Council-certified Indoor Air Quality Manager (CIAQM):

Exam Study/Review Guide

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Disclaimer

This document is designed to aid candidates in preparation for the Council-certified Indoor Air Quality Manager (CIAQM) certification examination. To this end, the document provides discussion of the domains of knowledge addressed by the exam and the exam topics identified by the CIAQM certification board. These discussions are intended as guides to reading and study of the reference texts from which individual exam items are drawn.

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CIAQM EXAMINATION TOPICS

BASIC PRINCIPLES: THE "IAQ TRIANGLE"

Many factors combine to affect indoor air quality (IAQ), but three are predominant, and they form what may be called the "IAQ Triangle." They are the presence of regular building occupants, contaminant sources, heating, ventilation and air conditioning (HVAC) systems and other transport mechanisms.

Building Occupants

Since the health and safety of building occupants is the goal of IAQ management, occupants form the first and most important part of the IAQ Triangle. It is helpful to consider persons who normally occupy the building rather than visitors to the structure who spend short periods of time there. Occupants most likely to be troubled by IAQ issues are small children, persons with heart problems, allergies, asthma, respiratory diseases, autoimmune deficiencies and contact lens wearers. Occupant complaints include physical manifestations of poor IAQ situations that effect either comfort or health. These include, but are not limited to, nausea, bronchial irritations, skin irritations, eye irritations, dizziness, shortness of breath, headache and chronic fatigue from such stress factors. These complaints can be difficult to assess as they may stem not only from IAQ-related issues but also from office dynamics and personal life stressors. Such non-IAQ-related factors include lighting, ambient noise and ergonomic stressors in the workplace.

Occupants who express complaints related to indoor air quality are sometimes said to suffer from Sick Building Syndrome (SBS). This phenomenon is a result of a combination of pollutants at concentrations so low they prove hard to measure and sometimes hard to identify. This syndrome is different from Building-Related Illness (BRI), which involves the presence and circulation of a measurable and present disease within a building envelope. Examples of BRI include Legionnaire's Disease and hypersensitivity pneumonitis. These diseases are often serious and sometimes life-threatening. A third IAQ health concern is Multiple Chemical Sensitivity (MCS). This controversial affliction involves hypersensitivity to a number of chemicals at low concentrations in indoor air. It is presently not recognized by the major medical organizations but remains an issue in light of Workers' Compensation regulations. A final concern for building managers is illness that occurs in clusters. When outbreaks of potentially harmful illness occur in a short period of time in a single building, workers are prone to worry and panic. These clusters of health problems should be referred to state or local health departments.

Contaminant Sources

Sources of contamination can be categorized to include outdoor pollutants, indoor pollutants resulting from housekeeping and facility/mechanical maintenance issues and occupant pollutants such as cooking odors, remodeling odors, cosmetic odors or smoking. These pollutants are far from localized, as building air pathways and driving forces distribute them to the far corners of the building envelope.

While the concept of contaminants brings to mind images of suspicious and toxic substances marked “Poison” with skull and crossbones, most contaminant sources are common products and furnishings present in nearly all indoor environments. Contaminant sources include familiar cleaning products, paints and supplies, pesticides, adhesives, cosmetic and personal care products, automotive products, hobby supplies, furnishings and clothing, building materials, combustion appliances, tobacco smoke, animal droppings, soils, potable water, humidifiers and contaminated groundwater.

Household and commercial cleaning products contain non-metal particulates (phosphates and other inert powders), and they also contain volatile organic compounds (VOCs) such as aromatic hydrocarbons like toluene and p-dichlorobenzene, halogenated hydrocarbons, alcohols, ketones, aldehydes, esters and ethers. These products include aerosol bathroom cleaners, unpressurized aerosol window cleaners and liquid all-purpose cleaners. Powdered abrasive cleaners, dishwashing detergents and concentrated spot removers also make the list. Further sources include aerosol furniture wax, aerosol and solid room deodorants, paste furniture wax, liquid floor wax and the notorious oven cleaners. All but the last of these are products used not only in household maintenance, but also in maintaining office and commercial buildings.

Paints, aerosol products and some adhesives contain warning labels listing known carcinogens and health threats and admonishing users to take necessary precautions during usage. These products include not only oil, urethane and acrylic paints, but also varnishes and shellacs, wood stains, paint thinners, brush cleaners and paint removers. Additional contaminants include lead, mercury and chromium metal particulates and VOCs such as aromatic hydrocarbons, aliphatic hydrocarbons, halogenated hydrocarbons, alcohols, ketones, ester and ethers.

A pest control regimen is common in most geographic locales both for household and commercial building maintenance. Yet the chemicals used in controlling and exterminating pests contain non-metal particulates such as sulfur and lime as well as VOCs such as aliphatic hydrocarbons (kerosene), aromatic hydrocarbons and halogenated hydrocarbons. Termite treatments, aerosol all-purpose household pesticides, roach and flea killers, mold and mildew growth inhibitors, houseplant insecticides, moth repellents, rodenticides and fungicides all may contain such ingredients.

Aerosol products and some adhesives, sometimes “huffed” by adolescents looking for a high, contain VOCs such as aliphatic hydrocarbons, aromatic hydrocarbons, halogenated hydrocarbons, alcohols, organic nitrogen compounds, ketones, esters and ethers. Products as common as rubber cement, plastic model glue, floor tile adhesive, ceramic adhesive, carpet adhesive and all-purpose adhesives may boast labels with product contents such as these.

Hydraulic fluids, motor oils, gasoline, automotive cleaners and automotive waxes all may make the short list of automotive products containing such VOCs as aliphatic hydrocarbons, aromatic hydrocarbons, halogenated hydrocarbons, alcohols, ketones and amines.

Indoor furnishings such as carpets, upholstered furniture, plastic furniture, shower curtains, draperies, blankets and mattresses all contain VOCs, as do many building materials. Pressed wood products used in framing, as well as in some household furnishings, construction adhesives, insulating materials, plastic piping and vinyl or plastic wall coverings all contain VOCs such as aliphatic hydrocarbons, aromatic hydrocarbons, halogenated hydrocarbons, aldehydes, ketones, ethers and esters. Insulation materials also release fibrous particulates such as fiberglass or asbestos.

Heating, ventilating and air-conditioning systems (e.g., furnaces that burn carbon-based fuels) and air conditioner reservoirs are known sources of inorganic gases such as sulfur dioxide and nitrogen oxides as well as carbon monoxide and carbon dioxide. They emit VOCs such as aliphatic hydrocarbons (methane) and polynuclear aromatic hydrocarbons such as benzo(a)pyrene. In addition, some release silica-based fiberglass, mold and smoke particulates.

Garages are a major source of inorganic gases, particulates, VOCs, polynuclear aromatic hydrocarbons, and metal particulates, all originating from vehicular exhaust and stored chemicals such as pesticides, paints, solvents and gasoline.

Tobacco smoke tops the list as the most common source of contaminants, containing over 3,800 compounds including inorganic gases, metals, particulates, radioactive contaminants, VOCs, organic nitrogen compounds, ketones and polynuclear aromatic hydrocarbons. Additionally, indoor plants, pets, soils and even rocks are contaminant sources. Outdoor air, volatized potable water and contaminated groundwater are also known contaminant sources.

Virtually every product, appliance and furnishing useful in today's world contains something potentially harmful to the environment or user if abused. Consumer awareness should top the list for methods of limiting unnecessary indoor air contamination. While some of these contaminants are not health hazards, others may be life threatening with prolonged or improper exposure.

(See Section II for a discussion of the chemical properties and risks involved with specific indoor air contaminants.)

Transport Mechanisms

Transport mechanisms form the third component of the "IAQ Triangle." They are also referred to as pollutant pathways. Since air naturally moves from areas of high temperature and pressure to areas of relatively low temperature and pressure, any open spaces that allow this movement can become pathways for airborne pollutants. Chief among these, of course, is the building's HVAC system, designed specifically for this purpose. However, all open spaces can act as pollutant pathways, and the IAQ manager should keep this in mind when investigating the source of an IAQ problem. Stairwells, elevator shafts, mechanical chases, above-ceiling plenums, cracks or holes in partition walls and broken seals around windows and doors can become transport mechanisms for airborne contaminants, as can broken or compromised air filters.

HVAC systems are a critical aspect of indoor air quality. They have a significant and constant effect on the temperature, ventilation and pressure in all buildings. Thermal comfort can be affected in several ways. Temperature stratification, the process by which warm air rises and cool air falls in a room, can cause comfort problems when HVAC systems fail to mix air properly. Additional problems include radiant heat and vertical space drafts. Buildings with vast quantities of windows gain heat rapidly in full sun and lose heat with equal rapidity as sunlight fades. Vertical spaces suffer draftiness from naturally convecting air. Both windows and vertical spaces pose challenges to good mechanical systems.

Humidity, too, can be affected by HVAC systems. Raising relative humidity is equivalent in matters of physical comfort to raising the temperature in a room. However, excessive moisture often introduces further IAQ problems by encouraging the growth of mold and mildew.

Ventilation includes the process by which conditioned air - air that is filtered, heated or cooled - is distributed throughout a building. It also (usually) includes the introduction of outdoor air into the living spaces and/or the exhaustion of "stale" indoor air to the outdoors. As ambient temperature varies from room to room given changing environmental factors, comfortable IAQ is maintained by controlling airflow and temperature between building spaces. Two major HVAC designs exist for this purpose. Constant volume systems provide constant airflow and vary air temperature from room to room. Variable Air Volume (VAV) systems provide constant temperature while varying airflow to occupant spaces.

Circulated air, driven from the HVAC system can carry with it odors from various sources. Circulation patterns may distribute these odors far from their actual sources, proving perplexing for the IAQ investigator. Odor control can be affected through dilution, control of pressure relationships between rooms, local exhaust systems (a.k.a. exhaust ventilation systems) and air cleaning and filtration systems.

Dilution is the process of mixing indoor air with outdoor (clean or different) air to lessen odors. The effectiveness of dilution is limited by the strength of the odor and the effectiveness of the ventilation design.

Pressure control is maintained by controlling the levels of air introduced and expelled from room to room. Regarding the HVAC system, rooms said to have negative air pressure are supplied with less air than is removed from the room in question. These rooms are, in effect, bled of their air. Conversely, positive pressure can exist in a room that is fed more air ("supply-air", which can be made up of only indoor (circulated/conditioned) air, a blend of indoor/outdoor air, or 100% outdoor air) than is being removed from the room. Air in positively pressurized rooms always seeks release. Consequently, when a room with negative pressure is located next to a room with positive pressure, the air from the positively pressurized room will seek the negatively pressurized room, carrying odors with it.

Local exhaust systems can be effective in releasing some odors from indoor environments. An example of this is the range hood exhaust fan. These are effective only when air is exhausted to the outdoors.

Air cleaning and filtration systems should be used under advisement, as many of these have not been tested for either effectiveness or health risks. Many of these use chemicals to treat air as it flows through ventilation systems. Some of these cleaning compounds have not been approved for such use and have unknown permissible exposure limits, posing further health risks for indoor air quality.

Airflow patterns also affect IAQ. Some of these are the result of natural forces such as wind; some result from human activity and traffic patterns; others are the result of mechanical ventilation systems. To control these, one must consider the building envelope as part of the air distribution system. For example, high-rise buildings are subject to the stack effect, wherein pressure driven flow is produced by natural convection. Poorly sealed buildings, in their turn, are subject to wind pressurization. The interaction of these driving forces can move contaminants from their sources to remote building locations.

BASIC PRINCIPLES: INDOOR AIR CONTAMINANTS

Asbestos and Particulates

A particulate is a solid or liquid that is suspended in the air. This definition includes dusts, aerosols (which are a combination of particulates and air), and fumes. The health effects associated with particulates are dependent upon their toxicity and dose. The body has three major lines of defense against particulates. The first of these, the nasopharyngeal region, filters out large particulates through impaction on airway walls. Consequently, mouth breathers may have a higher particulate exposure as this first line of defense is by-passed. The tracheobronchial region filters particulates that are too small to be trapped in the nasopharyngeal region. These particles, 1 to 10 micrometers in size, are deposited by the process of diffusion. The pulmonary region, the last life of defense, targets particulates from 1 to 3 micrometers in size, also through diffusion and the action of macrophages. If these means are not effective in removing particulates, they may form a deposit in the air sac, possibly resulting in health effects.

Asbestos is a term for a group of naturally occurring, fibrous minerals, some of which were used an estimated 3,000 commercial products, including thermal system insulation, fireproofing, and other building products. When these materials are friable and disturbed, asbestos fibers can be released into and air, where they can be inhaled by workers or others in the area.

From the late 1800's to the first part of the 1970's, asbestos diseases were identified in various groups of workers (e.g., those working in insulation, ship repair, and construction) exposed to high levels of asbestos during handling of friable materials. The most important of these diseases were asbestosis (fibrous scarring of the lungs), lung cancer, and mesothelioma (cancer of the lining of the chest or abdominal cavity).

Today, asbestos-containing building materials are present in many facilities. These materials can be safely managed in place until such time as renovation, demolition, material condition, or other activities require that they be disturbed. Required work practices establishing the procedures that must be used in managing or removing asbestos-containing materials have been established by OSHA (Occupational Safety and Health Administration) and the EPA (Environmental Protection Agency). In addition, many states and local authorities also have specific asbestos-related requirements.

In 1991, EPA released a public advisory stating that the risk of disease associated with asbestos depends upon airborne exposure to it. If the level of airborne asbestos in a building is low, health risks associated with asbestos are low. Consequently, removal and disturbance of ACM is not always necessary or desired, and, improper removal of asbestos can result in exposure that would not have occurred if either proper methods were used or the asbestos was properly managed in place.

Every facility in which asbestos materials are present should have an appropriate asbestos management plan and trained and informed personnel insuring the required, necessary, and proper practices and procedures are in place and are followed.

Formaldehyde and Other Known VOCs

One of the most widely recognized IAQ contaminants is formaldehyde (HCHO). Sources of this compound include many products used in construction and renovation, including particleboard, hardwood plywood, paneling and flooring materials, as well as furniture and permanent press, soil-resistant fabric. An additional source is residual environmental tobacco smoke (ETS) contamination.

HCHO generally measures low in non-residential buildings and higher in manufactured homes. Its presence is more common in new construction or recently remodeled and renovated spaces. Formaldehyde's carcinogenic properties have drawn increasing lawsuits from those subjected to acute or chronic exposure. Symptoms of formaldehyde exposure include upper airway irritation in low concentrations and lower airway and pulmonary effects in higher concentrations. It is a known suspect of obstruction of pregnancy for women of childbearing age and may prove toxic to the unborn. Skin contact may cause dermatitis (skin inflammation) and urticaria (skin lesions).

Additional organic contaminants can be grouped into three basic categories including VOCs, semi volatile organic compounds (SVOCs) and nonvolatile organic compounds (NVOCs). VOCs exist entirely in vapor phase at ambient temperatures and have vapor pressures greater than 1mmHg (millimeters of mercury). SVOCs are present in vapor and particle bound states and have vapor pressures in the range of 10 to 1 mm Hg. NVOCs are present only as particulates and have vapor pressures of less than 2 mm Hg.

Over 900 VOCs have been measured and identified in indoor air environments. These emanate from compounds present in building materials, consumer products, furnishings, pesticides, fuels and even contaminated water when heated for bathing or cooking. However, household solvents prove the most likely sources of exposure. The six most common VOCs found in household solvents include methylene chloride, 1,1,1-trichloroethane, trichlorethylene, tetrachlorethylene, carbon tetrachloride and 1,1,2-trichlorotrifluoroethane. While chlorocarbon concentrations vary from brand to brand among cleaning products and solvents, the database for VOCs found in both healthy and sick buildings, combined with the data from consumer surveys, show exposure to VOCs is widespread and difficult to measure, often occurring in parts per billion by volume (ppbv)

Chemicals may enter a body through inhalation, dermal contact, ingestion or injection. Of these four routes, inhalation is the predominant source of VOC exposure and the source that proves most damaging, as chemicals can pass directly into the blood through the lung tissue.

Specific sources of VOC exposure include smoking as well as passive smoke, visiting dry cleaners, pumping gas, auto exhaust exposure, wood processing exposure, scientific laboratories, garage or repair work, metal work, exposure to printing chemicals, air fresheners, toilet bowl deodorizers and moth crystals. As is the case with formaldehyde, VOCs measure highest in new construction.

As many VOCs are strong chemicals that cause the depression of the central nervous system, undue exposure to VOCs may result in acute or chronic health effects. Some of these are mild irritations of the eyes and respiratory system. More serious health effects include sensitization of the skin, eyes, respiratory tract and heart and possible damage to the liver and kidneys. While sufficient research has yet to be done concerning the health risks of VOC exposure, cancer seems a likely threat. All this must be considered in light of the fact that where chemicals are concerned, the dose makes the poison. VOCs in high levels will prove significantly more dangerous than VOCs in lower levels.

Symptoms of VOC exposure vary to include fatigue, headache, drowsiness, dizziness, weakness, joint pains, peripheral numbness and tingling, euphoria, chest tightness, blurred vision, skin irritation, eye irritation and cardiac arrhythmias. When major symptoms of this list occur in unison (such as headache, irritability, difficulty concentrating and fine motor deficits), it is termed solvent encephalopathy. VOC exposure often provokes symptoms similar to those of sick building syndrome. Those who suffer from Multiple Chemical Sensitivity may be especially affected by VOCs.

Combustion Contaminants

A major source of indoor air problems is combustion contaminants. Primary sources of these include tobacco smoking, attached garages and improperly located air intake vents, as well as poorly maintained chimneys, flues and heat exchangers. Contaminants include tobacco smoke, vehicle exhaust and emissions from improperly vented gas appliances. Exposure symptoms include headaches, decreased alertness, nausea, confusion, fatigue, flu-like symptoms, chest pain and impaired judgment. The most commonly identified combustion contaminants include carbon monoxide, nitrogen oxides, sulfur dioxide, particulates and environmental tobacco smoke.

Carbon monoxide, a colorless, odorless and tasteless gas, is one such contaminant. It is produced from the incomplete combustion of carbon-containing fuel and is a chemical asphyxiant. Carbon monoxide combines rapidly and easily with hemoglobin to create carboxyhemoglobin (COHb). As oxygen is carried throughout the body by combining with hemoglobin to form COHb, the presence of carbon monoxide deters the relay of oxygen to the body because it is more readily accepted than oxygen. The primary effects of carbon monoxide poisoning are cardiovascular and neurobehavioral; however, the lungs also are taxed. The health effects and risks of carbon monoxide exposure are generally discussed in terms of levels of CO in blood work. The presence of greater amounts of CO in samples is directly correlative to higher contaminant toxicity. A possible source of indoor carbon monoxide pollution is an indoor air intake located too near the ground by which car exhausts are sucked into and circulated into and through the building.

Nitrogen oxides include both nitrogen dioxide and nitric oxide. Like carbon monoxide, these are produced when fossil fuels burn. Nitric oxide is a colorless, odorless and tasteless gas that is slightly water-soluble. Effects of nitric oxide are similar to those of carbon monoxide exposure. Nitrogen dioxide (NO_2) is a corrosive and highly oxidizing gas with an extremely acrid odor described by many as stinging, suffocating and irritating. A lung irritant, NO_2 has been shown to produce biochemical alterations and lung damage in laboratory animals. 80% to 90% of NO_2 in humans is absorbed upon inhalation, which makes this particular combustion contaminant particularly hard on asthmatics and small children.

Carbon dioxide and sulfur dioxide are both colorless gases. While carbon dioxide is odorless, sulfur dioxide (SO_2) has a strong odor. Water soluble, SO_2 works on the upper respiratory tract, causing increased airway resistance and placing asthmatics particularly at risk. Carbon dioxide (CO_2) acts as a respiratory stimulant. It speeds up breathing and changes blood pH and CO_2 levels, causing headaches, dizziness and nausea.

Particulates, fumes and soot are also a source of IAQ problems. These are especially significant in buildings heated with wood. Burning wood produces polynuclear (polycyclic) aromatic hydrocarbon compounds (PAHs), trace metals, nitrates and sulfates. These have been shown to have carcinogenic potential.

A final source of combustion contamination is environmental tobacco smoke (ETS). These emissions from burning tobacco products and exhaled smoke from such products contain over 3,800 chemical compounds including known irritants, carcinogens, mutagens and teratogens, which cause birth defects. Their presence in an indoor environment has been shown to increase risks of lung cancer and the instances of bronchitis and pneumonia in small children. Separate smoking areas in the work environment are an ineffective method of preventing such exposure, as air is recirculated through buildings by mechanical systems and pressure effects, further spreading the contaminants.

Biological Contaminants

Bacterial diseases and allergic reactions from biological sources are a growing concern in IAQ. While most viral and bacterial illnesses are spread by physical contact or by airborne droplets such as those produced by sneezing, viable studies show that transmission of bacteria through building-related airborne pathways such as heating, ventilation or air conditioning ducts is possible. This possibility is compounded in buildings with closed ventilation systems and tightly sealed envelopes. While stationary biogenic agents with their short-term direct toxicity present limited exposure threats to building occupants, the additional component of bioaerosolization broadens the threat of exposure, disseminating the toxins throughout the building system in their most potent forms.

Perhaps the most dramatic event of this kind occurred at the American Legion Conference in Philadelphia in 1976, where 182 veterans attending the conference contracted a flu-like illness that resulted in 29 deaths. The bacterial agent that caused the illness was *Legionella pneumophila*. The source of the Legionella was the cooling towwer of the air-conditioning system in the hotel where the conference was held. The disease it caused, named Legionnaire's disease for those who died so tragically, is a harsh multi-systemic illness involving the lungs, gastro-intestinal tract, central nervous system and kidneys. Two to three percent of all cases of the disease are fatal.

Legionella is a major cause of respiratory illness, accounting for 1 to 13% of all pneumonias in the United States, Canada, England and Germany. Most prevalent in the summer and fall, the bacteria are a hardy breed, capable of surviving in water for one-year periods. The bacteria can be found in forced-air heating systems, humidifiers, water flooding, hot water systems, hot tubs, vaporizers, nebulizers and cooling towers and evaporative condensers. Additional sources of

Legionella are dusts from construction and landscaping. Legionnaire's disease and Pontiac fever, both spread through aerosolization of water or soil, are the two most prevalent illnesses caused by these bacteria.

Pontiac fever derives its name from an incident in Pontiac, Michigan, at the Oakland County Health Department where 95 to 100 employees became ill with flu-like symptoms. Again the source was found to be the air conditioning system and the bacterial agent *L. pneumophila*. This disease constitutes a milder form of Legionnaire's disease, is usually self-limiting and is not fatal.

Perhaps the most dramatic recent incident involving biological contaminants was the exposure of several buildings in the eastern United States to anthrax in the fall of 2001. Anthrax spores were mailed to the Hart Senate Office Building (among other places) and were supposed to have entered the building's HVAC system. As a result, the building was closed for six months while investigators and IAQ experts decontaminated the area.

In addition, allergens (substances that cause allergies) pose a health threat in indoor environments. These cause allergic reactions and sensitization after secondary contact and are an ongoing foe for those with asthma. Viable allergens, also called antigens, include bacteria, fungi, amoebae and algae. Nonviable antigens include house dust, insect/spider parts, animal danders, mite fecal pellets, cockroach feces and dried animal excretions. Numerous chemical products may also act as antigens.

For allergic reactions to occur, a substance must act as a hapten, combining with an existing protein to form an antigen. This antigen may cause the formation of antibodies, and the first exposure results in a manifestation of the allergy.

Common manifestations of allergies may involve the skin, nose, airways or alveoli. Nearly 20% of the world population has genetic predispositions for allergies, which are probably related to the immune system.

In the respiratory tract, allergic reactions begin with localized inflammation accompanied by secondary effects like bacterial colonization. Effects include allergic rhinitis, allergic asthma, allergic bronchiopulmonary aspergillosis (ABPA), hypersensitivity pneumonitis and humidifier fever.

Allergic rhinitis, commonly known as hay fever, affects the respiratory tract producing sneezing, coughing and irritation of the eyes. It affects nearly 15% of the population and is most prevalent at the change of seasons.

Nearly 3% to 5% of the U.S. population suffers from allergic asthma. Caused by a variety of viable and nonviable agents, as well as emotional stress and cold weather, this condition causes wheezing, shortness of breath, sneezing, itching of the nose and rhinorrhea (i.e., running nose).

Allergic bronchiopulmonary aspergillosis (ABPA) is a reaction to inhalation of the soil fungus *Aspergillus fumigatus*. Occurring most frequently in winter months, it produces symptoms comparable to allergic asthma accompanied by a low-grade fever.

Hypersensitivity pneumonitis is an occupational disease contracted by agricultural and industrial workers exposed to fungal spores. Examples of this include bird fancier's lung, farmer's lung and ventilation pneumonitis. While causes of the first two mentioned diseases are due to inhalation of organic materials, exposures to inorganic compounds such as toluene diisocyante and copper sulfate may also cause pneumonitis. Ventilation pneumonitis is caused by fungi such as *Aspergillus*, *Penicillium*, *Alternaria*, *Rhizopus*, *Paecilomyces* and

Aureobasidium. Long-term exposure to these fungi can cause scarring of the lung tissue and lead ultimately to death.

Humidifier fever is a disease related to amoebae, bacteria and fungi. Sources include humidifier reservoirs, air coolers, air conditioners, spas and aquaria. Specific bacterial agents responsible for the contraction of humidifier fever include *Bacillus subtilis*, *A. polyphagia* and *N. gruberi* amoebae and bacterial endotoxins from Gram-negative bacteria.

Other allergenic agents include house dust mites (microscopic arachnids found in every household), cockroach body parts and secretions, fungi, insect excretions, domestic animals, tobacco smoke, chemical cleaners, carpet dyes, hair spray and evergreen Christmas trees. Fungi are chlorophyll-less eukaryotic organisms found in wet organic materials. Disease-producing fungi include *Alternaria*, *Cladosporium*, *Aspergillus* and *Merulius lachrymans*, *Candida*, *Scedosporium*, *Scopulariopsis*, *Geotrichium* and *Paecilomyces*.

These allergens and bacteria are representative of the bio-contaminants found in many day-care centers, hospitals, nursing homes, schools and office buildings; and they constitute a large portion of indoor air quality complaints and issues.

Biotoxins

Biotoxins are poisons that may enter the body through dermal exposure, inhalation or subcutaneous or intravenous injection, the effects of which may be acute or chronic. Reactions may involve the primary entry site (skin, lungs, esophagus, stomach) or metabolic sites (kidney, liver, bladder). They may prove systemic or neurotoxic in nature.

Most biotoxins are cytotoxic, disrupting the body's intricate cellular maturation process and retarding its ability to form proteins. This may be the leading cause of bleeding lungs in infants. Other biotoxins are teratogenic, causing malformations and birth defects. Still others are mutagenic, able to produce mutations in both cells and organs not only in fetuses but also in newborns. Additionally, biotoxins can be carcinogenic. Bacterial toxins are both part of infectious disease syndromes, such as tetanus, and ingested poisons, such as botulism. Mycotoxins, or fungal toxins, are primarily ingested. Even so, inhaled mycotoxins may be responsible for some IAQ-associated diseases.

The three most notable forms of biotoxins are bacterial endotoxins, mycotoxins and fungal volatile organic compounds. Bacterial toxins include exotoxins and endotoxins. Exotoxins are bacterial metabolites excreted into the environment. One such exotoxin is *Clostridium botulinum*, responsible for the botulism illness caused by ingesting poisoned food products. Endotoxins are a component of outer membranes of Gram-negative bacteria known as lipopolysaccharides (LPS). Endotoxins are fever-inducers (pyrogens) and are highly toxic. They may cause pulmonary changes and local inflammatory responses. Environmental exposure to such toxins includes occupational environments where organic materials containing Gram-negative bacteria are handled. The pulmonary disease byssinosis is caused by inhalation of endotoxins in cotton dust. Other environmental hazards include poultry and swine confinement buildings, composting facilities and grain elevators. These may prove contributing factors to immunologic sensitization for asthmatics.

Mycotoxins are fungi-produced metabolites ranging in toxic effects. *Aspergillus, Penicillium*, *Fusarium* and *Stachybotrys* are examples of some mycotoxins that have been widely studied. Some mycotoxins are toxic without metabolic activity while others require metabolic conversion for toxicity. These often affect the organ responsible for metabolism. Mycotoxins can enter the body through the skin, gastrointestinal tract or respiratory tract. These are aerosolized on substrate material, absorbed onto dust particles and spores of varying sizes and carried into the respiratory tract. The size of the particles to which the mycotoxins adhere determines the penetration of the mycotoxin into the respiratory system. Those that remain upon the lung surface longest are the most threatening, causing tissue damage and cancer-causing inflammation. Acute toxic effects are rare; however, when contaminants litter air ducts or plenums, air becomes contaminated, posing serious health risks to building occupants.

All organisms exude VOCs as they grow, and fungi are able to metabolize toxic solids into a gaseous state. Consequently, fungal VOCs, also known as microbial VOCs (mVOC), while little studied to date, have presented IAQ issues as benign as unpleasant odors and others as dangerous as toxic gas poisoning. Fungal VOCs are mucous membrane irritants and are responsible for symptoms such as those for which sick building syndrome was coined: headaches, nausea and dizziness.

IAQ PROGRAM ADMINISTRATION

The ability to prevent and resolve indoor air quality problems in commercial buildings depends upon the degree to which building management is prepared for such problems before they arise. To this end, it is recommended that prudent property managers and building owners develop a comprehensive IAQ policy for their buildings. Such a policy, when implemented effectively, can help building management formalize responses to occupant health concerns and resolve occupant IAQ complaints, thus increasing worker productivity. It can also help property owners comply with existing regulations and guidelines on indoor air quality issues. A comprehensive IAQ program should include three major components:

- Assembling an IAQ Management Team
- Constructing an IAQ Building Profile
- Implementing an IAQ Management Plan

Since effective communication and documentation is a necessary part of any successful IAQ program, construct a record keeping system to facilitate tracking IAQ complaints and their resolution.

The IAQ Management Team

The first step in a successful IAQ program is the designation of one person as the building IAQ manager. The IAQ manager should be responsible for overseeing and administrating the IAQ-related activities of the entire building. Such activities should include the following:

- Coordinating the management of complaints and complaint response procedures
- Maintaining a comprehensive record-keeping system of IAQ-related incidents and information
- Gathering and disseminating information on IAQ standards, codes and pending legislation
- Coordinating staff efforts that affect indoor air quality
- Keeping the building up to date on developing IAQ measurement technologies

The chief responsibility of the IAQ management team is the assessment of occupant complaints related to air quality and their possible effects on other building occupants. To this end, members of the IAQ management team should know the building extremely well. Prudent IAQ managers will, therefore, assemble their teams from existing facilities maintenance, housekeeping and building management staff whenever possible. The use of existing channels of communication, established relationships and personnel already familiar with IAQ issues will allow the IAQ program to be implemented with minimum impact on human and financial resources. IAQ will be addressed most profitably if it fits in naturally with the existing operation and maintenance structure of the building.

There are many skills related to indoor air quality will be helpful to the IAQ program. IAQ managers should consider employees who possess these skills as potential management team members.

The IAQ Building Profile

Developing an IAQ profile is a priority for all building managers. This document provides descriptions of a building's structural and functional features and occupancy patterns that affect indoor air quality. A profile serves as a baseline for all IAQ issues and is particularly useful in lease negotiations, complaint response and renovation planning. It aids in preparing repair and maintenance budgets and serves as a constant reference for building owners. Developing an IAQ building profile should include the following steps:

- Collecting and reviewing existing building records
- A walk-through building inspection
- Collecting detailed information concerning the factors of the IAQ Triangle
    - occupants
    - contaminant sources
    - pollutant pathways and transport mechanisms

Collecting and Reviewing Existing Records

This important first step of a building profile will establish a baseline of information from which the IAQ manager can begin to develop a management plan. If good records have not been kept previously, this review will point out areas where more detailed observations must first take place. All existing building documents should be reviewed, including commissioning reports for HVAC system components, operating manuals for building equipment and machinery, maintenance records, blueprints for remodeling projects and other records related to changes in building structure and usage. A thorough review of existing documentation related to prior IAQ complaints is also essential, as it may suggest a starting point for future remedial action.

Initial Walk-through

Before the initial walk-through, the IAQ manager should stop to consider the building as a whole. A basic understanding of building usage and changes in purpose since the time of original construction helps uncover many IAQ challenges and oversights. Have necessary changes and adjustments been made to the HVAC system to accommodate any renovations or usage changes? Are future related IAQ issues foreseeable?

During the walk-through, the investigator should note occupant activities and area/zone usage, airflow, odors and sanitation conditions. Particular attention should be given to any existing or potential mold/mildew growth, the storage of hazardous materials in the building and the cleanliness of maintenance areas and equipment. Additional notes should regard odd noises from fixtures or equipment, discoloration or stains of flooring or ceiling areas and cleanliness of hidden areas such as ceiling plenums. Rooms that house products or equipment that generate undue heat such as additional light fixtures, copy machines or cooking facilities should be noted. Note outdoor air intakes, as improper placement of these is often a prime culprit of mysterious odor complaints in buildings. Assemble inventories of possible pollutant sources and sketch possible pollutant pathways for each area or zone of the building. Record occupancy and usage information for each zone should, as well as areas where occupancy and use appear to differ significantly from building design specifications.

Investigators should take advantage of the walk-through to develop relationships with staff and personnel and to discover cleaning schedules, product usage and maintenance regimens. A working knowledge of occupants and their habits and use of the building may elucidate IAQ problems and provide helpful relationships for future problem solving.

Although sampling is not usually indicated during an initial walk-through, some specific measurements within the building may improve the accuracy and usefulness of building profiles. These can be obtained by building managers or subcontracted out to local IAQ professionals. Measurements may include airflow, temperature, relative humidity, carbon dioxide (CO_2) readings, pressure differentials, air volume at supply diffusers and exhaust grills and assessments of thermal and ventilation load requirements. Specificity and accuracy are key to a good profile. Additional understanding of the building's HVAC system operating principles and architectural and mechanical plans is also useful. (See HVAC System Design and Operation, page 34.)

Collecting Detailed Records

Whether or not previous building maintenance personnel kept detailed records related to IAQ, it is now imperative that such records be maintained. In 1991, the Environmental Protection Agency (EPA) published a complete set of blank forms designed to collect and track all information necessary for maintenance of IAQ in a commercial building. These are available for download at the EPA's website. More recently, however, integrated software programs have appeared which allow IAQ managers to link the data on these forms electronically. It is now possible to create a comprehensive, detailed IAQ portrait of a building in database form and to track the progress of each complaint response as it relates to other IAQ incidents both past and present.

To complete the building IAQ profile, detailed information on the three factors of the IAQ triangle must be collected as time is available. Inventories should be assembled of HVAC system condition and operation, of possible non-HVAC pollutant pathways, of pollutant sources and of building occupancy records. Tutorials offered with the software programs mentioned above often provide helpful suggestions as to the manner and method of assembling these inventories. The forms designed by the EPA for this purpose provide the basic structure of the information database, which the IAQ manager will assemble.

HVAC System Design and Operation

Heating, ventilation and air-conditioning (HVAC) are at the heart of indoor air quality, and a working knowledge of the basic components of an HVAC system will help the IAQ manager direct the activities of HVAC personnel under his authority.

According to most building codes, all occupied commercial buildings must have an outdoor ventilation air supply. The term “HVAC system” refers to the equipment or machinery responsible for providing this ventilation air, heating, filtering, cooling and controlling its humidity, distributing it as needed throughout the building and then exhausting it once more to be replaced by more ventilation air.

There are as many kinds of HVAC systems as there are buildings they serve. Not every building needs an air cooler, nor does every one need a heating unit. HVAC features differ to fit the particular needs of buildings and occupants. The design of a building, its age, the climate in which it exists, building usage and personal preferences all affect HVAC designs. In addition, codes at the time of construction, budget issues and building modifications all play a part in decisions that affect HVAC systems.

Types of HVAC Systems

The four types of HVAC systems are Single Zone, Multiple Zone, Constant Volume, and Variable Air Volume units. Single Zone units are named for their single thermostat that controls in unison all the zones heated by the unit. In larger buildings where temperature needs vary from space to space, this type of unit may fail to maintain comfort. In contrast, Multiple Zone units provide each zone with air at a different temperature by heating or cooling the air stream in each zone. This allows the extreme perimeteres of a building that receives much direct sunlight to receive less heat through the system, while the inner core of the building receives more heat as needed. Constant Volume units provide a continuous flow of air to each space. Changes in temperature are made by heating or cooling air or by switching the unit on and off, rather than by varying the amount of air supplied. Finally, Variable Air Volume (VAV) units work by varying the volume of heated and cooled air delivered to each area, rather than by changing the temperature of airflow. As the need for volume decreases, the HVAC system must either by-pass the supply air back to the system or slow down the HVAC supply air fan. Slowing down the fan is usually accomplished via a variable frequency drive (VFD) since this method saves energy. As most HVAC systems provide fresh air in the conditioned air delivered to an area, under-ventilation can become a problem with VAV system designs.

Basic System Components

The basic components of an HVAC System include an outdoor air intake, a mixed air plenum and outdoor air control, air filters, heating/cooling coils, humidifiers or dehumidifiers, supply fans, ducts, terminal devices, return air systems, exhaust or relief fans and air outlets. Additionally, systems may contain self-controlled heating/cooling units, controls, a boiler, cooling tower and water chiller.

Outdoor air intakes are usually fitted on the air intake side of ductwork so that ventilation air may be heated or cooled before distribution. The location of these intakes is crucial, as improper placement may result in the contamination of ventilation air and a full-building distribution of contaminants. Problems such as these arise as a result of entrainment, the process by which contaminated air is sucked into a building and distributed throughout. This may occur when rooftop air intakes are located next to exhaust fans or when intakes are fitted near parking garages where vehicular exhaust is present. Additionally, any airway obstructions may develop into IAQ problems as debris and mold is drawn into the system or block the system altogether, contaminating or eliminating the flow of filtered air within the system. Poor ventilation may cause entrainment problems as well, since buildings that are operating under negative pressure suck air through bad seals regardless of where these may be (i.e., near garbage disposal units, sewage systems, etc.). Consequently, the placement and maintenance of outdoor air intakes is of supreme importance for a building manager.

The air handler's **mixed air plenums** provide a locale for the mixing of outdoor air with return air. Dampers open to allow the flow of outdoor air at a pre-set minimum level until outdoor temperatures match indoor temperatures, at which point dampers open completely allowing the free flow of ventilation air into the plenums. One type of system uses "air economizer cooling." This makes use of outdoor air for cooling purposes by way of mixed air temperature controllers and a thermostat, blending air and delivering it throughout the building. Unfortunately, this type of system fails to account for humidity factors, often posing comfort issues for occupants.

Air filters are of great importance in HVAC units. Originally, their primary role was to protect the HVAC equipment. While still an important role, their primary purpose also includes their ability to remove particulates that might enter the building and contaminate indoor air supply. In addition to dirt and dust, filters remove bacteria, pollens, insects and soot from air.

They are produced in three types: low efficiency, medium efficiency and high efficiency. Low efficiency filters have a 10% to 20% rate of particulate removal and are deemed adequate for most residences, keeping lint and dust from clogging heating /cooling coils. Medium efficiency filters function at 30% to 60%. They provide better filtration than their low efficiency counterparts while lasting longer than most high efficiency filters without clogging, making them the best choice for most buildings. High efficiency, extended surface filters function at 85% to 95% and are recommended by some manufacturers as an exceptional manner of protecting indoor air quality.

The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) has developed a rating system for air filter efficiency based on the minimum efficiency reporting value (MERV). MERV ratings range from 1 to 20, with higher ratings corresponding to higher efficiencies. Filters with MERV ratings of 1-4 typically control particles larger than 10 micrometers such as pollen, dust mites, spray paint dust and carpet fibers, while MERV 20 filters control against contaminants as small as 3 tenths of a micrometer such as viruses, carbon dust and smoke.

All filters need regular maintenance and replacement. While dirty filters become more effective in removing particulates from the air, they impede air movement and reduce airflow to the building. Others "blow out," ceasing to provide any filtration at all and allowing contaminants and bacteria into ductwork. Dirty ductwork and humidity yields microbial growth and IAQ issues. Consequently, filters, too, are important IAQ factors for building managers.

Some filters are designed specially for the removal of gases and volatile organic compounds (VOCs).   These permanganate oxidizers, activated charcoal or partial bypass carbon filters and carbon-impregnated filters are not usually used in normal occupancy buildings. They are costly and require regular replacement for proper system functions.

Heating and cooling coils exist for the purpose of regulating building temperature. Placed in the air stream, they control temperatures of air delivered to zones. Cooling coils provide dehumidification as air passes over cold coils causing moisture condensation from the air stream, which, in turn, collects in the drain pan. Proper design of drain pans and proper drain traps eliminates the possibility of standing water, which might promote bacterial and fungal growth. Pans should be cleaned as a regular part of housekeeping. Condensation on poorly or under-insulated pipes can lead to microbial growth and IAQ issues. Additionally, heating set low for the purpose of energy conservation may fail to heat buildings properly or may result in the under-ventilation of a building.

Normal building humidification levels are 20% to 30% during heating seasons and below 60% in cooling seasons. The use of air conditioning units will keep humidity lower. Added humidity in cool climates where heat gains exist may cause mold if the humidistat set point is above 45%. Humidifiers can cause health problems if they are set inaccurately or are not designed to fit the building systems they serve.

After passing through coils and being conditioned, air passes through **supply fans** to the distribution system of **ducts** or **pressurized plenums**. A supply fan's performance is equivalent to its ability to move air quantity (cubic feet per minute or cfm) at a given resistance (measured in inches of water column). The size of duct openings, the resistance of duct configurations, the resistance of air filters and the velocity of the air determine performance in the system. Supply dampers restrict airflow and act as controls within the system.

HVAC systems can potentially distribute not only air but also dust and pollutants. Therefore, periodic cleaning of ductwork may be necessary for a properly functioning unit. While some dust is acceptable, building managers should look for water damage, biological growth, debris restricting proper airflow and dust discharging from supply diffusers. Ongoing housekeeping and management can alleviate IAQ pollutants by repair of leaks and water damage, prevention of moisture accumulation where unwanted, frequent dust removal and system part maintenance (i.e., cleaning drip pans). When spotting damage or problems, repairs should include an assessment and solution of the problem that caused the damage along with a fix of damaged portions.

HVAC **terminal devices** include supply diffusers, return/exhaust grilles and assorted dampers and controls designed to distribute and collect air from a zone. The number, design and location of these devices are important, as flaws in these can cause poor IAQ results such as bad odors, drafts, stagnant areas or short-circuiting.

Many buildings are designed with plenums acting as air returns. While this reduces the initial cost to builders, it is imperative that the soundness of the closed system be maintained to insure that it functions properly. Any loose or missing ceiling tiles may compromise the system and cause failure in other parts of the unit.

Buildings are required by most building codes to provide **exhaust fans** where contaminant sources are most potent such as bathrooms, janitorial closets, cooking facilities and parking garages. These are also suggested in reprographics areas, graphic arts facilities, beauty salons, smoking lounges, auto and hobby shops and any other places where undue airborne contaminants are present. For successful exhaust, the exhausted area must be at a lower pressure than its surrounding areas. Additionally, it must be isolated from the return air system so that contamination does not occur. Finally, clean air must be brought into the exhausted area to make up for what is exhausted, protecting the building from developing a negative pressure and sucking through poor seals.

Inventory of HVAC System

Use current maintenance records along with inspection checklists (such as those provided by the EPA or by the software designers mentioned above) to produce an inventory of HVAC system components in need of repair or replacement.

Inventory of Pollutant Pathways

Use the sketch plan of the building developed during the initial walk-through to record intended and actual relative pressure differentials between rooms in the same zone and between zones. Note the location of chases, shafts, stairwells and ductwork. Escape plans posted for fire evacuation may be helpful as beginning sketch plans for pollutant pathways. Use the checklists and forms provided by the EPA (or by the software designers) to track this information.

Inventory of Pollutant Sources

Use inventory forms to record the type and location of all hazardous chemicals stored in the building. Note the presence or absence of Material Safety Data Sheets (MSDSs) and the relative pressurization of storage areas. Note the presence or absence of local exhaust mechanisms in pollutant source areas.

Inventory of Occupancy Records

Zone by zone, record the details of intended and actual building usage. Determine whether current HVAC performance is supplying the correct amount of air and ventilation for current occupancy levels in each zone. Note the presence and location of mechanical exhaust in special use areas (e.g., kitchens, copier rooms, garages, etc.)

The IAQ Management Plan

In order to maintain good indoor air quality, managers must be prepared on several levels. First, they must be prepared to comply with guidelines related to IAQ that have been established by various government agencies and professional associations. Secondly, they must be prepared to maintain detailed records and documentation of all IAQ-related incidents and information, and they must work to maintain open lines of communication on indoor air quality between and among all interested parties. Finally, they must be prepared to combat IAQ problems before they arise through facilities maintenance and prevention techniques.

Liabilities and Guidelines

IAQ managers are responsible for keeping building management abreast of current regulations and guidelines pertinent to IAQ. Managers should also be prepared to keep their employers aware of potential legal liabilities arising from IAQ complaints.

Among the key government organizations with IAQ-related responsibilities is the Environmental Protection Agency (EPA), which conducts non-regulatory indoor air quality programs and issues regulations and guidelines under the laws for pesticides, toxic substances and drinking water.

The Occupational Safety and Health Administration (OSHA) enforces regulations governing health and safety in the workplace. OSHA has published Permissible Exposure Limits (PELs) for a variety of air contaminants, including VOCs, CO_2, ammonia, ozone and other inorganic chemicals. (No OSHA PELs exist for mold). OSHA's general duty clause makes employers liable for workers' IAQ-related complaints in the workplace.

The National Institute for Occupational Safety and Health (NIOSH), which is part of the Centers for Disease Control (CDC), recommends standards to the U.S. Department of Labor and conducts training on various issues including IAQ that impact safety and health in the workplace. NIOSH undertakes investigations at the request of employees, employers, other federal agencies and state and local agencies to identify and mitigate workplace problems.

The American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) publishes standards for ventilation that provide guidance to much of the IAQ industry. Specifically, ASHRAE Standard 62, "Ventilation for Acceptable Indoor Air Quality" provides a benchmark for IAQ investigations.

The American Conference of Government Industrial Hygienists (ACGIH) has published a guide to the mitigation of airborne biological contaminants. *Bioaerosols: Assessment and Control* (1999) recommends remediation procedures for mold, mildew and other microbial contaminants. ACGIH sets Threshold Limit Values (TLV™) for airborne contaminants, but has not set TLV™ for molds as of this printing.

IAQ managers should keep in mind that property managers and building owners are often in a difficult situation with regard to legal liability in a number of areas. IAQ has become one of these, with litigation increasing dramatically in recent years. An IAQ manager can help protect the building ownership and/or management from legal liability in two ways. First, he can maintain an awareness of current regulations touching IAQ and incorporating them effectively into the IAQ management plan. Second, he can exercise due care and diligence to see that potential threats to IAQ are dealt with promptly and correctly. Litigation in IAQ cases is often the result of negligence on the part of building maintenance staff - that is, conduct that falls below the standard of care established by law for the protection of customers against unreasonable risk.

Some Building Related Illness (BRI) cases provide good examples of the legal liabilities surrounding negligence and indoor air quality. If a discoverable direct link between a building source and the symptoms of the illness is established, property owners can be held liable for damages based on negligence. Such liability also leaves them responsible for all foreseeable and unforeseeable consequences related to IAQ. Such liability is thus worth avoiding, though it be at considerable cost. Fortunately, by fully documenting and tracking the progress of IAQ complaint resolution, wise IAQ managers can often establish proof of diligence in IAQ cases. The following kinds of documentation can be used this way in IAQ litigation cases:

- Operation and maintenance records
- Employee notifications
- Investigation and occupant interview notes
- IAQ personnel credentials
- Published IAQ policies and procedures
- Receipts for remediation costs

It should be noted that medical information on employees must be kept confidential.

Communication and Documentation

Effective communication between and among building occupants, facilities staff and IAQ management team members is absolutely critical to successful IAQ management. Everything from clear definition of responsibilities to correct handling of occupant complaints should be the responsibility of the IAQ manager. An efficient method of organizing IAQ records and documenting IAQ incidents can expedite the mitigation of IAQ problems, help prevent future incidents from occurring and provide valuable protection for property owners in instances where litigation is involved. Inadequate communication, on the other hand, can cause an IAQ problem to become complicated by anxiety, frustration and distrust. Worse still, inaccuracies in the recording and communicating of IAQ information can result in inappropriate remediation action, increasing both the time required to resolve the problem and the costs necessary to remediate it.

The EPA recommends a specific person, called an IAQ coordinator, to oversee IAQ documentation. With the advent of software technology designed for just this purpose, one person, even in large companies that operate at more than one location, may easily handle this task.

Maintenance and Prevention

Central among the duties and concerns of the IAQ manager is maintenance of IAQ-related equipment within the building. IAQ managers should work closely with facilities maintenance and housekeeping staff members to ensure that IAQ-related operational procedures are functioning at optimum levels for indoor air quality.

HVAC Maintenance

Maintenance is a primary issue for the proper functioning of most components of an HVAC system. General elements of an effective preventive maintenance program for HVAC equipment include the following:

- Inspection, cleaning and service on a regular schedule
- Adjustment and calibration of HVAC control system
- Acquisition of quality maintenance equipment and replacement parts

Self-contained conditioning units are often overlooked in routine building maintenance. These are frequently the source of IAQ problems, as dirty filters, coils, condensate pans and such impede their proper functioning. Regular housekeeping deters this. HVAC units may have manual or automatic controls. In either, regular maintenance and calibration are required for proper functioning. Additionally, all programmable timers and switches should be on battery back up in case of power outages. Control problems can result from improper thermostat placement or poorly designed temperature control zones.

HVAC boilers must be properly maintained so that they might operate at high enough heats to supply additional heat in cold weather. Gaskets and prevention of breeching must be maintained to prevent the escape of carbon monoxide. Fuel lines must be maintained, and adequate outdoor air must be present for proper combustion. Additionally, boiler exhausts must be properly situated to prevent entrainment of the exhaust. Likewise, cooling towers must be properly maintained to prevent contamination by pathogenic bacteria such as *Legionella*. Such housekeeping would include physical cleaning, chemical treatment and installation of drift eliminators.

Some systems in larger buildings make use of water chillers, which provide good performance for removing heat from buildings. However, vigilance and oversight of the system is necessary for the prevention of such problems as the release of fluids from chiller systems, which may damage building areas and cause damp places that encourage mold growth.

ASHRAE Standards for HVAC Commissioning and Startup

ASHRAE Standard 62, "Ventilation for Acceptable Indoor Air Quality" aids IAQ professionals by providing specific procedures and methodology for the commissioning and startup of HVAC systems. Among these procedures are the following:

- During the construction phase, **particle filters** should be installed and used according to the system design from the beginning of construction. Building materials should be protected from moisture before and after installation, and materials with visible microbial growth should not be installed.
- Construction procedures, which entail sanding or other activities likely to produce airborne particles, should be accompanied by appropriate **protective measures** such as sealing the construction area using temporary walls or plastic sheathing, exhausting the construction area and pressurizing contiguous occupied areas.
- Initial system startup should include **air balancing** conducted in accordance with ASHRAE's *HVAC Testing, Adjusting & Balancing Field Manual,* or SMACNA's *HVAC Systems-Testing, Adjusting and Balancing,* in order to confirm that total outdoor air supply flow meets ASHRAE guidelines for healthy indoor air quality.
- **Drain pans** should be field-tested to assure proper drainage and drain trap design and to minimize conditions of water stagnation that may result in microbial growth.
- **Ventilation air distribution systems** should be checked to be sure they are clean of dirt and debris at startup.
- **Outdoor air dampers** should be checked to ensure proper function in accordance with system design.
- **Exhaust systems** are working properly.

- A complete set of **documentation records** should be collected and retained with the building manager upon commissioning. Such a set of records should include operating and maintenance manuals for ventilation system components; HVAC controls information (diagrams, schematics, control sequence narratives and calibration information); an air balancing report and construction drawings of the entire HVAC system.

ASHRAE Guidelines for HVAC Maintenance

Much of indoor air quality and HVAC system performance depends upon the diligent oversight and consistent maintenance of a strong building manager or management team. Preventive measures and general housekeeping of these particular system components may avoid costly litigation and IAQ complaints as well as excessive financial output for expensive professional remediation. In IAQ, as in other matters, an ounce of prevention is worth a pound of cure. ASHRAE has published guidelines for the maintenance of HVAC systems in its Standard 62, "Ventilation for Acceptable Indoor Air Quality." Recommended maintenance procedures center around the development and maintenance of an **Operations and Maintenance Manual** for the working life of the applicable ventilation system equipment or components.

The Operations and Maintenance Manual should include operations and maintenance procedures, final design drawings and operations and maintenance schedules applicable to ventilation equipment. The manual should be updated as necessary and maintained in a central location. The operations and maintenance manual should be used as a guideline to oversee the regular maintenance and/or replacement of the following components on a regular basis:

- **Filters and air-cleaning devices**

- **Outdoor air dampers**
- **Humidifiers** (every three months)
- **Dehumidification coils** (yearly)
- **Drain pans** and adjacent areas of wetness (yearly)
- **Outdoor air intake louvers**, bird screens, mist eliminators and adjacent areas (every six months)
- **Sensors** whose primary function is dynamic minimum outdoor air control, such as those used for demand control ventilation.
- **Exhaust fans** and belts

In addition to periodic assessment and replacement of HVAC system parts, ASHRAE recommends the following preventive maintenance procedures:

- **Outdoor airflow verification**. The total quantity of outdoor air, except for units under 1,000 L/s (2000 cfm) of supply air, should be measured every five years and adjusted to fall within the minimum rate specified in original design documents.
- **Cooling tower** water systems should be treated to inhibit the growth of microbiological contaminants, including *Legionella sp.*
- **Accessibility** of the space provided for routine maintenance and inspection around ventilation equipment should be protected by keeping such areas clear of all obstructions.
- **Floor drains** located in air plenums or rooms that serve as plenums should be maintained to prevent transport of contaminants from the floor drain to the plenum.
- **Visible contamination** such as mold, mildew or water intrusion/accumulation should be investigated and rectified whenever it occurs.

Housekeeping

Many IAQ problems arise from the failure of housekeeping staff to eliminate dust and dirt. On the other hand, cleaning products are often a key source of IAQ contaminants. The IAQ manager should communicate with housekeeping staff members to make them aware of IAQ concerns. Often, they are in a good position to notice potential IAQ problems before they arise and can be a valuable resource for the IAQ manager who has developed appropriate lines of communication.

Parking lot entryways and sidewalks are often overlooked as venues through which dirt and oil products enter into buildings. Because these areas are sources, barrier mats (walk-off mats) designed to trap dirt and keep it out of the building should be used at all entryways, including pedestrian entrances, loading docks, receiving areas, freight entrances and garages into the building. Barrier mats should be long enough so that everyone entering the building will be taking five full steps on it prior to stepping on the flooring of the building.

Heavily used areas, such as entryways, should be thoroughly cleaned on a daily basis, and more frequently if needed. The use of carpet blowers is a must to dry carpets and prevent mold growth.

The selection of the proper cleaning products is very important as they may be a source of IAQ complaints if manufacturer's specifications are not followed. Also, open containers can be sources of spills as well as airborne odor. Training all cleaning personnel in the proper use and storage of cleaning products will assist in the prevention of possible problems in these areas.

Remodeling and Renovation

One of the chief sources of IAQ problems is construction, remodeling or tenant improvement (TI) projects. Such activities have the potential to pose threats to good indoor air quality in several ways. First, removal of old materials can disturb and release contaminants into the air and HVAC systems. Second, new construction can affect airflow and ventilation pathways. Third, new materials can introduce foreign irritants and contaminants into the indoor air environment. An effective IAQ management plan will provide procedures for preventing these potential IAQ problems before they arise.

The IAQ management team should develop a set of policies governing TI projects designed to protect the conditions for healthy indoor air quality. These policies should be clearly communicated to contractors involved in projects. In particular, such policies should prohibit practices that may introduce irritants into the general air supply, for example, the installation of fiberglass batting in above-ceiling return plenums. They should also forbid the introduction of materials that interfere with the building's designed airflow and heating/cooling cycles. Impervious wall coverings on perimeter walls or on both sides of a bathroom wall may trap moisture and promote microbial growth. Finally, TI policies should prohibit the installation of equipment that produces known indoor air contaminants, especially in areas that occupants cannot leave. In general, building managers should schedule TI projects when most building occupants are not present.

When choosing materials for a remodeling or renovation project, IAQ concerns should be kept in mind. Adhesives, paints and sealants, as well as carpet and furniture, can pose threats to IAQ because of the VOCs they emit when new or during the drying process. Potential health impact of the materials on sensitive building occupants should be considered. Information on product labels and MSDSs should be reviewed and taken into account when considering materials for purchase. MSDSs must be available at the construction site for workers, supervisors and other building occupants engaged in the use of hazardous materials.

Before renovation or remodeling begins, IAQ managers must define the work area and take measures to control the spread of contaminant sources that will inevitably be present there. The first pathway of concern should involve the HVAC system, which has the capability of transporting potentially contaminated construction-area air to other parts of the building. During remodeling or renovation, return ducts feeding construction areas should be sealed off. In addition, work areas must be kept under negative pressure at all times to inhibit the spread of contaminants to other parts of the building. Temporary barriers should be installed to control the spread of dust and noise, and a local exhaust system should be used which vents air from the work area to the outside.

Once construction or renovation begins, IAQ managers should continue their vigilance to prevent the spread of contaminants. If the construction project is a long-term one, dust can become a serious problem. Workers entering and leaving the work area are carriers for dust and other potential contaminants. This problem can be overcome by requiring construction workers to wear protective outer clothing in the work area and to remove it before entering the clean area. If necessary, an anteroom should be constructed which allows coveralls to be removed prior to entering clean building areas. The installation of tack mats just inside the doorway of the work area can also reduce the spread of dust, especially if they are large enough that both of the worker's feet make contact with the mat as he walks through the entry. It is also critical that temporary dust barriers remain well sealed for the duration of the construction project. Particle sampling should be used if needed to verify breaches in the work area enclosure. IAQ managers should designate a removal route for small quantities of debris being removed during business hours. Carts used for debris removal should be covered and their contents misted to inhibit the spread of dust, endotoxins and pathogenic fungal spores. All other regulations and guidelines applicable to such activities should be closely observed.

IAQ INVESTIGATIONS AND REMEDIATION

Regardless of the thoroughness of the preventive maintenance program in place, IAQ problems will inevitably arise. A sound IAQ management plan will respond quickly to handle occupant complaints and move to resolve them as completely as possible. The process of recording, assessing, verifying and responding to an IAQ complaint will involve the performance of an IAQ investigation and possibly the development and testing of a remediation strategy.

Responding Correctly to Occupant Complaints

If a proper communication and documentation structure is in place as part of the IAQ prevention and management program, the handling of occupant complaints will be smooth and effective. A wise IAQ manager will take every complaint seriously and evaluate it soberly. Careful attention to detail in recording and evaluating the complaint will most likely enable the IAQ management team to take appropriate action; also, care and concern on the part of IAQ staff will help foster a healthy relationship between IAQ personnel and the people they are serving. Such a relationship will foster increased communication and could help prevent future problems.

No complaint should be left undocumented, regardless of its seeming validity. Incident logs should be kept, and a new record initiated for each complaint. The response of the IAQ management team should be timely and appropriate to the situation. Some complaints may be resolved quickly and easily by removing a contaminant source from the premises. Others may require more concerted effort over longer periods. Some complaints may seem to have no basis in fact and may indeed be unrelated to indoor air quality altogether. In all situations, however, the complaint should be documented and taken seriously.

Conducting an IAQ Investigation

The IAQ investigation is a cycle of activities that is initiated by an occupant complaint. The cycle begins with information gathering and results in the formation and testing of hypotheses, which may often lead the investigator back to the problem area for more information.

The investigation should begin with a walk-through of the complaint area, during which information is gathered about the factors in the IAQ Triangle (sources, occupants, and pathways) that might have bearing on the cause of the complaint. Hypotheses developed as a result of this walk-through should be tested and evaluated, either by manipulating the HVAC system or attempting to control the pollutant sources or pathways. If hypotheses thus tested fail to explain the problem, investigators should begin collecting additional information about the factors related to the complaint. In some cases, sampling for specific contaminants or assistance by IAQ professionals may be necessary.

Initial Walk-through and Hypothesis Formation

The main focus of conducting the initial walk-through phase of the indoor air quality investigation is the "IAQ Triangle." Possible contaminant sources, pollutant pathways and occupant dynamics should figure into an investigator's initial observations of the complaint area. In many cases, observations thus made can lead directly to simple solutions to the problem (e.g., removal of contaminant sources). In any event, a basic knowledge of how the major IAQ factors bear on the specific situation will guide further action.

In preparation for the walk-through, the investigator should collect as much information about the history of the complaint as possible, including assembling a diagram (if one does not already exist) of the HVAC zones and components affecting the complaint area. During the walk-through, the investigator may productively interview occupants and staff about the nature and timing of the problem, always attempting to locate and identify pollutant sources and obvious deficiencies in the HVAC system serving the complaint area. Pathways other than HVAC components should also be considered and located during the initial walk-through. At any point during this process, the investigator should consider hypotheses that suggest themselves as possible explanations of the problem. If practical, steps may be taken to manipulate conditions in the complaint area to test these theories. Such steps may include adjusting HVAC system components or removing possible contaminant sources.

Collecting Additional Information

If hypotheses formed during the initial walk-through fail to present a solution to the problem, the investigator may need to gather additional information. The use of forms to keep information organized may be a useful strategy in this process, especially if they can be linked and cross-referenced as part of a comprehensive computer database of the type described above. Examples of forms developed by the EPA for this purpose include the following:

Forms Related to Occupants

Data gathered from building occupants can be used to define the complaint area precisely and to establish timing and symptom patterns, which may help the investigator define and locate the source of the problem.

- *Incident Logs* - used to track the course of a particular investigation from the receipt of the original complaint.
- *Occupant Interview Forms* – used to record the details of conversations with occupants about their experience of the IAQ problem. The investigator should be aware that the use of a standard interview form listing health symptoms might have drawbacks. Forms may prompt for a response from the occupant; hence, the response may be skewed.
- *Occupant Diaries* - used to encourage occupants to keep detailed records of the timing and location of the recurrence of their symptoms.
- *Staff Diaries* - used to encourage HVAC and maintenance staff to keep detailed records of their activities and the performance of the HVAC system.

Forms Related to Pollutant Pathways

Information gathered from a detailed look at the HVAC system as well as careful consideration of other pollutant pathways can be used to determine whether the current use of the building (in terms of HVAC system design and space usage) conforms to the original intent of building designers. It may also uncover problems with HVAC system maintenance that are causing the HVAC system itself to be a source of indoor air contamination. Finally, consideration of pollutant pathways may prompt the investigator to look to remote locations for the causes and sources of IAQ problems and to revise earlier assumptions about the boundaries of the complaint area.

- *Zone/Room Records* - used to evaluate the performance of the HVAC system from one zone of the building to another and to compare present usages with design specifications.
- *HVAC Checklists* - used to determine whether the HVAC system is functioning properly, sized appropriately and maintained adequately.
- *Pollutant Pathway Analysis Forms* - used to show the zones of the building that are connected by possible pollutant pathways and pressure differentials that could explain the occurrence of symptoms in remote locations.

Forms Related to Pollutant Sources

Information collected from an examination of possible pollutant sources may identify patterns linking chemical emissions to occupant complaints. It may also be helpful in designing or modifying preventive maintenance procedures to inhibit the spread of contaminants used or stored on the premises.

- *Pollutant Source Inventory Forms* - used to compile a list of potential pollution sources discovered during the investigation and the history of their remediation.
- *Chemical Inventory Forms* - used to compile a database of chemicals stored in the building and used for maintenance, housekeeping, operations and pest control. Includes their locations, characteristics, the location of MSDSs and potential risk levels.

The EPA has developed strategies for the use of these forms and the evaluation of their contents in its manual *Building Air Quality Manual*, Section 6: "Diagnosing IAQ Problems." Some IAQ software programs follow the recommendations of this publication very closely; thus, the manual remains an excellent source for guidance in the basics of conducting IAQ investigations.

Sampling and Professional Assistance

In some cases, sampling for specific indoor air contaminants may be indicated. Some background on sampling techniques and measurements will, therefore, be helpful to the IAQ manager in the decision making process for risk management.

Whatever the situation, every investigation should begin with routine air measurements to assess the case at hand. These should include temperature, relative humidity, air movement and CO_2 readings. Investigators should sample for specific substances only when preliminary investigations suggest likely pollutants. Sampling strategies should be meaningful and provide answers to all variables. Sampling blindly, or as the first step in an investigation, will often yield meaningless numbers while failing to correct the real problem.

Sampling is useful in determining a set of numerical controls by which to test hypotheses concerning problem sources. By sampling symptomatic (problem) areas, asymptomatic (similar control) areas and baseline (outdoor) areas, the professional is provided with data comparisons. Helpful test sites may include individual rooms, HVAC zones (interior vs. perimeter), complaint vs. non-complaint areas and areas adjacent in relationship to major pollutant sources. Thorough sampling will include measurements taken both before and after complaint events.

Carbon dioxide readings are a useful means of discovering under-ventilation problems. High CO_2 readings may suggest under-ventilation, while carbon monoxide over several ppm suggests excessive combustion by-products.

Further readings may be taken to discover bioaerosol concentration levels. However, few guidelines exist concerning permissible exposures. Neither OSHA nor the ACGIH have developed regulatory standards or voluntary guidelines for molds at present. Even so, these samples, in conjunction with a search of potential reservoirs, may yield telling information. This information must be scrupulously recorded so as to be presentable in a court of law. These records must contain the sample identification number, type, location, date and collection time. In addition, each sample must be handled in such a way as to retain a clear chain of custody (COC) detailing its possession by name since collection from person to person. All samples should include the sampler's name, the person to whom the sample was delivered and the person to whom results were delivered so as to eliminate any suspicion of tampering or compromising of the evidence such sampling may yield. IAQ is a litigious field, and all investigations and results must prove both accurate and well documented to stand up in a court of law.

The three basic sampling methods are air sampling, surface sampling and material (bulk) sampling. While bioaerosols most frequently necessitate the use of air sampling techniques, mold and bacterial growth, chemical spills and particulates can at times be detected through surface sampling. Material sampling, or the collection of such hard matter as drywall, carpet, wallpaper, dust and insulation, may show contamination and growth through microscopic evaluation.

Air sampling technology centers around two basic types called personal sampling and ambient sampling. Personal sampling is performed near the breathing zones of individuals affected by IAQ problems. Ambient sampling, performed in many locations at many times, may be chosen to reflect average exposure levels for all building occupants. These samples may be collected with a variety of sampling devices that use gravitation, centrifugal force, inertial impaction, filtration or electrostatic impaction. Of these, inertial impaction and filtration are most frequently used. When sampling for amorphous particles, liquid impingement on a smooth-surface, polycarbonate filter may be used. Airborne dust should be collected with pumps and filters.

Inertial impactors work by drawing air through an orifice using suction or by rotating collecting surfaces rapidly through the air. Called isokinetic sampling, this method directs ambient airflow into an orifice at a rate equal to that of the ambient air. Isokinetic sampling is most effective for larger particulates, as these are more likely impacted and counted. Sampling filtration devices rely on suction and are rated 100% reliable at trapping particles larger than the filtering pore size used in the device. Consequently, sampler choice must factor in particle size, fragility and concentration. While smaller particles may be best collected through suction, larger particles may be successfully obtained through isokinetic and impaction methods.

Volatile Organic Compound (VOC) Sampling

Sampling devices include the vacuum pump, direct-reading meter, detector tube kit and personal monitoring device (dosimeter). Each of these should be reset for non-industrial use because concentration levels will be much lower. Vacuum pumps work by drawing air through collection devices. These devices include filters for particulates, sorbent tubes for chemical vapors or an impinger, which bubbles contaminants through solutions in a test tube. Volatile aerosols are best sampled with liquid impingers in the case of water soluble VOCs or cold traps or adsorbents in the case of non-water soluble contaminants. Direct-reading meters estimate air concentrations and report chemicals or VOCs or other pollutants. Detector tube kits are hand pumps that draw air through a chemically treated tube to yield a color stain reaction correlative to the chemical concentration. Passive monitors can be carried or worn by individuals to measure personal exposure to particular chemicals. Some of these, called active monitors, include a pump. Others, called passive samplers, which may be used in routine exposure monitoring regimens, do not.

Sample times range from grab samples, taken in 5 minutes or less, to periods of hours, days or weeks. All samples must reflect both accuracy and precision. Accuracy refers to the amount by which the measured value deviates from the true value of the sampled microbial. Precision concerns the standard deviation of repeated measurements of the same variable. This is maintained by increasing the number of measurements at a particular sampling site with uniform sampling methods.

Measurements for simple ventilation and thermal comfort may be obtained with thermometers and psychrometer electronic sensors. Air movement may be tracked with chemical smoke. This is an effective means of evaluating HVAC systems. It may be useful in identifying HVAC short circuiting, which is air entering an area through a supply air grille or diffuser that returns to the HVAC system without properly mixing with the existing room air, and which is a prime culprit behind occupant complaints of "stuffiness" in occupied spaces. It aids in identifying possible pollutant pathways and identifies pressure differentials. The release of smoke near the building shell will prove the integrity of the building's positive pressure. Smoke guns, bottles, pencils and tubes are all available for these tests; however, most utilize toxic and corrosive chemicals, and precautions must be exercised when used around building occupants.

A Pitot tube or anemometer measures the velocity and cross-sectional area of an air stream. The average of several such measurements proves the best evaluation of building airflow and HVAC systems. Flow hoods are useful only for direct measurement of airflows at grilles, diffusers or exhausts. Buildings should maintain thermal balance, an air temperature within several degrees during occupancy periods. Pitot tubes or diffusers may be used to calculate total system airflow.

VOC concentrations may be measured by direct readings with low sensitivity reading instruments or by sorbent tubes or vacuum canisters with lab analysis. This may identify hot spots, sources or pathways. Identification of individual VOCs requires medium sensitivity test devices such as XAD-4 sorbent tubes (nicotine), charcoal tubes (for solvents) and chromosorb tubes (for pesticides). A passive dosimeter (charcoal badge) or portable gas chromatograph may also prove effective. High sensitivity techniques measure “trace organics.” Public health exposure guidelines may be obtained through the World Health Organization’s *Air Quality Guidelines for Europe*; however, no standards are available through the EPA or NIOSH.

Formaldehyde should be sampled when suspected materials are present. Impingers, sorbent tubes, passive dosimeters or direct-read instruments may be used to measure short-term peaks (2 hours).

Combustion products may be measured with direct-reading meters, detector tubes or passive dosimeters. Inorganic gases such as ammonia, ozone or mercury can be measured with detector tubes or impinge methods.

Gas and vapor can be detected by pump, diffusion or direct readings. Pump methods identify carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), asbestos, bioaerosols, metals, volatile organic compounds (VOCs,) organochloride pesticides and formaldehyde (HCHO). Diffusion identifies CO, NO_2, and SO_2. Direct readings detect CO, NO_2, SO_2 and respirable particles.

Gas and vapor analysis methods include electrical, electromagnetic, electro-chemical, thermal, gas chromatography, magnetic and radioactive methods.

Direct reading infrared meters are effective for obtaining CO_2 readings. These readings should be taken at various times of day, away from known CO_2 pollutant sources for true readings. Extended period monitoring is best and most defensible. Extended period monitoring can accurately identify ventilation effectiveness, which identifies the amount of outdoor air that reaches the occupied zone.

Microbial Sampling

Biocontaminants should be considered when nothing else accounts for building conditions or when a walk-through assessment detects microbial involvement. An inspection of building sanitation and air sampling with pump is recommended. However, no guidelines or tolerance levels exist for comparison.

When sampling for viable microorganisms, sampling devices must be chosen with care to avoid damage of cells. Impaction, and the media used therein, must not harm the cell viability. Consequently, any wetting agents, antibacterial agents and anti-fungal agents are to be avoided. Rather, use a rich media culture in samplers to protect samples until the time of analysis. Culture plate impactors, liquid impingers, membrane filter cassettes and high-volume electrostatic devices can all be used for such collections.

Viable cultural sampling makes use of equipment such as the Anderson N-6, Aerotech A-6, SAS, RCS Bites, impingers and gravity plates. For sampling for the exact colony-forming units (CFU) counts of microscopic organisms, use eight-hour membrane filter cassette sampling.

Spore-trap sampling is used for total (viable and non-viable) sampling and pulls air onto a sticky microscope slide surface for staining and evaluation, at which point spore types are identified and counted, yielding spore counts per cubic meter of air (s/m3). This method fails to distinguish *Penicillium* and *Aspergillus* genera as the two appear similar. Equipment used for spore trap sampling includes the Allergenco, Air-O-Cell cassettes or Burkhardt.

Surface sampling methods include clear cellophane tape lift, by which tape is gently pressed to a surface and lifted off. RODAC plates are Petri dishes pressed against surfaces to obtain samples. Swab wipes are sterile swabs wiped across contaminated surfaces.

The analysis of collected samples is equally important as the sampling itself. Petri dish sampling, used for viable sampling, pulls air onto a dish full of nutrient agar, allowing it to incubate for 7 to 10 days, at which point colonies are identified and cultured. The most commonly used agars are MEA (malt extract) and PDA (potato dextrose).

Bioaerosols must be analyzed by one of five methods. These can be broken into two main categories called culturable analysis and microscopic evaluation. Culturable analysis allows mold or bioaerosols to grow out over a period of time before counts and measurements are taken. Microscopic evaluation mounts particulates or microbials on a slide for evaluation. Direct microscopy is used to count fungi that can be detected by microscopic evaluation.

Viruses are detected by scanning electron microscopy (SEM), molecular methods (i.e., PCR) and immuno assays. Immunoassay is based upon the extraction of a water-soluble fraction of a specific antigen source. The three types of immunoassay are radioallergo sorbent test (RAST) or ELISA inhibition assays, direct RAST or ELISA assays or immunoblot assays. Bioassays and chemical analysis involves three limulus assays including the gel-clot method, which evaluates gel formation, turbidimetric-kinetic assay, which evaluates the rate of gel formation and chromogenic assay, which evaluates pigment. Gas/liquid chromatography and mass spectroscopy (GC/MS) may be used for *Fusarium* toxins. This may be used for endotoxin analysis and microbial volatile organic compounds (MVOCs) from microbial growth as well. Data interpretation is often difficult as neither OSHA nor the ACGIH have developed exposure levels for microbial organisms. Even so, basic principles show that indoor levels should be lower than outdoor ones, and distribution should be similar indoors and outdoors. The absence or presence of indicator organisms in a sample should also be noted.

Developing a Remediation Strategy

Three basic engineering strategies govern the remediation of indoor air quality problems: control of the sources of contamination, dilution through ventilation and air cleaning and filtration. Particular emphases vary from situation to situation depending upon the details of the complaint and the results of the IAQ investigation. Particularly important, of course, is the type of contaminant discovered during the investigation. It is important to realize that each IAQ remediation project may involve all three engineering principles to one degree or another.

The basics of applying a remediation strategy differ little from the basics of conducting the initial IAQ investigation. Care should be taken to note the components of the IAQ Triangle involved in the particular complaint. Attention should always be paid to maintenance issues related to the HVAC system serving the complaint area. Ventilation rates and volumes should be manipulated to conform to guidelines for acceptable indoor air quality (as published, for example in *ASHRAE Standard 62*). Informal modifications or obstructions to the designed HVAC system should be removed, and the sources of the complaints that precipitated such modifications should be investigated. Filters and air cleaners serving the complaint area should be sized correctly, cleaned or replaced when necessary and preventive maintenance schedules initiated. In the case of large-scale machines that produce contaminants, local exhaust systems should be installed to eliminate contaminated air and ventilation systems modified accordingly to provide sufficient replacement air. Whenever possible, of course, contaminant sources should be removed entirely or, in the case of things like VOC contamination from walls or furniture, sealed to prevent further emissions.

The IAQ manager should evaluate proposed methods of remediation before selecting one. Several factors contribute to the overall success of a particular method.

- *Permanence:* Solutions that not only solve the immediate problem, but also modify conditions so that the problem does not recur, are the most desirable and cost effective in the long run.
- *Operating Principle:* Methods that utilize the correct engineering strategy will be more likely to provide permanent solutions to IAQ problems. Focusing on dilution ventilation to combat the introduction of contaminated outdoor air, for example, will only make the problem more serious, whereas air cleaning and filtration would seem a wiser choice. On the other hand, ventilation may be just the solution for reducing carbon dioxide levels in a particular area of the building. In this second case, it may be necessary to provide a pathway for building exhaust or exfiltration for the air introduced to displace.
- *Institutionalization:* An IAQ solution, which can be effected with existing personnel, equipment and maintenance procedures, is more likely to succeed in the long run than a solution which requires the use of exotic or expensive equipment or which requires the extensive retraining of facilities maintenance personnel.
- *Installation and Operating Costs:* Cost analysis of a proposed IAQ solution should take into account operating costs over the long run, not just initial purchasing and installation. Also important is staff time required for maintenance of new equipment and cost differentials resulting from new materials and supplies for operation and maintenance.
- *Conformity to Codes: Modifications to building structures or mechanical systems* must comply with all existing federal, state and local building, fire and electrical codes.

Source Removal: Two Special Cases

A significant part of IAQ remediation is the removal of contaminated material from the building. In two cases in particular, this process is potentially dangerous, both physiologically and legally. Closer attention to the specifics of asbestos and mold remediation will reinforce the principles of IAQ management that this manual has attempted to articulate.

Asbestos Remediation

The health threats posed by friable asbestos (asbestos that can be crushed by hand pressure) have been discussed in another section of this manual. IAQ managers planning renovation or remodeling projects who suspect that their buildings may contain asbestos containing materials (ACM) bear a weighty responsibility. The EPA has ruled that both building owners and construction contractors bear responsibility before the law for addressing the issue of ACM in building materials about to be disturbed. OSHA has issued formal regulations on the removal of ACM in its 29 CFR 1910 and 29 CFR 1926. Among these is that the building owner is liable for the improper removal of ACM by a restoration contractor in his employ.

For these reasons, it is wise for an IAQ manager to consider ACM as a possible threat before engaging in any remodeling or renovation project where building materials will be removed. Especially in the case of ceiling or flooring materials, in which asbestos was commonly used until the early 1980’s, building managers must assume the presence of ACM and act accordingly. The EPA has published guidelines for the remediation of asbestos in *Managing Asbestos in Place: A Building Owner’s Guide to Operations and Maintenance Programs for Asbestos-Containing Materials* (1990). In some, but not all, cases, bulk sampling of questionable material may be indicated in order to prove the <u>absence</u> of asbestos. Under NESHAP and before renovation work begins, bulk sampling to prove the absence or presence of asbestos is often required. Only AHERA-certified asbestos inspectors may perform such sampling. In addition, state governments in the United States regulate asbestos work via state license programs. The EPA and OSHA have recommended managing asbestos in place rather than removing it unless renovation work will disturb asbestos containing materials. Regulations for the state that the facility is located in should be consulted for exact regulatory requirements for sampling. For more information, consult *Managing Asbestos in Place* (EPA, 1990).

Mold Remediation

Understanding correct procedures for the remediation of mold contamination problems is a critical issue for all IAQ managers. The risks involved with mold exposure involve both short-term and long-term health effects as well as potential legal liability for property owners and managers. Persons exposed to elevated levels of mold spores, even for a short time, may experience irritation of the eyes, nose and throat, shortness of breath, dizziness, lethargy, fever or digestive problems. In addition, allergies, mycosis and various forms of immunosuppression are possible results of long-term exposure. The Occupational Safety and Health Administration (OSHA) can cite property managers under its "general duty clause" for the exposure of their workers to mold contamination.

Managers should be aware that mold spores are present everywhere and that they need only moisture and nutrients to grow, thrive and reproduce. Nutrients for mold growth exist in all building environments. Mold can grow on any carbon-based material, including latex paint, wood, carpet, clothing, insulation, drywall, furniture, paper and dirt. It is impossible to deprive mold spores of the nutrients they need to grow. Moisture control is, therefore, essential to the containment of mold. The moisture necessary for mold growth can come from any one of a long list of sources, including roof and plumbing leaks, sewer back-ups, floods, condensation and construction defects such as improperly installed windows and doors.

The IAQ manager will be able to exert some control over condensation by the manipulation of relative humidity and temperature in the building environment. Since cold air can hold less moisture than warm air, its relative humidity is always higher and reaches the dew point first. Condensation is thus most likely to form on the coldest surfaces in a particular area. Such surfaces are primary breeding grounds for mold. Maintaining relative humidities near interior surfaces below the dew point is an essential strategy in mold containment. This can be accomplished by reducing the moisture content of the air or increasing the temperature and thus raising the dew point. As a further measure to control condensation, IAQ managers in warm, humid regions should take care to keep HVAC systems operating to maintain a positive net pressure with respect to the outdoors. This will prohibit the entry of unconditioned (moisture laden) air into the building envelope.

Though ventilation and air cleaning certainly factor into the remediation process where mold is concerned, mold problems will not be resolved without specific attention to **source control** as a primary strategy. Two major approaches to source control are the application of biocides and antimicrobials and the removal of contaminated material.

IAQ managers should be aware of the differences between biocides and antimicrobials. **Antimicrobial** agents are chemical formulations that are incorporated into or applied onto materials during manufacturing to suppress, prevent or retard the development of vegetative or bacterial fungal growth. **Biocides** are chemicals (sanitizers, disinfectants or sterilants) that kill or inactivate microorganisms such as bacteria and fungi. It should be noted that killing microorganisms does not destroy their toxic properties. Biocides also require a certain contact time with the contaminated material to be effective, and they pose potential health threats to building occupants. For these reasons, biocides are not recommended for mold remediation by the ACGIH. In any case, they are not a substitute for removal of contaminated material, and the applicator should realize that their application may suppress one organism while giving an advantage to others.

In most cases, source control is the indicated strategy for mold remediation. Source control begins with addressing and correcting the moisture problem that is causing microbial issues. It also usually involves the complete removal of contaminated material as well as cleaning and drying to inhibit further contamination.

In preparation for a mold remediation project, **containment** is a priority. To prevent cross-contamination from occurring during the removal process, the work area should be isolated from the remainder of the building and an intentional directed airflow set up to keep the work area at a net negative pressure relative to surrounding building spaces. Isolation of the work area is accomplished by the use of 6-mil fire-rated, polyethylene sheeting to form critical barriers. These barriers should block off all HVAC components, fixtures and openings, completely sealing off the work area. Directed airflows are established by the use of negative air machines which create a favorable pressure differential between clean areas and work areas. Decontamination chambers should also be constructed for entry into and exit from the remediation site. Proper signage is needed to advise building occupants of the work and warn of entry into the remediation containments.

Demolition work involves removing all contaminated materials including drywall, insulation, ceiling tiles, carpet and carpet backing. Contaminated materials should be doublebagged immediately in 6-mil plastic. HEPA vacuum cleaners should be used to keep the work area free from spore-laden dust. All tools, negative air machines and vacuum cleaners must be damp-wiped and sealed before leaving the containment area. Debris from the demolition should be moved from the work site to a secure location immediately. A combination of HEPA vacuuming and damp-wiping should be performed on every surface of the containment area to eliminate as much dust as possible before breakdown of the containment structure.

Respiratory Protection

IAQ managers should consider the health and safety of remediation workers when planning a remediation project. This may involve the selection of respiratory protection devices. In 2004, NIOSH published a guide for this purpose entitled *Respirator Selection Logic*.

The NIOSH guide includes instructions for selecting respirators for a variety of exposure conditions relevant to indoor air quality, though it does not address the selection of respirators for portection against infectious agents. Before selecting respirators, IAQ managers may have to categorize exposure conditions. Important categories for this purpose include including oxygen deficient atmospheres, atmospheres posing "immediate danger to life and health" (IDLH) and atmospheres where gases and vapors are present.

Oxygen concentrations below 6% at sea level will cause death, and any atmosphere with less than 19.5% oxygen is considered oxygen deficient. According to NIOSH, entry into an oxygen deficient atmosphere requires a supplied air respirator (SAR) with an auxiliary self-contained breathing apparatus (SCBA). IDLH and similar atmospheres require escape respirators, which should be chosen based on the time needed to escape from a suddenly occurring respiratory hazard. An atmosphere is categorized as IDLH if it cannot be escaped within 30 minutes. In atmospheres containing gases and vapors, IAQ managers should consider pressure-demand supplied-air respirators with a full face piece, as they provide the highest level of protection.

APPENDIX

The following information has been provided by the US EPA as part of its I-Beam software program for Indoor Air Quality managers.

Conversion Equivalents

1 atmosphere	**equals**	**14.696 pounds/sq. in** **760 mm of mercury** **29.92 in of mercury (0°C)** **33.91 ft. of water (4°C)**
Celsius	**equals**	**1.8°C + 32 Fahrenheit**
1 cubic foot/min (cfm)	**equals**	**0.472 liters/sec (l/s)**
1 cubic foot	**equals**	**0.02832 cubic meters**
1 cubic meter	**equals**	**35.31 cubic feet**
Fahrenheit	**equals**	**(°F-32)/1.8 Celsius**
1 liter/sec. (l/s)	**equals**	**2.119 cfm**
1 meter	**equals**	**3.281 feet**
1 sq foot	**equals**	**0.09290 sq meters**
1 sq meter	**equals**	**10.764 sq feet**

***EPA – I-Beam Software Program**

Glossary of IAQ Terms

· A ·

Term	Definition
Absorption	The process of one substance entering into the inner structure of another.
Abrasion	The wearing away of a solid surface by friction.
Abrasive Cleaners	Products that clean through abrasive or scouring action.
Acceptable Indoor Air Quality	Air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.
ACGIH	American Conference of Governmental Industrial Hygienists.
ACH	Air changes per hour
Activated Charcoal	A highly absorbent form of carbon used to remove odors and toxic substances from liquids or gases.
Acute Exposure	A single exposure to a toxic substance which results in biological harm or death; usually characterized as lasting no longer than a day.
Acute Toxicity	The ability of a substance to cause poisonous effects resulting in severe biological harm or death soon after a single exposure or dose. Any severe poisonous effect resulting from a short-term exposure.
Adhesion	Molecular attraction that holds the surfaces of two substances in contact.
Adsorption	The adhesion of a thin film of liquid or gases to the surface of a solid substance.
Adverse Health Effect (occurrence)	Any abnormal, harmful, or undesirable effect (occurrence) on the physical, biochemical, biological, or behavioral well-being of a person that results from being exposed to pollutants in the environment.
Aerosol	A suspended liquid or solid particle in a gaseous medium.
AHU	Air handling unit; a component of an HVAC system that includes the fan(s), filters, and coils to condition the air.
AIA	American Institute of Architects
Air	A mixture of gasses constituting a compressed fluid tied to the planet by gravitational attraction. Air is 79.0% nitrogen, 20.9% oxygen, and less than 0.1% a mixture of carbon dioxide, argon, helium, and hundreds of other gasses originating from natural and man-made sources.
Air Changes Per Hour (ACH)	Volume of air moved in one hour. One air change per hour in a room, home, or building means that all the air in that environment will be replaced in one hour.

Air Cleaning	An IAQ control strategy to remove various airborne particulates and/or gases from the air. The three types of air cleaning most commonly used are particulate filtration, electrostatic precipitation, and gas sorption.
Air Cleaning System	A device or combination of devices applied to reduce the concentration of airborne contaminants, such as microorganisms, dusts, fumes, respirable particles, other particulate matter, gases, and/or vapors in air.
Air-Conditioning	The process of treating air to meet the requirements of a conditioned space by controlling its temperature, humidity, cleanliness, and distribution.
Air Exchange Rate	Used in two ways: 1) the number of times that the outdoor air replaces the volume of air in a building per unit time, typically expressed as air changes per hour; 2) the number of times that the ventilation system replaces the air within a room or area within the building.
Air Handling Unit	For purposes of this program refers to equipment that includes a blower or fan, heating and/or cooling coils, and related equipment such as controls, condensate drain pans, and air filters. Does not include ductwork, registers or grilles, or boilers and chillers.
Air Pollutant	Any unwanted substance in air.
Algae	Simple rootless plants that grow in sunlit waters in proportion to how many nutrients are available.
Allergen	A chemical or biological substance (e.g., pollen, animal dander, or house dust mite proteins) that induces an allergic state or reaction, characterized by hypersensitivity.
Allergen	A substance that induces allergic reaction.
Annoyance	A general feeling of displeasure or adverse psychological reaction toward a source. Associated with disturbance, distress and frustration.
ANSI	American National Standard Institute
Antimicrobial	Agent that kills microbial growth. See "disinfectant," "sanitizer," and "sterilizer."
Asbestos	A naturally-occurring mineral fiber that can cause cancer.
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
Asthma	A condition marked by recurrent attacks of difficult or labored breathing and wheezing resulting from spasmodic contraction and hypersecretion of the bronchi. It is caused by exposure to allergens such as drugs, foods, environmental pollutants, or intrinsic factors.
ASTM	American Society for Testing and Materials
Atmosphere	A standard unit of pressure exerted by a 29.92-inch column of mercury at sea level and equal to 1000 grams per square centimeter.

· B ·

Term	Definition
BAQ	Building Air Quality
BRI	See "Building-Related Illness"
Bacteria	Microscopic living organism.
Baghouse Filter	A large fabric bag used to eliminate intermediate and large particles. It operates like a vacuum cleaner bag, allowing air and smaller particles to pass through it, while entrapping larger particles.
Biocide	Any poison that kills a living organism.
Biodegradability	The ability of an organic material to break down or change into a natural substance such as water or carbon dioxide.
Biodegradable	Able to break down or decompose rapidly under natural conditions.
Biological Contaminants	Agents derived from or that are living organisms (e.g., viruses, bacteria, fungi, and mammal and bird antigens) that can be inhaled and can cause many types of health effects including allergic reactions, respiratory disorders, hypersensitivity diseases, and infectious diseases. Also referred to as "microbiologicals" or "microbials."
Bioremediation	The management of microorganisms.
BOCA	Building Officials and Code Administrators
BOMA	Building Owners Management Association
Breathing Zone	Area of a room in which occupants breathe as they stand, sit, or lie down.
Buffer Action	A substance's resistance to a change in pH.
Building Envelope	Elements of the building, including all external building materials, windows, and walls, that enclose the internal space.
Building-Related Illness	Diagnosable illness whose symptoms can be identified and whose cause can be directly attributed to airborne building pollutants (e.g., Legionnaire's disease, hypersensitivity pneumonitis).

· C ·

Term	Definition
Carbon Dioxide (CO_2)	A colorless, odorless, nonpoisonous gas which results from fuel combustion and human activity indoors. Elevated levels of CO_2 indicate ineffective ventilation indoors.
Carbon Monoxide (CO)	A colorless, odorless, poisonous gas which results from incomplete combustion.
Carcinogen	A substance that can cause or contribute to cancer.
Caustic	Able to burn, corrode, dissolve, or eat away other substances.
Caustic Soda	Sodium hydroxide, a strong alkaline substance used as the cleaning

agent in some detergents.

CAV See constant air volume.

Ceiling Plenum Space below the flooring and above the suspended ceiling that accommodates the mechanical and electrical equipment and that is used as part of the air distribution system. The space is kept under negative pressure.

Central AHU See "Central Air Handling Unit."

Central Air Handling Unit For purposes of this document, this is the same as an AHU, but serves more than one area.

CFM Cubic feet per minute. The amount of air, in cubic feet, that flows through a given space in one minute.

Chemical Cleaning Cleaning by using a chemical instead of mechanical or abrasive cleaning.

Chemical Disinfection Disinfection by using chemicals instead of heat and other physical, electrical, or radioactive methods.

Chemical Mixture Any combination of two or more substances.

Chemisorb To take up and hold, usually irreversibly, by chemical forces.

Chlorinated Solvents Organic solvents containing chlorine atoms. Examples include methylene chloride, perchloroethylene and 1,1,1 trichloroethylene used as cleaning agents.

Chronic Exposure Long-term exposure lasting several weeks to a lifetime.

Chronic Toxicity The ability of a substance to cause long-term poisonous human health effects.

Cinogenic Able to induce a cancer response at the cellular level.

Cleaning The process of removing unwanted substances and putting them in their proper place.

CO Carbon monoxide.

CO_2 Carbon dioxide

Coagulation A joining together of particles that settle out in waste water. Lime, alum, and iron salts induce the clumping of particles.

Combustion Burning or rapid oxidation accompanied by a release of energy.

Commissioning Start-up of a building that includes testing and adjusting HVAC, electrical, plumbing, and other systems to assure proper functioning and adherence to design criteria. Commissioning also includes the instruction of building representatives in the use of the building systems.

Concentration The quantity of one constituent dispersed in a defined amount of another.

Conditioned Air Air that has been heated, cooled, humidified, or dehumidified to maintain an interior space within the "comfort zone." (Sometimes referred to as "tempered" air.)

Constant Air Volume System	Air handling system that provides a constant air flow while varying the temperature to meet heating and cooling needs.
Contaminant	Any physical, chemical, biological, or radioactive substance that can adversely affect air, water or soil.
Corrosion	Action or effect of eating away gradually. This can occur through oxidation, the action of strong acids, or caustic alkali.
Corrosive	A chemical agent that reacts with a surface, causing it to deteriorate or wear away.
Crawl Space	The area beneath floors that provides access to utilities and other services. Other options are basements and slabs on grade.
Cubic Feet per Minute (CFM)	A measure of the volume of a substance flowing through air within a fixed period of time. Indoors, it is the amount of air measured in cubic feet that is delivered and exchanged in one minute.

· D ·

Term	Definition
DA	Distribution apportionment; the relationship between the proportion of the outside air (OA) quantity being delivered to portion a building and the proportion of the people in the building that are actually located in that portion of the building.
Dampers	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.
DDC	Direct digital control.
Decibel (dB)	A unit of sound measurement. Sound doubles in loudness for every 10 decibels.
Decomposition	The breakdown of matter by bacteria and fungi.
Degreaser	A chemical such as soap, solvents, alkali, or detergent that dissolves and helps remove greases and oils.
Depressurization	A condition that occurs when air pressure inside a structure is lower than air pressure outside.
Desiccant	A chemical agent that absorbs moisture.
Detergent	1. Synthetic washing agent that helps remove dirt and oil. Some contain compounds that kill bacteria or encourage algae growth. 2. A chemical composition that cleans.
DI	DI distribution integrity; the relationship between the outside air (OA) quantity entering the HVAC equipment and the OA that actually gets delivered to the building occupants.
Diffusers and Grilles	Components of the ventilation system that distribute and diffuse air to promote air circulation in the occupied space. Diffusers supply air and grilles return air.

Digestion	The biochemical decomposition of organic matter, resulting in partial gasification, liquefaction, and mineralization of pollutants.
Dilution	A concentration made less concentrated by adding gas or liquid.
Dilution Ventilation	Dilution of contaminated air with uncontaminated air in a general area, room, or building for the purpose of health hazard or nuisance control.
Disinfectants	One of three groups of antimicrobials registered by EPA for public health uses. EPA considers an antimicrobial to be a disinfectant when it destroys or irreversibly inactivates infectious or other undesirable organisms, but not necessarily their spores. EPA registers three types of disinfectant products based upon submitted efficacy data: limited, general or broad spectrum, and hospital disinfectant.
Disinfection	A chemical or physical process that kills pathogenic organisms.
Disposal	Final placement or destruction of wastes.
Dissolved Solids	Disintegrated organic or inorganic material contained in water.
Dose	The amount of exposure undergone at one time.
Dust	An air suspension of particles (aerosol) of any solid material, usually with particle size less than 100 micrometers.

· E ·

Term	Definition
Ecology	The relationship of living things to one another and their environment.
Ecosystem	The interacting system of a biological community and its environmental surroundings.
Electrostatic Precipitator (ESP)	An air-pollution control device that removes particles from an air stream. The ESP imparts an electrical charge to particles causing them to adhere to metal plates inside the precipitator.
Emission	Pollution discharge from a source.
Emulsion	Two or more liquids that do not dissolve in each other but are held in suspension, one in the other.
Energy Recovery Ventilation System	A device or combination of devices applied to provide the outdoor air for ventilation in which energy is transferred between the intake and exhaust airstreams.
Environment	The sum of all external conditions affecting the life of an organism.
Environmental Factors	Conditions other than indoor air contaminants that cause stress, comfort, and/or health problems (e.g., humidity extremes, drafts, lack of air circulation, noise, and over-crowding).
EPA	U.S. Environmental Protection Agency
Epidemic	Widespread outbreak of a disease.
Ergonomics	The study of people adjusting to their work environment; the science

	of adapting working conditions to the worker.
Etiology	The science of causes or origins; the cause of a specific disease.
ETS	Environmental tobacco smoke.
EVR	Effective ventilation rate; the ventilation rate based on the actual quantity of outdoor air delivered to the occupied areas of a building or space.
Exfiltration	Air leakage outward through cracks and interstices and through ceilings, floors, and walls of a space or building.
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., piece of equipment, room, or general area).
Exposure	An event in which an organism comes in contact with a chemical or biological agent.
Exposure Assessment	Measurement or estimation of the magnitude, frequency, duration, and route of exposure of humans, animals, materials, or ecological components to substances in the environment. The assessment also describes the size and nature of the exposed population.

· F ·

Term	Definition
Fabric Filter	A cloth that catches dust particles.
Fatigue	Physical or mental exhaustion; weariness; tiredness.
Flash Point	The lowest temperature at which a combustible liquid or gas gives off a flammable vapor that will burn when exposed to an open flame.
Flow Hood	Device that easily measures airflow quantity, typically up to 2,500 cfm.
Flue Gas	The air coming out of a chimney after combustion in the burner it is venting.
Fogging	Applying a liquid chemical by rapidly heating it to form fine droplets that resemble smoke or fog.
Ft^2	Square feet.
Fumes	Airborne particles, usually less than 1 micrometer in size, formed by condensation of vapors, sublimation, distillation, calcination or chemical reaction.
Fumigant	A biocide that is vaporized to kill pests. Used indoors or outdoors.
Fungi	A group of organisms that lack chlorophyll, including molds, mildews, yeasts, mushrooms. They receive their nutrition from decomposing organic matter. Some cause disease in humans.
Fungicide	Biocides used to control, prevent, or kill fungi.

· G ·

Term	Definition
Gas	A state of matter in which substances exist in the form of nonaggregated molecules, and which, within acceptable limits of accuracy, satisfies the ideal gas laws; usually a highly superheated vapor.
Gas Sorption	Devices used to reduce levels of airborne gaseous compounds by passing the air through materials that extract the gases. The performance of solid sorbents is dependent on the airflow rate, concentration of the pollutants, presence of other gases or vapors, and other factors.

· H ·

Term	Definition
Habitat	The place where a population lives, including its living and non living surroundings.
Hard Water	Alkaline water containing dissolved salts that interfere with some industrial processes and prevent soap from lathering.
Hazard	Risk, peril, jeopardy to which an individual is subjected.
Hazardous Waste	By-products of society that can pose a substantial or potential hazard to human health or the environment when improperly managed. They have at least one of four characteristics: they are ignitable, corrosive, reactive, or toxic.
Heavy Metals	Metallic elements with high atomic weights such as mercury, chromium, cadmium, arsenic, and lead. They can damage living organisms at low concentrations.
Hedonic Tone	The degree to which an odor is perceived as pleasant or unpleasant. Expressed in terms of preference by phrases such as "dislike very much" or "like slightly" or by facial expressions such as smiling or frowning.
HEPA	High efficiency particulate arrestance (filters).
Humidity	The measure of moisture in the atmosphere.
HVAC	Heating, ventilation, and air-conditioning system.
Hydrocarbons (HC)	Chemical compounds made up entirely of carbon and hydrogen.
Hypersensitivity	The immune system's exaggerated response to an allergen.
Hypersensitivity Diseases	Diseases characterized by allergic responses to animal antigens. The hypersensitivity diseases most clearly associated with indoor air quality are asthma, rhinitis, and hypersensitivity pneumonitis. Hypersensitivity pneumonitis is a rare but serious disease that involves progressive lung damage as long as there is exposure to the causative agent.

· I ·

Term	Definition
IAP	Indoor air pollution
IAQ	IAQ Indoor air quality.
IAQ Coordinator	An individual at the school and/or school district level who provides leadership and coordination of IAQ activities.
IAQ Management Plan	A set of flexible and specific steps for preventing and resolving IAQ problems.
Ignitable	Capable of burning or causing a fire.
Immune System	All internal structures and processes providing defense against disease-causing organisms such as viruses, bacteria, fungi, and parasites.
Indicator Compounds	Chemical compounds, such as carbon dioxide, whose presence at certain concentrations may be used to estimate certain building conditions (e.g., airflow, presence of sources).
Individual Risk	The increased risk for a person exposed to a specific concentration of a toxicant.
Indoor Air	The air that people breathe inside a built environment.
Indoor Air Pollutant	Particles of dust, fibers, mists, bioaerosols, and gases or vapors.
Indoor Climate	Temperature, humidity, noise, and lighting inside a structure.
Infiltration	Air leakage inward through cracks and interstices and through ceilings, floors, and walls of a space or building.
Inflammation	A protective tissue response to injury that destroys, dilutes, or walls off both the injurious agent and the injured tissue, characterized by symptoms such as pain, heat, redness, swelling, and loss of function.
Inhalable	Particles small enough to be inhaled, but large enough so that they are not quickly exhaled.
IPM	Integrated pest management.

· J ·

There are no entries for this letter

· K ·

There are no entries for this letter

· L ·

Term	Definition
Lethal Concentration (LC50)	The concentration of a substance needed to kill half of a population at a specific time of observation.
Lethargy	A condition of abnormal drowsiness or torpor; a great lack of energy; apathy.
Lipid Solubility	The maximum concentration of a chemical that will dissolve in fatty substances. Lipid-soluble substances do not dissolve in water.
Liquefaction	Changing a solid into a liquid.

· M ·

Term	Definition
Maintenance	Care and upkeep of the surrounding environment.
Make-Up Air	Air brought into a building from outdoors through the ventilation system and that has not been previously circulated through the system.
Makeup Air	Outdoor air supplied to replace exhaust air and exfiltration.
Malaise	A vague feeling of discomfort or uneasiness.
Masking	The phenomenon where a quality in a mixture obscures one or more other qualities in it.
MCLs	Maximum Contaminant Levels.
MCS	See "Multiple Chemical Sensitivity."
mg/M^3	Milligrams per cubic meter.
Microbes	Microscopic organisms such as algae, insects, viruses, bacteria, fungi, and protozoa, some of which cause diseases.
Microbiologicals	See "Biological Contaminants."
Microenvironment	A particular part of the large environment that is in some way whole by itself. Used to describe a subset of the global environment such as the indoor environment.
Micron	A unit of linear measure equal to one millionth of a meter, or one thousandth of a millimeter.
Microorganism	A microscopic organism, especially a bacterium, fungus, or protozoan.
Mist	Liquid particles measuring between 40 and 500 microns. By contrast, particles making up fog are less than 40 microns.
Mitigation	Measures taken to reduce adverse effects on the environment.
Morbidity	The number of sick individuals or cases of disease in a population.
Mortality	The number of individual deaths in a population.
MSDS	Material Safety Data Sheet.

Multiple Chemical Sensitivity	A term used by some people to refer to a condition in which a person is considered to be sensitive to a number of chemicals at very low concentrations. There are a number of views about the existence, potential causes, and possible remedial actions regarding this phenomenon.
Mutagen	Any substance e that can cause a change in genetic material.
Mutagenic	Able to cause a permanent change in the structure of DNA.

· N ·

Term	Definition
Natural Ventilation	The movement of outdoor air into a space through intentionally provided openings, such as windows and doors, or through nonpowered ventilators or by infiltration.
Negative Pressure	Condition that exists when less air is supplied to a space than is exhausted from the space, so that the air pressure within that space is less than in surrounding areas.
NIOSH	National Institute for Occupational Safety and Health.
	.
Nitrogen Oxides (NOX)	Nitrogen compounds such as NO and NO_2 produced by combustion. They help to from ozone and photochemical smog.
NO_2	Nitrogen Dioxide

· O ·

Term	Definition
OA	Outdoor air.
Occupied Zone	The region within an occupied space between planes 3 and 72 in. (75 and 1800 mm) above the floor and more than 2 ft (600mm) from the walls or fixed air-conditioning equipment.
Odor	A quality of gases, liquids, or particles that stimulates the olfactory organ or sense of smell.
Odor Character or Quality	The property of the odor sensation that permits a person to distinguish odors of different substances based on prior exposure.
Odor Descriptor	Adjective given to an odor such as "floral," "caramel," "putrid."
Odorant	A substance that stimulates the olfactory receptors.
Odor Pervasiveness	The rate of decrease of odor perception associated with the decrease in odorant concentration.
Odor Threshold	Concentration of odorous air at which half of the judges in a panel detect the odor.
Odorimetry	Measurement of olfactory sensations.

Opacity	The amount of light obscured by particulate matter in the air.
Organic	1. Any compound containing carbon. 2. Substances derived from living organisms.
OSHA	Occupational Safety and Health Administration.
Outdoor Air	Air taken from the external atmosphere and, therefore, not previously circulated through the system.
Oxidation	A substance containing oxygen that reacts chemically to produce a new substance.
Oxidation	A reaction in which oxygen combines with another substance.
Ozone (O_3)	A very reactive oxidant containing three atoms of oxygen.

· P ·

Term	Definition
PA	Pascal; unit of pressure measurement.
PAHs	Polycyclic Aromatic Hydrocarbons.
Particulate Matter	A state of matter in which solid or liquid substances exist in the form of aggregated molecules or particles. Airborne particulate matter is typically in the size range of 0.01 to 100 micrometers.
Particulates	Fine liquid or solid particles such as dust, smoke, mist, fumes, and fog found in air and emissions.
Pathogenic	Capable of causing disease.
Pathogens	Microorganisms that can cause disease in other organisms, humans, animals, or plants.
PCBs	Polychlorinated biphenyls.
pCi/l	Picocuries per liter; a measure of radon concentration.
PELs	Permissible Exposure Limits (standards set by OSHA).
Perception	Awareness of the effects of stimuli.
Persistence	Length of time a compound remains in the environment once introduced.
Pest	Any form of animal, plant, or terrestrial life that is injurious to health or the environment.
Pesticide	Substance intended to control, prevent, or kill a pest.
pH	A measure of acidity or alkalinity on a scale of 0 to 14 where 7 is neutral. A pH less than 7 is acid and a pH greater than 7 is alkaline or base.
Phosphates	Alkaline builders used in detergents to soften water.
Phytotoxic	Something that harms plants.
PICs	Products of incomplete combustion. All particles and gases that are emitted from an object at the time it is burning.

PIU	Perimeter induction unit.
Plenum	Air compartment connected to a duct or ducts.
Plug Flow	A flow regime where the flow is predominately in one direction and contaminants are swept along with the flow.
Plume	A visible or measurable discharge of a contaminant body from a given point of origin. Can be a visible body of pollution such as smoke coming from a stack or a measured amount such as heat in water coming from a power plant boiler.
PM	Preventive Maintenance.
Pollutant Pathways	Avenues for distribution of pollutants in a building. HVAC systems are the primary pathways in most building, however all building components interact to affect how air movement distributes pollutants.
Pollution	Unwanted by-product of human activity. the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects.
Positive Pressure	Condition that exists 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.
PPB	Parts per billion.
PPM	Parts per million.
Pressure, Total	In flowing air, the sum of the static pressure and the velocity pressure.
Pressure, Velocity	In flowing air, the pressure due to the velocity and density of the air.
Preventive Maintenance	Regular and systematic inspection, cleaning, and replacement of worn parts, materials, and systems. Preventive maintenance helps to prevent parts, material, and systems failure by ensuring that parts, materials and systems are in good working order.
Productivity	The efficiency with which a person performing a specific function does a job, or the output of a worker under specific environments and conditions.
Psychological Factors	Psychological, organizational, and personal stressors that could produce symptoms similar to poor indoor air quality.

· Q ·

There are no entries for this letter

· R ·

Term	**Definition**

RA	Return air.
Radiant Heat Transfer	Radiant heat transfer occurs when there is a large difference between the temperatures of two surfaces that are exposed to each other, but are not touching.
Radon	A colorless, odorless gas that occurs naturally in almost all soil and rock. Radon migrates through the soil and groundwater and can enter buildings through cracks or other openings in the foundation. Radon can also enter well water. Exposure to radon can cause lung cancer.
Re-entrainment	Situation that occurs when the air being exhausted from a building is immediately brought back into the system through the air intake and other openings in the building envelope.
Re-entry	Situation that occurs when the air being exhausted from a building is immediately brought back into the system through the air intake and other openings in the building envelope.
Recirculated Air	Air removed from the conditioned space and used for ventilation, heating, cooling, humidification, or dehumidification.
RELs	Recommended Exposure Limits (recommendations made by NIOSH).
Respirable Particles	Respirable particles are those that penetrate into and are deposited in the nonciliated portion of the lung. Particles greater than 10 micrometers aerodynamic diameter are not respirable.
Return Air	Air removed from a space to be then recirculated or exhausted.
RH	Relative humidity.
RSP	Respirable suspended particles.
Residual	Amount of a pollutant remaining in the environment after a natural or technological process has taken place.
RF	Radio frequency; portion of electromagnetic spectrum.
Risk	The probability of injury, disease, or death under specific circumstances. In quantitative terms, risk is expressed in values ranging from zero, which represents the certainty that harm will not occur, to one, which represents the certainty that harm will occur.
Risk Assessment	1. The use of factual information to define the nature and impact of an adverse effect on individuals or populations who have been exposed to hazardous materials and situations. 2. A quantitative or qualitative evaluation to determine the probability of an adverse effect to human health or the environment by exposure to specific pollutants.
Risk Communication	Exchange of information about health or environmental risks between risk assessors, risk managers, the general public, and other interest groups such as the news media.
Risk Management	The process of evaluating alternative responses to risks and selecting among them. Includes consideration of technical, scientific, social, economic, and political information.

Route of Exposure	The means by which toxic agents gain access to an organism such as ingestion, inhalation, dermal exposures; and intravenous, subcutaneous, intermuscular administrations.
RTU	Roof top unit; a packaged AHU unit on the roof.

· S ·

Term	Definition
SA	Supply air.
Sanitation	1. Control of physical factors in the human environment that could harm development, health, or survival. 2. Process of putting an environment into a state that will not harm human health.
Sanitizer	One of three groups of antimicrobials registered by EPA for public health uses. EPA considers an antimicrobial to be a sanitizer when it reduces but does not necessarily eliminate all the microorganisms on a treated surface. To be a registered sanitizer, the test results for a product must show a reduction of at least 99.9% in the number of each test microorganism over the parallel control.
SBS	See "Sick Building Syndrome.
Sensitization	An allergic condition that usually affects the skin or lungs. Once exposure to a substance has caused a reaction, the individual may be sensitized to it, and further exposure may elicit an adverse reaction even at low levels.
Sewage	The waste and waste water produced by residential and commercial establishments and discharged into sewers.
Sewer	A channel or conduit that carries waste water and storm water runoff from the source to a treatment plant or receiving stream.
SF_6	Sulfur hexafluoride; a physiologically inert gas used as a tracer in building investigations.
Short-Circuiting	Situation that occurs when the supply air flows to exhaust registers before entering the breathing zone. To avoid short-circuiting, the supply air must be delivered at a temperature and velocity that results in mixing throughout the space.
Sick-Building Syndrome	Term sometimes used to describe situations in which building occupants experience acute health and/or comfort effects that appear to be linked to time spent in a particular building, but where no specific illness or cause can be identified. The complaints may be localized in a particular room or zone, or may be spread throughout the building.
Sludge	A solid residue from air or water treatment processes. Can be a hazardous waste.
Smoke	The airborne solid and liquid particles and gases that evolve when material undergoes pyrolysis or combustion.

Soil Gases	Gases that enter a building from the surrounding ground (e.g., radon, volatile organics, pesticides).
Solvent	1. A substance capable of dissolving or dispersing one or more other substances. 2. The liquid component of a solution in which a substance is dissolved.
Sources	Sources of indoor air pollutants. Indoor air pollutants can originate within the building or be drawn in from outdoors. Common sources include people, room furnishings such as carpeting, photocopiers, art supplies, etc.
Stack Effect	Pressure-driven airflow produced by convection as heated air rises, creating a positive pressure area at the top of a building and a negative pressure area at the bottom of a building. The stack effect can overpower the mechanical system and disrupt ventilation and circulation in a building.
Static Pressure	Condition that exists when an equal amount of air is supplied to and exhausted from a space. At static pressure, equilibrium has been reached.
Sterilization	The destruction of all living organisms in water or on the surface of various materials. In contrast, disinfection is the destruction of most living organisms.
Sterilizer	One of three groups of antimicrobials registered by EPA for public health uses. EPA considers an antimicrobial to be a sterilizer when it destroys or eliminates all forms of bacteria, fungi, viruses, and their spores. Because spores are considered the most difficult form of a microorganism to destroy, EPA considers the term sporicide to be synonymous with "sterilizer."
Supply Air	That air delivered to the conditioned space and used for ventilation, heating, cooling, humidification, or dehumidification.
Surfactant	1. Surface active agent used in detergents to cause lathering. 2. Surface active agent that cleans.
Synergism	Cooperative interaction of two or more chemicals or other phenomena producing a greater total effect than the sum of their individual effects.

· T ·

Term	Definition
Teratogen	Substance that causes malformation or serious deviation from normal development of embryos and fetuses.
Threshold Limit Value	Air concentration of chemical substances to which healthy workers can be exposed for 8-hour work days during a 40-hour work week without suffering an adverse effect.
TLVs	Threshold Limit Values (guidelines recommended by ACGIH).

Total Suspended Particulate Matter	The mass of particles suspended in a unit volume of air when collected by a high-volume air sampler.
Toxic	Of, affected by, or caused by a toxin; to cause a poisonous reaction.
Tracer Gases	Compounds, such as sulfur hexafluoride, which are used to identify suspected pollutant pathways and to quantify ventilation rates. Tracer gases may be detected qualitatively by their odor or quantitatively by air monitoring equipment.
Transfer Air	The movement of indoor air from one space to another.
TSP	Total suspended particulate concentration.
Turbidity	Haziness in air caused by particles, or cloudy condition in water caused by suspended silt or organic matter.
TVOCs	Total volatile organic compounds.

· U ·

Term	Definition
uG/M^3	Micrograms per cubic meter.
UL	Underwriters' Laboratory.
Ulocladium	A rapidly growing, dark brown or black fungus that is a potential allergen. Its spores are unusually large (1015 um). It is typically found in soil and is frequently encountered at low levels indoors.
uM	Micrometer.
Upper Respiratory Tract	Structures that conduct air into the lungs, including the nasal cavity, mouth, pharynx, and larynx.

· V ·

Term	Definition
Vapor	A substance in gas form, particularly one near equilibrium with its condensed phase, which does not obey the ideal gas laws; in general, any gas below its critical temperature.
Variable Air Volume System	Air handling system that conditions the air to a constant temperature and varies the outside airflow to ensure thermal comfort. Ventilation Air-Defined as the total air, which is a combination of the air brought into the system from the outdoors and the air that is being recirculated within the building. Sometimes, however, used in reference only to the air brought into the system from the outdoors.
VAV	Variable air volume system.
Vector	An organism that carries disease such as an insect or rodent.
Ventilation	The process of supplying and removing air by natural or mechanical means to and from any space. Such air may or may not be conditioned.

Viscosity	Friction or resistance to the flow of a liquid.
VOCs	See "Volatile Organic Compounds."
Volatile	1. Able to evaporate readily. 2. Able to go to gas phase from a liquid or solid phase.
Volatile Organic Compounds (VOCs)	Compounds that evaporate from the many housekeeping, maintenance, and building products made with organic chemicals. These compounds are released from products that are being used and that are in storage. In sufficient quantities, VOCs can cause eye, nose, and throat irritations, headaches, dizziness, visual disorders, memory impairment; some are known to cause cancer in animals; some are suspected of causing, or are known to cause, cancer in humans. At present, not much is known about what health effects occur at the levels of VOCs typically found in public and commercial buildings.

Further Reading

1. American Council for Accredited Certification, *Code of Conduct*, http://www.acac.org

2. ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality* (ASHRAE, 2013)

3. ASHRAE Standard 52.2, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size* (ASHRAE, 1999)

4. EPA, *Building Air Quality: A Guide for Building Owners and Facility Managers* (Washington: EPA, 1991)

5. H. E. Burroughs and Shirley J. Hansen, *Managing Indoor Air Quality*, 5th edition (Lilburn, GA: Fairmont Press, 2011).

6. Nancy Bollinger, NIOSH Respirator Selection Logic 2004 (Cincinnati: NIOSH, 2004), www.acac.org/forms/rclibrary/nioshresp2004.pdf