6-2 Indoor Air Quality as a Public Health Concern

While buildings with less than optimum air quality have certainly existed for many years, the energy crisis of the 1970s spawned thousands of buildings designed and constructed to meet targets for conservation of energy. Heating, cooling, and filtering air, as well as delivering it throughout the building requires consumption of energy. A poorly designed HVAC system, or one that is not properly maintained, will require more energy to operate than one that is installed and operated correctly. Indoor air quality, or more accurately, the lack of it, is typically associated with a set of common complaints among building occupants. The most common complaints are reports of odors, uncomfortable temperatures (too hot or too cold), and physical symptoms, such as headaches and respiratory irritation, which are attributed to chemicals or biological agents. As building occupancy levels increase, so does the number of complaints. The most common types of complaints include those associated with the following parameters:

- Temperature – Too hot, too cold, drafts, and similar complaints are often heard. The specific problems may vary with seasonal changes in temperature and HVAC operation.
- Humidity – The air being too dry is a common complaint, contributing to irritation of the respiratory tract and eyes. Too much humidity contributes to the growth of microorganisms, and encourages odors and mustiness.
- Stuffiness or lack of air circulation – These can be related to location of the diffusers or outlets relative to the occupants. There may also be a lack of air movement attributed to a less than adequate supply of air from the HVAC system. Poor circulation may lead to stratification of the building air, with some areas receiving plenty of air and others little or none. These "dead zones" might allow odors and carbon dioxide (CO_2) to accumulate to unacceptable levels.
- Odors – Objectionable odors are a common complaint and are as varied as flavored coffee smells to body odor, vehicle exhaust, or chemical smells. Indoor sources of odors may include newly painted surfaces, off gassing of furniture or carpet, or smells produced by operation of copy machines and other office equipment. Odors may also be drawn into the HVAC system from outside sources if the outdoor air intakes are located near areas such as loading docks, trash dumpsters, incinerators, or exhaust stacks from a chemical process.
- Physical symptoms – Occupants may report an array of symptoms ranging from dryness of the eyes or respiratory tract to headaches, tiredness, upset stomach, runny noses and congestion, and others. Some of these symptoms may be attributable to contaminants in the air; for example, CO_2 levels above 1,000 ppm may cause headaches or drowsiness in some people. Unfortunately, most of these symptoms are also nonspecific enough that a cause-and-effect relationship between the symptoms and one or more air contaminants is often not apparent, or difficult to establish, at best. The exception to this would be an outbreak, such as Legionnaire's disease, in which a set of severe symptoms would appear among a group of people occupying the same building, making it easier to establish the cause. Aside from these clear-cut situations, is important for the investigator to understand that the lack of a clear link between the reported symptoms and the building's air supply does not diminish the possibility of a correlation between the two.

> The **olf** was first used by researchers in Denmark to measure the bioeffluent odor load produced by a "standard" building occupant, defined as a person who bathes about 0.7 times/day, changes their underwear daily, has a skin surface area of 1.8 square meters, and spends their day in sedentary or seated tasks. Some studies of IAQ use the olf to quantify odor levels, and sources of undesirable odor are assigned an olf equivalency. For example, a wet and moldy filter in an air conditioner might produce an undesirable odor at a level equivalent to 10 standard persons or olfs.

NIOSH indoor air quality investigations performed in the United States in the last 25 years have revealed an interesting set of statistics. For one, a large percentage (about half in the NIOSH studies)

Box 6-1 ■ Two Case Studies

These case studies illustrate the difficulties that can be encountered in identifying the specific offending contaminants causing poor indoor air quality. In some situations, the culprit is clear, firm conclusions can be reached, and concrete recommendations can be made. In others, there are no clear answers, and an educated guess is the best conclusion that can be made from the available data.

Case 1

An industrial hygienist was called upon to help identify the cause of periodic incidences of respiratory irritation that occurred among some workers at an offset printing location. Without exception, the staff that was in the area at the time of each event experienced an irritating, sulfur-like odor, and some persons reported more severe reactions involving the eyes, throat, and respiratory tract. The affected area included an office adjacent to an open work area where printed materials were sorted and bundled. Both areas were serviced by a roof-mounted HVAC unit that investigation revealed also serviced the photo processing room. This room was found to be under positive pressure relative to the rest of the plant.

Air sampling found measurable levels of sulfuric acid in the affected areas some 48-60 hours after each event. Inspection of the HVAC unit revealed that a minimal amount of outside air was being drawn into the unit, resulting in mostly recirculated air being supplied to the two areas. The indoor intake grille for the HVAC unit was located near the photo processing area. It was deduced that sulfuric acid – and possibly other irritating compounds present in the photo processing chemicals– were produced in the photo processing area, then drawn into the HVAC unit and circulated to the part of the building where the symptoms were experienced. Recommended corrective actions included increasing the amount of outside air being drawn into the HVAC unit, relocating the indoor intake grille, and installing a local exhaust ventilation system in the photo processing area to remove chemical vapors.

Case 2

An industrial hygienist was called upon to investigate the air quality of an office building as the result of occupant complaints of respiratory tract and other irritation. The building had windows that opened, high ceilings, personal cooling fans, and plenty of room for each occupant. There was no central HVAC unit, nor any individual units, servicing any part of the building. Some offices were equipped with window-mounted air conditioners, and some occupants ran these units on the fan setting, even during the winter, to draw some outside air into their work area. Heat was provided by a boiler, and the steam remained in the pipes and radiators when the boiler was operating. As an added precaution by the building maintenance staff, vents on each radiator had been installed and routed directly to the outside of the building through windows. The boiler had been cleaned using a chemical agent 18-24 months before the investigation.

The investigation included discussions with occupants, completion of questionnaires, and air sampling. Symptoms experienced by the occupants included irritation of eyes, nose, and throat, as well as the upper respiratory tract. Odors resembling urine and dead fish were also reported. Most questionnaire respondents indicated relatively high job satisfaction.

Air sampling was performed in a closed room directly above an open vent in the radiator, in efforts to simulate a worst-case situation. During sampling, the hygienist experienced symptoms of respiratory and eye irritation similar to those reported by the building occupants. These symptoms disappeared almost immediately upon leaving the sampling area. Laboratory analysis revealed no detectable levels of any of the suspected contaminants. For at least one of the suspected chemical contaminants, the limit of detection for the analytical method was well above the estimated odor threshold.

It was concluded that some building occupants might be sensitized to the chemicals used in the boiler, which would account for their reporting of symptoms even at the very low levels of chemicals that could have been present in the building. The hypothetical route for the chemicals entering the building was that chemical-containing steam was escaping out of the radiator vents, only to be drawn back into the building through open windows, or through the window-mounted air conditioners. However, a definitive solution could not be found, and specific corrective measures could not be offered.

of the IAQ problems were attributable to the HVAC system. These problems ranged from poor HVAC system design to improper maintenance. Other causes of IAQ problems were identified as chemical contaminants or microbes, either inside the building – i.e., the HVAC system itself – or drawn into the building from outside sources. In about 10 percent of the cases, the investigation failed to reveal an obvious source for the reported problem.

It should be noted that indoor air quality problems are sometimes linked to other factors that have no bearing on air quality, but may be linked to the occupants' perception of the air quality. One of these factors is job satisfaction, which encompasses a broad range of issues related to personal and professional relationships, level of experience, and other social and economic issues that are beyond the scope of our discussion. Still, it is worth mentioning here since the industrial hygiene professional who investigates IAQ complaints will find many questions related to this on the questionnaires that are a standard part of the IAQ investigator's toolbox (see Appendix 3, NIOSH questionnaire). It is worth noting that job satisfaction, or rather the lack of it, has been statistically linked to other occupational health issues, such as ergonomic injuries. Another significant issue is the degree of control that the building occupants have over their environment. Examples of this would be access to adjustable thermostats and temperature controls as well as to functional windows, which are windows that can be opened and that are near the desk or assigned work area.

Standards for Indoor Air Quality

Although OSHA has proposed development of a standard for IAQ in places of employment, a final standard has yet to be issued. The proposed standard contains provisions for 1) keeping CO_2 levels below 800 ppm; 2) maintaining relative humidity at or below 60 percent; 3) maintaining records on HVAC systems, including the original design specifications, cleaning, and repairs; 4) exhausting designated smoking areas to the outside and keeping them under negative pressure relative to the rest of the building; and 5) locating air intakes of systems to prevent capturing outside air contaminants. OSHA also proposed to require that HVAC systems be maintained and operated in a manner consistent with the building codes that were in force when the building was constructed and the HVAC unit was installed.

The lack of OSHA regulation, however, has not prevented the establishment of other consensus standards for minimum levels of performance for HVAC systems and the quality of air they supply to building inhabitants. Listed below are summaries of the more significant sources that are used for design and evaluation of HVAC systems. They consist primarily of standards developed by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE). As is the case with other consensus standards, these are not regulations, but guidelines that are followed by most professionals in the absence of regulatory standards. Because they are consensus standards and not OSHA regulations, changes and updates are easier. Market pressures as well as changes in building requirements also influence consensus standards. In some locations, the ASHRAE standards may be enforceable through incorporation into local building codes.

ASHRAE 62-1989, Ventilation for Acceptable Air Quality

This recommended standard describes some of the minimum features and performance capabilities for HVAC systems in 100 different types of occupied buildings, including specific recommendations for offices, classrooms, laboratories, smoking lounges, and others. Among the provisions contained in this standard:

- —There should be a method for verifying that the system is providing an adequate volume of airflow to the occupied space;
- —The system should deliver air to the areas in the space where the occupants are located;
- —The system should be designed to prevent the growth of microorganisms through design features such as self-draining condensate pans, steam humidifiers, and unlined ducts;
- —Relative humidity should be maintained below 60 percent; CO_2 levels below 1,000 ppm;
- —Air intakes and outlets should be located to avoid drawing contaminants into the system;
- —Filters, scrubbers, and other treatment methods should be used to remove air contaminants and maintain acceptable air quality;

—The HVAC unit should be located so that it is accessible for cleaning and maintenance.

ASHRAE 55-1992, Thermal Environmental Conditions for Human Occupancy

This recommended standard contains a description of the temperature and humidity conditions that should be acceptable to most occupants of a space. Factors such as air movement, humidity, clothing, and activity level are considered.

ASHRAE 52-1992, Methods of Testing Air Cleaning Devices Used in General Ventilation for Removing Particulate Matter

This recommended standard contains two methods that can be used to test the effectiveness of air filters: 1) the ASHRAE Arrestance test, for filters used to remove larger particles, and 2) the ASHRAE Dust Spot Efficiency Test for filters that are used to remove fine dusts and smaller particles from the air stream. These tests result in assignment of values for the percentage of the test agent that a specific filter removes. Foam-type filters may be found 70-80 percent efficient in the arrestor test but only 15-30 percent efficient for the dust spot test. Fibrous mat-type filters, by comparison, can be rated as high as 95 percent or more for the arrestor test and 90 percent or better for the dust spot test. Specific information on the rating of a filter can usually be obtained from the manufacturer.

Checking Your Understanding

1. Name four common areas of complaint related to IAQ.
2. Explain why IAQ problems are often linked to structures built or modified in the 1970s or later.
3. Aside from problems with the HVAC system, what other factors may contribute to poor IAQ (or the perception of poor IAQ)?
4. What are the ASHRAE-recommended levels for humidity and CO_2?
5. Name three significant ASHRAE standards and briefly describe what they address.
6. What are some of the proposed contents of the OSHA standard for IAQ?

6-3 Heating, Ventilating, and Air Conditioning Systems (HVAC)

It is no accident that HVAC systems are so often linked with problems of indoor air quality. The complexity of some of these systems is enough to require a regimented maintenance program; failure to follow schedules for cleaning and other general maintenance can lead to poor air quality. One of the first steps in performing an investigation into an IAQ complaint is to determine the type of HVAC system involved. Before we discuss the most common aspects of HVAC operation and IAQ problems, we must become familiar with the terms used to describe HVAC systems.

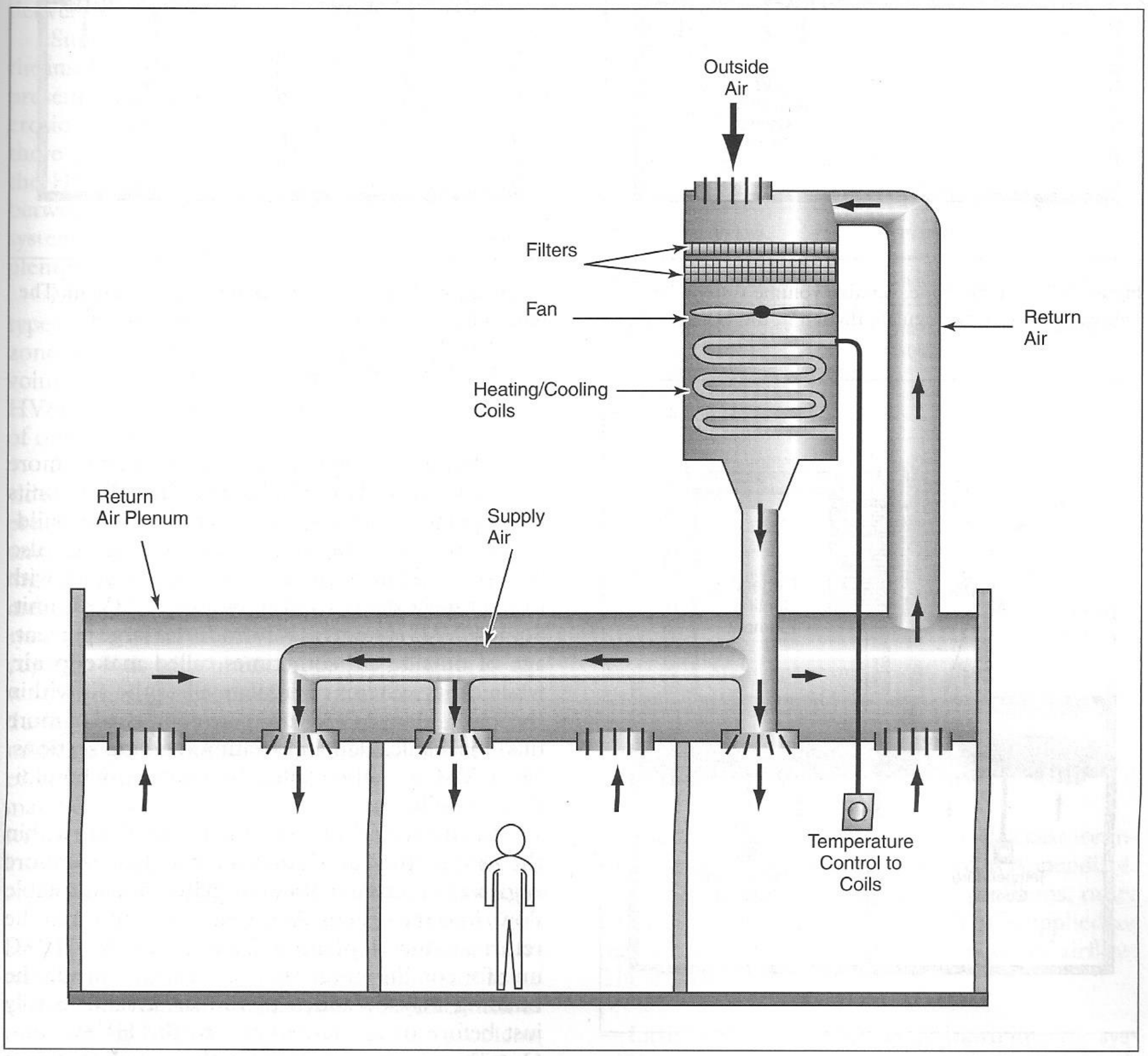

Figure 6-1: Typical single zone, constant volume HVAC unit. The temperature controls affect the heating/cooling of supply air by the unit.

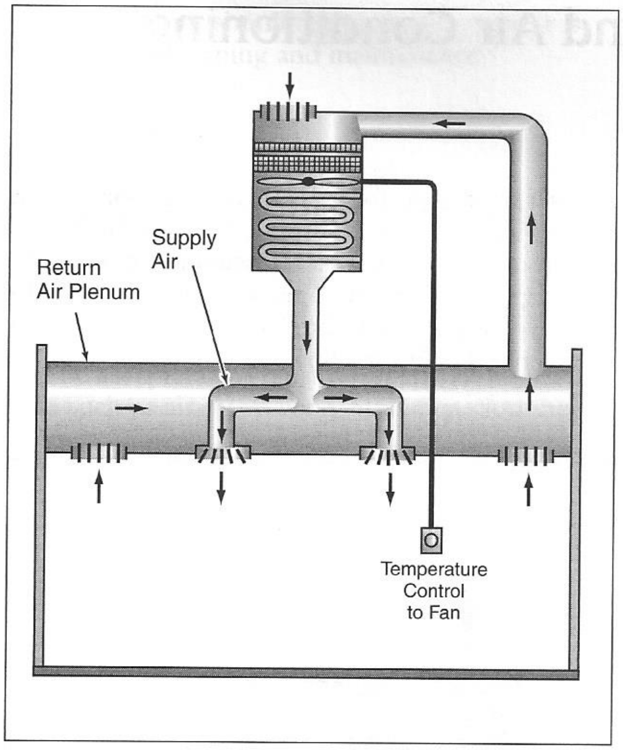

Figure 6-2a: Single zone, variable volume system. The temperature controls regulate the fan in the HVAC unit.

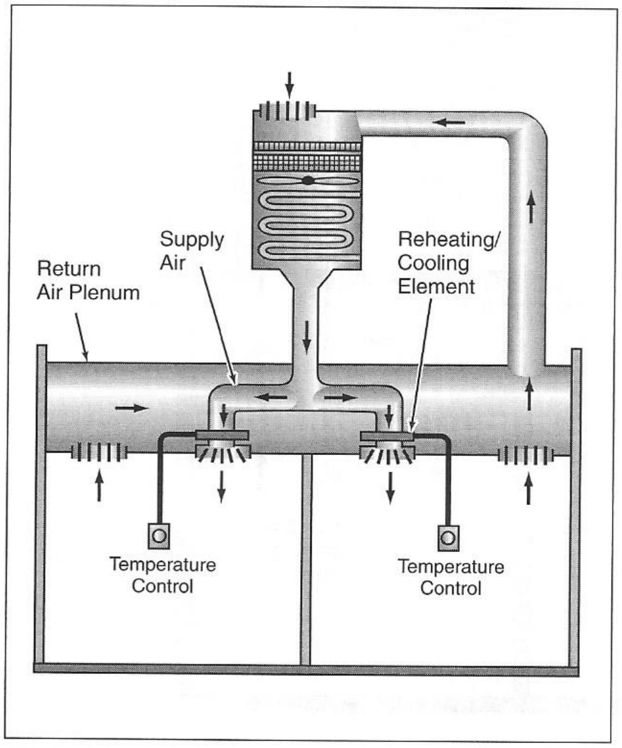

Figure 6-2b: Multiple zone, constant volume system. The temperature controls regulate reheating/cooling of supply air at the point of distribution.

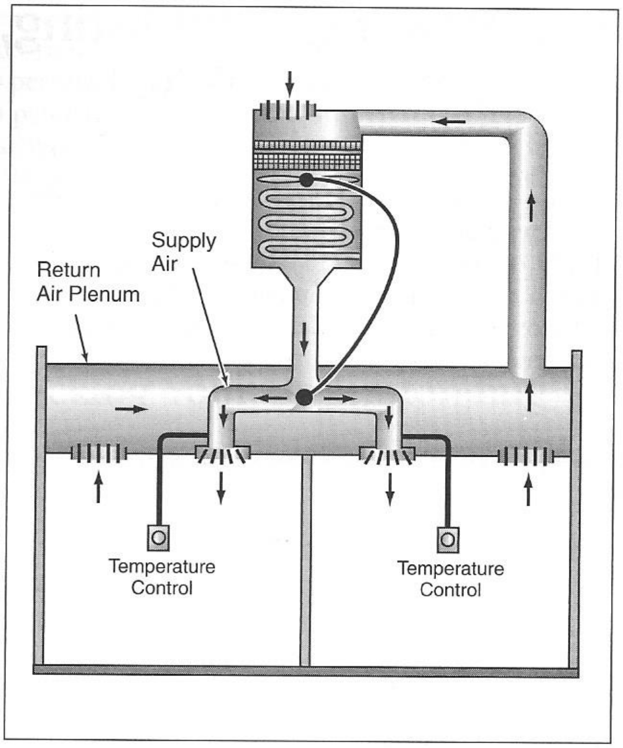

Figure 6-2c: Multiple zone, variable volume system. The temperature controls affect airflow at the point of distribution. The fan in the HVAC unit adjusts in response to pressure changes in the supply duct.

A building is typically serviced by one or more HVAC units. In larger buildings, the HVAC units may operate in unison to service the entire building. As an alternative to that, the building may also be separated into various air spaces, or **zones**, with each air space being serviced by a single HVAC unit. Some HVAC systems may introduce a large percentage of outside air, sometimes called **makeup air**, while other systems recirculate all of the air within the space. Many HVAC units are comprised of more than mechanical fan and heating/cooling sections. The HVAC may also contain humidifiers, dehumidifiers, and filters.

In the typical HVAC system, air from within the zone (**return air**) is drawn through one or more **registers** (adjustable flow) or **grills** (nonadjustable flow) into the system. As the air travels through the return air duct or **plenum**, it approaches the HVAC unit for conditioning. Makeup air from outside the building may be added to the air stream, usually just before or at the entrance to the HVAC unit. Outside air is introduced into the system to assure that the air contains an adequate amount of oxygen, as well as to dilute odors, carbon dioxide, and other contaminants. The air then enters the HVAC unit, where it is tempered (heated or cooled), filtered, humidified, or dehumidified. The air then travels via the **supply air ducts** back to the zone served by the unit.

The volume of makeup air introduced into the system is typically determined by the outside weather conditions. If the outdoor air temperature is moderate, more air will be allowed to enter the system. If the temperature of the outdoor air is very hot or cold, little or no makeup air will be drawn into the system. This is necessary to conserve energy that would be needed to cool or heat the air prior to delivery to the zone.

Supply and return ducts may be insulated on the inside or outside; ducts lined with insulation may present problems associated with cleanliness and erosion of the insulative lining. In some systems, there are no return air ducts. The air is drawn into the HVAC system from an area such as the space between a suspended ceiling and the roof. In these systems, the entire space functions as the return air plenum.

Most HVAC systems fall into one of four main types: 1) single zone, constant volume; 2) single zone, variable volume; 3) multiple zone, constant volume; or 4) multiple zone, variable volume. Some HVAC systems may be hybrids, combining aspects of one or more of these systems.

A single-zone, constant volume HVAC unit provides tempered and cleaned air to a single zone at a preset volume of flow. Similarly, multiple zone systems provide air to more than one zone in the building. Variable-volume systems are adjustable; this means that the volume of airflow provided by the system can be adjusted to suit the needs of the occupants. This adjustment capability presents an advantage during periods of low or no occupancy and during seasonal variations in temperature and humidity. Single zone systems are usually installed in or very near the zone they serve. Multi-zone units may be located some distance from the areas they serve; for example, they may be roof-mounted or installed in special rooms, such as mechanical rooms or fan rooms, or other dedicated areas in the building.

IAQ problems related to the operation of the HVAC system are often attributable to poor or irregular maintenance. Table 6-1 summarizes some of the more common maintenance-related contributors to poor IAQ. Many of the potential problems can show up in the HVAC unit itself, as well as at locations inside the zone. A simple checklist for inspecting an HVAC system is included as Appendix 4.

Potential Problems	Possible Cause
Mold, mildew, other microbes growing on filter media. Clogged filters preventing airflow. Dirt/contaminants recirculated in building air.	Wet/dirty filters
Spores, microscopic fragments of molds, etc. being circulated in building air. Odors from decaying matter circulated by HVAC.	Wet/decaying organic matter
Growth of mold, mildew; growth of microbial organisms including bacteria, algae; odors.	Standing water in drip/condensate pans
Odors; particles recirculated in building air.	Dirty cooling/heating coils
Odors; irritation or sensitivity from chemicals.	Residue from chemicals/cleaners
Little or no airflow.	Fan belts slipping/broken
Little or no airflow.	Drive motors inoperative
Growth of molds, mildew, bacteria; odors; erosion of damaged insulation resulting in airborne particles circulated in building air.	Wet, dirty, or damaged duct insulation
Encourages microbial growth; odors.	Settled water/signs of water damage (at any location in the HVAC system, unit, or ducts)
Dirt/stains on ceiling tiles around diffusers, grills, or registers.	Entrainment of dirt in system; poor filter maintenance; dirty duct interiors.

Table 6-1: Many operational HVAC characteristics are associated with poor IAQ. Problems with IAQ can arise during lapses in maintenance.

Aside from operations-related problems, other contributors to poor quality of HVAC-supplied air may be related to one or more aspects of airflow. These problems may be due to:

—Little or no outside air being drawn into the system;

—Poor system design, or installation of the system not as designed;

—Failure to maintain and operate the system as it was designed;

—Alterations and modifications to the system after installation, or alterations in the zones served by the unit;

—Placement of air intakes near outside sources of pollutants.

Inadequate outside air may be linked to buildup of noticeable odors as well as increased levels of carbon dioxide and other undesirable gases. Because humans produce carbon dioxide, its levels are often used as an indicator of the effectiveness with which the HVAC unit is able to supply fresh air to the building or occupied space. Some special IAQ instruments are now available that include sensors for measuring air velocity, temperature, relative humidity, and CO_2, all in one instrument. Less sophisticated methods, such as detector tubes, can also be used.

> The recommended amount of outside air has varied over the years. In 1905, the recommended rate was 30 cubic feet per minute (cfm) of outside air/person; in 1936, the recommendation was 10 cfm of outside air/person; in 1973, ASHRAE recommended 5 cfm of outside air/person, probably a reduction for energy conservation purposes. More recent ASHRAE recommendations – revised in 1989 – set the level at 20 cfm/person for an office area. This upward trend is the result of increased concerns with indoor air quality issues such as secondhand tobacco smoke. ASHRAE recommendations for outside air are minimums and should be considered such. If the occupied space contains sources of aerosol contaminants or odors, or combustion sources, additional outside air may be required.

To determine whether there is adequate intake of outside air, a number of causes or potential situations should be ruled out before more costly investigative measures are employed. The system design should be reviewed and compared to the present installation. It may be that the zone's requirements for air volume and flow exceed the capabilities of the unit. If the unit is capable of providing the necessary volume of flow, the unit should be checked to see if the outside air dampers are stuck or rusted closed. Sometimes these types of complaints are seasonal, becoming more common when air is being cooled in summer, or heated in winter months. Mechanical problems should also be ruled out. Fans, motors, and drive belts should be inspected to determine if there is need for repair or replacement. The supply ducts should also be checked to rule out blockage, sharp turns, and "user" modifications that interfere with airflow.

If the unit is supplying a volume of air (mixed with adequate outside air) that is appropriate for the occupied area, the problem may be one of inadequate air distribution. This can be linked to causes as simple as a blocked room diffuser or dampers being closed. Direct measurement of airflow is useful for determining whether the air supplied by the system meets design specifications. A **velometer** is an instrument commonly used to measure airflow. The reading is taken at the face of the diffuser or outlet, and the instrument provides a reading in feet per minute (fpm). Measurement of the length and width of the opening allows calculation of the area (measured in square feet). The velocity (fpm) multiplied by the area of the duct (ft^2) provides the volumetric airflow in cubic feet per minute (cfm). Airflow through a duct is defined by the following equation:

$$Q = VA$$

Where

Q = the volumetric rate of airflow in cfm,

V = the velocity of the air in fpm, and

A = the area of the duct.

Let us illustrate with an example. The IH is evaluating airflow to an office and measures the flow of air coming out of a 2 ft × 2 ft opening with a velometer. The reading is 10 fpm. The application of the equation, Q = VA, results in the following:

$$Q = VA$$
$$Q = (10\text{ fpm})(2\text{ ft} \times 2\text{ ft})$$
$$Q = (10\text{ fpm})(4\text{ ft}^2)$$
$$Q = 40\text{ cfm}$$

The amount of air that is being supplied to an area by the ventilation system is an easy measurement to take and can be useful for basic troubleshooting, as we will see later.

The addition or rearrangement of walls, partitions, or major furniture within the space, after the installation of the HVAC unit, may cause problems by creating a configuration of supply and return volumes that were not considered in the original design. This may give the impression of an apparently malfunctioning HVAC system. In order to ensure that mixing of air occurs in an occupied area, supply and return ducts should be placed as close as possible to the occupants. If this is not possible, persons who work in areas with poor mixing can be provided with pedestal or small personal fans that can be used as needed. Adding, blocking off, or removing ducts can also create an imbalanced system. It is sometimes possible to rebalance or optimize systems if a limited amount of changes have taken place; however, these changes should be made by a competent HVAC engineer.

Inspecting the ducts and intakes is a sometimes overlooked but important aspect of an IAQ evaluation. Ducts may be located in areas that are hard to inspect; above ceilings, in crawl spaces, under floors, and in walls. Nevertheless, with some effort, it is usually possible to locate and inspect most ducts. Worn insulation located inside ducts can lead to fibers or particles from the insulation being drawn into the HVAC system and circulated through the building. Wet insulation, or insulation with stains and other evidence of water damage, can be a breeding ground for microbes. Some of these cause disease, others are capable of causing allergic reactions among sensitized individuals, while yet others may cause building occupants to develop sensitivities.

Intakes are also areas that need to be checked visually. Like ducts, the intakes for a system may be difficult to locate or to inspect; they may be on roofs, on sides of buildings, or between floors. When inspecting intakes, the IH needs to check for blockage, including leaves, bird nests, and debris on screens; stuck or malfunctioning louvers, and other barriers to airflow. Potential sources of pollutants that could be drawn into the system need to be investigated. Garbage dumpsters, parking structures, loading docks, incinerators, and chemical storage areas are a few examples of potential sources of odors and contaminants. The presence of processes or odor-producing equipment must be considered, including machines that use solvents or fluids such as blueprint machines. Fresh air intakes should not be located near such machines, or near the exhaust of a ventilation system used for hazardous contaminant control. Another possibility to consider when odor problems develop suddenly is the relocation of a process, a machine, or any other possible source of the odor. It is possible that rearrangement plans did not take into account the ventilation requirements or the presence of air intakes. Ventilation equipment that has been disassembled, moved, and reinstalled, may not have been reassembled properly. Fan motors that are wired incorrectly will result in blades that turn in the opposite direction. In this case, some fans are still capable of moving air, but the volume of air that is moved is probably going to be less. Incorrect wiring is a common cause of less-than-optimal fan performance.

Checking Your Understanding

1. Name and describe the four basic types of HVAC systems.
2. Name five functions performed by the HVAC system.
3. List at least six operational aspects of an HVAC system, which can cause or contribute to poor indoor air quality.
4. Name four things that can affect the flow of air in a supply zone, including two items that are not related to changes in the HVAC system.
5. What is the volumetric rate of airflow from an opening measuring 12 × 24 inches, with a velometer reading of 8 fpm?

6-4 Basic Instruments for Use in IAQ Studies

In addition to inspecting systems visually, many simple instruments can be used to help the occupational health professional evaluate air quality. Table 6-2 describes some of them.

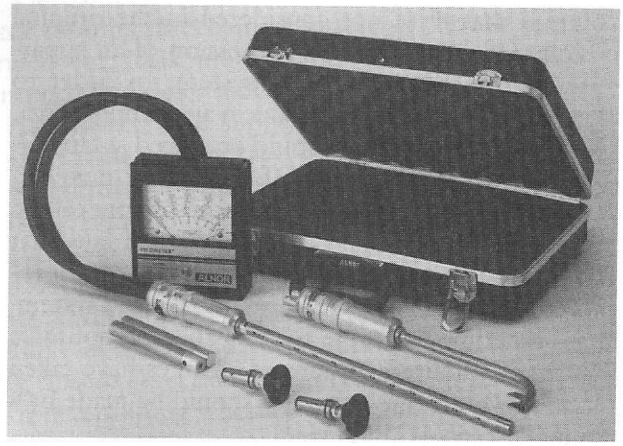

Figure 6-3: A velometer is a common instrument for measurement of air flow across the face of a duct or air diffuser. This measurement can be used to calculate the amount of air being supplied to the diffuser by the HVAC unit, which can then be compared to a recommended airflow.

Evaluating the Amount of Makeup Air

The function of makeup air is to ensure adequate oxygen content and to dilute indoor air contaminants to levels that are acceptable and healthful for most of the occupants of the space. Possible contaminants include carbon dioxide as well as odor- or symptom-producing gases, vapors, dusts, molds, and other airborne substances.

Instrument	Use/Purpose
Thermometer	Determine temperature of outside, supplied, and return air; helps in determining percentage of outside air being drawn into system.
Velometer; rotating vane anemometer; hot-wire anemometer	Direct measurement of velocity of airflow; can be used to evaluate actual performance of HVAC vs. design specifications.
Gas-detection instruments; detector tubes	Direct measurement of contaminant concentrations in ducts and areas of the building; carbon dioxide is commonly used as an indicator gas for IAQ benchmarking.
Psychrometer	Relative humidity
Smoke tubes	Generate small amounts of visible smoke used to observe airflow patterns.
IAQ multi-function instruments	These instruments are capable of providing direct-readout measurements such as: air temperature; humidity; CO_2; air velocity; and dewpoint. Many of them have computer-interface capabilities for downloading numerous stored measurements taken during an investigation.

Table 6-2: These are just a few of the instruments that are used to evaluate indoor air quality. Although many of the instruments are simple, the data they provide can assist in identifying most air quality problems associated with HVAC system operation.

Carbon dioxide is relatively easy to measure and is widely used as an indicator of the effectiveness with which the HVAC system is diluting contaminants and mixing the air. The levels of CO_2 present in a space will vary depending on how many people occupy the area; consequently, the levels will tend to increase in the course of a workday or shift. After

When using outside air conditions such as temperature or CO_2 concentration to evaluate flow into a space, the IH should try to obtain the data for outside air as near as possible to the air intake location. For example, if the CO_2 measurement is taken outside the main entry, it may be different from the concentration of CO_2 that might be obtained on the roof, or in the alley, where the intake is located.

the workers have gone home and the area is vacant, levels of CO_2 will drop if the HVAC system continues to provide outside air to the space. The predictability of this cycle allows for some simple evaluations of airflow in an occupied space, using CO_2 as the indicator gas. The basis for these tests is that a volume of outside air brought into a space will reduce the concentration of the indicator gas (in this case, CO_2) present by an amount proportional to the volume of outside air introduced.

A simple method for estimating the volume of outside air flowing into a space involves taking measurements of the CO_2 levels both inside and outside the space. The levels can be compared using the following equation:

$$Q_{OA} \approx \frac{13{,}000\ x}{C_{in} - C_{out}}$$

Where

Q_{OA} = the volumetric flow rate of outside air in cfm,

C_{in} = the concentration of CO_2 inside the space; and

C_{out} = the concentration of CO_2 outside the space.

To illustrate, let's assume the IH has done some preliminary IAQ investigative work and suspects that the HVAC system is not delivering enough outside air to a corner office. She counts 10 people occupying the space. By noon, the CO_2 concentration has leveled off at about 1,100 ppm, as indicated by a direct-reading instrument. The outdoor CO_2 concentration is 335 ppm. The IH inserts her data into the equation:

$$Q_{OA} \approx \frac{13{,}000\ x}{C_{in} - C_{out}}$$

$$Q_{OA} \approx \frac{13{,}000\ (10)}{1{,}100 - 335}$$

$$Q_{OA} \approx 170 \text{ cfm, or about } 17 \text{ cfm/person.}$$

This volume of airflow is lower than the current flow of 20 cfm/person recommended in ASHRAE Standard 62-1989.

An instrument as simple as a thermometer can provide a great deal of information about the efficiency of an HVAC in bringing outside air to the occupied space. There is a method for estimating the percentage of outside air that involves the use of temperature along with the following equation:

$$\%OA \approx \frac{T_{RA} - T_{SA}}{T_{RA} - T_{OA}} \times 100\%$$

Where

T_{RA} = the temperature of the return air,

T_{SA} = the temperature of the air supplied to the occupied area, and

T_{OA} = the temperature of the outside air.

An example of the use of this equation follows.

The following temperatures were measured at the designated locations in the HVAC system:

T_{RA} = 72°F

T_{SA} = 65°F; and

T_{OA} = 50°F

What is the percentage of outside air being drawn into the system?

Using the equation:

$$\%OA \approx \frac{T_{RA} - T_{SA}}{T_{RA} - T_{OA}} \times 100\%$$

$$\%OA \approx \frac{72 - 65}{72 - 50} \times 100\%$$

$$\%OA \approx 31.8, \text{ or } 32\ \%$$

The percentage of outside air must be compared to the total amount of air supplied by the HVAC unit to determine whether an adequate volume of outside air is being circulated by the unit. For example, if the 32 percent calculated above is applied to an HVAC unit supplying 1,000 cfm to an area occupied by 10 people, or 100 cfm/person, the system is providing approximately 32 cfm/person of outside air. This exceeds the minimum ASHRAE recommendation of 20 cfm/person.

A similar method involves the use of measured levels of CO_2 for estimating the percentage of outside air, using the equation:

$$\%OA \approx \frac{C_{RA} - C_{SA}}{C_{RA} - C_{OA}} \times 100\%$$

Where

C_{RA} = the concentration of CO_2 in the return air,

C_{SA} = the concentration of CO_2 in the air supplied to the occupied area, and

C_{OA} = the background concentration of CO_2, in outside air.

Let's assume the IH has taken some CO_2 measurements in the HVAC system, with the following results:

C_{RA} = 800 ppm

C_{SA} = 700 ppm

C_{OA} = 350 ppm

We can use the equation to estimate the amount of outside air as follows:

$$\%OA \approx \frac{C_{RA} - C_{SA}}{C_{RA} - C_{OA}} \times 100\%$$

$$\%OA \approx \frac{800 - 700}{800 - 350} \times 100\%$$

$$\%OA \approx 22\%$$

The percentage of outside air must be applied to the total volume being supplied to the occupied area as described above. If we assume that this example is for the same HVAC unit and occupancy levels, the amount of outside air is approximately 22 cfm/person. This is slightly above the ASHRAE minimum recommendation for outside air of 20 cfm/person.

Another simple but useful evaluation involves taking CO_2 measurements in the occupied space throughout the day, at specific times; for example, in the morning near the start of the day, at midday, after quitting time, and one hour or so later. These measurements will provide an indication as to how well the system is diluting buildup of CO_2 levels after the occupants leave. It is important that most of the people have gone from the building before taking the final two measurements. If the concentration of CO_2 does not drop, or if it drops slowly, it could be an indication that little or no outside air is being drawn into the system. Beware, too, of some systems that automatically dial back the amount of outside air after a preset quitting time.

Other equations are used to evaluate the performance of an HVAC system. Additional information about the use of other equations and/or more complex IAQ studies is available in the references at the end of the book.

Checking Your Understanding

1. Name four instruments commonly used for IAQ studies. What types of measurements do they provide?
2. What types of measurements can be used to estimate the amount of outside air drawn into an HVAC system? Where are the measurements taken?
3. In the course of conducting an IAQ investigation, the IH measures and records the following CO_2 levels inside the building: 8 am (500 ppm), 1 pm (1,200 ppm), and at 6 pm (1,000 ppm). Outside the building near the HVAC intake, the levels are measured and found to be 300 ppm. The workers have gone home at 5:00 pm. What conclusions might you draw from these data?

6-5 Microorganism Contamination and IAQ

Microorganisms in an HVAC system can lead to odors and in some cases, disease or allergic reactions. These problems arise when the numbers of bacteria, fungi, or viruses increase due to conditions that favor their growth. The presence of these types of contaminants might be suspected if the inspection of the HVAC system revealed wet filters, wet duct insulation, or standing water in any part of the system, such as condensate pans or ducts. The presence of greenish or other slimy growth in the wet areas is another obvious clue. The fact that intakes are located adjacent to cooling towers is also a potential clue. The solution in all these cases is to identify and remedy the uncontrolled source of the moisture and to clean or replace the affected areas of the system. However, strong-smelling cleaning solutions used in the HVAC system may produce undesired odors or may be irritating.

Among the notable incidents involving disease-causing organisms in HVAC systems, Legionnaire's disease is one of the best known. This pneumonia-like disease is caused by bacteria that have been found in hot water systems, air conditioners, cooling towers, and condensate pans. The bacteria are probably transmitted through air and are inhaled, causing high fever, chills, general aches and pains, headache, and digestive tract discomfort within two days to a week after exposure. Although Legionnaire's disease has achieved much notoriety, it causes illness to only five percent or less of the exposed population. The notoriety is more likely related to the approximate 15 percent death rate among those that do become ill.

Small mammals and birds might gain access to HVAC systems, building nests at intakes and traveling through ducts. They may leave droppings or they might die in the ducts, resulting in contaminants being drawn into the system and circulated in the building air. The **Hanta virus** has been isolated in the droppings of deer mice in the western United States, but is suspected to be present in other parts of the country as well. Infections occur when disturbance of the droppings or nest materials generates airborne dust containing the virus, which is then inhaled. The illness produces a series of flu-like respiratory symptoms, which may be mistaken for other diseases, such as flu or bronchitis, sometimes resulting in death. The Hanta virus can be easily neutralized using a three percent hypochlorite (bleach) solution, which should be applied to the potentially infected materials and surfaces, and allowed to soak for 30 minutes or so. The creation of dust during cleanup should be avoided. Respirators with high efficiency particulate air filters may be advisable if the cleanup involves a large amount of material, or if personnel routinely perform such cleanup activities in the course of their job. Once such materials are removed from an HVAC system, it is advisable to try to prevent re-entry of the rodents (a task sometimes more easily approached than solved!).

Histoplasmosis is a fungal infection that usually affects the lungs, resulting in an allergic response, or a serious illness, sometimes causing death. The fungus is found in bat guano and bird droppings, which is why it is also known as bird-fanciers disease. Chickens, pigeons, and starlings are among some of the common carriers of the fungus. The discovery of nests and/or droppings in an HVAC system could warrant installation of wire mesh barriers and cleaning of the area using a sterilizing solution of three percent hypochlorite. Again, the creation of dust should be avoided, and appropriate PPE should be worn.

Allergic reactions to airborne allergens can result from hair, dander, droppings, and other materials being present in the HVAC system and circulated in the air supply. Symptoms may include fever, cough, and chest tightness, often occurring within a few minutes or hours after exposure. Identifying and removing allergens can be a tricky and costly business.

If a microbial or allergen contamination of the HVAC system is suspected and is causing severe reactions, it is wise to consult with a professional who specializes in microorganism sampling and detection. The methods and equipment used for these types of sampling are specialized and beyond the price range of most building maintenance budgets. The cost of hiring a consultant to perform such an investigation might be justified by liability concerns on the part of the employer or building owner.

Checking Your Understanding

1. What are some of the visible clues or signs that odors or other complaints might be related to microorganism contamination of an HVAC system?
2. Name some of the methods that can be used to prevent animals and birds from entering and contaminating the HVAC system.
3. Why should one avoid creating dust when cleaning out nests or droppings?
4. Why is PPE recommended for cleaning operations where Hanta virus or other pathogenic microorganisms are suspected?

PRESERVING THE LEGACY

6–6 Radon and Asbestos

Radon

Radon is a **decay product** of radium-226, which itself is a product of the decay of uranium-238. Radioactive materials give off energy in the form of **alpha particles, beta particles,** or **gamma rays** – depending on the isotope – as they change to a more stable isotope. The process by which they give off this energy is called **decay**, and the intermediate steps in the process are the decay products; the decay products of radon are called **radon daughters**. Both radium-226 and uranium-238 occur naturally in rocks and soil, with higher concentrations occurring in some rocky geographic locations. Buildings made with brick or stone may therefore contain some radon. The U. S. Geological Survey has produced a map that shows the general locations of geologic formations with potential to contain radon across the United States.

Radon is a gas that enters a building by diffusion through cracks and pores in the building foundation. It may also enter through the water supply, though this is less common. The amount of radon that enters a building is directly related to its location, the porosity of the soils, the porosity of the building foundation, the presence of cracks or openings in the building foundation, and the air pressure of the building relative to the surrounding

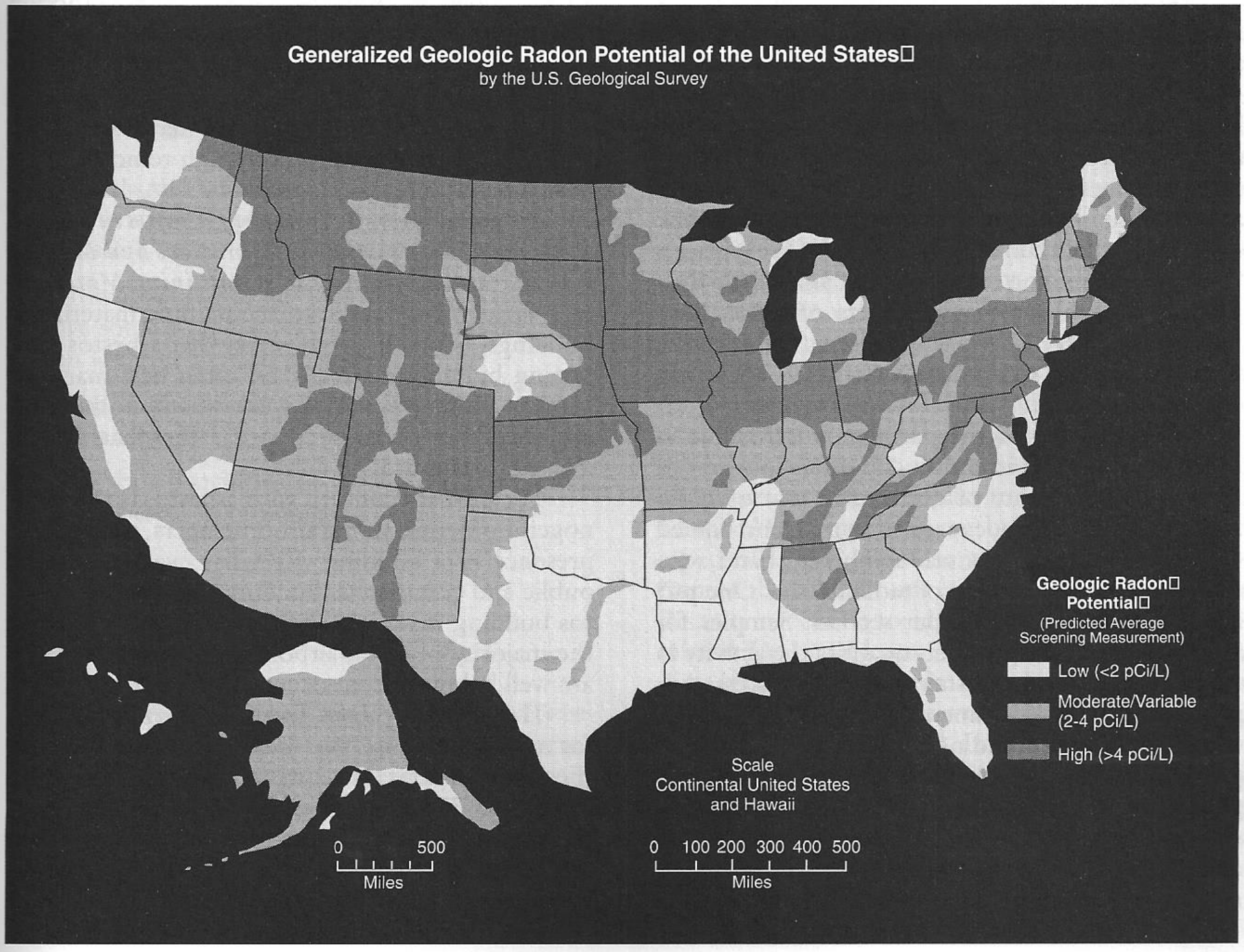

Figure 6-4: Map from USGS showing radon potential across the United States.

atmosphere. Buildings under low or negative pressure relative to the outdoors will tend to draw in air (and radon) from the outside. Because the basements of large buildings comprise a smaller proportion of the entire building volume, radon is of more concern in a single-family dwelling where the basement may comprise as much as 50 percent of the building volume.

The health concerns associated with radon are linked to two of its decay products, polonium-218 and polonium-214, both of which emit alpha particles as they decay to reach more stable forms. Alpha particles are composed of two protons and two neutrons, but have no electrons, resulting in a charge of +2. Alpha particles are primarily an internal hazard. They are not capable of traveling far through air – about two to four inches is the maximum range – or of penetrating simple barriers – skin or paper are effective shields – but if they are inhaled, they deposit their energy in tissues. This is suspected of causing lung cancer.

Related to decay is the **half-life**, which is the amount of time it takes for the radioactive material to decay to one-half of its original level of activity. Most radon decay products have very short half-lives and decay to stable forms quickly, in seconds or just a few minutes. However, for the two polonium isotopes mentioned above, the half-lives are about 30 minutes each, thus providing enough time to be inhaled. Other than inhalation of the particles themselves, building occupants can also inhale dust particles to which decay products of radon have become attached. This is why radon is considered a significant health risk where it occurs in high concentrations.

Like other radioactive particles, it is possible to describe radon and its radon daughters in terms of their **activity**, or rate of decay. The unit used for this is the **pico Curie**, expressed as **pCi**, and named for the physicists Marie Curie and her husband, who were pioneers in the field of radioactivity. One pCi is equal to 0.037 decays per second. Samples for radon and its decay products quantify the activity in terms of pCi per liter of air sampled, expressed as pCi/L. EPA has recommended that radon concentrations indoors should not exceed 4 pCi/L. Sampling for radon can be fairly simple and involves placement of canisters of activated charcoal in the space to be tested, leaving them for up to a week, and returning them to a laboratory for analysis. The most reliable measurements of radon are those taken over several months, since the concentration can vary on an hourly, daily, or even seasonal basis.

Since radon and its decay products pose an inhalation hazard, most control methods are aimed at reducing, removing, or preventing entry of radon gas into occupied areas of the building. Methods for controlling radon involve actions such as application of non-porous coatings on foundations or increasing ventilation of basements or crawl spaces. Each EPA regional office also has one or more persons assigned to radon issues, and state health departments provide local resources for information and testing.

Asbestos

The presence of asbestos is often perceived as an indoor air quality issue in many buildings. This is due to the general assumption that the mere presence of asbestos poses a health hazard, even though this has been proven not to be accurate. The EPA regulations of the 1980s and early 1990s resulted in many school districts launching full-scale removal of all asbestos-containing building materials – often by unskilled contractors – although removal of asbestos was never recommended by EPA. In fact, the EPA's "green book" (*Managing Asbestos in Place, a Building Owner's Guide to Operations and Maintenance Programs for Asbestos-Containing Materials*) on management of asbestos-containing materials in buildings, issued in 1990, states that asbestos-containing building materials are often best managed in place. Where removal work was done improperly, the removal actions created, rather than abated, an asbestos hazard.

The primary concern with asbestos is the carcinogenic potential of the airborne fibers, not its mere presence in a building. EPA has evaluated many public and commercial buildings containing asbestos building materials, with the conclusion that in the majority of cases, airborne asbestos fiber levels are well below current occupational limits.

The 1995 revisions to the OSHA regulations for asbestos require that building owners identify the asbestos-containing materials present in their buildings. They are also required to notify the occupants of the building that the materials are present and what actions, if any, personnel should take to avoid creating a hazard. Locations that contain large amounts of asbestos, such as mechanical rooms or boiler rooms, must be posted to alert persons to the presence of asbestos. Other provisions are included in the regulation to ensure that construction and maintenance contractors are informed about any asbestos that might be disturbed by their work.

The OSHA regulation does require air monitoring during an abatement action. Neither OSHA nor EPA require air sampling as part of the hazard assessment process once asbestos has been identified in the building. This is significant since recent studies have shown little correlation between levels of airborne asbestos fibers – which present a health risk – and the physical condition of asbestos. An assessment based on the physical condition of the asbestos-containing materials, their location and accessibility, likelihood and source of disturbances, as well as airborne fiber levels, is probably the best approach. Additional information about asbestos hazards and managing asbestos materials in place can be obtained from regional EPA offices, or from state environmental quality agencies.

Checking Your Understanding

1. What is the primary health concern associated with radon? What level does EPA consider to be safe?
2. How does radon get into buildings, and what are some ways for remediating a building with an identified radon problem?
3. What is the primary health concern associated with asbestos?
4. List four provisions of the OSHA regulations for asbestos in buildings.

Summary

Concern about indoor air quality is a relatively recent phenomenon that is increasingly encountered by occupational health professionals. Potential sources of air quality problems and contaminants include chemicals from cleaners and building materials such as furniture and carpet; odors from office equipment; plant pollen, microbes, and mold spores; and odors, chemicals, and various types of foreign materials that are drawn into the HVAC system from outside of the building. About half of NIOSH studies performed in the past 25 years found IAQ problems attributable to the HVAC system, specifically in terms of poor design or improper maintenance. Other problems associated with poor IAQ included chemical contaminants or microbes in the HVAC itself or drawn in from outdoors. In some situations, a low level of job satisfaction played a role, while in some others no obvious cause was identifiable. The possibility for poor IAQ is directly proportional to the density of the building population. Common complaints heard by occupational health professionals include problems with temperature extremes, humidity, stuffiness or lack of air circulation, odors, as well as physical symptoms such as headaches, dry eyes, respiratory irritation, and fatigue.

Although there is no OSHA standard for IAQ, consensus standards are used for design and evaluation of HVAC systems. These include ASHRAE standards for ventilation for acceptable air quality, thermal environmental conditions, and methods for testing air cleaning devices. These standards contain recommendations for minimum amounts of airflow in occupied areas, design requirements for location and maintenance of HVAC systems, recommended levels of humidity and CO_2, and others.

Most HVAC systems fall into one of four main types: 1) single-zone, constant volume; 2) single-zone, variable volume; 3) multiple zone, constant volume; or 4) multiple zone, variable volume. HVAC systems may also combine aspects of one or more of these four types. Each HVAC unit serves a portion of the building space, called a zone. Typically, the HVAC unit heats/cools, humidifies/dehumidifies, and filters air that it supplies to the zone it services. Many IAQ complaints can be attributed to some aspect of HVAC maintenance or operation. Inspection of the HVAC unit and the supply and return ducts is necessary to identify and correct HVAC-related IAQ problems. Accumulation of moisture, dirt, organic matter, animal droppings, or carcasses may all contribute to microbial growth and odors, which result in poor IAQ. Improper or blocked airflow is another possible HVAC problem. Checklists are provided in the Appendix to aid in performing HVAC inspections. The use of simple instruments to gather data on air temperature and CO_2 concentrations is explained, and sample problems are worked to show how these data can be used to evaluate HVAC system performance in practical situations.

Radon and asbestos are two of the more common IAQ concerns that may pose serious health hazards at high concentrations. Radon is a radioactive gas that is linked to lung cancer. It can be measured using simple passive detectors, which are analyzed by a laboratory following the sampling period. Effective methods for controlling radon are 1) ventilation, and 2) sealing cracks and other openings in basements and foundations to prevent the entry of radon gas.

Asbestos typically does not pose a hazard to building occupants, but may be of concern to maintenance and custodial workers whose job duties involve disturbance of installed asbestos-containing materials. OSHA regulations require building owners to identify asbestos-containing materials and inform building occupants, contractors, and others who perform work that might disturb the asbestos materials as to the location of such materials. Evaluation of the hazard posed by asbestos-containing materials present in an occupied building is probably best done through an assessment of the physical condition of the materials, their potential for disturbance, and through air sampling to evaluate levels of airborne asbestos fibers.

Critical Thinking Questions

1. Explain why IAQ studies may result in data that, while interesting, do not identify the source or cause of the complaints.

2. Why do you suppose that OSHA has not issued a regulation that dictates minimum air quality requirements for non-industrial settings? Are there any advantages to relying on consensus standards, and if so, what are they?

3. You are called upon to investigate complaints of moldy odors and stuffiness in the offices located at the front of the plant. Describe how you would complete the investigation, including your strategy for performing inspections and tests.

4. During a safety meeting, someone expresses concern about the presence of asbestos insulation in the penthouse mechanical room and then states that they have noticed a lot of people in the building suffering from respiratory illnesses. How would you respond?