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Indoor Air Quality – Part I: Factors Affecting Indoor Air Quality

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Indoor Air Quality
Part I
Factors Affecting Indoor Air Quality

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This course is based on an EPA document, Building Air Quality: A Guide for Building Owners and Facility Managers, which was developed as a joint undertaking of the Indoor Air Division in the Office of Atmospheric and Indoor Air Programs of the United States Environmental Protection Agency and the National Institute for Occupational Safety and Health.

Introduction

A healthy indoor environment is one in which the surroundings contribute to productivity, comfort, and a sense of health and well being. The indoor air is free from significant levels of odors, dust and contaminants and circulates to prevent stuffiness without creating drafts.
In a well designed facility, temperature and humidity are appropriate to the season and to the clothing and activity of the building occupants. There is enough light to illuminate work surfaces without creating glare and noise levels do not interfere with activities. Sanitation, drinking water, fire protection, and other factors affecting health and safety are well planned and properly managed.

Unfortunately, many commercial buildings do not meet the above mentioned standard for air quality even though good air quality is an important component of a healthy indoor environment. For the purposes of this document, the definition of good indoor air quality includes:

- Introduction and distribution of adequate ventilation air,
- Control of airborne contaminants, and
- Maintenance of acceptable temperature and relative humidity.

A practical guide to indoor air quality (IAQ) cannot overlook temperature and humidity, because thermal comfort concerns underlie many complaints about "poor air quality." Furthermore, temperature and humidity are among the many factors that affect indoor contaminant levels.

It is important to remember that while occupant complaints may be related to time at work, they may not necessarily be due to the quality of the air. Other factors such as noise, lighting, ergonomic stressors (work station and task design), and job related psychosocial stressors can - individually and in combination - contribute to the complaints.

Good indoor air quality enhances occupant health, comfort, and workplace productivity.

Failure to respond promptly and effectively to building environmental problems can have consequences such as:

- Increasing health problems such as cough, eye irritation, headache, and allergic reactions, and, in some rare cases, resulting in life-threatening conditions (e.g., Legionnaire's disease, carbon monoxide poisoning)
- Reducing productivity due to discomfort or increased absenteeism

- Accelerating deterioration of furnishings and equipment
- Straining relations between landlords and tenants, employers and employees
- Creating negative publicity that could put rental properties at a competitive disadvantage
- Opening potential liability problems

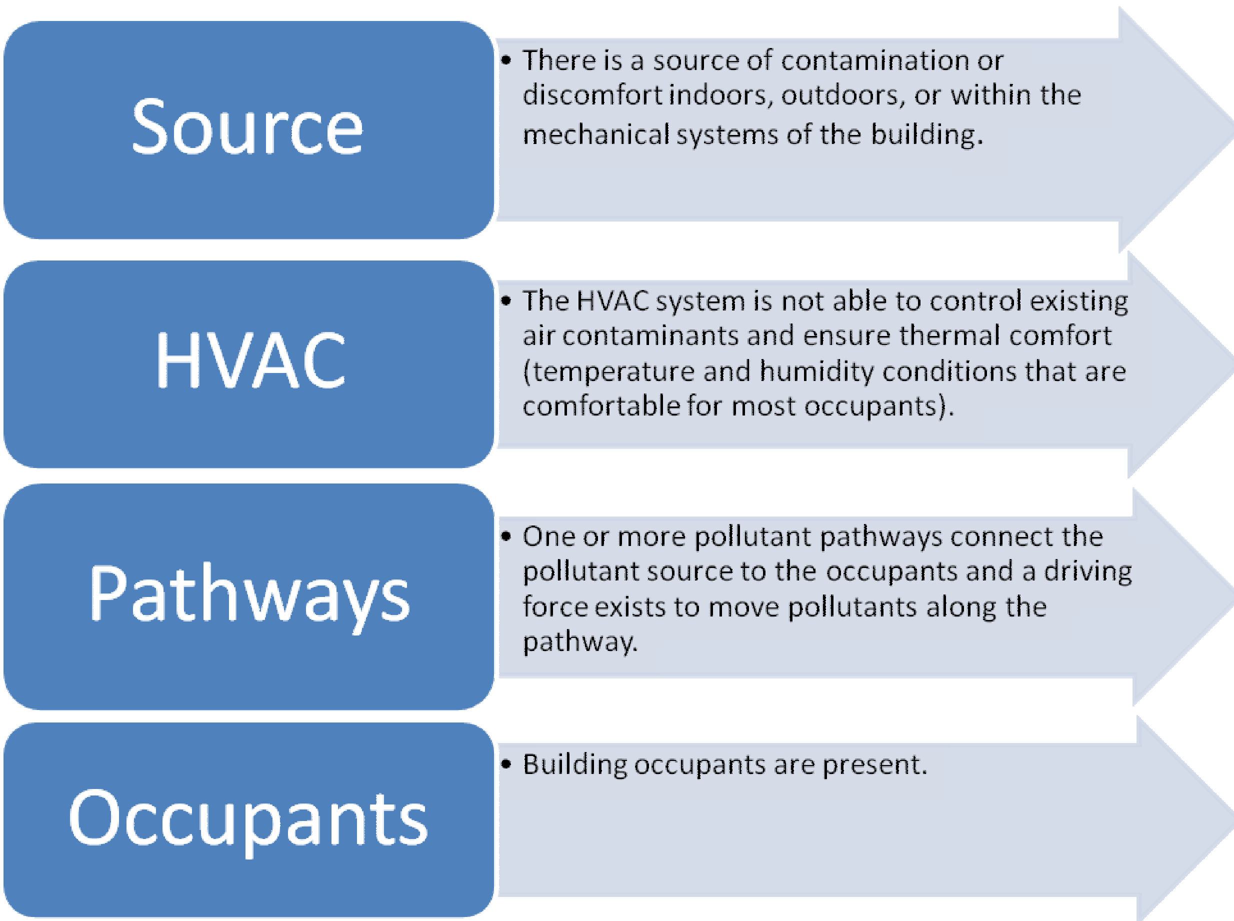
This course is the first in a two-part series. In this course, we will look at factors affecting indoor air quality and how to measure and evaluate indoor air quality. An explanation of how HVAC systems work is covered in chapter three and mold, mildew, asbestos and radon are covered in subsequent chapters.

The second course in this series discusses methods to mitigate indoor air quality problems and covers several common indoor air quality problems and potential solutions. But first, let's look at some of the factors that impact a building's air quality.

Chapter 1
Factors Affecting Indoor Air Quality

The indoor environment in any building is a result of the interaction between the site, climate, building system, construction techniques, contaminant sources (building materials and furnishings, moisture, processes and activities within the building, and outdoor sources), and building occupants.

The following four elements are involved in the development of indoor air quality problems:



It is important to understand the role that each of these factors may play in order to prevent, investigate, and resolve indoor air quality problems. Let's look at each element in a little more detail.

Sources of Indoor Air Contaminants

Indoor air contaminants can originate within the building or be drawn in from outdoors. If contaminant sources are not controlled, indoor air quality problems can arise, even if the HVAC system is properly designed and well-maintained. It may be helpful to think of air pollutant sources as fitting into one of the categories that follow. The examples given for each category are not intended to be a complete list.

Sources Outside Building

1. Contaminated outdoor air
    - Pollen, dust, fungal spores
    - Industrial pollutants
    - General vehicle exhaust

2. Emissions from nearby sources
    - Exhaust from vehicles on nearby roads or in parking lots, or garages
    - Loading docks
    - Odors from dumpsters
    - Re-entrained (drawn back into the building) exhaust from the building itself or from neighboring buildings
    - Unsanitary debris near the outdoor air intake

3. Soil gas
    - Radon
    - Leakage from underground fuel tanks
    - Contaminants from previous uses of the site (e.g., landfills)
    - Pesticides

4. Moisture or standing water promoting excess microbial growth
    - Rooftops after rainfall
    - Crawlspace

Equipment

1. HVAC system
    - Dust or dirt in ductwork or other components
    - Microbiological growth in drip pans, humidifiers, ductwork, coils

- Improper use of biocides, sealants, and/ or cleaning compounds
- Improper venting of combustion products
- Refrigerant leakage

2. Non-HVAC equipment
   - Emissions from office equipment (volatile organic compounds, ozone)
   - Supplies (solvents, toners, ammonia)
   - Emissions from shops, labs, cleaning processes
   - Elevator motors and other mechanical systems

Human Activities

1. Personal activities
   - Smoking
   - Cooking
   - Body odor
   - Cosmetic odors
2. Housekeeping activities
   - Cleaning materials and procedures
   - Emissions from stored supplies or trash
   - Use of deodorizers and fragrances
   - Airborne dust or dirt (e.g., circulated by sweeping and vacuuming)
3. Maintenance activities
   - Microorganisms in mist from improperly maintained cooling towers
   - Airborne dust or dirt
   - Volatile organic compounds from use of paint, caulk, adhesives, and other products
   - Pesticides from pest control activities
   - Emissions from stored supplies

Building Components and Furnishings

1. Locations that produce or collect dust or fibers
   - Textured surfaces such as carpeting, curtains, and other textiles
   - Open shelving
   - Old or deteriorated furnishings
   - Materials containing damaged asbestos

2. Unsanitary conditions and water damage
    - Microbiological growth on or in soiled or water-damaged furnishings
    - Microbiological growth in areas of surface condensation
    - Standing water from clogged or poorly designed drains
    - Dry traps that allow the passage of sewer gas

3. Chemicals released from building components or furnishings
    - Volatile organic compounds or
    - Inorganic compounds

Given our present knowledge, it is difficult to relate complaints of specific health effects to exposures to specific pollutant concentrations, especially since the significant exposures may be to low levels of pollutant mixtures.

Other Sources

1. Accidental events
    - Spills of water or other liquids
    - Microbiological growth due to flooding or to leaks from roofs, piping
    - Fire damage (soot, PCBs from electrical equipment, odors)

2. Special use areas and mixed use buildings
    - Smoking lounges
    - Laboratories
    - Print shops, art rooms
    - Exercise rooms
    - Beauty salons
    - Food preparation areas

3. Redecorating/remodeling/repair activities
    - Emissions from new furnishings
    - Dust and fibers from demolition
    - Odors and volatile organic and inorganic compounds from paint, caulk, adhesives
    - Micro-biological contaminants released from demolition or remodeling activities

Indoor air often contains a variety of contaminants at concentrations that are far below any standards or guidelines for occupational exposure. Given our present knowledge, it is difficult to relate complaints of specific health effects to exposures to specific pollutant concentrations, especially since the significant exposures may be to low levels of pollutant mixtures.

HVAC System Design and Operation

The HVAC system includes all heating, cooling, and ventilation equipment serving a building: furnaces or boilers, chillers, cooling towers, air handling units, exhaust fans, ductwork, filters, and steam piping. Most of the HVAC discussion in this document applies both to central HVAC systems and to individual components used as stand-alone units.

A properly designed and functioning HVAC system:

1. Provides thermal comfort,
2. Distributes adequate amounts of outdoor air to meet ventilation needs of all building occupants, and
3. Isolates and removes odors and contaminants through pressure control, filtration, and exhaust fans.

Thermal Comfort

A number of variables interact to determine whether people are comfortable with the temperature of the indoor air. The activity level, age, and physiology of each person affect the thermal comfort requirements of that individual. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standards describe the temperature and humidity ranges that are comfortable for most people engaged in largely sedentary activities. The ASHRAE standard assumes "normal" indoor clothing. Added layers of clothing reduce the rate of heat loss.

Uniformity of temperature is important to comfort. When the heating and cooling needs of rooms within a single zone change at different rates, rooms that are served by a single thermostat may be at different temperatures. Temperature stratification is a common problem caused by convection, the tendency of light, warm air to rise and heavier, cooler air to sink. If air is not properly mixed by the ventilation system, the temperature near the ceiling can be several degrees warmer than at floor level. Even if air is properly mixed, un-insulated floors over unheated spaces can create discomfort in some climate zones. Large fluctuations of indoor temperature can also occur when controls have a wide "dead band" (a temperature range within which neither heating nor cooling takes place).

Radiant heat transfer may cause people located near very hot or very cold surfaces to be uncomfortable even though the thermostat setting and the measured air temperature are within the comfort range.

Buildings with large window areas sometimes have acute problems of discomfort due to radiant heat gains and losses, with the locations of complaints shifting during the day as the sun angle changes. Large vertical surfaces can also produce a significant flow of naturally-convecting air, producing complaints of draftiness.

A number of variables, including personal activity levels, uniformity of temperature, radiant heat gain or loss, and humidity, interact to determine whether people are comfortable with the temperature of the indoor air.

Adding insulation to walls helps to moderate the temperature of interior wall surfaces. Closing curtains reduces heating from direct sunlight and isolates building occupants from exposure to window surfaces (which, lacking insulation, are likely to be much hotter or colder than the walls).

Humidity is a factor in thermal comfort. Raising relative humidity reduces the ability to lose heat through perspiration and evaporation, so that the effect is similar to raising the temperature. Humidity extremes can also create other indoor air quality problems. Excessively high or low relative humidity can produce discomfort, while high relative humidity can promote the growth of mold and mildew.

Ventilation to Meet Occupant Needs

Most air handling units distribute a blend of outdoor air and re-circulated indoor air. HVAC designs may also include units that introduce 100% outdoor air or that simply transfer air within the building. Uncontrolled quantities of outdoor air enter buildings by infiltration through windows, doors, and gaps in the exterior construction.

Thermal comfort and ventilation needs are met by supplying "conditioned" air (a blend of outdoor and re-circulated air that has been filtered, heated or cooled, and sometimes humidified or dehumidified).

Large buildings often have interior – or core - spaces in which constant cooling is required to compensate for heat generated by occupants, equipment, and lighting, while perimeter rooms may require heating or cooling depending on outdoor conditions.

Two of the most common HVAC designs used in modern public and commercial buildings are *constant volume* and *variable air volume* systems. Constant volume systems are designed to provide a constant airflow and to vary the air temperature to meet heating and cooling needs. The percentage of outdoor air may be held constant, but is often controlled either manually or automatically to vary with outdoor temperature and humidity. Controls may include a minimum setting that should allow the system to meet ventilation guidelines for outdoor air quantities under design conditions.

Variable air volume (VAV) systems condition supply air to a constant temperature and ensure thermal comfort by varying the airflow to occupied spaces. Most early VAV systems did not allow control of the outdoor air quantity, so that a decreasing amount of outdoor air was provided as the flow of supply air was reduced. More recent designs ensure a minimum supply of outdoor air with static pressure devices in the outdoor air stream. Additional energy-conserving features such as economizer control or heat recovery are also found in some buildings.

Good quality design, installation, and testing and balancing are critically important to the proper operation of all types of HVAC systems, especially VAV systems, as are regular inspections and maintenance.

The amount of outdoor air considered adequate for proper ventilation has varied substantially over time and the current guideline issued by ASHRAE maybe different than the building code that was in force when the building HVAC system was designed and may well have established a lower amount of ventilation (in cubic feet of outdoor air per minute per person) than is currently recommended.

Control of Odors and Contaminants

One technique for controlling odors and contaminants is to dilute them with outdoor air. Dilution can work only if there is a consistent and appropriate flow of supply air that mixes effectively with room air. The term *ventilation efficiency* is used to describe the ability of the ventilation system to distribute supply air and remove internally generated pollutants.

Another technique for isolating odors and contaminants is to design and operate the HVAC system so that pressure relationships between rooms are controlled. This control is accomplished by adjusting the air quantities that are supplied to and removed from each room. If more air is supplied to a room than is exhausted, the excess air leaks out of the space and the room is said to be under *positive pressure*. If less air is supplied than is exhausted, air is pulled into the space and the room is said to be under *negative pressure*.

Chases, crawlspaces, and other hidden spaces can be both sources and pathways for pollutants.

Control of pressure relationships is critically important in mixed use buildings or buildings with special use areas. Lobbies and buildings in general are often designed to operate under positive pressure to prevent or minimize the infiltration of unconditioned air, with its potential to cause drafts and introduce dust, dirt, and thermal discomfort. Without proper operation and maintenance, these pressure differences are not likely to remain as originally designed.

A third technique is to use local exhaust systems to isolate and remove contaminants by maintaining negative pressure in the area around the contaminant source. Local exhaust can be linked to the operation of a particular piece of equipment (such as a kitchen range) or used to treat an entire room (such as a smoking lounge or custodial closet). Air should be exhausted to the outdoors, not re-circulated, from locations which produce significant odors and high concentrations of contaminants (such as copy rooms, bathrooms, kitchens, and beauty salons).

Spaces where local exhaust is used must be provided with make-up air and the local exhaust must function in coordination with the rest of the ventilation system. Under some circumstances, it may be acceptable to transfer conditioned air from relatively clean parts of a building to comparatively dirty areas and use it as make-up air for a local exhaust system. Such a transfer can achieve significant energy savings.

Air cleaning and filtration devices designed to control contaminants are found as components of HVAC systems (for example, filter boxes in ductwork) and can also be installed as independent units. The effectiveness of air cleaning depends upon proper equipment selection, installation, operation, and maintenance. Caution should be used in evaluating the many new technological developments in the field of air cleaning and filtration.

Pollutant Pathways

Airflow patterns in buildings result from the combined action of mechanical ventilation systems, human activity, and natural forces. Pressure differentials created by these forces move airborne contaminants from areas of relatively higher pressure to areas of relatively lower pressure through any available openings.

The HVAC system is generally the predominant pathway and driving force for air movement in buildings. However, all of a building's components (walls, ceilings, floors, penetrations, HVAC equipment, and occupants) interact to affect the distribution of contaminants.

For example, as air moves from supply registers or diffusers to return air grilles, it is diverted or obstructed by partitions, walls, and furnishings, and redirected by openings that provide pathways for air movement. On a localized basis, the movement of people has a major impact on the movement of pollutants. Some of the pathways change as doors and windows open and close. It is useful to think of the entire building — the rooms and the connections between them — as part of the air distribution system. Natural forces exert an important influence on air movement between zones and between the building interior and exterior. Both the *stack effect* and wind can overpower a building's mechanical system and disrupt air circulation and ventilation, especially if the building envelope is leaky.

Stack effect is the pressure driven flow produced by convection (the tendency of warm air to rise). The stack effect exists whenever there is an indoor-outdoor temperature difference and becomes stronger as the temperature difference increases. As heated air escapes from upper levels of the building, indoor air moves from lower to upper floors, and replacement outdoor air is drawn into openings at the lower levels of buildings. Stack effect airflow can transport contaminants between floors by way of stairwells, elevator shafts, utility chases, or other openings.

Wind effects are transient, creating local areas of high pressure (on the windward side) and low pressure (on the leeward side) of buildings. Depending on the leakage openings in the building exterior, wind can affect the pressure relationships within and between rooms.

The basic principle of air movement from areas of relatively higher pressure to areas of relatively lower pressure can produce many patterns of contaminant distribution, including:

- Local circulation in the room containing the pollutant source
- Air movement into adjacent spaces that are under lower pressure (*note*: even if two rooms are both under positive pressure compared to the outdoors, one room is usually at a lower pressure than the other.)
- Recirculation of air within the zone containing the pollutant source or in adjacent zones where return systems overlap
- Movement from lower to upper levels of the building
- Air movement into the building through either infiltration of outdoor air or reentry of exhaust air

Air moves from areas of higher pressure to areas of lower pressure through any available openings. A small crack or hole can admit significant amounts of air if the pressure differentials are high enough.

Even when the building as a whole is maintained under positive pressure, there is always some location (for example, the outdoor air intake) that is under negative pressure relative to the outdoors. Entry of contaminants may be intermittent, occurring only when the wind blows from the direction of the pollutant source. The interaction between pollutant pathways and intermittent or variable driving forces can lead to a single source causing indoor air quality complaints in areas of the building that are distant from each other and from the source.

Building Occupants

The term "building occupants" is generally used in this course to describe people who spend extended time periods in the building. Clients and visitors are also occupants; they may have different tolerances and expectations from those who spend their entire workdays in the building, and are likely to be more sensitive to odors.

Groups that may be particularly susceptible to effects of indoor air contaminants include, but are not limited to:

- Allergic or asthmatic individuals
- People with respiratory disease
- People whose immune systems are suppressed due to chemotherapy, radiation therapy, disease, or other causes
- Contact lens wearers

Some other groups are particularly vulnerable to exposures of certain pollutants or pollutant mixtures. For example, people with heart disease may be more affected by exposure at lower levels of carbon monoxide than healthy individuals. Children exposed to environmental tobacco smoke have been shown to be at higher risk of respiratory illnesses and those exposed to nitrogen dioxide have been shown to be at higher risk from respiratory infections.

The basic principle of air movement from areas of relatively higher pressure to areas of relatively lower pressure can produce many patterns of contaminant distribution.

Because of varying sensitivity among people, one individual may react to a particular indoor air quality problem while surrounding occupants have no ill effects. (Symptoms that are limited to a single person can also occur when only one work station receives the bulk of the pollutant dose.) In other cases, complaints may be widespread.

A single indoor air pollutant or problem can trigger different reactions in different people. Some may not be affected at all. Information about the types of symptoms can sometimes lead directly to solutions. However, symptom information is more likely to be useful for identifying the timing and conditions under which problems occur.

Types of Symptoms and Complaints

The effects of indoor air quality problems are often nonspecific symptoms rather than clearly defined illnesses. Symptoms commonly attributed to indoor air quality problems include:

- Headache
- Fatigue
- Shortness of breath
- Sinus congestion
- Cough
- Sneezing
- Eye, nose, and throat irritation
- Skin irritation
- Dizziness
- Nausea

All of these symptoms, however, may also be caused by other factors, and are not necessarily due to air quality deficiencies. "Health" and "comfort" are used to describe a spectrum of physical sensations. For example, when the air in a room is slightly too warm for a person's activity level, that person may experience mild discomfort. If the temperature continues to rise, discomfort increases and symptoms such as fatigue, stuffiness, and headaches can appear.

Environmental stressors such as improper lighting, noise, vibration, overcrowding, ergonomic stressors, and job-related psychosocial problems can produce symptoms that are similar to those associated with poor air quality.

Some complaints by building occupants are clearly related to the discomfort end of the spectrum. One of the most common indoor air quality complaints is that "there's a funny smell in here." Odors are often associated with a perception of poor air quality, whether or not they cause symptoms. Environmental stressors such as improper lighting, noise, vibration, overcrowding, ergonomic stressors, and job-related psychosocial problems (such as job stress) can produce symptoms that are similar to those associated with poor air quality.

The term *sick building syndrome (SBS)* is sometimes used to describe cases in which building occupants experience acute health and comfort effects that are apparently linked to the time they spend in the building, but in which no specific illness or cause can be identified. The complaints may be localized in a particular room or zone or may be widespread throughout the building. Many different symptoms have been associated with SBS, including respiratory complaints, irritation, and fatigue. Analysis of air samples often fails to detect high concentrations of specific contaminants. The problem may be caused by any or all of the following:

- The combined effects of multiple pollutants at low concentrations
- Other environmental stressors (e.g., overheating, poor lighting, noise)
- Ergonomic stressors

- Job-related psychosocial stressors (e.g., overcrowding, labor-management problems)
- Unknown factors

Building-related illness (BRI) is a term referring to illness brought on by exposure to the building air, where symptoms of diagnosable illness are identified (e.g., certain allergies or infections) and can be directly attributed to environmental agents in the air. Legionnaire's disease and hypersensitivity pneumonitis are examples of BRI that can have serious, even life threatening consequences.

A small percentage of the population may be sensitive to a number of chemicals in indoor air, each of which may occur at very low concentrations. The existence of this condition, which is known as *multiple chemical sensitivity (MCS)*, is a matter of considerable controversy. MCS is not currently recognized by the major medical organizations, but medical opinion is divided, and further research is needed.

The applicability of access for the disabled and worker's compensation regulations to people who believe they are chemically sensitive may become concerns for facility managers.

Sometimes several building occupants experience rare or serious health problems (e.g., cancer, miscarriages, Lou Gehrig's disease) over a relatively short time period. These clusters of health problems are occasionally blamed on indoor air quality, and can produce tremendous anxiety among building occupants. State or local Health Departments can provide advice and assistance if clusters are suspected. They may be able to help answer key questions such as whether the apparent cluster is actually unusual and whether the underlying cause could be related to indoor air quality.

These are just a few of the factors affecting indoor air quality. In the next chapter we will discuss techniques for measuring and quantifying air quality.

Chapter 2
Indoor Air Quality Measurements

The following is a brief introduction to making measurements that might be needed in the course of investigating an indoor air quality complaint. Emphasis has been placed on the parameters most commonly of interest in non-research studies, highlighting the more practical methods. Most of the instruments discussed in this section are relatively inexpensive and readily available.

Overview of Sampling Devices

Air contaminants of concern in indoor air quality can be measured by one or more of the following methods:

Vacuum Pump

A vacuum pump with a known airflow rate draws air through collection devices, such as a *filter* (catches airborne particles), a *sorbent tube* (which attracts certain chemical vapors to a powder such as carbon), or an *impinger* (bubbles the contaminants through solution in a test tube). In some cases, test equipment that originated for industrial environments typically need to be adjusted to a lower detection limit for commercial building applications.

In adapting an industrial hygiene sorbent tube sampling method for indoor air quality, the investigator must consider at least two important questions. First: are the emissions to be measured from a product's end use the same as those of concern during manufacturing? Second: is it necessary to increase the air volume sampled? Such an increase may be needed to detect the presence of contaminants at the low concentrations usually found in non-industrial settings. For example, an investigator might have to increase sampling time from 30 minutes to five hours in order to detect a substance at the low concentrations found during indoor air quality investigations in commercial buildings. In cases where standard sampling methods are changed, qualified industrial hygienists and chemists should be consulted to ensure that accuracy and precision remain acceptable.

Direct-reading Meter

Direct-reading meters estimate air concentrations through one of several detection principles. These may report specific chemicals (e.g., CO_2 by infrared light), chemical groups (e.g., certain volatile organics by photo-ionization potential) or broad pollutant categories (e.g., all respirable particles by scattered light). Detection limits and averaging time developed for industrial use may or may not be appropriate for indoor air quality.

Detector tube kit

Detector tube kits generally include a hand pump that draws a known volume of air through a chemically treated tube intended to react with certain contaminants. The length of color stain resulting in the tube correlates to chemical concentration.

Personal monitoring devices

Personal monitoring devices (sometimes referred to as "dosimeters") are carried or worn by individuals and are used to measure that individual's exposure to particular chemical(s). Devices that include a pump are called "active" monitors; devices that do not include a pump are called "passive" monitors. Such devices are currently used for research purposes. It is possible that sometime in the future they may also be helpful in indoor air quality investigations in public and commercial buildings.

Simple Ventilation/Comfort Indications

Thermal Comfort: Temperature and Relative Humidity

The sense of thermal comfort (or discomfort) results from an interaction between temperature, relative humidity, air movement, clothing, activity level, and individual physiology. Temperature and relative humidity measurements are indicators of thermal comfort.

Measurements can be made with a simple thermometer and sling psychrometer or with electronic sensors (e.g., a thermo-hygrometer). Accuracy of within +/- 1°F is recommended for temperature measurements.

Indoor relative humidity is influenced by outdoor conditions. A single indoor measurement may not be a good indication of long-term relative humidity in the building. Programmable recording sensors can be used to gain an understanding of temperature or humidity conditions as they change over time.

Temperature and humidity directly affect thermal comfort. They may also provide indirect indications of HVAC condition and the potential for airborne contamination from biological or organic compounds. The humidity levels recommended by different organizations generally range between 30% and 60% RH. Comparison of indoor and outdoor temperature and humidity readings taken during complaint periods can indicate whether thermal discomfort might be due to extreme conditions beyond the design capacity of HVAC equipment or the building envelope.

Readings that show large variations within the space may indicate a room air distribution or mixing problem. Readings that are highly variable over time may indicate control or balance problems with the HVAC systems.

Tracking Air Movement with Chemical Smoke

Chemical smoke can be helpful in evaluating HVAC systems, tracking potential contaminant movement, and identifying pressure differentials. Chemical smoke moves from areas of higher pressure to areas of lower pressure if there is an opening between them (e.g., door, utility penetration). Because it is heatless, chemical smoke is extremely sensitive to air currents. Investigators can learn about airflow patterns by observing the direction and speed of smoke movement. Puffs of smoke released at the shell of the building (by doors, windows, or gaps) will indicate whether the HVAC systems are maintaining interior spaces under positive pressure relative to the outdoors.

Chemical smoke is available with various dispensing mechanisms, including smoke “bottles,” “guns,” “pencils,” or “tubes.” The dispensers allow smoke to be released in controlled quantities and directed at specific locations.

Observation of a few puffs of smoke released in mudroom or mid-cubicle can help to visualize air circulation within the space. Dispersal of smoke in several seconds suggests good air circulation, while smoke that stays essentially still for several seconds suggests poor circulation. Poor air circulation may contribute to sick building syndrome complaints or may contribute to comfort complaints even if there is sufficient overall air exchange.

Puffs of smoke released by HVAC vents give a general idea of airflow. This is helpful in evaluating the supply and return system and determining whether ventilation air actually reaches the breathing zone. “Short-circuiting” occurs when air moves relatively directly from supply diffusers to return grilles, instead of mixing with room air in the breathing zone. When a substantial amount of air short-circuits, occupants may not receive adequate supplies of outdoor air and source emissions may not be diluted sufficiently.

Carbon Dioxide (CO_2) as an Indicator of Ventilation

CO_2 is a normal constituent of the atmosphere. Exhaled breath from building occupants is an important indoor CO_2 source. Indoor CO_2 concentrations can, under some test conditions, provide a good indication of the adequacy of ventilation. Comparison of peak CO_2 readings between rooms, between air handler zones, and at varying heights above the floor, may help to identify and diagnose various building ventilation deficiencies.

CO_2 can be measured with either a direct reading meter or a detector tube kit. The relative occupancy, air damper settings, and weather should be noted for each period of CO2 testing. CO_2 measurements for ventilation should be collected away from any source that could directly influence the reading (e.g., hold the sampling device away from exhaled breath). Individual measurements should be short-term. As with many other measurements of indoor air conditions, it is advisable to take one or more readings in "control" locations to serve as baselines for comparison. Readings from outdoors and from areas in which there are no apparent indoor air quality problems are frequently used as controls. Outdoor samples should be taken near the outdoor air intake. Measurements taken to evaluate the adequacy of ventilation should be made when concentrations are expected to peak. It may be helpful to compare measurements taken at different times of day. If the occupant population is fairly stable during normal business hours, CO_2 levels will typically rise during the morning, fall during the lunch period, and then rise again, reaching a peak in mid-afternoon. In this case, sampling in the mid- to late-afternoon is recommended. Other sampling times may be necessary for different occupancy schedules.

Peak CO_2 concentrations above 1,000 ppm in the breathing zone indicate ventilation problems. Carbon dioxide concentrations below 1,000 ppm generally indicate that ventilation is adequate to deal with the routine products of human occupancy. However, there are several reasons not to conclude too quickly that a low CO_2 reading means no indoor air quality problem exists. Problems can occur in buildings in which measured CO_2 concentrations are below 1,000 ppm. Although CO_2 readings indicate good ventilation, for example, if strong contaminant sources are present, some sort of source control may be needed to prevent indoor air quality problems. Errors in measurement and varying CO_2 concentrations over time can also cause low readings that may be misleading.

Elevated CO_2 may be due to various causes alone or in combination, such as: increased occupant population, low air exchange rates, poor air distribution, and poor air mixing. A higher average CO_2 concentration in the general breathing zone than in the air entering return grilles is an indication of poor air mixing.

If CO_2 measurements taken before the occupied period begins are higher than outdoor readings taken at the same time, there may be an operating problem with the HVAC system. Potential problems include the following:

- Ventilation terminated too early the evening before (as compared with the occupancy load on the space)

- Combustion by-products from a nearby roadway or parking garage are drawn into the building
- A gas-fired heating appliance in the building has a cracked heat exchanger

Outdoor CO_2 concentrations above 400 ppm may indicate an outdoor contamination problem from traffic or other combustion sources. Note, however, that detector tubes cannot provide accurate measurements of CO_2 in hot or cold weather.

Measurements of airflow allow investigators to estimate the amount of outdoor air that is entering the building and to evaluate HVAC system operation. The most appropriate measurement technique depends on the characteristics of the measurement location.

Airflow quantities can be calculated by measuring the velocity and cross-sectional area of the airstream. For example, if air is moving at 100 feet per minute in a 24" x 12" duct, the airflow is:

100 feet/minute x 2 square feet duct area = 200 cubic feet/minute

Air velocity can be measured with a pitot tube or anemometer. Air velocity within an airstream is likely to vary considerably. For example, it is extremely difficult to measure air velocity at supply diffusers because of turbulence around the mixing vanes. The best estimates of air velocity can be achieved by averaging the results of a number of measurements. The cross-sectional area of the airstream is sometimes easy to calculate, but can be very complicated at other locations such as mixing boxes or diffusers.

Flow hoods can be used for direct measurement of airflows at locations such as grilles, diffusers, and exhaust outlets. They are not designed for use in ductwork.

Airflow measurements can be used to determine whether the HVAC system is operating according to design and to identify potential problem locations. Building investigations often include measurements of outdoor air quantities, exhaust air quantities and airflows at supply diffusers and return grilles.

Estimating Outdoor Air Quantities

Outdoor air quantities can be evaluated by measuring airflow directly. Investigators often estimate the proportion of outdoor air quantities using techniques such as thermal mass balance (temperature) or CO_2 measurements. Estimation of outdoor air quantity using temperature measurements is referred to as "thermal balance" or sometimes "thermal mass balance."

The *Thermal Balance* methodology requires the following conditions:

1. Airstreams representing return air, outdoor air, and mixed air (supply air before it has been heated or cooled) are accessible for separate measurement. Some systems are already equipped with an averaging thermometer that is strung diagonally across the mixed air chamber; the temperature is read out continuously on an instrument panel. Some panels read out supply, return, outdoor, and/or mixed air temperature.

2. There is at least a several degree temperature difference between the building interior and the outdoor air.

3. Total air flow in the air handling system can be estimated either by using recent balancing reports or pitot tube measurements in ductwork. As an alternative, the supply air at each diffuser can be estimated (e.g., using a flow measuring hood), and the results can be summed to calculate total system air flow.

Temperature measurements can be made with a simple thermometer or an electronic sensor. Several measurements should be taken across each airstream and averaged.

It is generally easy to obtain a good temperature reading in the outdoor air and return airstreams. To obtain a good average temperature reading of the mixed airstream, a large number of measurements must be taken upstream of the point at which the airstream is heated or cooled. This may be difficult or impossible in some systems. The percentage or quantity of outdoor air is calculated using thermal measurements as shown to the right.

The *thermal mass balance* methodology involves carbon dioxide measurements. The CO_2 readings can be taken at supply outlets or air handlers to estimate the percentage of outdoor air in the supply airstream. The percentage or quantity of outdoor air is calculated using CO_2 measurements as shown to the right.

The results of this calculation can be compared to the building design specifications and applicable building codes.

Air Contaminant Concentrations

Air contaminants include volatile organic compounds, formaldehyde, biological contaminants, airborne dust, combustion products, and other inorganic gases.

Volatile Organic Compounds (VOCs)

Hundreds of organic chemicals are found in indoor air at trace levels. VOCs may present an indoor air quality problem when individual organics or mixtures exceed normal background concentrations.

Several direct-reading instruments are available that provide a low sensitivity “total” reading for different types of organics. Such estimates are usually presented in parts per million and are calculated with the assumption that all chemicals detected are the same as the one used to calibrate the instrument. A photo-ionization detector is an example of a direct-reading instrument used as a screening tool for measuring total voltaic organic compounds.

A laboratory analysis of a sorbent tube can provide an estimate of total solvents in the air. Although methods in this category report *total volatile organic compounds* (TVOCs) or *total hydrocarbons* (THC), analytical techniques differ in their sensitivity to the different types of organics.

Different measurement methods are useful for different purposes, but their results should generally not be compared to each other. Direct-reading instruments do not provide sufficient sensitivity to differentiate normal from problematic mixtures of organics. However, instantaneous readouts may help to identify “hot spots,” sources, and pathways. TVOCs or THC determined from sorbent tubes provide more accurate average readings, but are unable to distinguish peak exposures. A direct reading instrument can identify peak exposures if they happen to occur during the measurement period.

High concentrations of individual volatile organic compounds (VOCs) may also cause indoor air quality problems. Individual VOCs can be measured in indoor air with a moderate degree of sensitivity through adaptations of existing industrial air monitoring technology. Examples of medium sensitivity testing devices include sorbent tubes (for nicotine), charcoal tubes (for solvents), and chromosorb tubes (for pesticides). After a sufficient volume of air is pumped through these tubes, they are sent to a lab for extraction and analysis by gas chromatography. Variations use a passive dosimeter to collect the sample or a portable gas chromatograph onsite for direct injection of building air. These methods may not be sensitive enough to detect many trace level organics present in building air.

High sensitivity techniques have recently become available to measure “trace organics” — VOCs in the air (i.e. measurements in parts per billion.) Analysis involves gas chromatography followed by mass spectroscopy.

Measurement of trace organics may identify the presence of dozens to hundreds of trace VOCs whose significance is difficult to determine. It may be helpful to compare levels in complaint areas to levels in outdoor air or non-complaint areas.

Formaldehyde

Small amounts of formaldehyde are present in most indoor environments. Itching of the eyes, nose, or throat may indicate an elevated concentration. Sampling may be helpful when relatively new suspect materials are present.

A number of measurement methods are available. Sensitivity and sampling time are very important issues in selecting a method; however, many methods allow detection of concentrations well below 0.1 ppm. Measurement of short-term peaks is ideal for evaluating acute irritation. Dosimeters may accurately record long-term exposure but may miss these peaks. Two commonly used methods that are generally acceptable for indoor air quality screening involve impingers and sorbent tubes.

Various guidelines and standards are available for formaldehyde exposure. Several organizations have adopted 0.1 ppm as guidance that provides reasonable protection against irritational effects in the normal population. Hypersensitivity reactions may occur at lower levels of exposure. Worst-case conditions are created by minimum ventilation, maximum temperatures, and high source loadings.

Biological Contaminants

Human health can be affected by exposure to both living and non-living biological contaminants. The term "bio-aerosols" describes airborne material that is or was living, such as mold and bacteria, parts of living organisms (e.g., insect body parts), and animal feces.

Testing for biological contaminants should generally be limited to:

- Cases where a walkthrough investigation or human profile study suggests microbiological involvement
- Cases in which no other pollutant or physical condition can account for symptoms

Inspection of building sanitary conditions is generally preferred over sampling, because direct sampling can produce misleading results. Any sampling should be accompanied by observations of sanitary conditions and a determination as to whether any health problems appear likely to be related to biological contamination. No single technique is effective for sampling the many biological contaminants found in indoor environments. A variety of specific approaches are used to retrieve, enumerate, and identify each kind of microorganism from water, surfaces, and air. Other specific methods are used for materials such as feces or insect parts. The utility of these techniques depends upon their use by professionals who have a thorough understanding of the sample site and the target organism.

Where air sampling is desired, several approaches are available. The most common type of air sampler uses a pump to pull air across a nutrient *agar*, which is then incubated. Any bacterial or fungal colonies that subsequently grow can be counted and identified by a qualified microbiologist. Different types of agar and incubation temperatures are used to culture different types of organisms. Only living organisms or spores in the air are counted by this method. Settling plates, which are simply opened to room air and then incubated, are sometimes used to identify which bio-aerosols are present in different locations. The drawbacks to this technique are that it does not indicate the quantity of bio-aerosols present and that only the bio-aerosols that are heavy enough to fall out onto the agar will be recorded.

> ***Agar*** is a gelatinous substance obtained from various kinds of red algae and used in biological culture media.

Quantities and types of bio-aerosols can vary greatly over time in any given building, making sampling results difficult to interpret. Comparison of relative numbers and types between indoors and outdoors or between complaint areas and background sites can help to establish trends; however, no tolerance levels or absolute guidelines have been established. Low bio-aerosol results by themselves are not considered proof that a problem does not exist, for a variety of reasons:

- The sampling and identification techniques used may not be suited to the type(s) of bio-aerosols that are present
- Biological growth may have been inactive during the sampling period
- The analysis technique used may not reveal non-living bio-aerosols (e.g., feces, animal parts) that can cause health reactions

Airborne Dust

Particles and fibers suspended in the air generally represent a harmless background but can become a nuisance or cause serious health problems under some conditions.

A variety of collection and analytical techniques are available. Dust can be collected by using a pump to draw air through a filter. The filter can then be weighed (gravimetric analysis) or examined under a microscope. Direct readouts of airborne dust are also available (such as using meters such as those equipped with a "scattered light" detector).

Indoor air quality measurements for airborne dust will be well below occupational and ambient air guidelines except under the most extreme conditions. Unusual types or elevated amounts of particles or fibers can help identify potential exposure problems.

Combustion Products

Combustion products are released by motor vehicle exhaust, tobacco smoke, and other sources, and contain airborne dust along with potentially harmful gases such as carbon monoxide and nitrogen oxides.

Direct-reading meters, detector tubes, and passive dosimeters are among the techniques most commonly used to measure carbon monoxide and nitrogen oxides.

Comparison with occupational standards will reveal only whether an imminent danger exists. Any readings that are elevated above outdoor concentrations or background building levels may indicate a mixture of potentially irritating combustion products, especially if susceptible individuals are exposed.

Other Inorganic Gases

Although they are not routinely sampled in most indoor air quality studies, a variety of other gases may be evaluated where conditions warrant. Examples might include ammonia, ozone, and mercury.

ASTM references should be consulted for specific sampling techniques. Detector tubes or impinge methods are applicable in some cases. No generalization can be applied to this diverse group of substances.

Chapter 3
HVAC Systems

This chapter provides information about specific HVAC system designs and components in relation to indoor air quality. It also serves as introductory material of the terminology and concepts associated with HVAC (heating, ventilating, and air conditioning) system design. Further detailed information can be found in ASHRAE manuals and guides.

All occupied buildings require a supply of outdoor air. Depending on outdoor conditions, the air may need to be heated or cooled before it is distributed into the occupied space. As outdoor air is drawn into the building, indoor air is exhausted or allowed to escape, thus removing air contaminants.

The term *HVAC system* is used to refer to the equipment that can provide heating, cooling, filtered outdoor air, and humidity control to maintain comfort conditions in a building. Not all HVAC systems are designed to accomplish all of these functions. Some buildings rely on only natural ventilation. Others lack mechanical cooling equipment, and many function with little or no humidity control. The features of the HVAC system in a given building will depend on several variables, including:

- Age of the design
- Climate
- Building codes in effect at the time of the design
- Budget that was available for the project
- Planned use of the building
- Owners' and designers' individual preferences
- Subsequent modifications

HVAC systems range in complexity from stand-alone units that serve individual rooms to large, centrally controlled systems serving multiple zones in a building. In large modern office buildings with heat gains from lighting, people, and equipment, interior spaces often require year-round cooling. Rooms at the perimeter of the same building may need to be heated and/or cooled as hourly or daily outdoor weather conditions change. In buildings over one story in height, perimeter areas at the lower levels also tend to experience the greatest uncontrolled air infiltration.

Some buildings use only natural ventilation or exhaust fans to remove odors and contaminants. In these buildings, thermal discomfort and unacceptable indoor air quality are particularly likely when occupants keep the windows closed because of extreme hot or cold temperatures.

Problems related to under-ventilation are also likely when infiltration forces are weakest, such as during the “swing seasons” and summer months. Modern public and commercial buildings generally use mechanical ventilation systems to introduce outdoor air during the occupied mode. Thermal comfort is commonly maintained by mechanically distributing conditioned air throughout the building. In some designs, air systems are supplemented by piping systems that carry steam or water to the building perimeter zones. As this document is concerned with HVAC systems in relation to indoor air quality, the remainder of this discussion will focus on systems that distribute conditioned air to maintain occupant comfort.

Type of HVAC Systems

Single Zone

A single air handling unit can only serve more than one building area if the areas served have similar heating, cooling, and ventilation requirements, or if the control system compensates for differences in heating, cooling, and ventilation needs among the spaces served. Areas regulated by a single thermostat are referred to as zones. Thermal comfort problems can result if the design does not adequately account for differences in heating and cooling loads between rooms that are in the same zone. This can easily occur if:

- The cooling load in some areas within a zone changes due to an increased occupant population, increased lighting, or the introduction of new heat-producing equipment.
- Areas within a zone have different solar exposures. This can produce radiant heat gains and losses that, in turn, create unevenly distributed heating or cooling needs.

Multiple Zone Systems

Multiple zone systems can provide each zone with air at a different temperature by heating or cooling the airstream in each zone. Alternative design strategies involve delivering air at a constant temperature while varying the volume of airflow, or modulating room temperature with a supplementary system (e.g., perimeter hot water piping).

Constant Volume

Constant volume systems, as their name suggests, generally deliver a constant airflow to each space. Changes in space temperatures are made by heating or cooling the air or switching the air handling unit on and off, not by modulating the volume of air supplied. These systems often operate with a fixed minimum percentage of outdoor air or with an “air economizer” feature.

Variable Air Volume

Variable air volume systems maintain thermal comfort by varying the amount of heated or cooled air delivered to each space, rather than by changing the air temperature. (However, many VAV systems also have provisions for resetting the temperature of the delivery air on a seasonal basis, depending on the severity of the weather). Overcooling or overheating can occur within a given zone if the system is not adjusted to respond to the load. Under-ventilation frequently occurs if the system is not arranged to introduce at least a minimum quantity of outdoor air as the VAV system throttles back from full airflow, or if the system supply air temperature is set too low for the loads present in the zone.

Basic Components of an HVAC System

The basic components of an HVAC system that delivers conditioned air to maintain thermal comfort and indoor air quality are:

- Outdoor air intake
- Mixed-air plenum and outdoor air control
- Air filter
- Heating and cooling coils
- Humidification and/or de-humidification equipment
- Supply fan
- Ducts
- Terminal device
- Return air system
- Exhaust or relief fans and air outlet
- Self-contained heating or cooling unit
- Control
- Boiler
- Cooling tower
- Water chiller

Figure 1 below shows the general relationship between many of these components; however, many variations are possible.

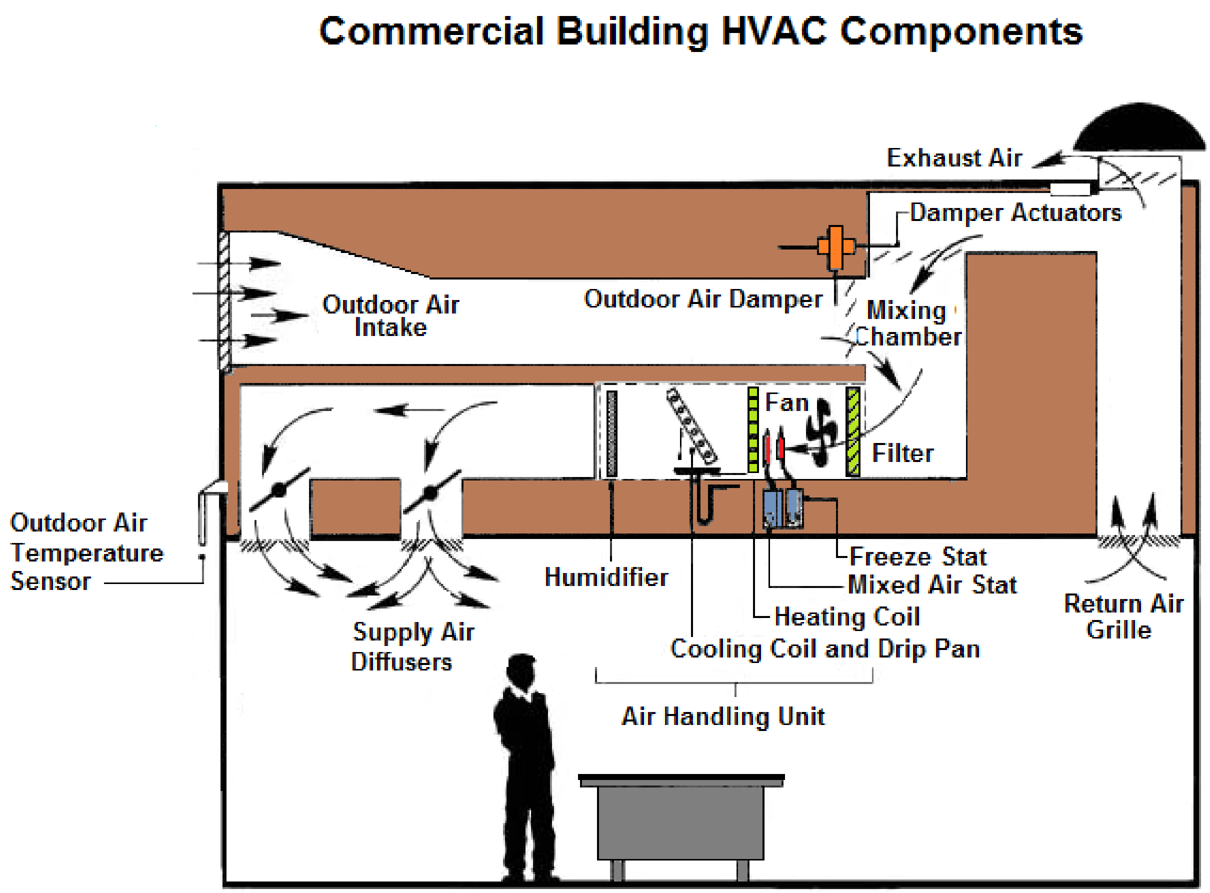


Figure 1

The information on the following page is a brief discussion of testing and balancing for HVAC systems.

TESTING AND BALANCING

HVAC systems typically use sophisticated, automatic controls to supply the proper amounts of air for heating, cooling, and ventilation in commercial buildings. Problems during installation, operation, maintenance, and servicing the HVAC system could prevent it from operating as designed. Each system should be tested to ensure its initial and continued performance. In addition to providing acceptable thermal conditions and ventilation air, a properly adjusted and balanced system can also reduce operating costs and increase equipment life.

Testing and balancing involves the testing, adjusting, and balancing of HVAC system components so that the entire system provides airflows that are in accordance with the design specifications. Typical components and system parameters tested include:

- All supply, return, exhaust, and outdoor airflow rates
- Control settings and operation
- Air temperatures
- Fan speeds and power consumption
- Filter or collector resistance

The typical test and balance contractor coordinates with the control contractor to accomplish three goals: verify and ensure the most effective system operation within the design specifications, identify and correct any problems, and ensure the safety of the system.

A test and balance report should provide a complete record of the design, preliminary measurements, and final test data. The report should include any discrepancies between the test data and the design specifications, along with reasons for those discrepancies. To facilitate future performance checks and adjustments, appropriate records should be kept on all damper positions, equipment capacities, control types and locations, control settings and operating logic, airflow rates, static pressures, fan speeds, and horsepower's.

Testing and balancing of existing building systems should be performed whenever there is reason to believe the system is not functioning as designed or when current records do not accurately reflect the actual operation of the system. The Associated Air Balance Council recommends the following guidelines in determining whether testing and balancing is required:

- When space has been renovated or changed to provide for new occupancy.
- When HVAC equipment has been replaced or modified.
- When control settings have been readjusted by maintenance or other personnel.
- After the air conveyance system has been cleaned.
- When accurate records are required to conduct an indoor air quality investigation.
- When the building owner is unable to obtain design documents or appropriate air exchange rates for compliance with indoor air quality standards or guidelines.

Because of the diversity of system types and the interrelationship of system components, effective balancing requires a skilled technician with the proper experience and instruments. Due to the nature of the work, which involves the detection and remediation of problems, it is recommended that an independent test and balance contractor be used.

Outdoor Air Intake

Building codes require the introduction of outdoor air for ventilation in most buildings. Most non-residential air handlers are designed with an outdoor air intake on the return side of the ductwork. Outdoor air introduced through the air handler can be filtered and conditioned before distribution. Other designs may introduce outdoor air through air-to-air heat exchangers and operable windows.

Indoor air quality problems can be produced when contaminants enter a building with the outdoor air. Rooftop or wall-mounted air intakes are sometimes located adjacent to or downwind of building exhaust outlets or other contaminant sources. Problems can also result if debris (e.g., bird droppings) accumulates at the intake, obstructing airflow and potentially introducing microbiological contaminants.

If more air is exhausted than is introduced through the outdoor air intake, then outdoor air will enter the building at any leakage sites in the shell. Indoor air quality problems can occur if the leakage site is a door to a loading dock, parking garage, or some other area associated with pollutants.

Mixed-Air Plenum and Outdoor Air Controls

Outdoor air is mixed with return air in the mixed-air plenum of an air handling unit. Indoor air quality problems frequently result if the outdoor air damper is not operating properly (e.g., if the system is not designed or adjusted to allow the introduction of sufficient outdoor air for the current use of the building. The amount of outdoor air introduced in the occupied mode should be sufficient to meet needs for ventilation and exhaust make-up. It may be fixed at a constant volume or may vary with the outdoor temperature.

When dampers that regulate the flow of outdoor air are arranged to modulate, they are usually designed to bring in a minimum amount of outdoor air (in the occupied mode) under extreme outdoor temperature conditions and to open as outdoor temperatures approach the desired indoor temperature. Systems that use outdoor air for cooling are called *air economizer cooling* systems. Air economizer systems have a mixed air temperature controller and thermostat that are used to blend return air (typically at 74°F) with outdoor air to reach a mixed air temperature of 55° to 65°F.

The mixed air is then further heated or cooled for delivery to the occupied spaces. Air economizer systems have a *sensible control* that signals the outdoor air damper to go to the minimum position when it is too warm or humid outdoors. Note that economizer cycles which do not provide dehumidification may produce discomfort even when the indoor temperature is the same as the thermostat setting. If outdoor air make-up and exhaust are balanced, and the zones served by each air handler are separated and well defined, it is possible to estimate the minimum flow of outdoor air to each space and compare it to ASHRAE ventilation standards. Techniques used for this evaluation include the direct measurement of the outdoor air at the intake and the calculation of the percentage of outdoor air by a temperature or CO_2 balance. Carbon dioxide measured in an occupied space is also an indicator of ventilation adequacy.

Some investigators use tracer gases to assess ventilation quantities and airflow patterns. There are specific methods for each of these assessments.

Many HVAC designs protect the coils by closing the outdoor air damper if the airstream temperature falls below the set point of a freeze-stat. Inadequate ventilation can occur if a freeze-stat trips and is not reset, or if the freeze-stat is set to trip at an excessively high temperature. Stratification of the cold outdoor air and warmer return air in the mixing plenums is a common situation, causing nuisance tripping of the freeze-stat. Unfortunately, the remedy often employed to prevent this problem is to close the outdoor air damper. Obviously, solving the problem in this way can quickly lead to inadequate outdoor air in occupied parts of the building.

Air Filters

Filters are primarily used to remove particles from the air. The type and design of filter determine the efficiency at removing particles of a given size and the amount of energy needed to pull or push air through the filter. Filters are rated by different standards and test methods such as *dust spot* and *arrestance* which measure different aspects of performance.

Low efficiency filters (ASHRAE Dust Spot rating of 10% to 20% or less) are often used to keep lint and dust from clogging the heating and cooling coils of a system. In order to maintain clean air in occupied spaces, filters must also remove bacteria, pollens, insects, soot, dust, and dirt with an efficiency suited to the use of the building. Medium efficiency filters (ASHRAE Dust Spot rating of 30% to 60%) can provide much better filtration than low efficiency filters.

To maintain the proper airflow and minimize the amount of additional energy required to move air through these higher efficiency filters, pleated-type extended surface filters are recommended. In buildings that are designed to be exceptionally clean, the designers may specify the equipment to utilize both a medium efficiency pre-filter and a high efficiency extended surface filter (ASHRAE Dust Spot rating of 85% to 95%). Some manufacturers recommend high efficiency *extended surface filters* (ASHRAE Dust Spot rating of 85%)

without pre-filters as the most cost effective approach to minimizing energy consumption and maximizing air quality in modern VAV systems that serve office environments.

Air filters, whatever their design or efficiency rating, require regular maintenance (cleaning for some and replacement for most). As a filter loads up with particles, it becomes more efficient at particle removal but increases the pressure drop through the system, therefore reducing airflow. Filter manufacturers can provide information on the pressure drop through their products under different conditions. Low efficiency filters, if loaded to excess, will become deformed and even “blow out” of their filter rack.

When filters blow out, bypassing of unfiltered air can lead to clogged coils and dirty ducts. Filtration efficiency can be seriously reduced if the filter cells are not properly sealed to prevent air from bypassing.

Filters should be selected for their ability to protect both the HVAC system components and general indoor air quality. In many buildings, the best choice is a medium efficiency, pleated filter because these filters have a higher removal efficiency than low efficiency filters, yet they will last without clogging for longer than high efficiency filters.

Choice of an appropriate filter and proper maintenance are important to keeping the ductwork clean. If dirt accumulates in ductwork and if the relative humidity reaches the dew point (so that condensation occurs), then the nutrients and moisture may support the growth of micro-biological contaminants. Attention to air filters is particularly important in HVAC systems with acoustical duct liner, which is frequently used in air handler fan housings and supply ducts to reduce sound transmission and provide thermal insulation. Areas of duct lining that have become contaminated with microbiological growth must be replaced. Sound reduction can also be accomplished with the use of special duct-mounted devices such as attenuators or with active electronic noise control.

Air handlers that are located in difficult to access places will be more likely to suffer from poor air filter maintenance and overall poor maintenance. Quick release and hinged access doors for maintenance are more desirable than bolted access panels.

Filters are available to remove gases and volatile organic contaminants from ventilation air; however, these systems are not generally used in normal occupancy buildings. In specially designed HVAC systems, permanganate oxidizers and activated charcoal may be used for gaseous removal filters. Some manufacturers offer *partial bypass* carbon filters and carbon impregnated filters to reduce volatile organics in the ventilation air of office environments. Gaseous filters must be regularly maintained (replaced or regenerated) in order for the system to continue to operate effectively.

Heating and Cooling Coils

Heating and cooling coils are placed in the airstream to regulate the temperature of the air delivered to the space. Malfunctions of the coil controls can result in thermal discomfort. Condensation on under-insulated pipes and leakage in piped systems will often create moist conditions conducive to the growth of molds, fungus, and bacteria.

During the cooling mode, the cooling coil provides dehumidification as water condenses from the airstream. Dehumidification can only take place if the chilled fluid is maintained at a cold enough temperature (generally below 45°F for water). Condensate collects in the drain pan under the cooling coil and exits via a deep seal trap. Standing water will accumulate if the drain pan system has not been designed to drain completely under all operating conditions (sloped toward the drain and properly trapped). Under these conditions, molds and bacteria will proliferate unless the pan is cleaned frequently.

It is important to verify that condensate lines have been properly trapped and are charged with liquid. An improperly trapped line can be a source of contamination, depending on where the line terminates. A properly installed trap could also be a source, if the water in the trap evaporates and allows air to flow through the trap into the conditioned air. During the heating mode, problems can occur if the hot water temperature in the heating coil has been set too low in an attempt to reduce energy consumption. If enough outdoor air to provide sufficient ventilation is brought in, that air may not be heated sufficiently to maintain thermal comfort or, in order to adequately condition the outdoor air, the amount of outdoor air may be reduced so that there is insufficient outdoor air to meet ventilation needs.

Humidification and Dehumidification Equipment

In some buildings, there are special needs that warrant the strict control of humidity, such as in operating rooms and computer rooms. This control is most often accomplished by adding humidification or dehumidification equipment and controls. In office facilities, it is generally preferable to keep the relative humidity above 20% or 30% during the heating season and below 60% during the cooling season.

The use of a properly designed and operated air conditioning system will generally keep relative humidity below 60% RH during the cooling season, in office facilities with normal densities and loads.

Office buildings in cool climates that have high interior heat gains, thermally efficient envelopes (e.g., insulation), and economizer cooling may require humidification to maintain relative humidity within the comfort zone. When humidification is needed, it must be added in a manner that prevents the growth of micro-biological contaminants within the ductwork and air handlers.

Steam humidifiers should utilize clean steam, rather than treated boiler water, so that occupants will not be exposed to chemicals. Systems using media other than clean steam must be rigorously maintained in accordance with the manufacturer's recommended procedures to reduce the likelihood of microbiological growth.

Mold growth problems are more likely if the humidistat setpoint located in the occupied space is above 45%. The high limit humidistat, typically located in the ductwork downstream of the point at which water vapor is added, is generally set at 70% to avoid condensation in the ductwork. Adding water vapor to a building that was not designed for humidification can have a negative impact on the building structure and the occupants' health, if condensation occurs on cold surfaces or in wall or roof cavities.

Supply Fans

After passing through the coil section where heat is either added or extracted, air moves through the supply fan chamber and the distribution system. Air distribution systems commonly use ducts that are constructed to be relatively airtight. Elements of the building construction can also serve as part of the air distribution system (e.g., pressurized supply plenums or return air plenums located in the cavity space above the ceiling tiles and below the deck of the floor above). Proper coordination of fan selection and duct layout during the building design and construction phase and ongoing maintenance of mechanical components, filters, and controls are all necessary for effective air delivery.

Fan performance is expressed as the ability to move a given quantity of air at a given resistance or static pressure. Airflow in ductwork is determined by the size of the duct opening, the resistance of the duct configuration, and the velocity of the air through the duct. The static pressure in a system is calculated using factors for duct length, speed of air movement and changes in the direction of air movement.

It is common to find some differences between the original design and the final installation, as ductwork must share limited space with structural members and other "hidden" elements of the building system (e.g., electrical conduit, plumbing pipes).

Air distribution problems can occur, particularly at the end of duct runs, if departures from the original design increase the friction in the system to a point that approaches the limit of fan performance. Inappropriate use of long runs of flexible ducts with sharp bends also causes excessive friction. Poor system balancing is another common cause of air distribution problems.

Dampers are used as controls to restrict airflow. Damper positions may be relatively fixed (e.g., set manually during system testing and balancing) or may change in response to signals from the control system. Fire and smoke dampers can be triggered to respond to indicators such as high temperatures or signals from smoke detectors. If a damper is designed to modulate, it should be checked during inspections to see that it is at the proper setting. ASHRAE and the Associated Air Balance Council both provide guidance on proper intervals for testing and balancing.

DUCT LEAKAGE

Leakage of air from ducts can cause or exacerbate air quality problems, in addition to wasting energy. In general, sealed duct systems specified with a leakage rate of less than 3% will have a superior life cycle cost analysis and reduce the likelihood of problems associated with leaky ductwork. Examples of excessive duct leakage leading to problems include:

- Leakage of light troffer-type diffusers at the diffuser/light fixture interface when they are installed in a return plenum. Such leakage has been known to cause gross short-circuiting between supply and return, wasting much of the conditioned air. If the “room” thermostat is located in the return plenum, the room can be very uncomfortable while the temperature in the plenum is operating at the control setpoint.
- Leakage of supply ductwork due to loose-fitting joints and connections or “blow outs” of improperly fabricated seams
- Leakage of return ducts located in crawl spaces or below slabs, allowing soil gases and molds to enter the ductwork

Ducts

The same HVAC system that distributes conditioned air throughout a building air can distribute dust and other pollutants, including biological contaminants. Dirt or dust accumulation on any components of an air handling system — its cooling coils, plenums, ducts, and equipment housing —may lead to contamination of the air supply.

There is widespread agreement that building owners and managers should take great precautions to prevent dirt, high humidity, or moisture from entering the ductwork; there is less agreement at present about when measures to clean up are appropriate or how effective cleaning techniques are at making long-term improvements to the air supply or at reducing occupant complaints.

The presence of dust in ductwork does not necessarily indicate a current microbiological problem. A small amount of dust on duct surfaces is normal and to be expected. Special attention should be given to trying to find out if ducts are contaminated only where specific problems are present, such as: water damage or biological growth observed in ducts, debris in ducts that restricts airflow, or dust discharging from supply diffusers.

Problems with dust and other contamination in the ductwork are a function of filtration efficiency, regular HVAC system maintenance, the rate of airflow, and good housekeeping practices in the occupied space. Problems with biological pollutants can be prevented by minimizing dust and dirt build-up, promptly repairing leaks and water damage, preventing moisture accumulation in the components that are supposed to be dry, and cleaning the components such as the drip pans that collect and drain water.

In cases where sheet metal ductwork has become damaged or water-soaked, building owners will need to undertake clean-up or repair procedures. For example, in cases where the thermal liner or fiberboard has become water-soaked, building managers will need to replace the affected areas. These procedures should be scheduled and performed in a way that does not expose building occupants to increased levels of pollutants and should be carried out by experienced workers.

Correcting the problems that allowed the ductwork to become contaminated in the first place is important. Otherwise, the corrective action will only be temporary. The porous surface of fibrous glass duct liner presents more surface area (which can trap dirt and subsequently collect water) than sheet metal ductwork. It is therefore particularly important to pay attention to the proper design, installation, filtration, humidity, and maintenance of ducts that contain porous materials. In addition, techniques developed for cleaning unlined metal ducts often are not suitable for use with fibrous glass thermal liner or fiberboard. Such ducts may require a special type of cleaning to maintain the integrity of the duct while removing dirt and debris.

Terminal Devices

Thermal comfort and effective contaminant removal demand that air delivered into a conditioned space be properly distributed within that space. Terminal devices are the supply diffusers, return and exhaust grilles, and associated dampers and controls that are designed to distribute air within a space and collect it from that space. The number, design, and location (ceiling, wall, and floor) of terminal devices are very important. They can cause a HVAC system with adequate capacity to produce unsatisfactory results, such as drafts, odor transport, stagnant areas, or short-circuiting.

Occupants who are uncomfortable because of distribution deficiencies (drafts, odor transport, stagnant air, or uneven temperatures) often try to compensate by adjusting or blocking the flow of air from supply outlets. Adjusting system flows without any knowledge of the proper design frequently disrupts the proper supply of air to adjacent areas. Distribution problems can also be produced if the arrangement of movable partitions, shelving, or other furnishings interferes with airflow. Such problems often occur if walls are moved or added without evaluating the expected impact on airflows.

Return Air Systems

In many modern buildings the above ceiling space is utilized for the un-ducted passage of return air. This type of system approach often reduces initial HVAC system costs, but requires that the designer, maintenance personnel, and contractors obey strict guidelines related to life and building codes that must be followed for materials and devices that are located in the plenum. In addition, if a ceiling plenum is used for the collection of return air, openings into the ceiling plenum created by the removal of ceiling tiles will disrupt airflow patterns. It is particularly important to maintain the integrity of the ceiling and adjacent walls in areas that are designed to be exhausted, such as supply closets, bathrooms, and chemical storage areas.

After return air enters either a ducted return air grille or a ceiling plenum, it is returned to the air handlers. Some systems utilize return fans in addition to supply fans in order to properly control the distribution of air. When a supply and return fan are utilized, especially in a VAV system, their operation must be coordinated in order to prevent under- or over-pressurization of the occupied space or over-pressurization of the mixing plenum in the air handler.

Exhausts, Exhaust Fans, and Pressure Relief

Most buildings are required by building codes to provide for exhaust of areas where contaminant sources are strong, such as toilet facilities, janitorial closets, cooking facilities, and parking garages. Other areas where exhaust is frequently recommended but may not be legally required include: reprographics areas, graphic arts facilities, beauty salons, smoking lounges, shops, and any area where contaminants are known to originate.

For successful confinement and exhaust of identifiable sources, the exhausted area must be maintained at a lower overall pressure than surrounding areas. Any area that is designed to be exhausted must also be isolated from the return air system so that contaminants are not transported to another area of the building. In order to exhaust air from the building, make-up air from outdoors must be brought into the HVAC system to keep the building from being run under negative pressure. This make-up air is typically drawn in at the mixed air plenum as described earlier and distributed within the building. For exhaust systems to function properly, the make-up air must have a clear path to the area that is being exhausted.

It is useful to compare the total CFM of powered exhaust to the minimum quantity of mechanically-introduced outdoor air. To prevent operating the building under negative pressures, the amount of make-up air drawn in at the air handler should always be slighter greater than the total amount of relief air, exhaust air, and air ex-filtrating through the building shell. Excess makeup air is generally relieved at an exhaust or relief outlet in the HVAC system, especially in air economizer systems. In addition to reducing the effects of unwanted infiltration, designing and operating a building at slightly positive or neutral pressures will reduce the rate of entry of soil gases when the systems are operating.

For a building to actually operate at a slight positive pressure, it must be tightly constructed. Otherwise unwanted ex-filtration will prevent the building from ever achieving a neutral or slightly positive pressure.

Self-Contained Units

In some designs, small decentralized units are used to provide cooling or heating to interior or perimeter zones. With the exception of induction units, units of this type seldom supply outdoor air. They are typically considered a low priority maintenance item. If self-contained units are overlooked during maintenance, it is not unusual for them to become a significant source of contaminants, especially for the occupants located nearby.

Controls

HVAC systems can be controlled manually or automatically. Most systems are controlled by some combination of manual and automatic controls. The control system can be used to switch fans on and off, regulate the temperature of air within the conditioned space, or modulate airflow and pressures by controlling fan speed and damper settings. Most large buildings use automatic controls, and many have very complex and sophisticated systems. Regular maintenance and calibration are required to keep controls in good operating order. All programmable timers and switches should have “battery backup” to reset the controls in the event of a power failure.

Local controls such as room thermostats must be properly located in order to maintain thermal comfort. Problems can result from:

- Thermostats located outside of the occupied space (e.g., in return plenum)
- Poorly designed temperature control zones (e.g., single zones that combine areas with very different heating or cooling loads)
- Thermostat locations subject to drafts or to radiant heat gain or loss (e.g., exposed to direct sunlight)
- Thermostat locations affected by heat from nearby equipment

One method to test whether or not a thermostat is functioning properly is to set it to an extreme temperature. This experiment will show whether or not the system is responding to the signal in the thermostat, and also provides information about how the HVAC system may perform under extreme conditions.

Boilers

Like any other part of the HVAC system, a boiler must be adequately maintained to operate properly. However, it is particularly important that combustion equipment operate properly to avoid hazardous conditions such as explosions or carbon monoxide leaks, as well as to provide good energy efficiency. Codes in most parts of the country require boiler operators to be properly trained and licensed.

Both ASME and ASHRAE have made recommendations of how much combustion air is needed for fuel burning appliances.

Elements of boiler operation that are particularly important to indoor air quality and thermal comfort include:

- Operation of the boiler and distribution loops at a high enough temperature to supply adequate heat in cold weather.
- Maintenance of gaskets and breeching to prevent carbon monoxide from escaping into the building.
- Maintenance of fuel lines to prevent any leaks that could emit odors into the building.
- Provision of adequate outdoor air for combustion.
- Design of the boiler combustion exhaust to prevent re-entrainment.

Modern office buildings tend to have much smaller capacity boilers than older buildings because of advances in energy efficiency. In some buildings, the primary heat source is waste heat recovered from the chiller (which operates year-round to cool the core of the building).

Cooling Towers

Maintenance of a cooling tower ensures proper operation and keeps the cooling tower from becoming a niche for breeding pathogenic bacteria, such as *Legionella* organisms. Cooling tower water quality must be properly monitored and chemical treatments used as necessary to minimize conditions that could support the growth of significant amounts of pathogens. Proper maintenance may also entail physical cleaning to prevent sediment accumulation and installing drift eliminators.

Water Chillers

Water chillers are frequently found in large building air conditioning systems because of the superior performance they offer. A water chiller must be maintained in proper working condition to perform its function of removing the heat from the building. Chilled water supply temperatures should operate in the range of 45°F or colder in order to provide proper moisture removal during humid weather. Piping should be insulated to prevent condensation.

Other than thermal comfort, indoor air quality concerns associated with water chillers involve potential release of the working fluids from the chiller system. The rupture disk of the system should be piped to the outdoors, and refrigerant leaks should be located and repaired.

Waste oils and spent refrigerant should be disposed of properly.

Chapter 4
Moisture, Mold and Mildew

Molds and mildew are fungi that grow on the surfaces of objects, within pores, and in deteriorated materials. They can cause discoloration and odor problems, deteriorate building materials, and lead to allergic reactions in susceptible individuals, as well as other health problems.

The following conditions are necessary for mold growth to occur on surfaces:

- Temperature range between 40°F and 100°F,
- Mold spores,
- Nutrient base, and
- Moisture.

Human comfort constraints limit the use of temperature control. Spores are almost always present in outdoor and indoor air, and almost all commonly used construction materials and furnishings can provide nutrients to support mold growth. Dirt on surfaces provides additional nutrients.

Cleaning and disinfecting with nonpolluting cleaners and antimicrobial agents provides protection against mold growth. However, it is virtually impossible to eliminate all nutrients. Moisture control is thus an important strategy for reducing mold growth.

Mold growth does not require the presence of standing water; it can occur when high relative humidity or the hygroscopic properties (the tendency to absorb and retain moisture) of building surfaces allow sufficient moisture to accumulate. Relative humidity and the factors that govern it are often misunderstood.

Water enters buildings both as a liquid and as water vapor. Water, in its liquid form, is introduced intentionally in bathrooms, kitchens, and laundries and accidentally by way of leaks and spills. Some of that water evaporates and joins the water vapor that is exhaled by building occupants as they breathe or that is introduced by humidifiers. Water vapor also moves in and out of the building as part of the air that is mechanically introduced or that infiltrates and ex-filtrates through openings in the building shell. A lesser amount of water vapor diffuses into and out of the building through the building materials themselves. Figure 2 illustrates locations of moisture entry. The ability of air to hold water vapor decreases as the air temperature is lowered. If a unit of air contains half of the water vapor it can hold, it is said to be at 50% relative humidity (RH). As the air cools, the relative humidity increases. If the air contains all of the water vapor it can hold, it is at 100% RH, and the water vapor condenses, changing from a gas to a liquid.

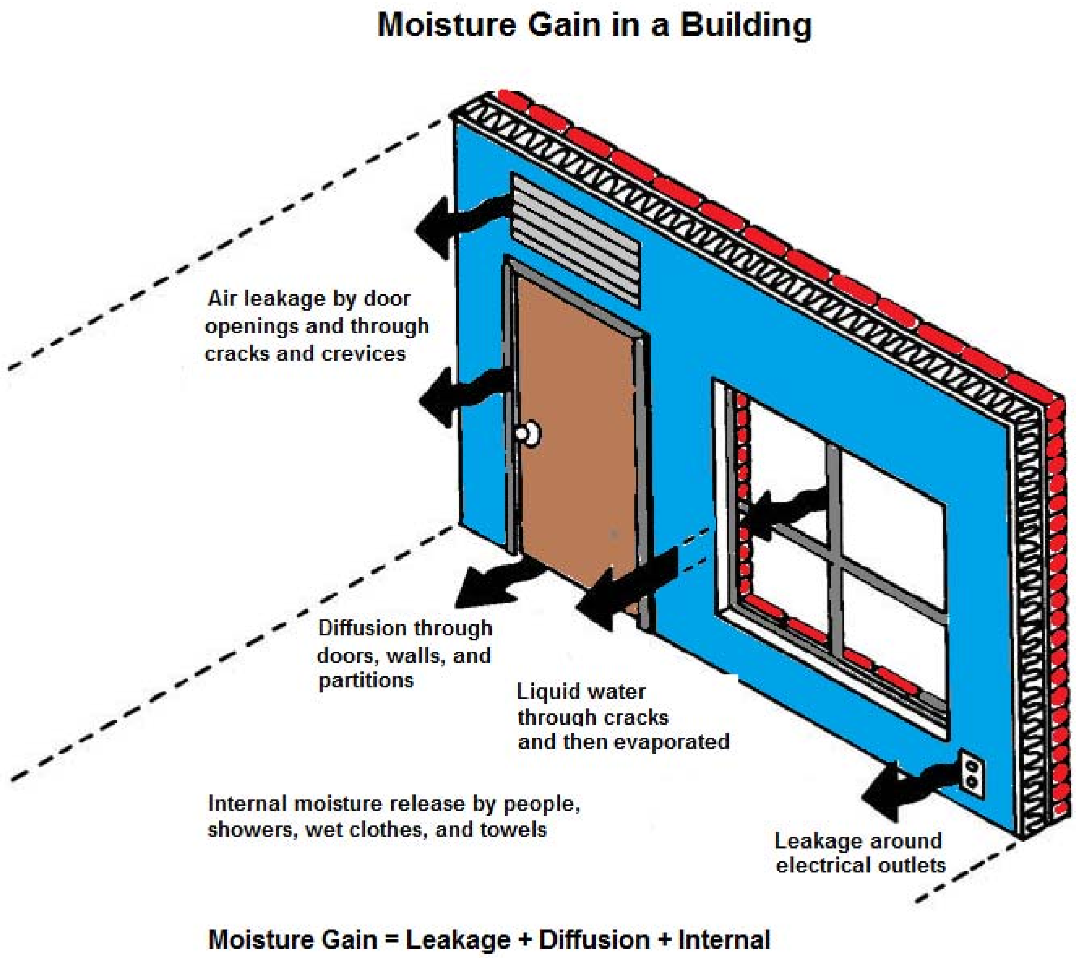


Figure 2

It is possible to reach 100% RH without changing the amount of water vapor in the air (its "vapor pressure" or "absolute humidity"); all that is required is for the air temperature to drop to the *dew point*. Relative humidity and temperature often vary within a room, while the absolute humidity in the room air can usually be assumed to be uniform. Therefore, if one side of the room is warm and the other side cool, the cool side of the room has a higher RH than the warm side. See Figure 3 for a graphic of the relationship of relative humidity, temperature, and moisture.

The highest RH in a room is always next to the coldest surface. This is referred as the "first condensing surface," as it will be the location where condensation first occurs, if the relative humidity at the surface reaches 100%. It is important to understand this when trying to understand why mold is growing on one patch of wall or only along the wall-ceiling joint. It is likely that the surface of the wall is cooler than the room air because there is a void in the insulation or because wind is blowing through cracks in the exterior of the building.

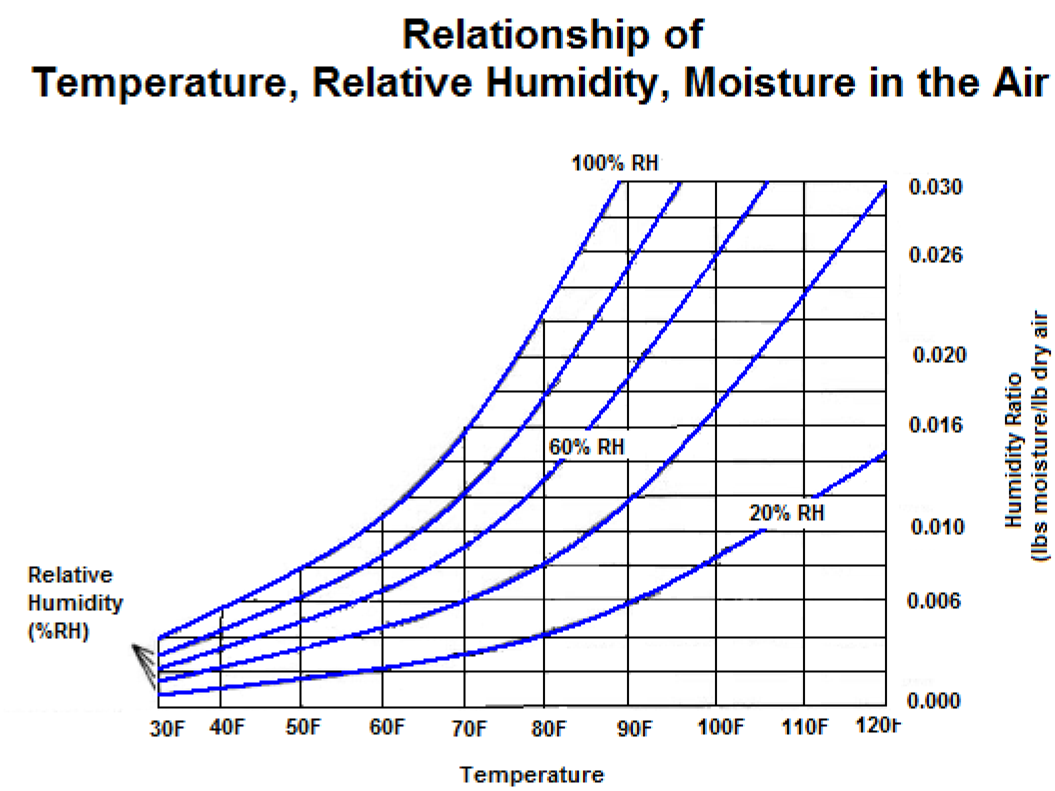


Figure 3

Mold and mildew growth can be reduced where the relative humidity near surfaces can be maintained below the dew point. This can be accomplished by reducing the moisture content (vapor pressure) of the air, increasing air movement at the surface, or increasing the air temperature (either the general space temperature or the temperature at building surfaces).

Either surface temperature or vapor pressure can be the dominant factor in causing a mold problem. A surface temperature-related mold problem may not respond very well to increasing ventilation, whereas a vapor pressure-related mold problem may not respond well to increasing temperatures. Understanding which factor dominates will help in selecting an effective control strategy.

Consider an old, leaky, poorly insulated building. It is in a heating climate and shows evidence of mold and mildew. Since the building is leaky, its high natural air exchange rate dilutes interior airborne moisture levels, maintaining a low absolute humidity during the heating season.

Providing mechanical ventilation in this building in an attempt to control interior mold and mildew probably will not be effective in this case. Increasing surface temperatures by insulating the exterior walls, and thereby reducing the relative humidity next to the wall surfaces, would be a better strategy to control mold and mildew.

Reduction of surface temperature dominated mold and mildew is best accomplished by increasing the surface temperature through either or both of the following approaches:

- Increase the temperature of the air near room surfaces either by raising the thermostat setting or by improving air circulation so that supply air is more effective at heating the room surface.
- Decrease the heat loss from room surfaces either by adding insulation or by closing cracks in the exterior wall to prevent wind-washing (air that enters a wall at one exterior location and exits another exterior location without penetrating into the building).

Vapor pressure-dominated mold and mildew can be reduced by one or more of the following strategies:

- Source control (e.g., direct venting of moisture-generating activities such as showers) to the exterior
- Dilution of moisture-laden indoor air with outdoor air that is at a lower absolute humidity
- Dehumidification

Note that dilution is only useful as a control strategy during heating periods, when cold outdoor air tends to contain less moisture. During cooling periods, outdoor air often contains as much moisture as indoor air.

Identifying and Correcting Mold and Mildew Problems

Exterior Corners

Exterior corners are common locations for mold and mildew growth in heating climates, and in poorly insulated buildings in cooling climates. They tend to be closer to the outdoor temperature than other parts of the building surface for one or more of the following reasons:

- Poor air circulation (interior)
- Wind-washing (exterior)
- Low insulation levels
- Greater surface area of heat loss

Sometimes mold and mildew growth can be reduced by removing obstructions to airflow (e.g., rearranging furniture). Buildings with forced air heating systems and/or room ceiling fans tend to have fewer mold and mildew problems than buildings with less air movement, other factors being equal.

"Set Back" Thermostats

Set back thermostats are commonly used to reduce energy consumption during the heating season. Mold and mildew growth can occur when building temperatures are lowered during unoccupied periods. Mold and mildew can often be controlled in heating climate locations by increasing interior temperatures during heating periods. Unfortunately, this also increases energy consumption and reduces relative humidity in the breathing zone, which can create discomfort.

Air Conditioned Spaces

The problems of mold and mildew can be as extensive in cooling climates as in heating climates. The same principles apply: either surfaces are too cold, moisture levels are too high, or both.

A common example of mold growth in cooling climates can be found in rooms where conditioned "cold" air blows against the interior surface of an exterior wall. This condition, which may be due to poor duct design, diffuser location, or diffuser performance, creates a cold spot at the interior finish surfaces. A mold problem can occur within the wall cavity as outdoor air comes in contact with the cavity side of the

Identifying Mold and Mildew Problems

Mold and mildew are commonly found on the exterior wall surfaces of corner rooms in heating climate locations. An exposed corner room is likely to be significantly colder than adjoining rooms, so that it has a higher relative humidity (RH) than other rooms at the same water vapor pressure. If mold and mildew growth are found in a corner room, then relative humidity next to the room surfaces are above 70%. However, is the RH above 70% at the surfaces because the room is too cold or because there is too much moisture present.

The amount of moisture in the room can be estimated by measuring both temperature and RH at the same location and at the same time. Suppose there are two cases. In the first case, assume that the RH is 30% and the temperature is 70°F in the middle of the room. The low RH at that temperature indicates that the water vapor pressure is low. The high surface RH is probably due to room surfaces that are "too cold." Temperature is the dominating factor, and control strategies should involve increasing the temperature at cold room surfaces. In the second case, assume that the RH is 50% and the temperature is 70°F in the middle of the room. The higher RH at that temperature indicates that the water vapor pressure is high and there is a relatively large amount of moisture in the air. The high surface RH is probably due to air that is "too moist." Humidity is the dominating factor, and control strategies should involve decreasing the moisture content of the indoor air.

cooled interior surface. It is a particular problem in rooms decorated with low maintenance interior finishes (e.g., impermeable wall coverings such as vinyl wallpaper) which can trap moisture between the interior finish and the gypsum board. Mold growth can be rampant when these interior finishes are coupled with cold spots and exterior moisture.

Possible solutions for this problem include:

- Preventing hot, humid exterior air from contacting the cold interior finish (i.e., controlling the vapor pressure at the surface)
- Eliminating the cold spots (i.e., elevating the temperature of the surface) by relocating ducts and diffusers
- Ensuring that vapor barriers, facing sealants, and insulation are properly specified, installed, and maintained
- Increasing the room temperature to avoid overcooling

In this case, increasing temperature decreases energy consumption, though it could cause comfort problems.

Thermal Bridges

Localized cooling of surfaces commonly occurs as a result of "thermal bridges," elements of the building structure that are highly conductive of heat (e.g., steel studs in exterior frame walls, un-insulated window lintels, and the edges of concrete floor slabs). Dust particles sometimes mark the locations of thermal bridges, because dust tends to adhere to cold spots. The use of insulating sheathings significantly reduces the impact of thermal bridges in building envelopes.

Windows

In winter, windows are typically the coldest surfaces in a room. The interior surface of a window is often the first condensing surface in a room. Condensation on window surfaces has historically been controlled by using storm windows or "insulated glass" (e.g., double-glazed windows or selective surface gas-filled windows) to raise interior surface temperatures. The advent of higher performance glazing systems has led to a greater incidence of moisture problems in heating climate building enclosures, because the buildings can now be operated at higher interior vapor pressures without visible surface condensation on windows. In older building enclosures with less advanced glazing systems, visible condensation on the windows often alerted occupants to the need for ventilation to flush out interior moisture.

Concealed Condensation

The use of thermal insulation in wall cavities increases interior surface temperatures in heating climates, reducing the likelihood of interior surface mold, mildew and condensation. However, the use of thermal insulation also reduces the heat loss from the conditioned space into the wall cavities, decreasing the temperature in the wall cavities and therefore increasing the likelihood of concealed condensation.

The first condensing surface in a wall cavity in a heating climate is typically the inner surface of the exterior sheathing, the "back side" of plywood or fiberboard. As the insulation value is increased in the wall cavities, so does the potential for hidden condensation.

Concealed condensation can be controlled by either or both of the following strategies:

- Reducing the entry of moisture into the wall cavities (e.g., by controlling infiltration and/or ex-filtration of moisture- laden air)
- Elevating the temperature of the first condensing surface. In heating climate locations, this change can be made by installing exterior insulation. In cooling climate locations, this change can be made by installing insulating sheathing to the interior of the wall framing and between the wall framing and the interior gypsum board.

Chapter 5
Asbestos and Radon

Asbestos and Radon are two issues that create many potential indoor air quality problems in commercial buildings. Both of these substances are believed to be carcinogenic. We will look at each of these very briefly in this Chapter.

Asbestos

Asbestos describes six naturally occurring fibrous minerals found in certain types of rock formations. When mined and processed, asbestos is typically separated into very thin fibers that are normally invisible to the naked eye. They may remain in the air for many hours if released from *asbestos-containing material* (ACM) and may be inhaled during this time. Three specific diseases — asbestosis (a fibrous scarring of the lungs), lung cancer, and mesothelioma (a cancer of the lining of the chest or abdominal cavity) — have been linked to asbestos exposure. It may be 20 years or more after exposure before symptoms of these diseases appear; however, high levels of exposure can result in respiratory diseases in a shorter period of time.

Most of the health problems resulting from asbestos exposure have been experienced by workers whose jobs exposed them to asbestos in the air over a prolonged period. Asbestos fibers can be found nearly everywhere in our environment. While the risk to occupants is likely to be small, health concerns remain, particularly for the custodial and maintenance workers in a building. Their jobs are likely to bring them into proximity to ACM and may sometimes require them to disturb the ACM in the performance of maintenance activities.

It is estimated that *friable* (i.e. easily crumbled) ACM can be found in an estimated 700,000 commercial buildings. About 500,000 of those buildings are believed to contain at least some damaged asbestos. Significantly damaged ACM is found primarily in building areas not generally accessible to the public, such as boiler and mechanical rooms, where asbestos exposures generally would be limited to service and maintenance workers.

However, if friable ACM is present in air plenums, it can be distributed throughout the building, thereby possibly exposing building occupants.

When is asbestos a problem? OSHA says that intact and undisturbed asbestos materials do not pose a health risk. The mere presence of asbestos in a building does not mean that the health of building occupants is endangered. ACM which is in good condition, and is not damaged or disturbed, is not likely to release asbestos fibers into the air.

When ACM is properly managed, release of asbestos fibers into the air is reduced, and the risk of asbestos-related disease is thereby correspondingly reduced.

There are a number of guidelines and regulations that govern asbestos exposure. Occupational standards for preventing asbestos-related diseases are recommended by OSHA. The OSHA standards set Permissible Exposure Limits (PELs). The standards also contain many other measures, such as surveillance, medical screening, analytical methods, and methods of control. OSHA regulations provide guidance on day-to-day activities that may bring workers in contact with ACM.

EPA recommends a practical approach that protects public health by emphasizing that ACM in buildings should be identified and appropriately managed, and that those workers who might disturb it should be properly trained and protected.

In an effort to calm unwarranted fears that a number of people seem to have about the mere presence of asbestos in their buildings and to discourage the decisions by some building owners to remove all ACM regardless of its condition, the EPA produced this summary on EPA's recommendations for asbestos control:

1. Although asbestos is hazardous, the risk of asbestos-related disease depends upon exposure to airborne asbestos fibers.
2. Based upon available data, the average airborne asbestos levels in buildings seem to be very low. Accordingly, the health risk to most building occupants also appears to be very low.
3. Removal is often not a building owner's best course of action to reduce asbestos exposure. In fact, an improper removal can create a dangerous situation where none previously existed.
4. EPA only requires asbestos removal in order to prevent significant public exposure to airborne asbestos fibers during building demolition or renovation activities.
5. EPA does recommend a pro-active, in-place management program whenever asbestos-containing material is discovered.

In some cases, an asbestos operations and maintenance program is more appropriate than other asbestos control strategies, including removal. Proper asbestos management is neither to rip it all out in a panic nor to ignore the problem.

In-place management means having a program to ensure that the day-to-day management of the building is carried out in a manner that minimizes release of asbestos fibers into the air, and that ensures that when asbestos fibers are released, either accidentally or intentionally, proper control and clean-up procedures are implemented. Such a program may be all that is necessary to control the release of asbestos fibers until the asbestos- containing material in a building is scheduled to be disturbed by renovation or demolition activities.

The first step is to identify asbestos containing materials, through a building wide inventory or on a case-by-case basis, before suspect materials are disturbed by renovations or other actions. According to EPA rules public and commercial buildings facing major renovations or demolition, require inspections for the presence of ACM. A carefully designed air monitoring program can be used as an adjunct to visual and physical evaluations of the asbestos-containing materials.

After the material is identified, controls can be instituted to ensure that the day-to-day management of the building is carried out in a manner that prevents or minimizes the release of asbestos fibers into the air. These controls will ensure that when asbestos fibers are released, either accidentally or intentionally, proper management and clean-up procedures are implemented.

Another concern is to ensure proper worker training and protection. In the course of their daily activities, maintenance and service workers in buildings may disturb materials and thereby elevate asbestos fiber levels and asbestos exposure, especially for themselves, if they are not properly trained and protected. For these persons, risk may be significantly higher than for other building occupants. Proper worker training and protection, as part of an active in-place management program, can reduce any unnecessary asbestos exposure for these workers and others.

In addition to the steps outlined above, an in-place management program will usually include notification to workers and occupants of the existence of asbestos in their building, periodic surveillance of the material, and proper recordkeeping.

Radon

Radon is a radioactive gas produced by the decay of radium. It 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 their foundations. Radon's decay products can cause lung cancer, and radon is second only to smoking as a cause of lung cancer in America.

Extensive research and case studies in the field have demonstrated practical remediation methods that typically reduce the indoor radon concentrations below four picocuries per liter (pCi/L), the current EPA action level for all occupied buildings.

Three elements must be present for radon to be a problem: a radon source, a pathway that allows radon to enter the building, and a driving force that causes the radon to flow through the pathway and into the building. Preventing radon from entering the building is always desirable compared with mitigation after radon has entered. The reduction of pathways and driving forces are therefore usually the focus of attention during diagnostic and remediation efforts.

Now that technical guidance is being successfully used to reduce human health risk in homes, the emphasis is on developing radon measurement, mitigation, and prevention techniques for large buildings. Preliminary data from a nationwide survey of Federal buildings indicates that radon will probably not be as widespread a problem in large buildings as it is in homes. One of the major factors for this difference is that multi-story buildings have proportionally less space in direct contact with the earth when compared to homes.

Some of the control technologies utilized for homes are being studied for their appropriateness to other building types. In addition, new methods and technologies are being developed to ensure a practical and cost-effective reduction of radon in these buildings.

A protocol specific to large buildings is necessary due to the major differences in building dynamics, HVAC systems, and occupancy patterns between large buildings and homes, and how these impact radon.

Due to the diversity and complexity of large buildings generalized building diagnostic and remediation methodologies are not readily available.

Summary

A healthy indoor environment is one in which the surroundings contribute to productivity, comfort, and a sense of health and well being.

In this course, we have looked at the factors affecting indoor air quality and how to measure and evaluate indoor air quality. Good indoor air quality includes: Introduction and distribution of adequate ventilation air, control of airborne contaminants, and maintenance of acceptable temperature and relative humidity. In addition to measuring and quantifying methods, the course included an explanation of how HVAC systems as well as the air quality impacts of mold, mildew, asbestos and radon.

The second course in this series discusses methods to mitigate indoor air quality problems and covers 15 common indoor air quality problems and potential solutions.

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