-tech-support/international-green-construction-code-igcc/international-green-construction-code/. [Accessed January 12, 2016.]

A-9. **National Association of Home Builders:** "ICC 700 National Green Building Standard, January 2013. " Available at https://builderbooks.com/2012-icc-700-national-green-building-standard.html. [Accessed January 12, 2016.]

A-10. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): *ASHRAE Position Document on Indoor Air Quality*. Atlanta, GA: ASHRAE, 2014. Available at https://www.ashrae.org/about-ashrae/position-documents. [Accessed January 12, 2016.]

A-11. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): *Energy Standard for Buildings Except Low-Rise Residential Buildings* (ANSI/ASHRAE/IES Standard 90.1-2013). Atlanta, GA: ASHRAE, 2013. Free viewing at https://www.ashrae.org/standards-research__technology. [Accessed January 12, 2016.]

A-12. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): *Energy-Efficient Design of Low-Rise Residential Buildings* (ANSI/ASHRAE Standard 90.2–2007). Atlanta, GA: ASHRAE, 2007. Free viewing at https://www.ashrae.org/standards-research__technology. [Accessed January 12, 2016.]

A-13. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): "Advanced Energy Design Guides." Free download available at https://www.ashrae.org/standards-research--technology/advanced-energy-design-guides. [Accessed January 12, 2016.]

A-14. Passivhaus Institut: "The Passivhaus Standard." Available at http://www.passivhaus.org.uk. [Accessed January 12, 2016.]

A-15. Passive House Institute US (PHIUS): "PHIUS Certification for Buildings and Products." Available at http://www.phius.org. [Accessed January 12, 2016.]

Appendix B:

Common IAQ Problems and Possible Causes

Complaint	*Symptoms Might Include*	*Possible Causes*	*Predisposing Factors*	*Prevalence*
Sick Building Syndrome	Headaches, irritation, congestion, fatigue	Not clearly known, likely associated with combinations of factors. Not known to be related to the presence of specific chemicals or biological agents.	Worse when and where outdoor air ventilation is inadequate; elevated temperature and dust identified as risk factors	Common (a small number of cases may occur in well-maintained buildings)
Allergic Reactions	Swelling, itching, congestion, excess mucus, breathing complaints or asthma	Unsanitary conditions (excessive dust or mold growth); presence of common human allergens (e.g. cat allergen and others)	Individuals with identified allergies at higher risk of these complaints usually have history of allergies (about 10–20% of population)	Moderate
Hypersensitivity Illness	Cough, shortness of breath, fever, chills, fatigue, symptoms often pronounced in some individuals	Repeated exposure to microbial aerosols	Initially sensitized to high level exposures to certain types of microbial contamination	Rare

Complaint	*Symptoms Might Include*	*Possible Causes*	*Predisposing Factors*	*Prevalence*
Irritation	Watering, burning or dryness of eyes, difficulty in wearing contact lenses, hoarse voice, nose, or throat irritation, may be accompanied by other nonspecific symptoms such as headache, nausea, or fatigue	Excessive concentrations of volatile chemicals such as solvents or formaldehyde; might also be because of low humidity	Some people are more sensitive; tends to be worse during peak emissions or episodes of low humidity (e.g. winter months)	Moderate
Carbon Monoxide Poisoning	Headache, dizziness, nausea, loss of consciousness, coma, death	Combustion gases	Cardiac and respiratory disease in more sensitive individuals	Rare
Neurological	Headaches, tremors, loss of memory	Insecticide misuse	Some individuals are more sensitive	Rare
Respiratory Infections	Diagnosed infection such as legionellosis or aspergillosis	Should be related to specific contaminant in building	Immune system deficiencies	Rare
Comfort (thermal)	Too hot, too cold, too stuffy, too drafty	HVAC	Difficulty in obtaining thermal satisfaction of all occupants, often straight-forward to diagnose	Common
Comfort (nuisance)	No symptoms, just concern for unusual odor, unusual quantities of settled dust, dust stains near supply air diffusers, or other conditions	Inadequate control of source emissions or contamination, poor housekeeping	Stressful work or personal conditions may trigger or exacerbate such complaints	Moderate
Psychosocial Stressors	Headaches, fatigue, muscle aches	Stressful work conditions, poor labor relations, overcrowding, thermal discomfort, malodors, unrelated concerns	Poor communication, internal and external stressors, workforce having many personal issues	Common
Mass Psychogenic Illness	Hyperventilation, fainting, vomiting, dizziness, skin irritation	Symptoms spread by visual and verbal cues	Visual and verbal contact between affected individuals	Rare
Ergonomic Problems	Muscle aches, fatigue, eyestrain, headaches	Uncomfortable seating, repetitive motion		Moderate
Lighting	Eyestrain, headaches	Detailed visual tasks		Moderate
Noise	Headaches, fatigue	Excessive noise from HVAC system, office equipment, poor acoustics	Area design, loud occupants, insulation needs	Moderate
Cluster of Adverse Health Effects	Headaches, respiratory symptoms, fatigue	May be communicable infectious diseases or illnesses (flu, common cold, etc.)		Moderate

Appendix C:

EPA Guidelines for IAQ Problem Causes and Solutions

(Adapted from EPA I-BEAM software. Available at http://www.epa.gov/iaq)

Indoor Sources

The following table identifies sources of contaminants commonly found in office buildings and offers some measures for maintaining control of these contaminants. Follow these measures to help maintain a healthy indoor environment.

<table>
<tr><th>Category/Common Sources</th><th>Tips for Mitigation and Control</th></tr>
<tr><td>Housekeeping and Maintenance
Cleansers; waxes and polishes; disinfectants ;air fresheners; adhesives; janitor's/storage closets; wet mops; drain cleaners; vacuuming; paints and coatings; solvents; pesticides; lubricants</td><td>• Use low-emitting products
• Avoid aerosols and sprays
• Dilute to proper strength (manufacturer's instructions)
• Do not overuse; use during unoccupied hours
• Use proper protocol when diluting and mixing
• Store properly with containers closed and lid tight
• Use exhaust ventilation for storage spaces (eliminate return air)
• Clean mops: store mop top up to dry
• Avoid "air fresheners"—clean and exhaust instead
• Use high efficiency vacuum bags/filters
• Use Integrated Pest Management</td></tr>
<tr><td>Occupant-Related Sources
Tobacco products; Office equipment (Printers, copiers); cooking/ microwaves; art supplies; marking pens; paper products; personal products (e.g., perfume); tracked in dirt/pollen</td><td>• Smoking policy
• Use exhaust ventilation with pressure control for major local sources
• Low emitting art supplies/marking pens
• Avoid paper clutter
• Education material for occupants and staff</td></tr>
<tr><td>Building Uses as Major Sources
Print/photocopy shop; science laboratory; medical office; cafeteria</td><td>• Use exhaust ventilation and pressure control
• Use exhaust hoods where appropriate; check hood airflows</td></tr>
<tr><td>Building-Related Sources
Plywood/compressed wood; construction adhesives; asbestos products; insulation; wall/floor coverings; (vinyl/plastic); carpets/carpet adhesives; wet building products; transformers; upholstered furniture; renovation/remodeling</td><td>• Use low emitting products
• Air out in an open/ventilated area before installing
• Increase ventilation rates during and after installing
• Keep material dry prior to enclosing
• Use renovation guidelines</td></tr>
</table>

Category/Common Sources	*Tips for Mitigation and Control*
HVAC system contaminated filters; contaminated duct lining; dirty drain pans; humidifiers; lubricants; refrigerants; mechanical room; maintenance activities; combustion appliances (boilers/furnaces; DHW; generators; stoves)	• Perform HVAC preventive maintenance • Use filter change protocol • Clean drain pans; proper slope and drainage • Use potable water for steam humidification • Keep duct lining dry; move lining outside of duct if possible • Fix leaks/clean spills (see filter change protocol) • Maintain spotless mechanical room (not a storage area) • Avoid back drafting • Check/maintain flues from boiler to outside • Keep combustion appliances properly tuned • Disallow unvented combustion appliances • Perform polluting activities during unoccupied hours
Moisture	• Keep building dry
Mold	• Mold and Moisture Control Protocol
Vehicles Underground/attached garage	• Use exhaust ventilation • Maintain garage under negative pressure relative to the building • Check air flow patterns frequently • Monitor CO

Outdoor Sources

The following table identifies common sources of contaminants that are introduced from outside buildings. These contaminants frequently find their way inside through the building shell, openings, or other pathways to the inside.

Category/Common Sources	***Tips for Mitigation and Control***
Ambient Outdoor Air air quality in the general area	• Filtration or air cleaning of intake air
Vehicular Sources local vehicular traffic vehicle idling areas loading dock	• Locate air intake away from source • Require engines shut off at loading dock • Pressurize building/zone • Add vestibules/sealed doors near source
Commercial/Manufacturing Sources laundry or dry cleaning; restaurant ; photo-processing; automotive shop/gas station; paint shop; electronics manufacture/assembly; various industrial operations	• Locate air intake away from source • Pressurize building relative to outdoors • Consider air cleaning options for outdoor air intake • Use landscaping to block or redirect flow of contaminants, but not too close to air intakes
Utilities/Public Works utility power plant; incinerator; water treatment plant	
Agricultural pesticide spraying; processing or packing plants; ponds	
Construction/Demolition	• Pressurize building • Use walk-off mats
Building Exhaust bathrooms exhaust; restaurant exhaust; air handler relief vent; exhaust from major tenant (e.g., dry cleaner)	• Separate exhaust or relief from air intake • Pressurize building
Water Sources pools of water on roof; cooling tower mist	• Proper roof drainage • Separate air intake from source of water • Treat and maintain cooling tower water
Birds and Rodents fecal contaminants; bird nesting	• Bird proof intake grilles • Consider vertical grilles • Use Integrated Pest Management
Building Operations and Maintenance trash and refuse area; chemical/ fertilizers/ grounds keeping storage; painting/roofing/ sanding	• Separate source from air intake • Keep source area clean/lids on tight • Isolate storage area from occupied areas

Category/Common Sources	*Tips for Mitigation and Control*
Ground Sources soil gas; sewer gas; underground fuel storage tanks	• Depressurize soil • Seal foundation and penetrations to foundation • Keep air ducts away from ground sources
Painting	• Establish a protocol for painting and insure that the protocol is followed by both in-house personnel and by contractors. • Use low VOC emission, fast drying paints where feasible. • Paint during unoccupied hours. • Keep lids on paint containers when not in use. • Ventilate the building with significant quantities of outside air during and after painting. Insure a complete building flush prior to occupancy. • Use more than normal outside air ventilation for some period after occupancy. • Avoid spraying, when possible.
Shipping and Receiving	• Establish and enforce a program to prevent vehicle contaminants from entering the building. • Do not allow idling of vehicles at the loading dock. Post signs and enforce the ban. • Pressurize the receiving area relative to the outside to insure that contaminants from the loading area do not enter the building. Use pressurized vestibules and air locks if necessary. • Periodically check the pressure relationships and compliance with the protocol. • Notify delivery company supervisors of policy.

Category/Common Sources	*Tips for Mitigation and Control*
Managing Moisture and Mold	Mold thrives in the presence of water. The secret to controlling mold is to control moisture and relative humidity • Keep relative humidity below 60% (50%, if feasible, to control dust mites) Keep all parts of the building dry that are not designed to be wet • Adequately insulate exterior walls or ceilings to avoid condensation on cold surfaces • Insulate cold water pipes to avoid sweating • Clean spills immediately. Thoroughly clean and dry liquid spills on porous surfaces such as carpet within 24 hours, or discard the material • Do not allow standing water in any location • Maintain proper water drainage around the perimeter of the building • Provide sufficient exhaust in showers or kitchen areas producing steam Thoroughly clean areas that are designed to be wet • Wash floors and walls often where water accumulates (e.g., showers) • Clean drain pans often and insure a proper slope to keep water draining • Insure proper maintenance and treatment of cooling tower operations • Discard all material with signs of mold growth Discard furniture, carpet, or similar porous material having a persistent musty odor • Discard furniture, carpet, or similar porous material that has been wet for more than 24 hours • Discard ceiling tiles with visible water stains

Appendix D:

Background Information Checklist

The following checklist provides prompts to aid in gathering necessary and useful information at the initiation of an IAQ investigation. Not all of the information would be necessary or relevant to all IAQ investigations, so it is appropriate to tailor the list, as needed. Much of this information can be gathered prior to an on-site evaluation.

1. Facility Identification
   A. Building name/number
   B. Address
   C. Location
   D. Owner
   E. Operator
   F. Tenant(s)
2. Contact Persons
   A. Facility manager
   B. HVAC operator
   C. Maintenance supervisor
   D. Primary client contact

3. Facility Description
   A. Nature of business or activities conducted by
      - tenant(s)
      - other occupants
   B. Number of occupants in each space
   C. Activities conducted in or near the building
      - laboratory
      - manufacturing
      - industrial operations
      - cafeteria
      - parking garage
      - list volatile chemicals in use within the building
      - other chemical users/releasers
   D. Time of day/Days of week
      - total number of employees on duty
      - office employees on duty
      - maintenance employees on duty
      - facility open for business
   E. Construction
      - general description (no. of floors, style of construction)
      - floor area per floor
      - year constructed
      - intended use
      - major renovations (include dates and areas)
   F. Finishes and Furnishings
      - floor coverings
      - wall coverings
      - partitions
      - ceilings
      - office furniture
4. Neighborhood
   A. Principal use (rural, urban, commercial)
   B. Proximity to major traffic routes
   C. Density of Traffic
   D. Neighboring facilities or issues that could contribute to the complaints

5. Facility Maintenance
   A. Typical and atypical activities/products regarding:
      - outdoor and indoor pesticide use
      - grounds and landscaping activities
      - asbestos, other insulation removal
      - new furniture or upholstery
      - leaking water pipes
      - water intrusion
      - electrical, plumbing, or HVAC repair or renovation
      - new partitions, plumbing, or HVAC repair or renovation
      - painting, staining, varnishing
      - insulation
      - wax stripping
      - flooding
      - lead-based paint removal
      - cleaned floor coverings, wall coverings, upholstery

Appendix E:

Occupant Interview Form

General: Try to interview the employee individually, in a quiet office or by telephone. Avoid group interviews as some persons may be reluctant to respond because of group dynamics, and responses may be suppressed. Indicate to the interviewed employee that their responses will be kept confidential. If a report is submitted, you may wish to only provide a summary to the employer, and avoid identifying persons by name. Handing out copies of this form to be completed by employees is generally not recommended, since questions and responses may be difficult to interpret. Be advised that by asking questions about medical conditions, the information in these forms may trigger health confidentiality issues. This form should be protected from distribution unless you have received appropriate release documentation and concurrence from the individual who has been interviewed, or their legal guardian.

Employee name:	Date:
Location where you spend most of your time:	
How long have you worked for your employer?	
How long have you worked in this building?	
How long have you worked at your present location (work station)?	
Tell me about any health or thermal comfort concerns or complaints about your occupancy in the building	
Have you seen a doctor about your concerns? ❑ Yes ❑ No *(Questions regarding medical issues may not be necessary if the complaints do not involve medical symptoms e.g., odors, temperature extremes, etc.).* If yes, did the doctor provide a diagnosis of your condition? ❑ Yes ❑ No	
Are you taking any medications (over-the-counter or prescription) because of these complaints? ❑ Yes ❑ No If yes, what are you taking, and how often? Do/does the medication(s) help?	
Do you have any allergies, sensitivities, or wear contact lenses?	
When did you first experience these issues? Have you been able to perceive any particular patterns associated with the timing of the complaints you experience? ❑ Yes ❑ No What day of the week do you experience them? What time of day? Do you experience them at home or on weekends or holidays? Are the issues better or worse certain times of the year (Spring, Summer, Fall, Winter)?	

Are you bothered by any of the following (if yes, please provide a description):		
Odors?	❑ Yes	❑ No
Irritation?	❑ Yes	❑ No
Air circulation?	❑ Yes	❑ No
Drafts?	❑ Yes	❑ No
Temperature too warm?	❑ Yes	❑ No
Temperature too cool?	❑ Yes	❑ No
Temperature swings, too high/low?	❑ Yes	❑ No
Humidity?	❑ Yes	❑ No
Dust?	❑ Yes	❑ No
Any changes in the work environment?		
New type of job or job duties?	❑ Yes	❑ No
New equipment?	❑ Yes	❑ No
New products (e.g., chemical, material, paper)?	❑ Yes	❑ No
New personnel in area or department?	❑ Yes	❑ No
Have you changed where you spend most of your time in the building in the last 3 months? 6 months? 1 year?	❑ Yes	❑ No
Are there any problems with your workstation?		
Lighting?	❑ Yes	❑ No
Glare?	❑ Yes	❑ No
Chair, seating comfort?	❑ Yes	❑ No
Ergonomics?	❑ Yes	❑ No
Any building renovation/repairs recently in your area?	❑ Yes	❑ No
What?		
When?		
Did this trigger any specific comfort or health complaints? Describe.	❑ Yes	❑ No
Do you have any other comments you wish to add?		
What do you think is the cause of the problem? Any ideas for solutions?		

Appendix F:

OSHA Guidelines for Computer Workstation Lighting Problems and Solutions

(Source: "OSHA Computer Workstations eTool." Available at https://www.osha.gov/SLTC/etools/computerworkstations/wkstation_enviro.html. [Accessed January 12, 2016.])

Lighting	
Potential Problem	*Possible Solutions*
Bright lights shining on the display screen "wash out" images, making it difficult to clearly see work. Straining to view objects on the screen can lead to eye fatigue.	• Place rows of lights parallel to your line of sight. • Provide light diffusers so that desk tasks (writing, reading papers) can be performed while limiting direct brightness on the computer screen. • Remove the middle bulbs of 4-bulb fluorescent light fixtures to reduce the brightness of the light to levels more compatible with computer tasks if diffusers or alternative light sources are not available. Note: a standard florescent light fixture on a nine-foot ceiling with four, 40-watt bulbs will produce approximately 50 foot-candles of light at the desktop level. • Provide supplemental task/desk lighting to adequately illuminate writing and reading tasks while limiting brightness around monitors. - Generally, for paper tasks and offices with CRT displays, office lighting should range between 20 to 50 foot-candles. If LCD monitors are in use, higher levels of light are usually needed for the same viewing tasks (up to 73 foot-candles).
Bright light sources behind the display screen can create contrast problems, making it difficult to clearly see work.	• Use blinds or drapes on windows to eliminate bright light. Blinds and furniture placement should be adjusted to allow light into the room, but not directly into your field of view. Note: vertical blinds work best for East/West facing windows and horizontal blinds for North/South facing windows. • Use indirect or shielded lighting where possible and avoid intense or uneven lighting in your field of vision. Ensure that lamps have glare shields or shades to direct light away from your line of sight. • Reorient the workstation so bright lights from open windows are at right angles with the computer screen.
High contrast between light and dark areas of the computer screen, horizontal work surface, and surrounding areas can cause eye fatigue and headaches.	• For computer work, use well-distributed diffuse light. The advantage of diffuse lighting is that - There are fewer hot spots (or glare surfaces) in the visual field, and - The contrasts created by the shape of objects tend to be softer. • Use light, matte colors and finishes on walls and ceilings to better reflect indirect lighting and reduce dark shadows and contrast.

Glare	
Potential Problem	*Possible Solutions*
Direct light sources (for example, windows, overhead lights) that cause reflected light to show up on the monitor make images more difficult to see, resulting in eye strain and fatigue.	• Place the face of the display screen at right angles to windows and light sources. Position task lighting (for example, a desk lamp) so the light does not reflect on the screen. • Clean the monitor frequently. A layer of dust can contribute to glare. • Use blinds or drapes on windows to help reduce glare. Note: vertical blinds work best for East/West facing windows and horizontal blinds for North/South facing windows. • Use glare filters that attach directly to the surface of the monitor to reduce glare. Glare filters, when used, should not significantly decrease screen visibility. Install louvers, or "egg crates", in overhead lights to re-direct lighting. • Use barriers or light diffusers on fixtures to reduce glare from overhead lighting.
Reflected light from polished surfaces, such as a keyboard, may cause annoyance, discomfort, or loss in visual performance and visibility.	• To limit reflection from walls and work surfaces around the screen, paint them with a medium colored, non-reflective paint. Arrange workstations and lighting to avoid reflected glare on the display screen or surrounding surfaces. • Tilt down the monitor slightly to prevent it from reflecting overhead light. • Set the computer monitor for dark characters on a light background; they are less affected by reflections than are light characters on a dark background.
Note: Generally, a large number of low powered lamps rather than a small number of high powered lamps will result in less glare.	

Appendix G:

Noise Sources in Offices and Possible Corrective Actions

(adapted from Canada Safety Council "Office Noise and Acoustics." Available at https://canadasafetycouncil.org/workplace-safety/office-noise-and-acoustics. [Accessed January 12, 2016.] and Bradley, J.S. "Acoustical Design for Open-Plan Offices." National Research Council of Canada, Institute for Research in Construction: 2004. Available at http://www.nrc-cnrc.gc.ca/ctu-sc/ctu_sc_n63. [Accessed January 12, 2016.]

Noise Sources	*Possible Corrective Actions*
HVAC system	Determine if regular maintenance is up to date. Are repairs needed? (ensure system not exceeding 40 dBA in the office area)
	Is ductwork insulation present and in good condition?
Office equipment	Determine if regular maintenance is up to date. Are repairs needed? (ensure not exceeding 40 dBA in the office area)
	Place soft mats under equipment.
	Use anti-vibration mounts to dampen vibration of equipment.
	Isolate noisy equipment from work areas with barriers.
	Relocate equipment to enclosed space.
Occupant generated sounds/ speech privacy	Encourage office workers to lower their voices.
	Encourage workers to use conference rooms for discussions.
Outside building (traffic, construction, other activities)	Increase insulation, sound absorbing materials and barriers.
Area design issues/poor acoustics	Place sound absorptive materials on walls, ceilings, other large surfaces.
	Install carpeting or soft floor surfaces.
	Use office dividers (walls, panels, partitions, other barriers) to reduce or redirect sound away from workstations.
	Install heavy drapes or sound-absorbing wall panels.
	Place plants in the work area.
	Locate workstations away from high traffic areas.
	Avoid crowding too many workstations into one area.
	Enlarge workstations if possible.
	Place screens, partitions, furniture, and office equipment for maximum acoustical benefits (not adversely affecting lighting and ventilation systems). Can raise panels above floor for air circulation.
	Avoid flat lens light fixtures.
	Purchase quiet equipment.
	Masking sounds (if not distracting to others and not exceeding 45 dBA) with: • white noise generators • sound conditioning systems • individuals using low volume music or radio *Note: Headsets or ear plugs can interfere with the ability to hear sounds alerting the worker of a danger and are not generally recommended.*

Appendix H:

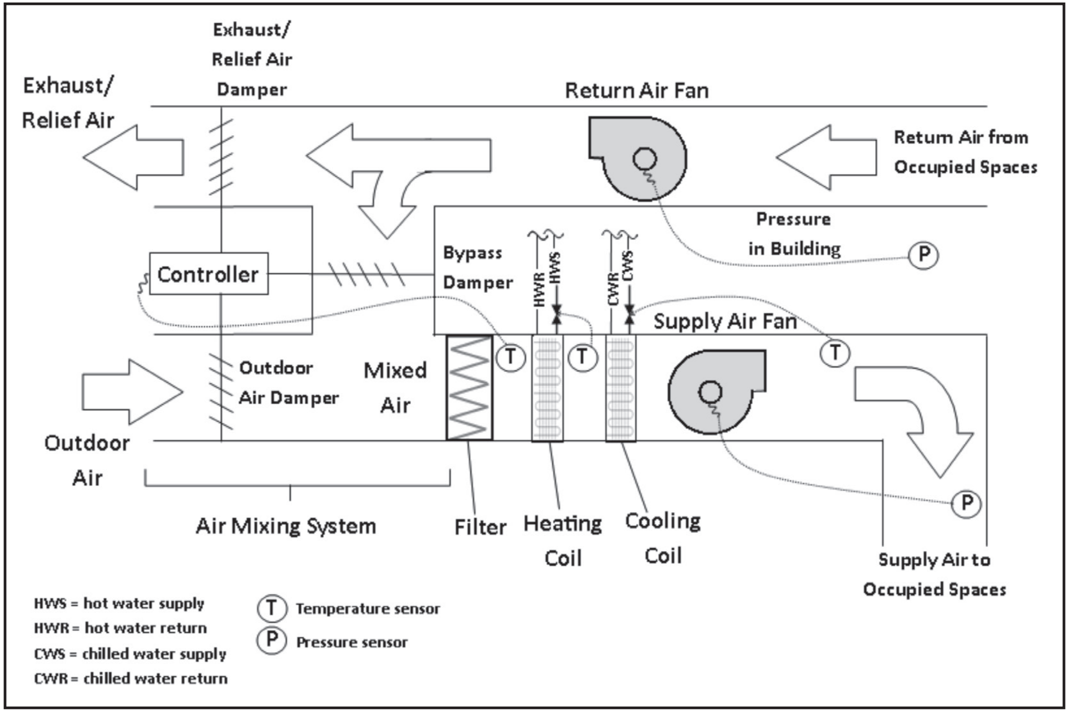
HVAC System Types

Diagrams, descriptions and applications of some typical HVAC system types and components include the following:

- General Layout of Air Handling System
- Constant Volume (CV) System
- Variable Air Volume (VAV) System
- Dual-Duct (DD) System
- Multi-Zone System
- Unit Ventilator

Figure A: H-1 General Layout of an Air Handling System.

Air handlers usually connect to a ductwork system that distributes the conditioned air through the building, and then returns it to the AHU. Sometimes AHUs directly discharge supply air to, and admit return air from, the space served without the use of any ductwork.



(Source: E. Gunderson)

Numerous variations and hybrids of these systems may be encountered.

The basic components of the air handling unit (AHU) within the HVAC system are:

- outdoor air intake
- mixed-air plenum and outdoor air control
- blower
- air filter racks or chambers
- heating and cooling coils
- humidification and/or de-humidification equipment
- temperature and pressure sensors
- sound attenuators
- dampers

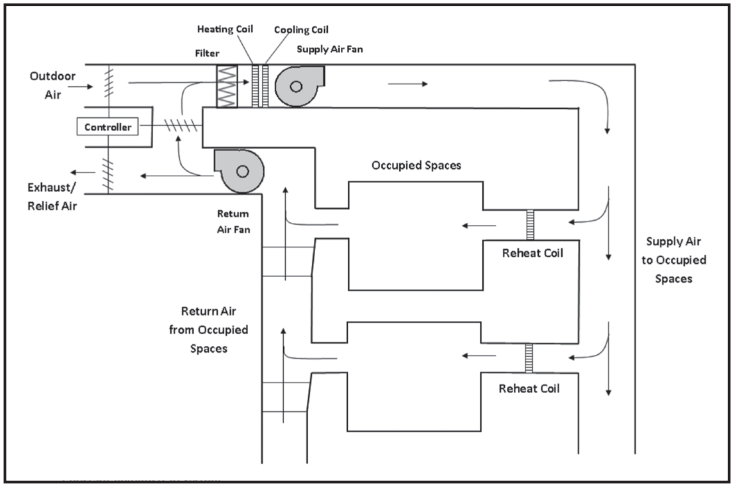
Small air handlers, for local use, are called terminal units, and may only include an air filter, heating/cooling coil, and blower. These simple terminal units are usually referred to as blower coils or fan coil units (see "unit ventilator" below, a type of fan coil unit). A larger air handler that conditions 100% outside air, and does not recirculate air from the spaces served, is known as a makeup air unit (MAU). An air handler designed for outdoor use, which is typically mounted on the roof of the building, is known as a packaged unit (PU) or rooftop unit (RTU).

Figure A: H-2 Constant Volume (CV) System.

A constant volume (CV), or constant air volume (CAV), system is one where the air handler delivers a constant airflow to each space. Changes in space temperatures are made by heating or cooling the air at the air handler, switching the unit on and off, changing the relative rates of outdoor air intake and recirculation, changing damper positions in the air handler, or a combination of these approaches. CAV systems often operate with a fixed minimum percentage of outdoor air or with an "air economizer."

CAV systems are often found in small buildings and residences with a single thermal zone, but are also used in larger applications such as concert halls, gymnasiums, and warehouses. Variations of CAV systems can serve multiple zones and larger buildings. Some examples are:

- Single duct CAV systems are found in buildings that require little differences in air supply and temperature between spaces, such as in a home or a warehouse.
- Reheat CAV systems are found in buildings with a single main space surrounded by smaller, user specific spaces. The air-handling unit can control the environment in the main space, and the smaller spaces can be individually heated or cooled if they have different needs than the main space. An example would be a gymnasium with adjacent locker-rooms and offices.
- Mixed Air CAV systems are found in office buildings, schools, and similar structures. Since there are mixing boxes at each of the different spaces served, for temperature adjustment, mixed air systems can have individualized control.



(Source: E. Gunderson)

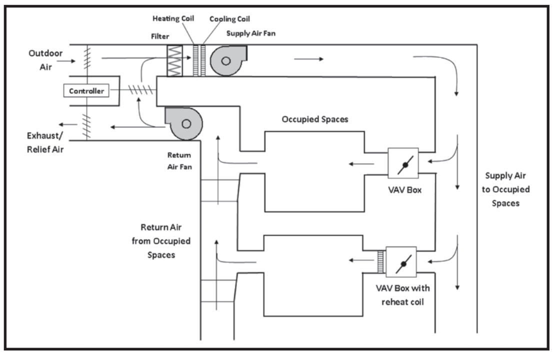
Figure A: H-3 Variable Air Volume (VAV) System.

A variable air volume (VAV) HVAC system modulates the amount of air supplied to a space in response to changes in thermal needs of the space. A central air handling unit supplies air through a common duct pathway to all spaces serviced by the unit. Each zone is provided with a VAV box (terminal control box) that adjusts air supply volume in response to the zone thermostat. The temperature of air supplied by the air handling unit may be varied to adapt to building-wide changes, but day-to-day control of each zone is achieved through varying the supply air flow rate. A basic VAV system does not provide simultaneous heating and cooling.
A VAV terminal unit, often called a VAV box, is the zone-level flow control device. It is basically a calibrated air damper with an automatic actuator. The VAV terminal unit is connected to either a local or a central control system.

VAV systems are widely used for various applications. Typically they are found in larger buildings that require individual temperature control. Several applications for VAV systems include:

- Medium to large public office buildings or residential apartment complexes;
- Arenas;
- Exhibition halls, and
- Theaters.

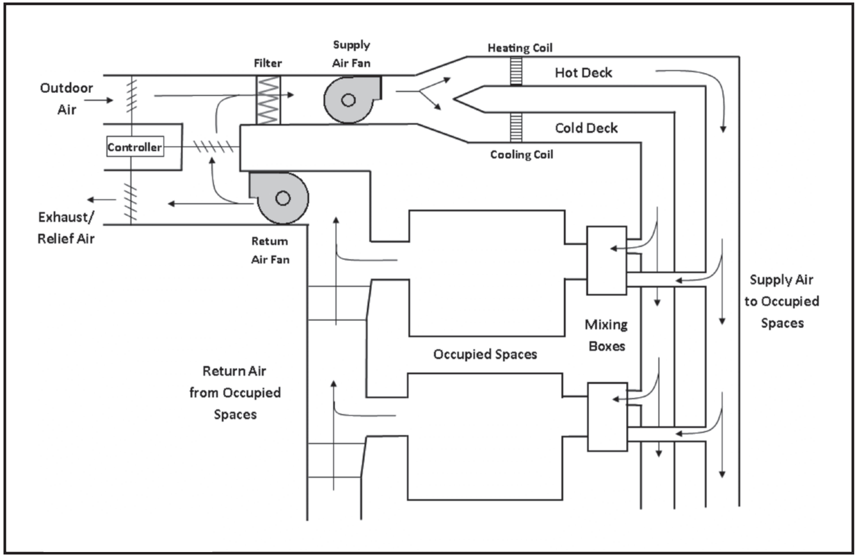
One of the challenges for VAV systems is providing adequate temperature control for multiple zones with different environmental conditions, such as an exterior office of a glass in building vs. an interior conference room down the hall. Reheating the air at a terminal box in the space in a single duct VAV system is often done. Alternatively, dual duct VAV systems provide cool air in one duct, and warm air in a second duct, to provide an appropriate temperature of mixed supply air for any zone. There are also multi-zone VAV systems used in certain applications.



(Source: E. Gunderson)

Figure A: H-4 Dual Duct (DD) System.

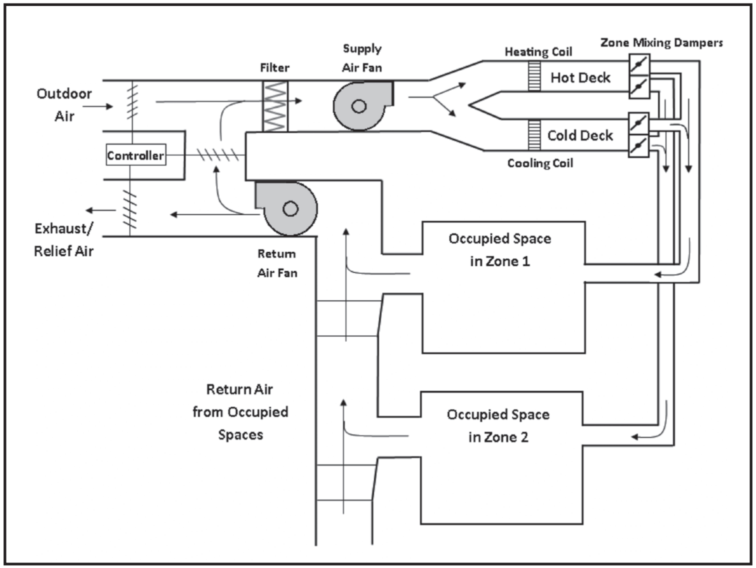
In a dual duct HVAC system, the central air handling unit provides two conditioned air streams - a "cold" deck and a "hot" deck. These air streams are distributed throughout the area served by the air handling unit in separate and parallel ducts (not necessarily of equal size, depending upon building heating and cooling loads). A terminal mixing box is provided for each zone. Dampers in the mixing box are controlled by the zone thermostat. The air streams are mixed in the terminal box to provide a supply air temperature that will properly condition the zone. A dual duct system can use either constant or variable supply airflow. These systems are generally limited to older buildings.



(Source: E. Gunderson)

Figure A: H-5 Multi-Zone System (only two zones shown for clarity).

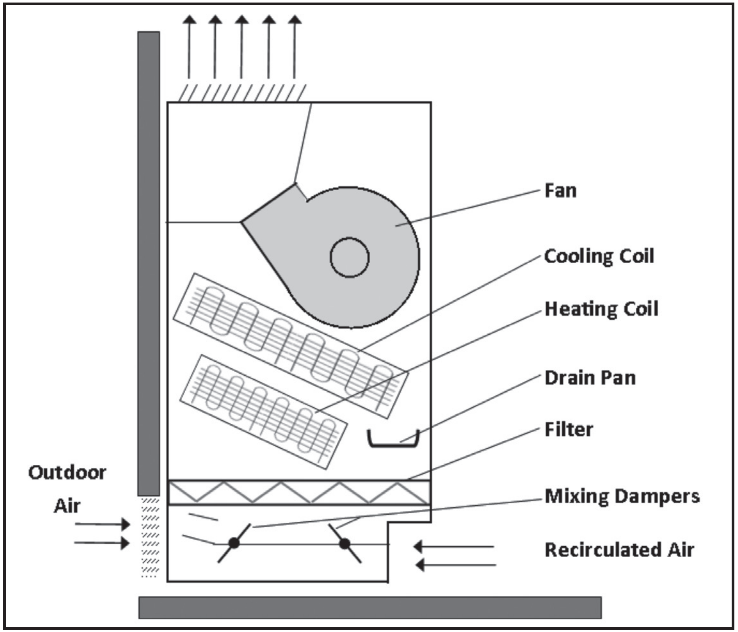
In a multi-zone HVAC system, individual supply air ducts are provided for each zone in a building. Cool air and hot (or return) air are mixed at the air handling unit to meet the needs of each zone. Once mixed at the air handler, air for a particular zone is not mixed with air from any other zone — thus the need for separate supply ducts. A special air handling unit, with parallel air flow paths at the heating and cooling coils and internal mixing dampers, is used in this type of system. Due to physical restrictions on duct connections and damper size, the normal commercial multi-zone air handler is limited to a maximum of around 12 zones. Multi-zone systems can be either constant volume or variable air volume.



(Source: E. Gunderson)

Figure A: H-6 Unit Ventilator.

A unit ventilator is a simple HVAC system consisting of a filter, heating and/or cooling coil and fan. It is not typically connected to ductwork and is used to control the temperature in the space where it is installed, or serve multiple spaces. It is controlled either by a manual on/off switch or by a thermostat. Unit ventilators can be wall mounted, or hung from the ceiling, and are found mainly in classrooms, hotels, apartments and condominium applications.



(Source: E. Gunderson)

Appendix I:

Building Engineering HVAC Inspection Checklist

Check all that apply.

1. Is there a mechanical HVAC system?	
Note which floors/rooms are served by each system.	
	VAV (variable air volume)
	VAV with induction
	VAV with recirculation
	CAV (constant air volume)
	Mixed systems (zones served by both VAV and CAV)
	Terminal reheat
	Heat pumps
	Fan coil
	Induction unit
	Ceiling plenum (supply)
	Ceiling plenum (return)
	Ducted return air system

2. If VAV:	
	What is the supply air temperature set point?
	Is there a minimum flow setting?
	What is it?
3. Type of HVAC functions:	
	Heating
	Cooling
	Dehumidification
	Humidification
	Filtration
	Outdoor air supply
	Indicate location of functional units
4. Perimeter heating or cooling?	
	What type?
5. Any recent repairs or significant modifications to the HVAC system?	
6. HVAC maintenance/operation	
Note scheduled times and indicate if done by in-house staff or outside contractor	
	Boiler water treatment
	Change filters
	Clean coils
	Clean ducts
	Clean drain pans
	Clean other surfaces inside the air handling unit
	Clean outdoor air intake
	Clean mechanical equipment room
	Control system maintenance

7.	**Has airflow within the HVAC system been measured? (Often referred to as a "balance" report.)**
	If so, when?
	Obtain a copy and examine to determine if there were deficiencies and if recommendations, if any, have been addressed.
8.	**HVAC controls (e.g. thermostat, wall or return air sensors with computer controlled components)**
	Original controls?
	Modified?
	Economizer?
	Duty cycling?
	Set back?
9.	**Are system components controlled automatically?**
	When were sensors last calibrated?
10.	**What is the minimum amount of outdoor air entering the HVAC systems? (This may need to be measured with the economizer louvers in their most restricted setting.)**
11.	**How is the HVAC system controlled?**
	Where are thermostats located?
	Do occupants have access to the thermostats?
	When were thermostats last calibrated?
	What is the cycle of the day/night controller, if used?
12.	**Is the ventilation in the work area(s) decreased or shut off overnight or on weekends?**
	If decreased, the system goes down overnight to what percentage of daytime?
	Shutoff/decrease hours are which hours during the week?
	Shutoff/decrease hours on weekends are which hours/days?
	Which hours/days is the building open?
13.	**Is there a filter system in the outdoor air intake?**
	How often are the filters changed?
	What types are the filters?
	What is their theoretical efficiency?

14. Humidification equipment present?	
	What type: steam jet, air washer, water spray, pan type, or atomizing?
15. Dehumidification system present?	
	Central (other than cooling coil)
	Local
16. Heating system type?	
	Energy source? (oil, gas, electric, other)
	Primary fluid? (steam, hot water, air, other)
	Supply system? (pipe, duct, plenum, other)
	Distribution system? (radiators, ceiling grilles, other)
	Return system? (pipe, duct, plenum, other)
	Location of heat source?
	Local heating units?
17. Cooling equipment present:	
	Chilled water, direct expansion, absorption, cooling tower, air cooled condensing?
	Location of chillers?
	Window units used?
18. Checklist of client documents available	
	Floor plans
	Diagrams
	Design specifications
	Distribution system drawings
	Mechanical room drawings
	Sheet metal drawings
	Plumbing drawings
	Vent specifications
	Equipment schedule
	Previous environmental reports
19. Are HVAC components accessible to maintenance?	
	Indicate which areas/components are not accessible.

20.	**Are any chemicals, solvents, and/or cleaners stored in the air handling unit/mechanical equipment room (AHU/MER)?**
21.	**Are there any leaks (oil, water, steam) from the HVAC components in the AHU/MER?**
22.	**Are any fans not working?**
23.	**Does the building have an air-conditioning system?**
	What is its operating schedule?
	Is the system operating today?
	How often are the condensate trays cleaned?
	Is there slime on the condensate trays or the cooling coils?
	Are there moldy odors in the system?
	Is there water accumulation on the ground?
24.	**Outdoor air intakes**
	Are intakes below third floor level and above a busy street?
	Are intakes above entrance to a loading dock?
	Are intakes above entrance or exit to a parking garage?
	Any other pollution sources near the intakes?
	Are there any obstructions lodged in the intake?
	Are dampers functioning?
	Are intakes within 30 feet of any HVAC, restroom, kitchen or laboratory exhausts?
	Are open doors or windows used for outside air?

25. Filters in AHU	
	Does the filter fit so poorly that air bypasses it at the edges (blow-by)?
	Are filters matted/dirty/wet?
26. Are the vent ducts or mixing room of the AHU lined with insulation?	
	Is it external or internal?
	What type is it: fiberglass, polystyrene, or asbestos?
	Is internal lining dirty/wet/shredded/torn?
27. Roof	
	Any flooding or ponding?
28. Operational problems experienced with the HVAC system	

Appendix J:

IAQ Sampling Equipment and Monitors

The following lists some common types of equipment used in IAQ investigations. Only trained personnel should conduct air sampling and testing. To ensure accurate results the investigator should confirm that the equipment has been regularly maintained and is calibrated for the specific parameters or air contaminants to be sampled. The user needs to be aware of the limitations of the equipment, including its lower limit of detection and potential interfering substances or conditions that would affect the results.

Equipment/Monitor	Measures	Notes
IAQ Basic Tools		
Camera(s)	• Any basic camera for recording observations • Infrared thermal imaging camera can help locate areas of moisture intrusion, visually document water damaged building materials • Video borescope inspection camera	
Ventilation		
Thermal anemometer	• Temperature, relative humidity, air velocity	
Smoke tubes	• Air motion, circulation	Qualitative
Balometer™ (flow hood)	• Air flow at diffusers	
Micromanometer	• Differential air pressure	
Carbon dioxide monitor	• Carbon dioxide	
Moisture meter	• Moisture in materials	Surface and pin types, comparative
Tracer gas analyzer	• Sulfur hexafluoride • Carbon dioxide • Nitrous oxide • Helium	Quantification of ventilation efficiency and distribution. Odor pathway studies.
Chemical Contaminants		
Carbon monoxide monitor	• Carbon monoxide	
Direct-reading portable gas monitors	• Carbon dioxide • Carbon monoxide • VOCs • Formaldehyde • Ozone • Hydrogen sulfide • Others	Calibration needed, check for interferences
Combustible gas monitors	• Carbon monoxide • Carbon dioxide • Methane, other combustible gases • Nitrogen oxides	Calibration needed, check for interferences
Photoionization detector	• VOCs	Some have ppb sensitivity, non-specific, check for interferences

Sampling pumps, sorbent tubes, filters, impingers	• Specific sampling/analytical methods • Many chemicals and VOCs	Laboratory analysis of collected samples
Passive monitors, detectors	• Radon • VOCs • Formaldehyde • Others	Laboratory analysis of collected samples
Gas sample bags, evacuated canisters	• VOCs by specific methods	Laboratory analysis of collected samples
Colorimetric indicating ("detector") tubes	• Carbon dioxide • Carbon monoxide • Nitrogen oxides • Formaldehyde • Ozone • Others with appropriate sensitivity	Inexpensive, direct reading, may not be reliable at low contaminant levels typical of offices, check for interferences
Biological Contaminants		
Moisture meter	• Moisture in materials	
Sampling pumps, cassettes with filters and treated filters, glass slide, media samplers, impingers	• Fungal spores • Culturable fungi and bacteria • Pollen • Allergens • Insect parts • Skin cell fragments • Beta glucans • Micotoxins • Endotoxins	Microscopic analysis, immunologic and other bioassays, GC/MS analysis
Particle size selective samplers (impactors, cyclones with culture media)	• Culturable fungi and bacteria	Microscopic analysis
Surface wipe samplers, swabs, tape-lift, micro-vacuums, bulk samples	• Fungal spores • Culturable fungi (bulk or swab) • Bacteria • Allergens from fungi, cat dander, dust mites, cockroaches • Beta glucans • Mycotoxins • Endotoxins	Microscopic analysis, immunologic and other bioassays, GC/MS analysis

Particulates		
Sampling pumps, filters, particle size selective samplers (impactors, cyclones)	• Airborne particulates	Gravimetric, microscopic analysis, some differentiate between total and respirable particles, multistage impactors give particle size range
Surface wipe samplers, swabs, tape-lift, micro-vacuums	• Particulates on surfaces	Microscopic analysis
Particle size selective samplers and monitors measuring concentration or particle count	• Airborne particulates	
Direct reading dust sampler	• Dusts • Fumes • Smoke • Spores • Fibers • Other substances	Some distinguish and measure particle size fractions
Direct reading ultrafine particle counters	• Ultrafine particles	Helps in tracking contamination pathways
Lighting		
Light meter	• Lighting	
Noise		
Sound level meter	• Sound levels	Direct reading; octave band (frequency) analyzers
Noise dosimeter	• Sound level averaged over time period	

Appendix K:

Radon Information, Standards and Guidelines, Sampling Methods and Mitigation

What is Radon?

Radon is a naturally occurring, radioactive, colorless, odorless, tasteless gas produced from the decay of uranium and radium found in most soil and rock. Natural soils and rock such as granite, shale, and coral, contaminated soils from uranium processing mills, contaminated building materials, and groundwater water supplies directly from wells are a few common sources of radon. Radon can be found at some level in all indoor and outdoor air. It is chemically inert and can move easily through porous materials or void space.

Typically, most radon gas is generated from the surrounding soil or bedrock, moves up through the ground to the air above and into structures through cracks and other holes in the foundation.

1. Cracks in solid floors
2. Construction joints
3. Cracks in walls
4. Gaps in suspended floors
5. Gaps around service pipes
6. Cavities inside walls
7. The water supply
8. Warm air rises and escapes, creating negative air pressure within the structure, pulling in soil gases.

Figure A: K-1 – How Radon Enters a Building (source: www.epa.gov/radon/)

The strength of the radon source has the biggest impact on indoor radon concentrations. The route of entry, the building's ventilation rate, foundation type and differences in soils beneath the building can affect the indoor radon concentrations. Soil gas infiltration is recognized as the most important source of residential radon. Other sources, including building materials and water extracted from wells, are less important in most circumstances.

Standards and Guidelines

There is no federal regulation for radon in indoor air. The EPA states that any level of radon carries some risk and there are no safe levels, and has established an action level of 4.0 pCi/L for schools and residential dwellings. In a 1991 survey of US homes, the average indoor radon concentration was 1.3 pCi/L.[K-1] EPA recommends that homeowners take action to reduce indoor radon levels if test results indicate levels at or above 4 pCi/L. Table A: K-1 gives radon standards and guidelines from various agencies.

TABLE A: K-1 – Radon Standards and Guidelines

	Concentration (pCi/L)
EPA action level	4.0
OSHA PEL	100
OSHA posting requirement	>25
US GSA action levels: • residential buildings and commercial buildings w/daycare centers • all other occupancies	 4 25
Health Canada guideline	5
WHO recommendations: • annual avg. reference level; or • if not achievable, not to exceed	 3 8
US avg. residential (1991 survey)	1.3
US avg. outdoor (1991 survey)	0.4

pCi/L = picoCuries per liter
GSA = General Services Administration
WHO = World Health Organization

How is Radon Measured?

A summary of radon sampling methods is given in Table A: K-2. Initial radon tests are often made with passive samplers containing activated carbon. These devices are commercially available and can be purchased in hardware stores and online. Radon measurements are made in frequently occupied rooms with substantial ground contact. The duration of short term measurements can range from two to 90 days. Prior to placement of the radon measurement devices, general observations are performed to verify test conditions, identify device placement locations, and determine structural and mechanical building components. Radon test devices are placed in such a way to limit unintentional interference from building occupants. Ideally, the measurement devices should be placed at least three feet from doors, windows to the outside, at least one foot from exterior walls, at least four feet from heat sources, out of the direct flow of ventilation ducts and sunlight, and suspended in the general breathing zone. After sampling, passive devices are sent to a laboratory for analysis. The laboratory calculates the radon concentration after measuring the gamma activity by the radon decay products produced from the random decay of the collected radon. The State of Illinois is an example of one state that has adopted stringent regulations and licensing requirements for radon measurement consultants and radon mitigators.[K-2]

Indoor radon concentration varies with the construction of buildings and ventilation. These concentrations not only vary substantially with the season but also from day to day and even from hour to hour. Because of these fluctuations, estimating the annual average concentration of radon in indoor air requires reliable measurements of mean radon concentrations for at least three months and preferably longer. Short-term measurements provide only a crude indication of the actual radon concentration. Quality assurance for radon measurement devices is highly recommended in order to ensure the quality of measurements.[K-3]

Ideally, measurements by professionals should be obtained by following a plan based on a recognized protocol, such as that outlined in "EPA Indoor Radon and Radon Decay Product Measurement Device Protocols" (EPA 520-1/89-009) and "Protocols for Radon and Radon Decay Product Measurements in Homes" (EPA 402-R-92-003).[K-4, K-5] The plan should document and describe the necessary quality assurance procedures and provide a clear, concise, and complete plan for the radon measurements.

The results of the radon measurements are interpreted to determine the need for additional testing and assess the quality and confidence of the measurement data. Typically, follow-up measurements will be recommended in every room with results greater than 4.0 pCi/L. Mitigation is not usually recommended based solely on the initial measurement results and follow-up testing using long term measurements is recommended. EPA recommends actions be taken when long term measurements exceed 4 pCi/L. Some owners may decide to take action when levels are above 2 pCi/L.

TABLE A: K-2. Radon Sampling Methods

Radon Air Sampling Method	*Sampling period*		*Notes*
	Short term <90 days	*Long term >90 days*	
Passive			
Activated carbon adsorption	✓		Diffusion sampler, laboratory analysis of radiation decay, may be used for screening
Charcoal liquid scintillation	✓		
Electret ion chambers	✓	✓	
Etched track (or alpha track)	✓	✓	
Continuous monitoring			
Scintillation	✓	✓	
Ionization chamber	✓	✓	
Solid-state detection	✓	✓	
Standard methods			
ASTM D6327 Standard Test Method for Determination of Radon Decay Product Concentration and Working Level in Indoor Atmospheres by Active Sampling on a Filter	✓		http://www.astm.org/Standards/D6327.htm

Radon Mitigation

According to the EPA *Consumer's Guide to Radon Reduction*,(K-6) radon levels in buildings can be reduced by:

- Soil suction methods, both active and passive
- Subslab suction methods, both active and passive
- Block wall suction
- Submembrane suction in crawlspaces
- Increasing under-floor ventilation
- Installing a radon sump system in the basement or under a solid floor
- Avoiding the passage of radon from the basement into living rooms
- Sealing cracks and other openings in foundations, floors and walls
- House or room pressurization
- Heat recovery ventilator
- Improving the ventilation of the house

The radon reduction method chosen will depend upon the building foundation type, the levels of radon measured, and the building size. Installation of mitigation systems should only be done by experienced contractors. When remedial action is taken, the radon level should be reduced to a value as low as practicable.

Many states and local jurisdictions in the U.S. have incorporated radon prevention in building codes to minimize radon entry and reduce radon levels in homes and buildings under construction. More information is available on EPA's Radon-Resistant New Construction (RRNC) program and website.(K-7)

TABLE A: K-3. Radon Resources

EPA website	http://www.epa.gov/radon/
WHO Handbook on Indoor Radon (2009)	http://whqlibdoc.who.int/publications/2009/9789241547673_eng.pdf
EPA 520-1/89-009 EPA Indoor Radon and Radon Decay Product Measurement Device Protocols	http://www.nepis.epa.gov/
EPA 402-R-92-003 Protocols for Radon and Radon Decay Product Measurement in Homes	http://www.epa.gov/radon/protocols-radon-and-radon-decay-product-measurements-homes

References

K-1. U.S. Environmental Protection Agency (EPA): *National Residential Radon Survey, Summary Report*. Washington, D.C.: EPA, 1992. Available at http://nepis.epa.gov/. [Accessed January 12, 2016.]

K-2. State of Illinois Emergency Management Agency (IEMA): "Radon." Available at http://www.illinois.gov/iema/NRS/Radon/Pages/default.aspx. [Accessed January 12, 2016.]

K-3. World Health Organization (WHO): *WHO Handbook on Indoor Radon, A Public Health Perspective*. Geneva, Switzerland: WHO, 2009. Available at http://www.who.int/ionizing_radiation/env/9789241547673/en/. [Accessed January 12, 2016.]

K-4. U.S. Environmental Protection Agency (EPA): "Indoor Radon and Radon Decay Product Measurement Device Protocols." [Accessed January 12, 2016.]

K-5. **U.S. Environmental Protection Agency (EPA):** *Consumer's Guide to Radon Reduction*. EPA, 2013. Available at http://www.epa.gov/radon/consumers-guide-radon-reduction-how-fix-your-home. [Accessed January 12, 2016.]

K-6. **U.S. Environmental Protection Agency (EPA):** "Protocols for Radon and Radon Decay Product Measurements in Homes." EPA 402-R-92-003. Available at http:.//www.epa.gov/radon/protocols-radon-and-radon-decay-product-measurements-homes. [Accessed January 12, 2016].

K-7. **U.S. Environmental Protection Agency (EPA):** "Radon-Resistant New Construction." Available at http://www.epa.gov/radon/radon-resistant-new-construction-home-buyers. [Accessed January 12, 2016.]

The IAQ Investigator's Guide, 3rd edition

Edited by Ellen C. Gunderson, CIH, CSP

A good IAQ investigator is calm, observant, thorough, and discerning. They should be skilled in knowing what questions to ask, have knowledge of building systems, and possess a willingness to engage the public promptly and communicate results clearly to all involved parties. This guide discusses the initial investigation, an HVAC overview and inspection, considerations for special indoor environments, risk communication, and report preparation. Eleven appendices are also included, providing the reader with guidelines, checklists, and forms to assist in their investigations.

STOCK NUMBER: IAQG16-144

AIHA®
Protecting Worker Health

A Publication by
American Industrial
Hygiene Association