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7 Indoor Environmental Quality

7.1 General Overview

During the past few decades the general public has become increasingly aware of the health hazards related to contaminated air. A variety of factors have been found to contribute to poor indoor-air quality in buildings, the primary one being indoor pollution sources that release gases or particles into the air. Other major sources include outdoor pollutants near the building; pollution carried by faulty or inadequate ventilation systems; and a variety of combustion sources such as tobacco smoke, gas, oil, kerosene, coal, wood, and emissions from building materials, furnishings, and various types of equipment. The relative importance of a particular source depends mostly on the amount of a given pollutant it emits and how hazardous those emissions are. The people who are affected most by poor indoor-air quality are those who are exposed to it for the longest periods of time. These groups typically consist of the young, the elderly, and the chronically ill, especially those suffering from respiratory or cardiovascular disease.

Poor indoor environmental quality has become a major concern in homes, schools, and workplaces; it can lead to poor health, learning difficulties, and productivity problems. Since the majority of us spend up to 90 percent of our time indoors (especially in the United States), it is not surprising that we should expect our indoor environment to be healthy and free from the plethora of hazardous pollutants. Yet studies by the American College of Allergies show that roughly 50 percent of all illness is aggravated or caused by polluted indoor air. Moreover, cases of building-related illness (BRI) and sick-building syndrome (SBS) continue to rise. The main reason is that the indoor environment we live in is often contaminated by various toxic or hazardous substances as well as pollutants of biological origin (Figure [7.1]). In fact, recent studies point to the presence of more than 900 possible contaminants, from thousands of different sources, in a given indoor environment.

Indoor-air pollution is now generally recognized as having a greater potential impact on public health than most types of outdoor-air pollution, causing numerous health problems from respiratory distress to cancer. Furthermore, a building interior’s air quality is one of the most pivotal factors in maintaining building occupants’ safety, productivity, and wellbeing.

This heightened public awareness has led to a sudden surge of demands from building occupants for compensation for their illnesses. Tenants are not only suing building owners but also architects, engineers, and others involved in the building’s construction. To shift the blame, building owners have made claims against the consultant, the contractor, and others involved in the construction of the facility.
While architects and engineers to date have not been a major target of publicity or litigation arising out of IAQ issues, nevertheless the potential scope and cost of some of the incidents have resulted in everyone associated with a project being blamed when the inside air of a building appears to be the cause of occupants becoming sick. This is causing great concern among design professionals, because it can result in a loss of reputation as well as time and money.

Due to the intense competition to maintain high occupancy rates, forward-thinking owners and managers of offices and public buildings find themselves under increasing pressure to meet or exceed the demands of the marketplace in attracting and retaining tenants. Moreover, in today’s increasingly litigious society, they add another factor to be addressed – protecting their investment from liability due to air-quality issues.

Technological breakthroughs are bringing down the cost of facility monitoring systems and making them more affordable for a wider range of building types. By reducing the cost of facility monitoring many financial and maintenance obstacles are removed, making permanent monitoring systems an appropriate consideration for a broader range of facility managers. Schools, healthcare facilities, and general office buildings can benefit from measuring many of the environmental conditions and using that information to respond to occupant complaints, optimize facility performance, and
keep energy costs in check. In addition, feedback from the indoor environment can be used to establish baselines for building performance and document improvements to indoor-air quality.

Facility monitoring systems can be valuable instruments for improving indoor-air quality, identifying energy-savings opportunities, and validating facility performance. Automating the process of recording and analyzing relevant data and providing facility managers adequate access to this information can improve their ability to meet the challenge of maintaining healthy, productive environments.

Buildings are dynamic environments – but sometimes the original design calculations, which may have been sound, need modifying after they are operational. Experience tells us that a building’s functions and occupancy rates may change. These changes can have a significant impact on the HVAC system’s ability (as originally designed) to maintain a balance between occupant comfort, health, productivity, and operating costs.

Indoor pollution is found to exist under many diverse conditions from dust and bacterial buildup in ductwork to secondhand smoke and the offgassing of paint solvents, all of which are potential health hazards.

The primary causes of poor indoor-air quality are sources that release gases or particles into the air. Inadequate ventilation is considered the single most common cause of pollutant buildup (Figure 7.2a) because it can increase indoor pollution levels by not bringing enough outdoor air in to dilute emissions from indoor sources and by not removing indoor-air pollutants to the outside. High temperature and humidity levels can also increase concentrations of some pollutants. The second most common cause of pollutant buildup is inefficient filtration (Figure 7.2b). But despite fundamental improvements in air-filter technology, far too many buildings persist in relying on inefficient filters or continue to be negligent in the maintenance of filters.

An investigation into indoor-air contamination can be triggered by several factors including the presence of biological growth (mold), unusual odors, and adverse health concerns of occupants, including respiratory problems, headaches, nausea, irritation of eyes, nose, or throat, and fatigue.

![Ventilation Status](image1)

![Filtration Status](image2)

**Figure 7.2** (a) Inadequate ventilation is the single most common cause of pollutant buildup. (b) Inefficient filtration is the second most important factor in indoor pollution. 
*Source: HBI Database.*
Indoor environmental quality (IEQ) and energy efficiency may be classified into three basic categories: comfort and ventilation, air cleanliness, and building pollutants. Within these basic categories, facility-wide monitoring systems are available that can provide independent measurement of a range of parameters, such as temperature, humidity, total volatile organic compounds (TVOCs), carbon dioxide (CO₂), carbon monoxide (CO), and airborne particulates. Any information that is extracted from continuous monitoring can help minimize the total investigative time and expense needed to respond to occupant complaints; the information can also be used proactively in the optimization of building performance.

Unfortunately, to this day there has been insufficient federal legislation governing indoor-air quality. This has led several engineering societies such as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) to establish guidelines, which are now generally accepted by designers as minimum design requirements for commercial buildings. ASHRAE has established two procedures for determining minimum acceptable ventilation rates: the ventilation-rate procedure, which stipulates a minimum ventilation rate based on space functions within a specified building type and respiration rates resulting from occupants’ activities; and the indoor-air quality procedure, which requires the monitoring of certain indoor-air contaminants below specified values.

Air sampling techniques require the use of a device to impinge organisms from a specific volume of air and place it onto a sterile agar growth medium. The sample is then incubated for a specified period of time (say, seven days). The colonies are then counted and the results recorded. When testing the air of a potentially contaminated area, it is best practice to have comparative samples of air from both the contaminated area and the air outside the potentially contaminated building.

Sometimes building occupants complain of symptoms that do not appear to fit the pattern of any specific illness and are difficult to trace to any specific source. This has been labeled sick building syndrome (SBS) and is a fairly recent phenomenon. It is a term used to describe situations in which building occupants experience acute health and discomfort effects that appear to be attributed to time spent in a building, but often no specific illness or cause can be identified. Complaints may be localized in a particular room or zone or may be widespread throughout the building. Factors that may impact SBS include, noise, poor lighting, thermal discomfort, and psychological stress. The EPA’s indoor-air-quality website contains pertinent information regarding strategies for identifying the causes of SBS as well as finding possible solutions to the problem. SBS indicators include:

- Building occupants complaining of symptoms associated with acute discomfort, such as eye, nose, or throat irritation; headaches; respiratory infections and dry cough; dry or itchy skin; erythema (redness of the skin, inflammation); dizziness and nausea; irritability and forgetfulness; difficulty in concentrating; fatigue or lethargy; and sensitivity to odors.
- Cause of symptoms not identified.
- Most complainants find relief shortly after leaving building.

In contrast, building-related illness (BRI) is the general term used to describe symptoms of a medically diagnosable illness that is caused by or related to occupancy of
a building and that can be attributed directly to airborne building contaminants. The causes of BRIs can be determined and are typically related to allergic reactions and infections. BRI indicators of include:

- Building occupants complain of symptoms such as cough, fever, chills, chest tightness, and muscle aches.
- Symptoms can be clinically defined and have clearly identifiable causes.
- Complainants may require extended recovery times after leaving the building.

It should be noted that there is no particular manner in which these health problems appear. Sometimes, they begin to appear as workers enter their offices and diminish or disappear as workers leave; at other times symptoms persist until the illness is treated. On occasion there are outbreaks of illness among many workers in a single building; in other cases, they show up only in individual workers.

Complaints may also result from other causes. Since SBS symptoms are quite diverse and nonspecific, it can seem that they could arise from numerous other ailments completely unrelated to indoor air quality. In light of these types of complaints, technical and medical scholars have searched for a satisfactory definition of SBS, especially since it is the most common indoor-air-quality problem in commercial buildings today. To this end, some World Health Organization (WHO) experts estimated that 30 percent of all new and renovated commercial buildings in the U.S. suffer from SBS, and furthermore the expenses in terms of medical costs and lost production may be in the tens of billions of dollars per year in the U.S. alone.

According to industry IAQ standards, SBS is diagnosed if significantly more than 20 percent of a building’s occupants complain of adverse health effects such as headaches, eye irritation, fatigue, and dizziness over a period of two weeks or more, but no clinically diagnosable disease is identified, and the SBS symptoms disappear or are diminished when the complainants leave the building.

We are surrounded by microorganisms both indoors and outdoors. Some microorganisms are good for our health, while others can harm us; most microorganisms are benign. It is important to prevent buildings from becoming breeding grounds for harmful microbes, and to do that one needs to deprive them of the essentials they need to live. Water is one of microbes’ main survival ingredients. It can come from leaky roofs, burst water pipes, or warm, moist air, as when water is absorbed by ceiling tiles, drywall, and carpet padding.

The greatest amount of our time is spent indoors, and more than half of today’s workforce spends much of it sitting in front of a computer screen. It is not surprising that we should witness a steady increase in chronic work-related illness, including repetitive stress injuries, asthma, and cardiovascular disease— all suggesting that much of our artificial environment is hazardous to workplace productivity.

It has been known for some time that indoor environments strongly affect human health. The EPA, for example, has estimated that pollutant concentration levels (such as volatile organic compounds) inside a building may be two to five times higher than outside levels. A 1997 study by W.J. Fisk and A.H. Rosenfeld (“Estimates of Improved Productivity and Health from Better Indoor Environments,” Indoor Air, vol. 7, pp. 158–172) estimates that the cost to the nation’s workforce of upper-respiratory diseases in
1995 reached $35 billion in lost work, which doesn’t include an estimated additional $29 billion in healthcare costs. The report suggests that these costs could be reduced by 10 to 30 percent by healthier and more efficient indoor environments.

Certain attributes of indoor environments can also have a strong impact on occupant wellbeing and functioning; these include personal control over environmental conditions, the amount and quality of light and color, the sense of privacy, access to window views, connection to nature, and sensory variety. Proper design that takes into consideration occupants’ psychological well-being will have a positive impact on worker productivity and effectiveness as well as on other high-value issues, such as stress reduction, job satisfaction, and organizational loyalty.

In order to fully profit from the fiscal, physical, and psychological benefits of healthy buildings, projects need to incorporate a comprehensive, integrated design and development process that seeks to:

- Ensure adequate ventilation
- Provide maximum access to natural daylight and views to the outdoors
- Eliminate or control sources of indoor-air contamination
- Prevent water leaks and unwanted moisture accumulation
- Improve the psychological and social aspects of space

There are currently several environmental rating methods for buildings, but it is not always clear whether these methods assess the most relevant environmental aspects or whether other considerations lie behind the specific methods chosen. The Swedish rating method bases the selection on a number of factors such as the severity and extent of problems, mandatory rules, official objectives, and current practice. Upon identifying the presence of building-related health problems, possible indicators for monitoring these problems can be tested with respect to the theoretical and practical criteria applied in order to better understand the strengths and limitations of different indicators.

Concern for occupant health continues to increase with increased awareness, and this has translated into public demand for more exacting performance requirements for materials selection and installation, improved ventilation practices, and better commissioning and monitoring protocols.

Many of the building products used today contain chemicals that evaporate or off-gas for significant periods of time after installation. When substantial quantities of these products are utilized inside a building or products are used that have particularly strong emissions, they pollute the indoor air and can be hazardous. Some products readily trap dust and odors and release them over time. Building materials, particularly when damp, can also support growth of mold and bacteria, which can cause allergic reactions, respiratory problems, and persistent odors – i.e., SBS symptoms.

The Insurance Information Institute (III) reports a dramatic increase in IAQ-related lawsuits within the United States; there are currently more than 10,000 IAQ-related cases pending. Several lawsuits have resulted in large damage awards to building occupants suffering from health problems linked to chemicals off-gassed from building materials, setting legal precedents across the country.
The flood of IAQ-related lawsuits has prompted insurance companies to reexamine their policies and their clients’ design and building methods. An effective way to reduce health risks and thus minimize potential liability is to follow a rigorous selection procedure for construction materials aimed at minimizing harmful effects to occupants.

7.2 Indoor Environmental Quality and Factors Affecting the Indoor Environment

According to a report on indoor environmental quality released by the United States Access Board in July 2005, there is a growing number of people suffering a range of debilitating physical reactions from exposures to everyday materials and chemicals found in building products, floor coverings, cleaning products, and fragrances, among others. In addition, there are those who have developed an acute sensitivity to various types of chemicals, a condition known as multiple chemical sensitivity (MCS). The range and severity of these reactions vary as do the potential triggering agents.

7.2.1 Indoor-Air Quality

The health and productivity of employees and tenants are greatly influenced by the quality of the indoor environment, and studies consistently reinforce the correlation between improved indoor environmental quality and occupants’ health and wellbeing. The adverse effects to building occupants caused by poor air quality and lighting levels, the growth of molds and bacteria, and off-gassing of chemicals from building materials can be significant. One of the chief characteristics of sustainable design is to support the wellbeing of building occupants by reducing indoor-air pollution. This can best be achieved through the selection of materials with low off-gassing potential, appropriate ventilation strategies, adequate access to daylight and views, and optimum comfort through control of lighting, humidity, and temperature levels.

7.2.1.1 Inorganic Contaminants

Inorganic substances such as asbestos, radon, and lead are among the leading indoor contaminants whose exposure can create significant health risks.

7.2.1.1.1 Asbestos

Asbestos is a generic term given to a variety of naturally occurring, hydrated fibrous silicate minerals that possess unique physical and chemical properties that distinguish them from other silicate minerals. Such properties include thermal, electric, and acoustic insulation; chemical and thermal stability; and high tensile strength, all of which have contributed to their wide use by the construction industry (Figure 7.3).

High concentrations of airborne asbestos can occur during demolition and after asbestos-containing materials are disturbed by cutting, sanding, and other activities. Inadequate attempts to remove these materials could release asbestos fibers into the air,
Sample Asbestos-Containing Material List

| Asbestos-Containing Materials                                      | Asbestos-Containing Materials                                      |
|-------------------------------------------------------------------|-------------------------------------------------------------------|
| Acoustical ceiling texture                                         | Gray roofing paint                                                |
| Asphalt flooring                                                  | High temperature gaskets                                          |
| Base flashing                                                     | HVAC duct insulation                                              |
| Blown-in insulation                                               | Incandescent light fixture backing                                |
| Boiler/tank insulation                                            | Joint compound/wallboard                                          |
| Breaching insulation                                              | Laboratory hoods/table tops                                      |
| Brick mortar                                                      | Laboratory fume hood                                              |
| Built-up roofing                                                  | Mudded pipe elbow insulation                                      |
| Caulking/putties                                                  | Nicolet (white) roofing paper                                     |
| Ceiling tiles/panels/mastic                                       | Packing materials                                                 |
| Cement board                                                      | Paper fire box in walls                                           |
| Cement pipes                                                      | Pipe insulation/fittings                                          |
| Cement roofing shingles                                           | Plaster/wall joints                                               |
| Chalkboards                                                       | Poured flooring                                                   |
| Construction mastics                                              | Rolled roofing                                                    |
| Duct tape/paper                                                   | Roofing shingles                                                  |
| Ductwork flexible connections                                     | Sink insulation                                                   |
| Electrical cloth                                                  | Spray-applied insulation                                          |
| Electrical panel partitions                                       | Stucco                                                            |
| Electrical wiring insulation                                      | Sub flooring slip sheet                                           |
| Elevator brake shoes                                              | Textured paints/coatings                                          |
| Fire blankets                                                     | Vapor barrier                                                     |
| Fire curtains/hose                                                | Vermiculite                                                       |
| Fire doors                                                        | Vinyl floor tile/mastic                                           |
| Fireproofing                                                      | Vinyl sheet flooring/mastic                                       |
| Furnace insulation                                                | Vinyl wall coverings                                               |

**Note:** This is a sample list of products that may contain asbestos. It is intended as a general guide to show which types of materials may contain asbestos and is not all inclusive.

**Figure 7.3** Partial list of materials that may contain asbestos.

thereby increasing asbestos levels and endangering people living or working in these spaces.

Asbestos-containing material has become a high-profile public concern after federal legislation known as AHERA (Asbestos Hazard Emergency Response Act) was enacted in 1987. The Environmental Protection Agency and Consumer Product Safety Commission have also banned several asbestos products, and manufacturers have voluntarily limited uses of asbestos. Today, asbestos can still be found in older homes, in pipe and furnace insulation materials, shingles, millboard, textured paints and other coating materials, and floor tiles. Asbestos is considered the most widely recognized environmentally regulated material (ERM) during building evaluations.

Asbestos-containing materials are also found in concealed areas such as wall cavities, below ground level, and other hidden spaces. In many older establishments, asbestos-based insulation was used on heating pipes and on the boiler. An adequate asbestos survey requires the inspector to perform destructive testing (i.e., opening walls, etc.) to inspect areas likely to contain suspect materials.
7.2.1.1.2 Health Hazards

The most dangerous asbestos fibers are too small to be visible. The health danger of asbestos fibers depends mainly upon the quantity of fibers in the atmosphere and the length of exposure. Asbestos is made up of microscopic bundles of fibers that may become airborne when asbestos-containing materials are damaged or disturbed. Impaction and abrasion are typically the chief causes of increased airborne-fiber levels. The type, quantity, and physical condition of the asbestos-based material have a significant bearing on the degree of risk.

The risk of airborne asbestos fibers is generally low when the material is in good condition. However, when the material becomes damaged or if it is located in a high-activity area (family room, workshop, laundry, etc.) the risk increases. Increased levels of exposure to airborne asbestos fibers will cause disease. When these fibers get into the air, they may be inhaled and accumulate in the lung tissue, where they can cause substantial health problems including lung cancer, mesothelioma (a cancer of the chest and abdominal linings), and asbestosis (irreversible lung scarring that can be fatal). Symptoms of these diseases do not show up until many years after exposure began. Studies show that people with asbestos-related diseases were usually exposed to elevated concentrations on the job, although some developed disease from exposure to clothing and equipment brought home from job sites. While the process is slow and years may pass before health problems are evidenced, the results and thus the risks are well established.

7.2.1.1.3 Radon

Radon is a natural odorless, tasteless, radioactive gas that is emitted from the soil as a carcinogenic byproduct of the radioactive decay of radium-226, which is found in uranium ores (although radon itself does not react with other substances). The byproduct can cling to dust particles that, when inhaled, settle in bronchial airways. Generally, radon is drawn into a building environment by the presence of air-pressure differentials. The ground beneath a building is typically under higher pressure than the basement or foundation. Air and gas move from high-pressure areas to low-pressure areas. The gas can enter the building through cracks in walls and floors as well as penetrations associated with plumbing, electrical openings, and sump wells in building spaces coming in close contact with uranium-rich soil. Vent fans and exhaust fans also put a room under negative pressure and increase the draw of soil gas, which can increase the level of radon within a building. Radon exposure becomes a concern when it becomes trapped in buildings and indoor levels of concentrations build up.

Adequate ventilation is necessary to prevent radon from accumulating in buildings to dangerous levels, as this can pose a serious health hazard. Where radon is suspected, a survey should be conducted to measure the concentrations in the air and determine whether any actions will be required to reduce the contamination. Radon levels will vary from region to region, season to season, and building to building. Radon levels are typically at their highest during the coolest part of the day when pressure differentials are at their greatest.
According to the Environmental Protection Agency, radon is the cause of an estimated 14,000 lung-cancer deaths annually. The primary factors affecting radon concentrations in the air are ventilation and the radon source. The most common radon source is the presence of radium-226 in the soil and rock surrounding or adjoining basement walls and cellar floor slabs. Although you cannot see radon, it’s not hard to find out if you have a radon problem in your home or office. There are many kinds of inexpensive, state-certified do-it-yourself radon test kits available through the mail or in hardware stores and other retail outlets. When radon decays and is inhaled into the lungs, it releases energy that can damage the DNA in sensitive lung tissue and cause cancer.

When high concentrations of radon in air are detected, it is often an indication of possible radon contamination of the water supply (if a private water supply is present). In this case, a water test for radon is the prudent first step. Should high concentrations of radon be found in the water, then an evaluation of ventilation rates in the structure as well as air-quality tests for radon are highly recommended. Generally speaking, high radon concentrations are more likely to exist where there are large rock masses, such as in mountainous regions. The Environmental Protection Agency (EPA) recommends that buildings should be tested every few years to assess the safety of radon levels.

7.2.1.1.4 Radon Mitigation
Everything being equal, elevated radon levels should not necessarily deter investors from purchasing a property, as the problem can usually be easily be resolved, even in existing buildings, without having to incur great expense. However, lowering high radon levels requires technical knowledge and special skills, which means a trained radon-reduction contractor who understands how to fix radon problems.

With new construction, some builders have starting to incorporate radon-prevention techniques in their designs. Some municipalities also have local building codes requiring prevention systems. The EPA has published several brochures and instructional aids regarding radon-resistant construction. This is perhaps the most cost-effective way to handle a radon problem, as it is easier to build the system into the building rather than to retrofit it later. If your building has a radon system built in, the EPA recommends periodic testing to ensure that the system is working properly and that the radon level in your building has not changed. The development of foundation cracks is one example of how the radon level could change.

EPA studies suggest that elevated radon levels are more likely to exist in energy-efficient buildings than otherwise. The reason is that radon can become hazardous indoors due to the limited outside air to dilute the indoor concentrations afforded by efficient construction. Although energy-efficient construction may save energy bills, it may also increase occupants’ exposure to radon and other indoor-air pollutants. It is also recommended that testing for radon should also be conducted when any major renovations are made to the building.

7.2.1.1.5 Health Risks
The principal health hazard associated with exposure to elevated levels of radon is lung cancer. Research suggests that, while swallowing water with high radon levels
may also pose risks, these are believed to be much lower than those from breathing air containing radon.

During the decaying process, radon emits alpha, beta, and gamma radiation. However, the real threat is not so much from the gas itself but from the products that it produces when it decays, such as lead, bismuth, and polonium. These products are microscopic particles that readily attach themselves to dust, pollen, smoke, and other airborne particles in a building and are inhaled. Once in the lungs, the particles become trapped, and, as they begin to decay, they expose the sensitive lung tissue to the harmful radiation they emit during the decaying process. The effect is cumulative, and elevated levels of radon exposure cause lung cancer in both smokers and nonsmokers alike. The risk would be greatest for people with diminished lung capacity, asthma sufferers, and smokers.

7.2.1.1.6 Radon Testing Methods
For short-term testing, consultants typically use electret ionization chambers, which generally last about a week. The chamber method works by incorporating a small charged Teflon® plate screwed into the bottom section of a small plastic chamber. When the radon gas enters the chamber, it begins to decay and creates charged ions that deplete the charge on the Teflon® plate. By registering the voltage prior to deployment and then reading the voltage upon recovery, a mathematical formula is used to calculate the radon concentration levels within the building.

For long-term testing, consultants prefer to use either long-term electret chambers (like those used for the short-term measurements) or alpha tracks. The alpha track, when deployed in the building, records the number of alpha particles that scratch the plastic surface inside the detector. The laboratory counts these microscopic indentations and then mathematically calculates the radon levels within the building.

7.2.1.1.7 Lead
For many years now, lead has been recognized as a harmful environmental pollutant to the extent that in late 1991 the Secretary of the Department of Health and Human Services described it as the “number one environmental threat to the health of children in the United States.” There are many ways in which humans may be exposed to mineral particles of lead: in ambient air, drinking water, food, contaminated soil, deteriorating paint, and dust. Lead is a heavy metal; it does not break down in the environment and continues to be used in many materials and products to this day. Lead is a natural element; and most lead in use today is inorganic lead, which enters the body when an individual breathes (inhales) or swallows (ingests) lead particles or dust once it has settled. Lead dust or particles cannot penetrate the skin unless it is broken. (Organic lead, however, such as the type used in gasoline, can penetrate the skin.)

7.2.1.1.8 Indoor Lead Levels
Because of its widespread use, lead has for some time been known to be a common contaminant of interior environments. For centuries lead compounds such as white lead and lead chromate have been used as white pigments in commercial paints.
In addition to their pigment properties, these lead compounds were valued because of their durability and weather resistance, which made them viable particularly in exterior paints. In addition to lead’s durability properties, it was also added to paint to improve its drying characteristics.

Old lead-based paint is considered the most significant source of lead exposure in the U.S. today. In fact, the majority of homes and buildings built before 1960 contained heavily leaded paint. Even as recently as 1978 there were homes and buildings that used lead paint. This paint may have been used on window frames, walls, the building’s exterior, or other surfaces. The improper removal of lead-based paint from surfaces by dry scraping, sanding, or open-flame burning can create harmful exposures to lead. High concentrations of airborne lead particles in a space can also result from lead dust from outdoor sources, including contaminated soil tracked inside; Harmful effects can also result from the use of lead in certain indoor activities such as soldering and stained-glassmaking.

Because of potentially serious health hazards and negative publicity, lead content was gradually reduced until it was eliminated altogether in 1978 (in the U.S.). In commercial buildings, lead was used primarily as a paint preservative.

Lead piping has sometimes been used in older buildings, and, while not legally required to be replaced, it can create a health hazard because frequently the piping deteriorates and leaches into the building’s drinking water. In some buildings lead solder has also been used in copper-pipe installation, but in most jurisdictions this procedure has now been banned due to water contamination resulting from the deterioration of the solder. In any case, any evaluation for lead contamination requires that the water content be analyzed by a laboratory and action then taken to mitigate the hazards if lead content is found to be in excess of regulated limits. The potential for water contamination can often be removed by chemical treatment of the water. Where this cannot be accomplished, the piping may have to be replaced.

Unfortunately, lead is still allowed in paint for bridge construction and machinery and thus remains a significant source of exposure. Its continued use is mainly due to its ability to resist corrosion and its ability to expand and contract with the metal surface of a structure without cracking. But even if its use were banned today, there would still be potential exposure to workers and surrounding communities for many years to come because of the many metal structures such as bridges that have been coated with it.

7.2.1.1.9 Health Risks
Lead is a highly toxic substance that affects a variety of target organs and systems within the body, including the brain and the central nervous, renal, reproductive, and cardiovascular systems. High levels of lead exposure can cause convulsions, coma, and even death. However, the nervous system appears to be the main target organ system for lead exposure.

One of the best methods to assess human exposure to lead is to measure the blood lead level, because it is a sensitive indicator of exposure that has been correlated with a number of health endpoints. It also gives an immediate estimate of the level of a
person’s recent exposure to lead. The negative aspect of measuring blood lead level is that, while it will tell you how much lead is in the bloodstream, it will not tell you what is stored in soft tissues or bones. Additionally, the test will not spell out your body burden of lead or any damage if any that has occurred.

Effects of lead poisoning depend largely on dose exposure. Contact with lead-contaminated dust is the primary method by which most children are exposed to harmful levels of lead. It enters a child’s body mainly through ingestion. Lead-contaminated dust is often hard to see but can get into the body and create substantial health risks. Pregnant women, infants, and children are more vulnerable to lead exposure because lead is more easily absorbed into growing bodies, and the tissues of small children are more sensitive to the damaging effects of lead. Ingestion of lead has been proven to cause delays in children’s physical and mental development as well as negatively impacting their developing nervous systems, causing lower IQ levels, increased behavioral problems, and learning disabilities.

In adults, high lead levels have many adverse effects, including kidney damage, digestive problems, high blood pressure, headaches, diminishing memory and concentration, mood changes, nerve disorders, sleep disturbances, and muscle or joint pain. A single very high exposure to lead can also result in lead poisoning. Adults’ bones and teeth contain about 95 percent of the body burden (total amount of lead stored in the body). Likewise, lead can seriously impact the ability of both men and women to bear healthy children.

7.2.1.1.10 Testing for Lead Paint
Inspectors employ various methods and procedures to assist them in identifying the presence of lead paint. In the field, the most widely applied method is the use of an x-ray fluorescent lead-in-paint analyzer (XRF). The XRF analyzer is normally held up to the surface being tested for several seconds. The analyzer then emits radiation, which is absorbed and then fluoresces (is emitted) back to the analyzer. The XRF unit breaks down the signals to determine if lead is present and if so in what concentration. An XRF analyzer can normally read through up to 20 layers of paint, but these analyzers are expensive and should only be used by trained professionals.

7.2.1.2 Contaminants Generated by Combustion
Some examples of combustion byproducts include fine particulate matter, carbon monoxide (CO), and nitrogen oxides. Tobacco smoke is another source.

Combustion (burning) byproducts are essentially gases and tiny particles that are created by the incomplete burning of fuels. These fuels (such as natural gas, propane, kerosene, fuel oil, coal, coke, charcoal, wood, gasoline, and materials such as tobacco, candles, and incense), when burned, produce a wide variety of air contaminants. If fuels and materials used in the combustion process were free of contaminants and combustion were complete, emissions would be limited to carbon dioxide (CO2), water vapor (H2O), and high-temperature reaction products formed from atmospheric nitrogen (NOx) and oxygen (O2). Sources of combustion-generated pollutants in indoor
environments are many and include wood heaters and wood stoves, furnaces, gas ranges, fireplaces, and car exhaust (in an attached garage).

There are several combustion-generated contaminants including CO$_2$, H$_2$O, carbon monoxide (CO), nitrogen oxides (NOx) such as nitric oxide (NO) and nitrogen dioxide (NO$_2$), respirable particles (RSP), aldehydes such as formaldehyde (HCHO) and acetaldehyde, as well as a number of volatile organic compounds (VOCs); fuels and materials containing sulfur will produce sulfur dioxide (SO$_2$). Particulate-phase emissions may include tar and nicotine from tobacco, creosote from wood, inorganic carbon, and polycyclic aromatic hydrocarbons (PAHs).

Carbon dioxide (CO$_2$) is a colorless, odorless, heavy, incombustible gas that is found in the atmosphere and formed during respiration. It is typically obtained from the burning of, gasoline, oil, kerosene, natural gas, wood, coal, and coke. It is also obtained from carbohydrates by fermentation, by the reaction of acid with limestone or other carbonates, and naturally from springs. CO$_2$ is absorbed from the air by plants in a process called photosynthesis. Although carbon dioxide is not normally a safety problem, a high CO$_2$ level can indicate poor ventilation, which in turn can lead to a buildup of particles and more harmful gases such as carbon monoxide that can negatively impact people’s health and safety. CO$_2$ is used extensively in industry as dry ice or carbon dioxide snow, in carbonated beverages, fire extinguishers, etc.

Carbon Monoxide (CO) is an odorless, colorless, lighter than air, nonirritating gas that interferes with the delivery of oxygen throughout the body. CO is the leading cause of poisoning deaths in the United States; it occurs when there is incomplete combustion of carbon-containing material such as coal, wood, natural gas, kerosene, gasoline, charcoal, fuel oil, fabrics, and plastics.

At low concentrations levels, healthy people may experience fatigue and shortness of breath during exertion. Flushed skin, tightness across the forehead, and slightly impaired motor skills may also occur. People with heart disease may encounter chest pain. The first and most obvious symptom is usually a headache with throbbing temples. Infants, children, pregnant women, the elderly, and people with heart or respiratory problems are most susceptible to carbon-monoxide poisoning. The fact that CO cannot be seen, smelled, or tasted makes it especially dangerous, because you are not aware when you are being poisoned. Moreover, CO poisoning is frequently misdiagnosed by both victims and doctors.

Mild to moderate CO poisoning may cause flu-like symptoms or gastroenteritis, particularly in children, including nausea, lethargy, and malaise. As the CO level or exposure time increases, symptoms become more severe and additional ones appear: irritability, chest pain, fatigue, confusion, dizziness, and impaired vision and coordination. Higher levels cause fainting upon exertion, marked confusion, and collapse. At very high concentrations, we may witness coma and convulsion as well as permanent damage to the brain, central nervous system, or heart and finally death.

The four primary sources of CO in the environment are:

- Automobile exhaust from attached garages combined with inadequate ventilation is responsible for two-thirds of all accidental CO deaths. Lethal levels of the gas can accumulate
in as little as 10 minutes in a closed garage. Certain occupations are exposed regularly to elevated levels of CO. These include toll-booth attendants, professional drivers, highway workers, traffic officers, and tunnel workers. Likewise, certain indoor events, such as tractor pulls and car and truck exhibitions, if not adequately ventilated, can expose spectators and participants to elevated CO levels.

- Faulty heating equipment accounts for almost one-third of accidental CO fatalities. These fatalities can be caused by home or office heating systems (e.g., leaking chimneys and furnaces or back-drafting from furnaces, gas water heaters, wood stoves, fireplaces; and gas stoves) and also by improperly vented or unvented kerosene and gas appliances, propane space heaters, charcoal grills or hibachis, and Sterno-type fuels. Dangerous amounts of carbon monoxide can be released when there is inadequate fresh air or a flame is not sufficiently hot to completely burn a fuel.

- Fires have been found to raise CO levels in the blood of unprotected persons to 150 times normal in a single minute; CO poisoning is the most frequent cause of immediate death associated with fire. Environmental tobacco smoke can also cause elevated CO levels in both smokers and nonsmokers who are exposed to the smoke.

- Methylene chloride is a solvent used in some paints and varnish strippers that is readily absorbed by the body and changes to CO. Using products that contain methylene chloride for more than a few hours can raise CO levels in the blood 7 to 25 times normal. It is particularly dangerous for persons with preexisting cardiac conditions who use these products in unventilated spaces, as they risk heart attack and death.

An electronic device known as a carbon-monoxide alarm is the only reliable method currently used to test for the presence of carbon monoxide. Most fire departments, gas companies, and some specialized contractors have sophisticated equipment that can measure and record carbon-monoxide levels. In the home, detectors should be placed in areas where the family spends most of its time, such as the family room, bedroom, or kitchen. Detectors should be placed far enough away from obvious and predictable sources of CO, such as a gas stove, to avoid false alarms.

CO poisoning can be prevented by following a number of simple steps:

- Keep gas appliances properly adjusted and have them checked periodically for proper operation and venting.
- Open flues when fireplaces are being used and ensure that flues, chimneys, and vents are clear of debris and working properly.
- Have CO monitors installed at home and in the workplace and ensure that they are properly maintained.
- Refrain from using unvented space heaters, gas stoves, charcoal grills, or Sterno-type fuels as sources of heat. Wood stoves when used should be properly sized and certified to meet EPA emission standards.
- When working around CO sources such as propane-powered forklifts and space heaters, ensure that adequate ventilation is in place. Whenever exposure is unavoidable, CO monitoring badges should be worn.
- The car’s exhaust system should be checked regularly and properly maintained at all times. Cars or other gasoline-powered engines should not be run inside a garage, even with the doors open.
- Do not use paint strippers that contain methylene chloride. If the use of solvents containing this substance is unavoidable, make sure the area is properly ventilated.
A trained professional should be brought in at least once a year to inspect, clean, and tune up the central-heating system (furnaces, flues, and chimneys) and repair any leaks promptly.

Nitrogen dioxide (NO₂) is a colorless, odorless gas that irritates the mucous membranes in the eye, nose, and throat and causes shortness of breath when exposed to high concentrations. Nitrogen dioxide is also a major concern as an air pollutant because it contributes to the formation of photochemical smog, which can have significant impacts on human health. Documented evidence indicates that high concentrations or continued exposure to low levels of nitrogen dioxide increases the likelihood of respiratory problems. Because nitrogen dioxide is relatively nonsoluble in tissue fluids, it enters the lungs, where it may expose lower airways and alveolar tissue. Nitrogen dioxide inflames the lining of the lungs and can reduce immunity to lung infections. There is also documented evidence from animal studies that repeated exposures to elevated nitrogen-dioxide levels may lead or contribute to the development of lung diseases such as emphysema. People at particular risk from exposure to nitrogen dioxide include children with asthma and older people with heart disease or other respiratory diseases.

Exposure can cause problems such as wheezing, coughing, colds, flu, and bronchitis. Increased levels of nitrogen dioxide can also have significant impacts on people with asthma because it can cause more frequent and more intense attacks.

There are numerous combustion-generated contaminants including several mucous-membrane and upper-respiratory-system irritants. Aldehydes such as HCHO are the most common, although in some cases acrolein, RSP, and SO₂ may also be included. Aldehydes cause irritation to the eyes, nose, throat, and sinuses and are discussed in greater detail in the following section. Respirable particles vary in composition, and their primary effect is irritation of the upper-respiratory passages and bronchi. Because of its solubility in tissue fluids, SO₂ can cause bronchial irritation.

### 7.2.1.3 Organic Contaminants

In today’s environment, natural and synthetic organic chemicals comprise many different types and can be found virtually everywhere, including soil, ground water, surface water, plants, and our bodies. Modern industrialized societies have developed such a massive array of organic pollutants that it is becoming increasingly difficult to generalize in a meaningful way as to sources, uses, or impacts. These contaminants find their way into the natural environment through accidental leakage or spills, such as leaking underground storage tanks, or through planned spraying of pesticides to agricultural land and urban areas.

The main organic compounds include volatile organic compounds (VOCs), very volatile organic compounds (VVOCs), semivolatile organic compounds (SVOCs), and solid organic compounds (POMs). Solid organic compounds may comprise components of airborne or surface dusts. Organic compounds often pose serious indoor contamination problems; they include the aldehydes, VOCs, and SVOCs (which include a large number of volatile as well as less volatile compounds, and pesticides and biocides, which are largely SVOCs).
Organic compounds that are known to be contaminants of indoor environments include a large variety of aliphatic hydrocarbons, aromatic hydrocarbons, oxygenated hydrocarbons (such as aldehydes, ketones, alcohols, ethers, esters, and acids), and halogenated hydrocarbons (primarily those containing chlorine and fluorine).

Volatile-organic-compound concentrations levels are generally higher in indoor environments than in outdoor air. Studies suggest that indoor air may contain several hundred different VOCs. Moreover, VOCs can be released from products while being used and to a lesser degree while in storage. Fortunately, the amounts of VOCs emitted tend to decrease as the product ages and dries out.

There has been a steady increase in the number of identified VOCs in recent years. They are characterized by a wide range of physical and chemical attributes – the most important of which are their water solubility and whether they are neutral, basic, or acidic. VOCs are released into the indoor environment by many sources, including building materials, furnishings, paints, solvents, air fresheners, aerosol sprays, adhesives, fabrics, consumer products, building cleaning and maintenance materials, pest-control and disinfection products, humans themselves, office equipment, tobacco smoking, plastics, lubricants, refrigerants, fuels, solvents, pesticides, and many others.

Among the health hazards many VOCs pose is that they are potent narcotics that cause depression in the central nervous system; others can cause eye, nose, and throat irritation; headaches; loss of coordination; nausea; and damage to the liver, kidneys, and central nervous system (Figure 7.4). A number of these chemicals are suspected or known to cause cancer in humans.

Formaldehyde (HCHO) is a colorless, pungent-smelling gas, and one of the more common VOCs found indoors. It is an important chemical used widely by industry to manufacture building materials and household products. It is also a byproduct of combustion and certain other natural processes and thus may be present in substantial concentrations both indoors and outdoors.

Formaldehyde is the most common of the aldehydes and is considered by many as possibly the single most critical indoor pollutant because of its common occurrence and

Figure 7.4  Diagram showing inhalation of volatile organic compounds.
Source: Air Advice Inc.
its strong toxicity. Formaldehyde is a colorless, gaseous substance with an unpleasant smell. On condensing it forms a liquid with a high vapor pressure. Due to its high reactivity, it rapidly polymerizes with itself to form paraformaldehyde. Because of this reaction, liquid HCHO needs to be kept at a low temperature or mixed with a stabilizer (such as methanol) to prevent or minimize polymerization.

Formaldehyde, by itself or in combination with other chemicals, serves a number of purposes in manufactured products. For example, it is used to add permanent-press qualities to clothing and draperies, as a component of glues and adhesives, and as a preservative in some paints and coating products. It is also used in a variety of deodorizing commercial products, such as lavatory and carpet preparations.

Formaldehyde is commercially available as both paraformaldehyde and as formalin, an aqueous solution that typically contains 37 to 38 percent HCHO by weight and 6 to 15 percent methanol. HCHO is also used in many different chemical processes, such as the production of urea and phenol-formaldehyde resin.

Urea-formaldehyde (UF) copolymeric resins are present in many building materials such as wood adhesives, which are used in the manufacture of pressed-wood products including particle board, medium-density fiber board (MDF), and plywood and in finish coatings (acid-cured), textile treatments, and urea-formaldehyde foam insulation (UFFI).

People are often unaware that formaldehyde is given off by materials other than UFFI. Certain types of pressed-wood products (composition board, MDF, paneling, etc.), carpeting, and other materials can be formaldehyde sources. Many of these products use a urea-formaldehyde-based resin as an adhesive. Some of these materials will continue to give off formaldehyde much longer than UFFI. Like the majority of VOCs, formaldehyde levels will decrease substantially with time and/or with increased ventilation rates.

For some people formaldehyde can be a respiratory irritant, and continuous exposure to it can be dangerous. More specifically, chronic, low-level, continuous, and even intermittent exposure can cause chemical hypersensitivity and provide an accelerating factor in the development of chronic bronchitis and pulmonary emphysema. HCHO also has the ability to cause irritation, inflammatory-type symptoms, and symptoms of the central nervous system such as headache, sleeplessness, and fatigue. Elevated HCHO exposures (above 0.1 parts per million) can trigger asthma attacks, nausea, diarrhea, unnatural thirst, and menstrual irregularities.

Acetaldehyde is a two-carbon aliphatic aldehyde with a pungent, fruity odor. It is used in a number of industrial processes and is a major constituent of automobile exhaust fumes. It is also a predominant aldehyde found in tobacco smoke. Compared to HCHO, it is a relatively mild irritant of the eye and upper respiratory system.

Acrolein is a three-carbon aldehyde with one double bond. It is highly volatile gas with an unpleasant choking odor. It is primarily used in the production of a variety of compounds and products and is released into the environment as a combustion oxidation product from oils and fats containing glycerol, wood, tobacco, and automobile/diesel fuels. At relatively low exposure concentrations it is a potent eye irritant.
Glutaraldehyde is a five-carbon dialdehyde. It is found in liquid form and has a sharp, fruity odor. Its main application is as an active ingredient in disinfectant formulations widely used by the medical and dental professions. The main health effects associated with glutaraldehyde exposures include irritation of the nose and throat, nausea and headache, and pulmonary symptoms such as chest tightening and asthma.

Polychlorinated biphenyls (PCBs) are oils used primarily as coolants in electrical transformers. Although the production and sale of PCBs were banned by the Environmental Protection Agency (EPA) in 1979, a large number of PCB-filled transformers remain in use. It has also been estimated that some 2,000,000 mineral-oil transformers still contain some percentage of PCBs. PCBs may also be found in light ballasts and elevator hydraulic fluids. PCBs are a suspected carcinogen, but properly sealed or contained PCBs do not pose a hazard. However, PCBs do become a hazard when they catch fire, creating carcinogenic byproducts that can contaminate air, water, and the finishes and contents of a building. Leaking PCBs can also contaminate building materials and soil. PCB evaluations typically focus on identifying the presence of or potential for PCB leakage, measuring of PCB concentration levels, and determining the presence of combustible materials adjacent to PCB-containing equipment.

Hydrocarbons are a class of organic chemical compound consisting only of the elements hydrogen (H) and carbon (C). They are cardinal to our modern way of life and being one of the Earth’s most important energy resources. Hydrocarbons are the principal constituents of petroleum and natural gas and are also derived from coal. The bulk of the world’s hydrocarbons are used for fuels and lubricants, as well as for electrical-power generation and heating. The chemical, petrochemical, plastic, and rubber industries are also dependent upon hydrocarbons as raw materials. Hydrocarbons are colourless, flammable, toxic liquids.

Symptoms associated with exposure to aliphatic hydrocarbons may include watery eyes, nausea, vomiting, dizziness, weakness, and central-nervous-system effects such as depression, convulsions, and, in extreme cases, coma. Other symptoms may include pulmonary and gastrointestinal irritation, pulmonary edema, bronchial pneumonia, anorexia, anemia, nervousness, pain in the limbs, and numbness. Noticeable odors similar to gasoline and oil all suggest that some hydrocarbon contamination may be present. Likewise, leaking subsurface tanks at fuel stations and other facilities have created significant health and safety problems by contaminating the soil around the buildings. Benzene is found in most hydrocarbons and is considered to be one of the more serious contaminants, known to cause leukaemia. Air-quality tests may be necessary as well as tests for contaminants in the soil around the foundation.

Pesticides are chemical poisons, designed to control, destroy, or repel plants and animals such as insects (insecticides), weeds (herbicides), rodents (rodenticides), and mold or fungus (fungicides). They include active ingredients (those intended to kill the target) and inert ingredients, which are often not “inert” at all. Pesticides are generally toxic and can be absorbed through the skin, swallowed, or inhaled; as such are unique contaminants of indoor environments.

Studies show that approximately 16 million Americans are sensitive to pesticides; their immune systems have been damaged as a result of prior pesticide exposure.
In addition, pesticides have been linked to a wide range of serious and often fatal conditions: cancer, leukemia, miscarriage, genetic damage, decreased fertility, liver damage, thyroid disorders, diabetes, neuropathy, still-births, decreased sperm counts, asthma, and other autoimmune disorders (lupus, etc.).

Federal and state governments carefully regulate pesticides to ensure that they do not pose unreasonable risks to human health or the environment. There are currently more than 1055 active ingredients registered as pesticides, which are formulated into thousands of different products that are available in the marketplace, including some of the most widely used over the past 60 years. These include aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirex, toxaphene, and lindane (hexachlorocyclohexane, HCH). Many pesticides (most notably chlordane, used for termite treatment) are serious hazards. It is hoped that ecological methods of pest control will in the future replace the overdependence on chemicals that now threatens our ecosystem.

7.2.1.4 Biological Contaminants

Biological pollutants arise from various sources such as microbiological contamination – e.g., fungi, bacteria, viruses, mites, pollens – and the remains and dropping of pests such as cockroaches. Such pollutants of biological origin can significantly impact indoor-air quality and cause infectious disease through airborne transmission. Of particular concern are those biological contaminants that cause immunological sensitization manifested as chronic allergic rhinitis, asthma, and hypersensitivity pneumonitis.

Moisture in buildings is one of the major contributors to poor indoor-air quality, unhealthy buildings, and mold growth; by controlling the relative humidity level, the growth of some sources of biologicals can be minimized. Standing water, water-damaged materials, rainwater leaks, or wet surfaces also serve as a breeding ground for molds, mildews, bacteria, and insects. Likewise, damp or wet areas such as cooling coils, humidifiers, condensate pans, or unvented bathrooms can serve as suitable breeding grounds. Contaminated central HVAC systems can then distribute these contaminants through the building.

Proactive preventive and remedial measures include rainwater-tight detail design, preventing uncontrolled air movement, reducing indoor-air moisture content, reducing water-vapor diffusion into walls and roofs, selecting building materials that have appropriate water-transmission characteristics, and maintaining proper workmanship quality control.

A proven method for deterring rainwater intrusion into walls is the rain-screen approach, which incorporates cladding, air cavities, drainage planes, and airtight support walls to offer multiple moisture-shedding pathways. The concept of the rain screen is simple; it separates the plane in a wall where rainwater is shed and where air infiltration is halted. In terms of construction, this means that there is an outer plane that sheds rainwater but allows air to freely circulate and an inner plane that is relatively airtight.

7.2.1.4.1 Mold and Mildew

Mold and mildew are types of musty-smelling fungi that thrive in moist environments. Their function in nature is primarily to break down and decompose organic materials
such as leaves, wood, and plants. They grow, penetrate, and infect the air we breathe. There is no normal way to eliminate all mold and mold spores in the indoor environment, and thus the key to controlling indoor mold growth is to control moisture content. Exposure to fungi in indoor-air settings has emerged as a significant health problem of great concern in both residential environments as well as in workplace settings. There are three major health hazards associated with fungi: infection, allergies, and toxins.

Fungi are primitive plants that lack chlorophyll and therefore feed on organic matter that they digest externally and absorb. True fungi include yeast, mold, mildew, rust, smut, and mushrooms. Given sufficient moisture they can grow on almost any material, even inorganic. When mold spores land on a damp spot indoors, they can grow and digest whatever they are growing on. There are molds that can grow on wood, paper, carpet, fabric, and foods, but they usually grow best in dark, moist habitats, especially if organic matter is available.

There are thousands of species of molds, including pathogens, saprotrophs, aquatic species, and thermophiles. Molds are part of the natural environment and are present everywhere in nature; their presence is only visible to the unaided eye when mold colonies grow (Figure 7.5).

Molds produce small spores to reproduce; they float through indoor and outdoor air continually. These spores may contain a single nucleus or be multinucleate. Mold spores can be asexual or sexual; many species can produce both types. Some species can remain airborne indefinitely, and many are able to survive extremes of temperature (some molds can begin growing at temperatures as low as 2 degrees C) as well as extremes of pressure. When conditions do not foster or enable growth, most molds have the ability to remain alive in a dormant state within a wide range of temperatures before they die. Different mold species vary enormously in their tolerance to temperature and humidity extremes.

For mold to grow or establish itself, it needs four vital elements: viable spores, a nutrient source (organic matter such as wood products, carpet, and drywall), moisture, and warmth. The mere presence of humid air, however, is not necessarily conducive to fostering mold growth except where it has a relative humidity (RH) level at or above 80 percent and is in contact with a surface. Mold spores are carried by air currents and can reach all surfaces and cavities of buildings. When the surfaces and/or cavities are warm and contain the right nutrients and amounts of moisture, the mold spores will grow into colonies and gradually destroy what they grow on.

The key to controlling mold growth is to control indoor moisture and the temperatures of all surfaces, including interstitial surfaces within walls. Mold generally needs a temperature range between 40 and 100 degrees F to grow, and maintaining relative-humidity levels between 30 and 60 percent will help control many of these known biological contaminants. Humidity control prevents the indoor growth of mold, mildew, viruses, and dust mites. Winter humidification and summer dehumidification controls/modules can supplement central HVAC systems when climate excesses require additional conditioning measures. Likewise, by removing any of the four essential growth elements the growth process will be inhibited or nonexistent.
### Typical Molds Found in Damp Buildings

| Fungal Species         | Substrate                        | Possible Metabolites | Potential Health Effects                      |
|------------------------|----------------------------------|----------------------|-----------------------------------------------|
| *Alternaria alternata* | moist window-sills, walls        | allergens            | asthma, allergy                               |
| *Aspergillus versicolor* | damp wood, wallpaper glue      | mycotoxins, VOCs     | unknown                                       |
| *Aspergillus fumigatus* | house dust, potting soil         | allergens            | asthma, rhinitis, hypersensitivity pneumonitis|
| *Cladosporium herbarum* | moist window-sills, wood         | allergens            | asthma, allergy                               |
| *Penicillium chrysogenum* | Damp wallpaper, behind paint    | mycotoxins           | unknown                                       |
| *Penicillium expansum* | Damp wallpaper                   | mycotoxins           | nephrotoxicity?                               |
| *Stachybotrys chartarum (atra)* | Heavily wetted carpet, gypsum board | mycotoxins         | dermatitis, mucosal irritation, immunosuppression |

**Figure 7.5**  Table showing partial list of typical types of molds found in damp buildings.

The first step in a mold-remediation project includes determining the root cause of the mold growth. The next step is to evaluate the order of magnitude of the growth; this is usually done through visual examination. Since old mold growth may not always be visible, investigators may need to use instruments such as moisture meters, thermal-imaging equipment, or borescope cameras to identify moisture in building materials or “hidden” mold growth within wall cavities, HVAC ducts, etc. Mold assessments and inspections should always include HVAC systems and their air-handler units, drain pans, coils, and ductwork in their surveys. In addition, depending on the age of the building, the inspector should take samples of the building materials, such as ceiling tiles, drywall joint compounds, and sheet flooring for the presence of asbestos. All these organisms may contribute to poor indoor-air quality and can cause serious health problems.
Fungi in indoor environments include microscopic yeasts and molds, called microfungi, whereas plaster and wood-rotting fungi are referred to as macrofungi because they produce spores that are visible to the naked eye. Some molds produce toxic liquid or gaseous compounds, known as mycotoxins, in addition to infectious airborne mold spores, which often cause serious health problems to residents and workers. Toxicity can arise from inhalation or skin contact with toxigenic molds. Some of these toxic molds can only produce the dangerous mycotoxins under specific growing conditions. Mycotoxins are harmful or lethal to humans and animals when exposed to high concentrations. Toxic molds and fungi are a significant source of airborne VOCs that create IAQ problems (Figure 7.6).

7.2.1.4.2 Bacteria and Viruses

Tens of millions of people around the world suffer daily from viral infections of varying degrees of severity at immense cost to the economy, including the costs for medical treatment, lost income due to inability to work, and decreased productivity. In fact, viruses have been identified as the most common cause of infectious diseases acquired within indoor environments, particularly those causing respiratory and gastrointestinal infection. The most common viruses causing respiratory infections include influenza viruses, rhinoviruses, corona viruses, respiratory syncytial viruses (RSVs), and parainfluenza viruses (PIVs); viruses responsible for gastrointestinal infections include rotavirus, astrovirus, and Norwalk-like viruses (NLVs). Some of these infections, like the common cold, are very widely spread but are not severe, while influenza-like infections are relatively more severe.

Bacteria and viruses are minute in size and readily become airborne, remaining suspended in air for hours. Airborne bacteria and viruses in interior spaces are a cause of considerable concern due to their ability to transmit infectious diseases. Bacteria, viruses, and other bioaerosols that are common in both the home and the workplace may increasingly contribute to sick-building syndrome (SBS) if humidity levels are...
either too low or too high, depending on how their growth and our respiratory system are affected.

There are many pathways to infection spread, and among the most significant, from an epidemiological point of view is airborne transport. Microorganisms can become airborne when droplets are given off during speech, coughing, sneezing, vomiting, or atomization of feces during sewage removal. Q fever is another emerging infectious disease among U.S. soldiers serving in Iraq. Fever, pneumonia, and/or hepatitis are the most common signs of acute infection with Q fever.

Liquid and solid airborne particles (aerosols) in indoor air originate from many indoor and outdoor sources. These particles may differ in size, shape, chemical composition, and biological composition. Particle size signifies the most important characteristic affecting particle fate during transport, and it is also significant in affecting biological properties. Bacterial aerosols have also been found to be a means to transmit several major diseases, as shown in Figure 7.7.

Professor Lidia Morawska of Queensland University of Technology, Australia, says that the degree of hazard created by biological contaminants including viruses in indoor environments is controlled by a number of factors:

- The type of virus and its potential health effects
- Mode of exit from the body
- Concentration levels
- Size distribution of aerosol containing the virus
- Physical characteristics of the environment (temperature, humidity, oxygenation, UV light, suspension medium etc.)
- Air-circulation pattern
- Operation of heating, ventilation, and air-conditioning system

The physical characteristics of the indoor environment as well as the design and operation of building ventilation systems are of paramount importance. Ducts, coils, and recesses of ventilation systems often provide fertile breeding grounds for viruses and bacteria that have been proven to cause a wide range of ailments from influenza to tuberculosis. Likewise, a number of viral diseases may be transmitted in aerosols

| Disease                | Causal Organism                           |
|------------------------|-------------------------------------------|
| Tuberculosis           | *Mycobacterium tuberculosis*              |
| Pneumonia              | *Mycoplasma pneunomiae*                   |
| Diphtheria             | *Corynebacterium diphtheriae*             |
| Anthrax                | *Bacillus anthracis*                      |
| Legionnaires’ disease  | *Legionella pneumophila*                  |
| Meningococcal meningitis | *Neisseria meningitides*              |
| Respiratory infections | *Pseudomonas aeruginosa*                  |
| Wound infections       | *Staphylococcus aureus*                   |

Figure 7.7  Major infectious diseases associated with bacterial aerosols.
derived from infected individuals. A number of infectious viral diseases and associated causal viruses transmitted through air are shown below in Figure 7.8.

7.2.1.4.3 Mites
Mites are microscopic bugs that thrive on the constant supply of shed human skin cells (commonly called dander) that accumulate on carpeting, drapes, furniture coverings, and bedding (Figure 7.9). The proteins in the combination of feces and skin shedding are what cause allergic reactions in humans. Dust mites are perhaps the most common cause of perennial allergic rhinitis. Dust mites are the source of one of the most powerful biological allergens and flourish in damp, warm environments. Depending on the person and level of exposure, estimates given suggest that dust mites may be a factor in 50 to

| Disease             | Causal Organism   |
|---------------------|-------------------|
| Influenza           | Orthomyxovirus    |
| Cold                | Coronavirus       |
| Measles             | Paramyxovirus     |
| Rubella             | Togavirus         |
| Chickenpox          | Herpes virus      |
| Respiratory infection | Adenovirus       |

Figure 7.8 Some of the major infectious diseases associated with viral aerosols.

Figure 7.9 Drawing of a dust mite.
Source: EHSO.
80 percent of asthmatics, as well as in numerous cases of eczema, hay fever, and other allergic ailments.

It is estimated that up to 15 percent of people are allergic to dust mites, which due to their very small size (250 to 300 microns in length) and translucent bodies are not visible to the naked eye. To be able to give an accurate identification, one needs at least a 10x magnification. Dust mites have eight hairy legs, no eyes or antennae, a mouth group in front of the body (resembling a head), and a tough, translucent shell. Dust mites, like their insect cousins, have multiple developmental stages. They commence with an egg and develop into larva, several nymph stages, and finally the adult.

Biological contaminants such as dust mites prefer warm, moist surroundings like the inside of a mattress particularly when someone is lying on it, but they may also accumulate in draperies, carpet, and other areas where dust collects. The favorite food of mites appears to be dander (both human and animal skin). Humans generally shed about 0.2 ounce of dander (dead skin) a week.

Dust-mite populations are usually highest in humid regions and lowest in areas of high altitude and/or dry climates. Control measures are needed to reduce concentrations of dust-borne allergens in the living/working environment by controlling both allergen production and the dust that serves to transport it.

7.2.1.4.4 Rodent, Insect, and Animal Allergens
According to the Illinois Department of Public Health, a typical large city in the United States annually receives more than 10,000 complaints about rodent problems and performs tens of thousands of rodent-control inspections and baiting services. Effective measures should therefore be taken to prevent rodents, insects, and pests from entering the home or office. Cockroaches, rats, termites, and other pests have plagued commercial facilities for far longer than computer viruses. Increasingly, research has confirmed and pinpointed pest infestation as the trigger or cause of a host of diseases, and according to the National Pest Management Association pests can cause serious threats to human health, including such diseases as rabies, salmonellosis, dysentery, and staph. But in addition to these serious health concerns they also detract from a facility’s appearance and value.

Today, communities of rats exist within and beneath cities, traveling unnoticed from building to building along sewers and utility lines. Each rat colony has its own territory, which can span an entire city block and harbor more than 100 rats. As they explore their territories, rats and mice discover new food sources and escape routes. A rat’s territory or “home range” is generally within a 50- to 150-foot radius of the nest, while mice usually have a much smaller range, living within a 10- to 30-foot radius of the nest. In places where all their needs (food, water, shelter) are met, rodents have smaller territories (Figure 7.10).

Rodents are known to carry disease and fleas and to leave waste. Wild and domestic rodents reportedly harbor and spread as many as 200 human pathogens. Diseases include the deadly hantavirus and arena virus. Hantavirus is usually contracted by
inhaling airborne particles from rodent droppings, urine, or saliva left by infected rodents or through direct contact with infected rodents.

Today, more than 900,000 species of insects have been identified, and additional species are being identified every day. Some of these insects are known sources of inhalant allergens that may cause chronic allergic rhinitis and/or asthma. They include cockroaches, crickets, beetles, moths, locusts, midges, termites, and flies. Insect body parts are especially potent allergens for some people. Cockroach allergens are also potent and are commonly implicated as contributors to sick-building syndrome in urban housing and facilities with poor sanitation. Most of the allergens from cockroaches come from the insect’s discarded skins. As the skins disintegrate over time, they become airborne and are inhaled. This type of allergen can be resolved by eliminating the cockroach population.

Cockroaches are known carriers of serious diseases, such as salmonella, dysentery, gastroenteritis, and other stomach organisms. They adulterate food and spread pathogenic organisms with their feces and defensive secretions. Cockroaches have been reported to spread at least 33 kinds of bacteria, six kinds of parasitic worms, and at least seven other kinds of human pathogens. They can pick up germs on their bodies as they crawl through decaying matter and then carry these onto food surfaces (Figure 7.11). Cockroaches molt regularly throughout their life cycle. The discarded skin becomes airborne and can cause severe asthmatic reactions, particularly to children, the elderly, and people with bronchial ailments.

There are in excess of 20 varieties of ants invading homes and offices throughout the United States, particularly during the warm months of the year (Figure 7.12). Worldwide, there are more than 12,000 species, but of these only a limited number actually cause problems. The one trait all ants share is that they are unsightly and contaminate food. Ants range in color from red to black.

![Figure 7.10](image_url)  
**Figure 7.10** Drawing showing typical home range of rodents. *Source: Illinois Department of Public Health.*
Destructive ant species include fire and carpenter ants. Others types include the pharaoh, honey, house, Argentine, and thief ant. Fire ants are vicious, unrelenting predators and have a powerful, painful sting. More than 32 deaths in the U.S. have been attributed to severe allergic reactions to fire-ant stings.

Termites can pose a major threat to structures, which is why it is important to address any termite infestation as soon as possible. A qualified termite-control company or inspector should look for the many tell-tale signs termites usually provide, such as small holes in wood, straw-shaped mud tubes, crumbling drywall, termite insect wings, and sagging doors or floors (Figure 7.13).

Allergens are produced by many mammalian and avian species; they can be inhaled by humans and cause immunological sensitization as well as symptoms of chronic allergic rhinitis and asthma. These allergens are normally associated with dander, hair, saliva, and urine of dogs, cats, rodents, and birds. Likewise, pollens, ragweed, and a variety of other allergens find their way indoors from the outside. Ragweed is known to cause what is commonly referred to as “hay fever,” or what allergist/immunologists refer to as allergic rhinitis. In the United States seasonal allergic rhinitis (hay fever), which is caused by breathing in allergens such as pollen, affects more than 35 million people. Sufferers of allergic rhinitis exposure often experience sneezing, runny noses,
and swollen, itchy, watery eyes. These allergy symptoms can have a major impact on a person’s quality of life, including his or her ability to function well at school or work.

### 7.2.1.5 Reducing Exposure

Resolving air-quality problems in buildings requires first the consideration of all the various contaminants, causes, and concentrations to better be able to address the problems and find appropriate solutions. The location where a person is exposed may also play a pivotal role. While the average worker is exposed approximately 40 hours per
week, many individuals are in their home 24/7. Exposure times, therefore, as well as concentration levels become part of the equation.

Pollutant-source removal or modification is the best approach whenever sources are identified and control is possible. These may include:

- Routine maintenance of HVAC systems
- Applying smoking restrictions in the home and the office
- Venting contaminant-source emissions to the outdoors
- Proper storage and use of paints, pesticides, and other pollutant sources in well-ventilated areas and use during periods of nonoccupancy
- Allowing time for building materials in new or remodeled areas to off-gas pollutants before occupancy

Most mechanical ventilation systems in large buildings are designed and operated not only to heat and cool the air, but also to draw in and circulate outdoor air, and one cost-effective method to reduce indoor pollutant levels is to increase ventilation rates and air distribution. At a minimum, HVAC systems should be designed to meet ventilation standards in local building codes. In practice, however, many systems are not operated or adequately maintained to ensure that these design ventilation rates are in place. Often IAQ can be improved by operating the HVAC system to at least its design standard and to ASHRAE Standard 62-2001 if possible. When confronted with strong pollutant sources, local exhaust ventilation may be required to exhaust contaminated air directly from the building. The use of local exhaust ventilation is particularly advised to remove pollutants that accumulate in specific areas such as restrooms, copy rooms, and printing facilities. Air cleaners can also be a useful adjunct to source control and ventilation, although they are somewhat limited in their application. Air cleaners are discussed in Section 7.3.6 of this chapter.

Because the average person spends so much of his or her life indoors (roughly 90 percent), the quality of the indoor air is of paramount importance. In fact, indoor-air pollution is currently ranked among the top four environmental risks in America by the EPA. This may explain why for many forward-thinking real-estate property managers it is becoming a standard of doing business to have their buildings routinely inspected as part of a proactive IAQ monitoring program. Some advantages include:

- Proactive programs build value into the property by having a professional record of indoor environmental conditions that are formally documented over time.
- Having a proactive IAQ program in place can be used as an effective marketing tool to attract quality tenants in a very competitive real-estate market.
- Regular monitoring of ventilation rates, building air flows, and filtration efficiencies can dramatically improve IAQ, thereby creating a more comfortable and productive work environment.
- A proactive program reduces the likelihood of labeling a “healthy” building as causing SBS. Problems or potential problems can be quickly identified and resolved at minimal expense.
- Proactive IAQ monitoring shields owners and facility managers against liability. It shows that the owner has applied due diligence to ensure that his building remains healthy. Additionally, owners with large building portfolios can benefit from these routine inspections as a means to demonstrate that a cohesive, organized, and coordinated IAQ policy is in place.
A proactive IAQ program enhances management/tenant relations by demonstrating a genuine concern for the tenants and their employees. Less time is needed to investigate and resolve tenant complaints.

The proactive IAQ report provides critical third-party documentation certifying effective maintenance standards and supporting engineering or operation budgets.

Following are some steps to reduce asbestos exposure:

- Leave undamaged asbestos material alone if it is not likely to be disturbed.
- Trained and qualified contractors should be used for control measures that may disturb asbestos and for cleanup.
- Proper procedures should be followed when replacing wood-stove door gaskets that may contain asbestos.

Following are some steps to reduce radon exposure:

- Test home and office for radon.
- If radon level is found to be 4 picocuries per liter (pCi/L) or higher, it needs to be fixed.
- Radon levels less than 4 pCi/L still pose a risk and in many cases may be reduced.
- For additional information on radon, contact your state radon office or call 800-SOS-RADON.

Following are some steps to reduce lead exposure:

- Leave lead-based paint undisturbed if it is in good condition.
- Do not sand or burn off paint that may contain lead.
- Do not remove lead paint yourself.
- Avoid bringing lead dust into the home or workplace.
- If your work or hobby involves lead, change clothes and use doormats prior to entering your home or workplace.
- Keep areas where children play as dust-free and clean as possible.
- Eat a balanced diet, rich in calcium and iron.

Following are some steps to reduce respirable-particles exposure:

- Vent all furnaces to the outdoors and keep doors to remaining spaces open when using unvented space heaters.
- Choose properly sized wood stoves, certified to meet EPA emission standards, and ensure that doors on all wood stoves fit tightly.
- Use trained professional to inspect, clean, and tune up central heating systems (furnace, flues, and chimneys) annually and promptly repair any leaks.
- Change filters on central heating and cooling systems and air cleaners according to manufacturer’s directions.

Following are some steps to reduce formaldehyde exposure:

- Exterior-grade pressed-wood products should be used because they are lower-emitting (because they contain phenol resins, not urea resins).
- Use air conditioning and dehumidifiers to maintain a moderate temperature and reduce humidity levels.
- Increase ventilation, particularly after bringing new sources of formaldehyde into the home or workspace.
Pesticides are products that contain hazardous chemicals designed to kill or repel household pests (insecticides, termiticides, and disinfectants). Products are also used on lawns and gardens that drift or are tracked inside the property. Evidence of pests is typically found in different forms such as droppings (especially from cockroaches and rodents), frass (from wood borers), gnawing, tracks, and grease marks (from rodents), damage (such as powderpost-beetle exit holes), and shed insect skins. The presence of feeding debris or frass is one indication of infestation. Pests are also to be found behind baseboards, under furniture, behind moldings, in floor cracks, behind radiators, and in air ducts. Many pesticides contain harmful VOCs that contribute to poor indoor-air and environmental quality (IAQ/IEQ). Following are some steps to reduce pest and pesticide exposure:

- Pesticides should be applied in strict accordance with manufacturer’s instructions.
- Pesticides should be used in recommended quantities only.
- Check around door jambs for evidence of cockroaches and spiderwebs.
- Window sills should be examined regularly, as many pests fly or crawl towards light.
- Increase ventilation when using pesticides indoors. Take plants or pets outdoors when applying pesticides to them.
- Check for presence of moisture, as this can attract moisture-loving pests such as carpenter ants, termites, or mold.
- Use nonchemical methods of pest control where possible.
- If you use a pest-control company, select it carefully.
- Do not store unneeded pesticides inside the home; dispose of unwanted containers safely.
- Store clothes with moth repellents in separately ventilated areas if possible.
- Keep indoor spaces clean, dry, and well ventilated to avoid pest and odor problems.

In addition, evidence of damaged screens, doors, and walls, which could allow pest entry, should be fixed. Sanitation problems should be recorded and rectified. Presence of heavy landscaping near the foundation and plants such as ivy growing on walls need to be controlled or avoided, as they increase the risk of attracting outdoor pests inside. Moisture problems around the foundation, gutters, or air-conditioning units should be monitored and rectified, as they can attract moisture-related pests to a building. Bright exterior lights attract insects to the building’s exterior; they may then find their way indoors.

Following are some steps to reduce biological-contaminant exposure:

- Install and use exhaust fans in kitchens and bathrooms and have them vented to the outdoors; clothes dryers should also be vented to the outdoors. One benefit to using kitchen and bathroom exhaust fans is that they can also reduce levels of organic pollutants that vaporize from hot water used in showers and dishwashers.
- Ventilate any attic or crawl spaces to prevent moisture buildup and keep humidity levels in these areas below 50 percent to avoid water condensation on building materials.
- If using cool-mist or ultrasonic humidifiers, clean appliances according to manufacturer’s instructions and refill with fresh water daily. These humidifiers are susceptible to becoming breeding grounds for biological contaminants and can potentially cause diseases such as hypersensitivity pneumonitis and humidifier fever. Clean evaporation trays in air conditioners, dehumidifiers, and refrigerators regularly.
Water-damaged carpets and building materials can harbor mold and bacteria and therefore should be thoroughly cleaned and dried (within 24 hours if possible) or removed and replaced.

Keep the interior clean. Dust mites, pollens, animal dander, and other allergy-causing agents can be reduced, although not eliminated, through regular cleaning. Allergic individuals should also leave the space while it is vacuumed, as vacuuming can actually increase airborne levels of mite allergens and other biological contaminants. Using central vacuum systems that are vented to the outdoors or vacuums with high-efficiency filters may also be helpful.

Biological pollutants in basements can be minimized by regularly cleaning and disinfecting the basement floor drain. Operate a dehumidifier in the basement if needed to keep relative-humidity levels between 30 and 50 percent.

Below are a number of relevant standards, codes, and guidelines:

- ASHRAE Standard 62-1999: Ventilation for Acceptable Indoor Air Quality
- ASHRAE 129-1997: Measuring Air-Change Effectiveness
- South Coast Rule #1168, South Coast Air Quality Management District
- Regulation 8, Rule 51, the Bay Area Air Quality Management District
- Canadian Environmental Choice/Ecologo
- Best Sustainable Indoor Air Quality Practices in Commercial Buildings
- Guidelines for Reducing Occupant Exposure to Volatile Organic Compounds (VOCs) from Office Building Construction Materials
- Carpet and Rug Institute Green Label Indoor Air Quality Test Program

An investigation procedure into IAQ may be characterized as a cycle of information gathering, hypothesis formation, and hypothesis testing. It typically begins with a walkthrough inspection of the problem area to gather information relating to the four basic factors that influence indoor-air quality:

- A building’s occupants
- A building’s HVAC system
- Possible pollutant pathways
- Possible sources of contamination

Typical IAQ investigations include documentation of readily obtainable information regarding the building’s history and of any complaints. It would also include identifying known HVAC zones and complaint areas, notifying occupants of the upcoming investigation, and, identifying key individuals who may be needed for information and access. The walkthrough itself entails visual inspection of critical building areas and consultation with occupants and staff. However, if insufficient information is obtained from the walkthrough to formulate a hypothesis or if initial tests fail to reveal the source of the problem, the investigator needs to move on and collect additional information to allow formulation of additional hypotheses. The process of formulating hypotheses, testing them, and evaluating them continues until the problem is resolved.

It is very likely that in the coming years we will witness national and state regulations stipulating that architects, designers, facility managers, and property owners meet mandated indoor-air quality standards. The EPA, OSHA, ASHRAE, ASTM, and
other organizations are currently in ongoing discussions concerning national indoor-air quality standards.

7.2.2 Thermal Comfort

Thermal comfort is a state of wellbeing that almost defies definition. It involves temperature, humidity, and air movement among other factors. Perhaps the most frequent complaint facility managers hear from building occupants is that their office space is too cold. That would appear to be an easy enough problem to resolve if it wasn’t for the fact that the second most common complaint is that it’s too hot. Studies show that people from different cultures generally have different comfort zones; even people belonging to the same family may feel comfortable under different conditions, and keeping everyone comfortable at the same time is an elusive goal at best. Regarding levels of thermal satisfaction, the Center for the Built Environment states, “Current comfort standards specify a ‘comfort zone,’ representing the optimal range and combinations of thermal factors (air temperature, radiant temperature, air velocity, humidity) and personal factors (clothing and activity level) with which at least 80 percent of the building occupants are expected to express satisfaction.” This is the goal outlined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) in the industry’s gold standard of comfort, Standard 55, Thermal Environmental Conditions for Human Occupancy. ASHRAE Standard 55 also specifies which thermal conditions are deemed likely to be comfortable to occupants.

We have shown that employee health and productivity are greatly influenced by the quality of the indoor environment. Poor air quality and lighting levels, off-gassing of chemicals from building materials, and the growth of molds and bacteria can all adversely affect building occupants. Sustainable design supports the wellbeing of building occupants and their desire to achieve optimum comfort by reducing indoor-air pollution. This can be achieved by applying a number of strategies such as the selection of materials with low off-gassing potential, providing access to daylight and views, appropriate ventilation strategies, and controlling lighting, humidity, and temperature levels.

Based on the above, finding the right temperature to satisfy everyone in a space is probably impossible. However, when temperature extremes – too cold or too hot – become the norm indoors, all building occupants suffer. In spaces that are either very hot or very cold, individuals must expend physiological energy to cope with the surroundings – energy that could be better utilized to focus on work and learning, particularly since research has shown that people simply don’t perform as well and attendance declines in very hot and very cold workplaces.

7.2.3 Noise Pollution

Noise pollution is considered a form of energy pollution in which distracting, irritating, or damaging sounds are freely audible. Noise and vibration from sources including HVAC systems, vacuums, pumps, and helicopters can often trigger severe symptoms, including seizures, in susceptible individuals.
In the United States, regulation of noise pollution was stripped from the Environmental Protection Agency and passed on to the individual states in the early 1980s. Although two noise-control bills passed by the EPA remain in effect, the EPA can no longer form relevant legislation. Needless to say, a noisy workplace is not conducive to getting work done. What is not so apparent is that constant noise can lead to voice disorders for paraprofessionals in the office, where many employees spend time on the telephone or routinely use their voices at work. An increasing number of teachers and paraprofessionals are seeking medical care because they are chronically hoarse.

The voice is one of the most important instruments for professionals. What’s more, people living or working in noisy environments secrete increased stress hormones, and stress will cause significant distraction from the work and learning at hand. Studies have documented higher stress levels among children and staff whose schools are located on busy streets or near major airports. A number of studies have also shown that office workers consider noise pollution to be a major irritant.

Humans, whether tenants or building occupants, have a basic right to live in an environment relatively free from the intrusion of noise pollution. Unfortunately, this is not always possible in an industrialized/urbanized society that relies heavily on equipment that generates objectionable noise. Although good engineering design can mitigate noise-pollution levels to some extent, it is often not to acceptable levels, particularly if a significant number of individual sources combine to create a cumulative impact.

The City of Berkeley’s Planning and Development Department states that to understand noise, one must first have a clear understanding of the nature of sound. It defines sound as pressure variations in air or water that can be perceived by human hearing; the objectionable nature of sound could be caused by its pitch or its loudness. In addition to the concepts of pitch and loudness, there are several methods to measure noise. The most common is the use of a unit of measurement called a decibel (dB). On the decibel scale, zero represents the lowest sound level that a healthy, unimpaired human ear can detect. Sound levels in decibels are calculated on a logarithmic basis. Thus, an increase of 10 decibels represents a tenfold increase in acoustic energy, and a 20-decibel increase is 100 times more intense (10 \times 10), etc. The human ear likewise responds logarithmically, and each 10-decibel increase in sound level is perceived as approximately a doubling of loudness.

Sound is of great value; it warns us of potential danger and gives us the advantage of speech and the ability to express joy or sorrow. But sometimes sound can also prove to be undesirable. Often sound may interfere with and disrupt useful activities. Sometimes, too, sounds such as certain types of music (e.g., pop or opera), may become noise at certain times (e.g., after midnight), in certain places (e.g., a museum), or to certain people (e.g., the elderly). It is therefore a value judgment as to when sound becomes unwanted noise, which is why it is difficult to offer a clear definition of “good” or “bad” noise levels in any attempt to generalize the potential impact of noise on people.

Some sources confirm that elevated noise in the workplace or home can “cause hearing impairment, hypertension, ischemic heart disease, annoyance, sleep disturbance,
and decreased school performance. Changes in the immune system and birth defects have been attributed to noise exposure, but evidence is limited.” Hearing loss is potentially one of the disabilities that can occur from chronic exposure to excessive noise, but it may also occur in certain circumstances such as after an explosion. Natural hearing loss associated with aging may also be accelerated from chronic exposure to loud noise. In many developed nations the cumulative impact of noise is capable of impairing the hearing of a large fraction of the population over the course of a lifetime. Noise exposure has also been known to induce dilated pupils, elevated blood pressure, tinnitus, hypertension, vasoconstriction, and other cardiovascular impacts.

The Occupational Safety and Health Administration (OSHA) has a noise-exposure standard that is set at just below the noise threshold where hearing loss may occur from long-term exposure. The impact of noise on physical stress reactions can be readily observed when people are exposed to noise levels of 85 dB or higher. The safe maximum level is set at 90 dB averaged over eight hours. If the noise is above 90 dB, the safe exposure dose becomes correspondingly shorter. Adverse stress-type reaction to excessive noise can be broken down into two stages. The first stage is where noise is above 65 dB, making it difficult to have a normal conversation without raising one’s voice. The second is the link between noise and socioeconomic conditions, which may further lead to undesirable stress-related behavior, increase workplace accident rates, or in many cases stimulate aggression and other antisocial behaviors.

Most people accept the premise that, all else being equal, it is preferable to live in a house that is quiet than in a noisy one. This implies that there is an economic penalty associated with noise exposure. However, noise is not the only factor that can influence this decision. People living along heavily traveled roads may experience greater problems with traffic safety, air pollution, exhaust odor, crime, or loss of privacy. Cumulatively, these factors can significantly depress property values. Commercial uses may be mixed in with residential uses, which may further reduce the desirability of a property. Upon considering all of these factors together, it becomes difficult to isolate the level of economic impact directly attributable to noise alone. New purchasers and renters may be unaware of how intrusive the noise can be so that the undesirability level of living in a noisy environment may increase over time. Noise levels therefore may not significantly impact property values, especially when you take into consideration all of the other variables, bearing in mind that there may be a significant negative reaction to the noise levels encountered in the future.

The prevailing sources of artificial noise pollution in today’s urban communities that are outside the control of affected individuals include:

- Transportation: cars, trucks, buses, trains near railroad tracks, and aircraft near airports
- Routine activities of daily life
- Construction activity
- Industrial-plant equipment noise

The main difference between transportation and nontransportation noise sources is that a municipality can generally impose controls over the level and duration of noise at the property line of any nontransportation source of noise. Cities can only adopt noise-exposure standards for noise emanating from trucks, trains, or planes and prohibit
certain land uses in areas prone to excessive noise for an intended use. Cities also play a role in enforcing state vehicle code requirements regarding muffler operation and may set speed limits or weight restrictions on certain streets. However, a city’s actions are typically proactive with regard to nontransportation sources and reactive for sources outside the city’s control.

Noise abatement and reduction of excessive noise exposure can be accomplished using three basic approaches:

- Reduce the noise level at the source.
- Increase the distance between the source and the receiver.
- Place an appropriate obstruction between the noise source and the receiver.

A noise wall is sometimes the only practical solution, since vehicular noise is exempt from local control and relocation of sensitive land uses away from freeways or major roads is not practical. Yet noise walls have both positive and negative aspects. On the positive side, they can reduce the noise exposure to affected persons or other sensitive uses by effectively blocking the line of sight between source and receiver. A properly sited wall can reduce noise levels by almost 10 dB, which for most people translates to being about one-half as loud as before. Unfortunately, the social, economic, and aesthetic costs of noise walls are high. While noise walls would screen the traffic, it may also block beautiful views of trees, parks, and water and may also give drivers a claustrophobic feeling of being surrounded by massive walls.

The construction cost of a noise wall is not cheap, averaging between $100 and $200 per foot. This essentially means that one mile of wall would cost between $500,000 and $1,000,000. More importantly, many people have expressed great disappointment after completion of a sound wall because, while the noise problem was reduced, it did not disappear as had been their expectation. Caltrans, for example, has a number of noise-abatement programs in place that focus on employing walls or berms to reduce noise intrusion from state and/or federal highways. Likewise, Caltrans will generally support design features that minimize local objections, providing their design standards are met. Those standards include the following:

- Walls must reduce noise levels by at least 5 dB.
- Walls must be capable of blocking truck exhaust stacks that are located at 11.5 feet above pavement levels.
- Walls constructed within 15 feet of the outside of the nearest travel lane must be built upon safety-shaped concrete barriers.

Concrete and masonry are the preferred wall materials. The effectiveness of a material in stopping sound transmission is called the transmission loss (TL).

### 7.2.4 Daylighting and Daylight Factor (DF)

The sun has been our main source of light and heat for millions of years, and through evolution humans have become to totally depend on it for health and survival. The world and in particular the sustainable-design movement are now returning to nature because of an increasing concern with global warming, carbon emissions, and sustainable design.
and have started to take positive steps to increase use of managed admission of natural light in both residential and nonresidential buildings. Daylighting has come to play a pivotal role in programs such as LEED™ and now has increased recognition in California’s Title 24 energy code.

Craig DiLouie of the Lighting Controls Association defines daylighting as “the use of daylight as a primary source of illumination to support human activity in a space.” Daylight is simply visible radiation that is generated by the sun and that can reach us in one of three different forms: direct sunlight, skylight (i.e., sunlight that has been scattered in the atmosphere), and sunlight or skylight that has been reflected off the ground. Of the three, direct sunlight is the most powerful source and has the greatest impact on our lives; it not only provides visible light but also provides ultraviolet and infrared (heat) radiation (Figure 7.14).
### Recommended Illumination Levels

| Area                                      | Footcandles |
|-------------------------------------------|-------------|
| Building surrounds                        | 1           |
| Parking area                              | 5           |
| Exterior entrance                         | 5           |
| Exterior shipping area                    | 20          |
| Exterior loading platforms                | 20          |
| Office corridors & stairways              | 20          |
| Elevators & escalators                    | 20          |
| Reception rooms                           | 30          |
| Reading or writing areas                  | 70          |
| General office work areas                 | 100         |
| Accounting/Bookkeeping areas              | 150         |
| Detailed drafting areas                   | 200         |

**Figure 7.15** Table showing recommended illumination levels.

Evaluation of daylight quality in a room traditionally consisted of a manual average daylight-factor calculation or a computerized version of the manual method. But in light of recent technological advances, daylight design is rapidly moving forward and is now able to provide the kind of information that would accommodate all of the requirements of the daylight consultant, the architect, and the end user. The ideal package should integrate natural and electrical lighting calculations and also take into account an evaluation of the thermal impact of window design. **Figure 7.15** shows a table of recommended illumination levels for various locations and functions.

The term “average daylight factor” is sometimes construed to be the average factor on all surfaces, whereas the output from most computer-based calculations reflects average daylight factors derived from a series of points on the working plane.

The daylight factor (DF) is a very common measure for expressing the daylight availability in a room. Chris Croly, a building-services engineering associate with BDP Dublin and Martin Lupton, however, states that: “The calculation of daylight factors using traditional methods becomes particularly difficult when trying to assess the effects of transfer glazing, external overhangs, or light shelves. Modern radiosity or ray-tracing calculations are now readily available and are easy to use but still generally offer results in the form of daylight factors or lux levels corresponding to a particular static external condition.” They define daylight factor as “the ratio of the internal illuminance to that on a horizontal external surface located in an area with an unobstructed view of a hemisphere of the sky.” The DF thus describes the ratio of outside luminance over inside luminance, expressed in a percent. The higher the DF, the more natural light is available in the room. The impact of direct sunlight on both illuminances must be considered separately and is not included. The DF can be expressed as:

\[
DF = 100 \times \frac{E_{in}}{E_{ext}}
\]
where $E_{\text{in}}$ represents the inside illuminance at a fixed point and $E_{\text{ext}}$ represents the outside horizontal illuminance under an overcast (CIE) or uniform sky.

### 7.2.4.1 Daylighting Strategies

Documented research continues to demonstrate that effective daylighting saves energy while increasing the quality of the visual environment and reduces operating costs while improving occupant satisfaction. Thus, while daylight can reduce the amount of electric light needed to adequately illuminate a workspace and therefore reduce potential energy costs, allowing too much light or solar radiation into a space can have a negative effect, resulting in heat gain and offsetting any savings achieved by reducing lighting loads. Some architectural/design firms known for their sustainable design, such as HOK and Gensler, design the majority of their buildings to be internally load-dominated, meaning that the buildings need to be cooled for most of the year. It’s important to fine-tune the glazing system to harvest as much daylight as possible without creating the negative effects of too much heat gain.

Strategies for improved daylighting include the use of miniature optical light shelves, light-directing louvers, light-directing glazing, clerestories, roof monitors and skylights, light tubes, and heliostats. It is important to appreciate that whatever tools are applied in the daylighting design process, to be successful they will involve the integration of several key disciplines including architectural, mechanical, electrical, and lighting. As with sustainable design in general, these team members need to be brought into the design process early to ensure that daylighting concepts and strategies are satisfactorily implemented throughout the project (Figure 7.16).

![Figure 7.16](image)

1. Private office
2. Open office
3. Sunshade with building integrated photovoltaics
4. Roof with building integrated photovoltaics
5. Skylight
6. Energy efficient & occupancy sensor controlled light fixtures
7. Electrochromic glass
8. Radiant heat floor
9. Natural ventilation
10. High performance glass
11. Reduction of outdoor light pollution
12. Water efficient landscaping
13. Ground source heat pump

**Figure 7.16** Schematic drawing illustrating an integrated approach to the design of a building’s various systems in the new IDeAs headquarters.

*Source: Integrated Design Associates, Inc.*
The application of innovative, advanced daylighting strategies and systems can significantly improve the quality of light in an indoor environment as well improving energy efficiency by minimizing lighting, heating, and cooling loads, thereby reducing a building’s electricity consumption. By providing a direct link to the outdoors, daylighting helps create a visually stimulating and productive environment for building occupants, at the same time reducing as much as one-third of total building energy costs.

When light hits any surface, part of it is reflected back. This reflection is normally diffused (non-directional) and is dependent on the object’s reflection. The reflection of the outside ground is usually in the order of 0.2, or 20 percent. This signifies that in addition to the direct sunlight and skylight components, there also exists an indirect component, which can make a significant contribution to the lighting inside a building, especially since the light reflected off the ground will hit the ceiling, which is usually very bright.

### 7.2.4.2 Daylighting and Visual Comfort

The challenge that designers often face with natural light is the fluctuations in light levels, colors, and direction of the light source. This led architects and engineers to make some unwise design decisions, which in the 60s and 70s culminated in hermetically sealed office blocks that were fully air-conditioned and artificially lit. This in turn led to a sharp increase in complaints and symptoms attributed to building-related illnesses (BRIs) and sick-building syndrome. Gregg Ander, FAIA, says: “In large measure, the art and science of proper daylighting design is not so much how to provide enough daylight to an occupied space but how to do so without any undesirable side effects.”

The designer should adopt practical design strategies for sustainable daylighting design that will go a long way to achieving visual comfort by applying three primary approaches:

- Environmental: Using the natural forces that impact design, resource, and energy conservation.
- Architectonic: What has made daylighting design so difficult until now is the lack of specific design tools. Today most large architectural practices have a diverse team of consultants and design tools that enable them to undertake complex daylighting analysis, whereas the typical school or small office does not have this capability or the budget for it.
- Human factors: The impact on people and their experience; visual comfort. Designers need to achieve the best lighting levels possible while avoiding glare and high-contrast ratios. These can usually be avoided by not allowing direct sunlight to enter a workspace – e.g., through the use of shading devices.

These basic lighting approaches reflect the strategies of sustainability and thus support the larger ecological goal.

A study conducted by the Heschong Mahone Group (HMG), a California architectural consulting firm, concluded that students who received their lessons in classrooms with more natural light scored as much as 25 percent higher on standardized tests than students in the same school district whose classrooms had less natural light. This
appears to confirm what many educators have suspected – i.e., that children’s capacity to learn is greater under natural illumination from skylights or windows than from artificial lighting. The logical explanation given is that daylighting enhances learning by boosting the eyesight, mood, and/or health of students and their teachers.

Another investigation by HMG looked at the relationship of natural light to retail sales. The study analyzed the sales at 108 stores that were part of a large retail chain. The stores were all one story and virtually identical in layout except that two-thirds of the stores had skylights while the others did not. The study specifically focused on skylighting as a means to isolate daylight as an illumination source and avoid all of the other qualities associated with daylighting from windows. When they compared the sales figures for the various stores, they discovered a statistically compelling connection between skylighting and retail-sales performance and found that stores with skylight systems had increased sales by 40 percent – even though the design and operation of all the store sites was remarkably uniform except for the presence of skylights.

Skylights were found to have a major positive impact on the overall operation of the chain and were positively and significantly correlated to higher sales. The study showed that all other things being equal, an average nonskylit store in the chain would likely increase its sales by an average of about 40 percent just by adding skylights. HMG professes that this was determined with 99 percent statistical certainty.

Many architects are now specifying high-performance glass with spectrally selective coatings that only allow visible light to pass through the glass while keeping out the infrared wavelength. This eliminates most of the infrared and ultraviolet radiation while allowing the majority of the visible-light spectrum through the glass. But even with high-performance glass, much of the light can be converted to heat. Glass with high visible-light transmittance still allows light energy into a building, and when this light energy hits a solid surface, it is absorbed and reradiated into the space as heat.

The combination of daylighting and efficient electric-lighting strategies can provide substantial energy savings. The building’s planning module can often give indications as to how best to organize the lighting. In any case, the lighting system must correlate to the various systems in place, including structural, curtain wall, ceiling, and furniture. Likewise, initial lighting costs may rise when designing for sustainability and implementing energy-efficient strategies. These energy-saving designs may require items such as dimmable ballasts, photocells, and occupancy sensors, all of which are not typically covered in most initial project budgets (Figure 7.17). However, this could easily be compensated for by reducing building-system and load costs and even possibly reallocating some of this money to the lighting budget.

One of the main attributes of daylight is that it enhances the psychological value of space. Likewise, the introduction of daylight into a building reduces the need for electric lighting during the day while helping to provide a connection between indoor spaces and the outdoors for the building occupants. However, natural light is not without its negatives. These include glare, overheating, variability, and privacy issues. The designer needs to find ways to increase the positive aspects of using natural light in buildings while at the same time minimizing the negative.
Addressing glare means keeping sunlight out of the field of view of building occupants while protecting them from disturbing reflections. Addressing overheating means adding appropriate exterior shading, filtering incoming solar radiation, or even using passive control means such as thermal mass. Furthermore, addressing the variability and privacy issues requires creative ways to block or alter light patterns and compensate with other light sources.

It is only recently that daylighting strategies have started to be considered at an early stage of a building design. This is because tools that could predict the performance of advanced daylighting strategies were not available to the designer. For best results, daylight design strategies should be in place at the outset of the design process and the daylighting consultant should be involved very early in the process. The data output
from the daylighting studies could be extremely useful for fine-tuning and finalizing the building’s orientation, massing, space planning, and interior finishes.

Innovative daylighting systems are designed to redirect sunlight or skylight to areas where it is most needed while avoiding glare. These systems use optical devices that initiate reflection, refraction, and/or use the total internal reflection of sunlight and skylight. And with today’s advancing technology daylighting systems can be programmed to actively track the sun’s movement or passively control the direction of sunlight and skylight.

The financial and competitive pressures of powerful market forces are driving some owners and design teams to seek architectural solutions such as the utilization of highly glazed, transparent façades. While these trends may offer clear potential benefits, such approaches also expose owners to real risks and costs as well. The general interest in potential benefits from these design solutions can be summarized as follows:

● Most building owners desire daylight and find concepts and buildings that employ highly transparent façades preferable to the dark-tinted or reflective buildings of the 1970s and 1980s.
● Building owners are generally aware of the potential health and productivity benefits of daylight.
● The evident shift toward highly glazed façades is coupled with interior designs that reflect the desire of building owners to provide views and daylight to their employees. Open plans and low-height partition furniture layouts allow the daylit zones to be extended from a conventional 10 to 15 feet (3.0 to 4.6 m) depth to a 20- (6.1 m) or even 30-foot (9.1 m) depth from the window wall (Figure 7.18).
● The increased use of low-reflectance, higher-brightness flat-screen LCD monitors has allowed architects to employ design solutions that involve increasing daylight and

![Daylighted zone](image)

**Figure 7.18** A rule of thumb for daylight penetration with typical depth and ceiling height is 1.5 times head height for standard windows and 1.5 to 2.0 times head height with light shelf for south-facing windows under direct sunlight.

*Source:* Ernest Orlando, Lawrence Berkeley Laboratory.
luminance levels within buildings. But to take full advantage of natural daylight and avoid potential dark zones, it is critical that the lighting designer plans the lighting circuits and switching schemes in relation to the building’s fenestration system.

At the same time there are potential risks associated with highly glazed façades:

- Adequate tools are not always available to reliably predict the thermal and optical performance of components and systems and to assess environmental quality.
- Increased sun penetration and excessive brightness levels that exceed good practice may heighten visual discomfort.
- Elevated cost of automated shading systems; possible need to purchase lighting controls utilizing dimming ballasts and difficulty in commissioning systems after installation.
- High cost and technical difficulty of reliably integrating dimmable lighting and shading controls with each other and with building automation systems to ensure effective operation over time.
- Buildings utilizing transparent glazing generally use greater cooling loads and cooling energy, which has the potential for thermal discomfort (Figure 7.19).
- Uncertainty of occupant behavior with the use of automated, distributed controls in open landscaped office space and the potential for conflict between different needs and preferences.

To cash in on the potential benefits and minimize possible risks, there is a growing recognition that at least in workspaces (as distinct from corridors, lobbies, etc.), large glazed spaces require much better sun and glare control. Appropriate solutions must be delivered by systems that can rapidly respond to exterior climate and interior needs.

![Figure 7.19 Various sources of cooling loads. Source: Ernest Orlando, Lawrence Berkeley Laboratory.](image-url)
One of the challenges facing manufacturers is how to provide such needed functionality at lower cost and risk to owners. Due to their various advantages and disadvantages, lighting consultants usually recommend the use of switching for spaces with nonstationary tasks such as corridors and continuous dimming for spaces where users perform stationary tasks, such as offices. It has been shown that daylight harvesting using continuous dimming equipment automatically controlled by a photosensor can generate 30 to 40 percent savings in lighting energy consumption, thereby significantly reducing operating costs for the owner.

7.2.4.3 Shades and Shade Controls

To achieve the greatest benefit of harvesting daylight, it is essential to implement a shading strategy tailored to the building. In hot climates, exterior shading devices have been found to work well to both reduce heat gain and diffuse natural light prior to entering the workspace (Figure 7.19). Examples of such devices include light shelves, overhangs, vertical louvers, horizontal louvers, and dynamic tracking or reflecting systems. Thus, for example, exterior shading of the glass can eliminate up to 80 percent of the solar heat gain. Shades and shade control strategies are based upon the perception that occupants of commercial buildings typically prefer natural light to electric light. Shade-system goals would normally include:

- Maximizing use of natural light within a glare-free environment.
- Avoid direct solar radiation on occupants through interception of sunlight penetration.
- Facilitate occupant connectivity with the outdoors through increased glazing and external views.
- Provide manual-override capability for occupants.

The overall determination is to ensure that the shades are operational as much of the time as is possible without causing thermal or visual discomfort (Figure 7.20). Thermal comfort is maintained by solar tracking and the design of the external sun screens. Visual comfort is affirmed by managing the luminance on the window wall. The specifications for the manual-override system are based upon postoccupancy surveys of office-building occupants with automated shade systems. The prime recorded complaint in these studies was an occupant’s inability to control the operation of a shade device when required.

7.2.5 Views

Recent studies show that windows providing daylight and ample views can dramatically affect building occupants’ mental alertness, productivity, and psychological wellbeing. David Hobstetter, a principal in Kaplan-McLaughlin-Diaz, a San Francisco-based architectural practice, reaffirms this, saying, “Dozens of research studies have confirmed the benefits of natural daylight and views of greenspace in improving a person’s productivity, reducing absenteeism, and improving health and wellbeing.”

In many countries around the world views, whether high-rise or otherwise, are normally considered mere perks, but recent research suggests that the view from a
window may be even more important than the daylight it admits. The California Energy Commission’s 2003 study of workers in the Sacramento Municipal Utility District’s call center found that better views were consistently associated with better performance: “Workers with good views were found to process calls 7 percent to 12 percent faster than colleagues without views. Workers with better views also reported better health conditions and feelings of wellbeing, while their counterparts reported higher fatigue.” Another revealing study noted that computer programmers with views spent 15 percent more time on their primary task, while workers without views spent 15 percent more time talking on the phone or to one another.

Though some educators are of the opinion that views out of windows may be unnecessarily distracting to students, the CEC’s 2003 study of the Fresno school district found that a varied view out of a window that included vegetation or human activity and objects in the far distance supported better learning. Such findings confirm results of earlier research, such as a 1984 hospital study that concluded that postoperative patients with a view of vegetation took far fewer painkillers and experienced faster recovery times than patients looking at concrete walls.

Most building occupants relish contact with the outside world, even if only through a windowpane, and landscapes not surprisingly are preferred to cityscapes. Researchers have concluded that views of nature improve attention spans after extended mental activity has drained a person’s ability to concentrate. Among the main building types
that can most benefit from the application of daylighting are educational buildings such as schools, administrative buildings such as offices, storage facilities such as warehouses, and maintenance facilities.

7.3 Ventilation and Filtration

Throughout history buildings, whether a Babylonian palace, an Egyptian temple, or a Roman castle, were ventilated naturally using either *badger* (also known as *malqafs*)—wind shafts or towers—or some other innovative method (Figure 7.21), since mechanical systems did not exist at the time. Andy Walker of the National Renewable Energy Laboratory says, “Wind towers, often topped with fabric sails that direct wind into the building, are a common feature in historic Arabic architecture.” The incoming air is often routed past a fountain to achieve evaporative cooling as well as ventilation. At night the process is reversed, and the wind tower acts as a chimney to vent room air.” It is not surprising that with today’s increased awareness of the cost and environmental impacts of energy use, natural ventilation has once again come to the fore and become an increasingly attractive method for reducing energy use and cost and for providing acceptable indoor environmental quality.

Natural ventilation systems utilize the natural forces of wind and buoyancy—i.e., pressure differences—to move fresh air through buildings. These pressure differences can be a result of wind, temperature differences, or differences in humidity. The amount and type of ventilation achieved will depend to a large extent on the size and placement of openings in the building. Inadequate ventilation is one of the main culprits of indoor pollutant levels by not bringing in enough outdoor air to dilute emissions from indoor sources and by not carrying indoor-air pollutants out of the home or workplace.

7.3.1 Ventilation and Ductwork

Ventilation is vital for the health and comfort of building occupants. It is specifically needed to reduce and remove pollutants emitted from various internal and external sources. Good design combined with optimum airtightness is prerequisite to ensuring healthy air quality, occupant comfort, and energy efficiency. Sufficient air supply and movement can be tested and analyzed to determine the efficiency of an HVAC system. Regular maintenance of ductwork is pivotal to achieving both better indoor environment and system stability. Ductwork can be evaluated, cleaned, and sealed to prevent air-flow and quality issues. All ductwork should be analyzed by a professional trained and certified by the National Air Duct Cleaning Association.

7.3.2 Air Filtration

It is unfortunate that to date no federal standards have yet been adopted for air-filter performance. Air-cleaning filters are designed to remove pollutants from indoor air, so by properly filtering your facility’s air of harmful particles, you can improve the indoor
Different types of traditional wind catches.

Figure 7.21  Drawings depicting various types of wind catchers (*badgeer*/*malqaf*) used in traditional and ancient architecture. (a) Multidirectional traditional Dubai wind catcher. (b) Plan and section of Dubai wind catcher. (c) Ancient Assyrian wind catcher. (d) Section through traditional wind scoop. (e) Traditional Pakistani wind catchers.
environment and breathe cleaner air. Proper filtration removes dirt, dust, and debris from the air you breathe. It also reduces pollen and other allergens, which can cause asthmatic attacks and allergic reactions. But while air-cleaning devices may help to control the levels of airborne allergens, particles, and in some cases gaseous pollutants in a facility, they may not decrease adverse health effects from indoor-air pollutants.

There are several kinds of air-cleaning devices to choose from – some are designed to be installed inside the ductwork of a facility’s central heating, ventilating, and air-conditioning (HVAC) system to clean the air in the whole facility. Other types include portable room air cleaners, which are designed to be used to clean the air in a single room or specific areas and are not intended for complete facility filtration. There are various types of air filters currently on the market, such as: mechanical filters, electronic filters, hybrid filters, gas-phase, and ozone generators.

7.3.3 Air Purification

Some sources, such as building materials, furnishings, and household products including air fresheners, release pollutants more or less continuously. Other sources, related to activities carried out in the home or workplace, release pollutants intermittently. These include smoking, unvented or malfunctioning stoves, furnaces, space heaters, solvents in cleaning and hobby activities, paint strippers in redecorating activities, and cleaning products and pesticides. High pollutant concentrations can remain in the air for long periods after some of these activities have ended if action is not taken.

While air filtration removes particulate, air purification is required to remove what a filter does not, such as odors and gases. Chemicals in paints, carpets, and other building materials (i.e., VOCs) are harmful to building occupants and should be removed through air purification. There is also an increasing concern regarding the presence of biological infectious agents, and air purification on a regular basis is one way to address these potential problems.

7.3.4 Amount of Ventilation

Outdoor air normally enters and leaves a building through various means, particularly infiltration, natural ventilation, and mechanical ventilation. Outdoor air can infiltrate a building through openings, joints, and cracks in walls, floors, and ceilings and around windows and doors. Natural ventilation involves air moving through opened windows and doors. Air movement associated with infiltration and natural ventilation is a consequence of air-temperature differences between the indoor and outdoor air and of wind. When insufficient outdoor air enters a home, pollutants can accumulate to a degree that they can pose health and comfort problems.

In the event that natural ventilation is insufficient to achieve good air quality, there are a number of mechanical ventilation devices, from outdoor-vented fans that will intermittently remove air from rooms such as bathrooms and kitchens to air-handling systems that utilize fans and duct systems to continuously remove indoor air and distribute filtered and conditioned outdoor air to strategic points throughout the building.
The rate at which outdoor air replaces indoor air is known as the air-exchange rate. Insufficient air infiltration, natural ventilation, or mechanical ventilation means that the air-exchange rate is low and can result in rising pollutant levels.

Sometimes residents or occupants are in a position to take appropriate action to improve the indoor-air quality of a space by removing the source, altering an activity, unblocking an air-supply vent, or opening a window to temporarily increase the ventilation; in other cases, however, the building owner or manager is the only person in a position to remedy the problem. Building management should be prevailed upon to follow guidance in EPA’s IAQ Building Education and Assessment Model (I-BEAM). I-BEAM expands and updates EPA’s existing Building Air Quality guidance and is considered to be a complete state-of-the-art program for managing IAQ in commercial buildings. Building management should also be encouraged to follow guidance in EPA and NIOSH’s Building Air Quality: A Guide for Building Owners and Facility Managers. The BAQ guidance is available as a downloadable PDF file.

### 7.3.5 Ventilation Improvements

As previously stated, another approach to lowering the concentrations of indoor-air pollutants is to increase the amount of outdoor air coming indoors. Many heating and cooling systems, including forced-air heating systems, do not mechanically bring fresh air into the house. This can often be addressed by opening windows and doors or running a window air conditioner with the vent control open to increase the outdoor ventilation rate. In residences, local bathroom or kitchen fans that exhaust outdoors can be used to remove contaminants directly from the room where the fan is located while increasing the outdoor-air ventilation rate.

Good ventilation is especially important when undertaking short-term activities that can generate high levels of pollutants, such as painting, paint stripping, or heating with kerosene heaters. Such activities should preferably be executed outdoors whenever possible.

Advanced designs of new homes have recently come on the market that feature mechanical systems that bring outdoor air into the home as well as energy-efficient heat-recovery ventilators (also known as air-to-air heat exchangers).

The following design recommendations can help achieve better ventilation in buildings:

- Naturally ventilated buildings should preferably be narrow, as wide buildings pose greater difficulty in distributing fresh air to all areas using natural ventilation.
- Occupants should be able to operate window openings.
- Use of mechanical cooling is advised in hot, humid climates.
- Determine whether an open- or closed-building ventilation approach potentially offers the best results. A closed-building approach will work better in hot, dry climates, where there is a large diurnal temperature range from day to night. An open-building approach is more effective in warm and humid areas, where the temperature difference between day and night is relatively small.
- Consideration should be given to the use of fan-assisted cooling strategies. Andy Walker says that “Ceiling and whole-building fans can provide up to 9 degrees F effective
temperature drop at one-tenth the electrical energy consumption of mechanical air-conditioning systems."

- When possible, provide ventilation to the attic space, as this greatly reduces heat transfer to conditioned rooms below. Ventilated attics have been found to be approximately 30 degrees F cooler than unventilated attics.
- Maximize wind-induced ventilation by siting buildings so that summer wind obstructions are minimal.

### 7.3.6 Air Cleaners

There are a variety of types and sizes of air cleaners presently on the market, ranging from relatively inexpensive tabletop models to larger, more sophisticated and expensive systems. Some air cleaners are highly effective at particle removal, while others, including most tabletop models, are much less so. It should be noted that air cleaners are generally not designed to remove gaseous pollutants.

An air cleaner’s effectiveness is expressed as a percentage efficiency rate. It depends on how well it collects pollutants from indoor air and how much air it draws through the cleaning or filtering element. The latter is expressed in cubic feet per minute. Even an efficient collector that has a low air-circulation rate will not be effective; neither will an air cleaner with a high air-circulation rate but a less efficient collector. The long-term performance of any air cleaner relies largely on maintaining it in accordance with the manufacturer’s directions.

Another critical factor in determining the effectiveness of an air cleaner is the level and strength of the pollutant source. Tabletop air cleaners, in particular, may not be capable of adequately reducing amounts of pollutants from strong nearby sources. Persons who are sensitive to particular pollutant types may find that air cleaners are useful mostly when used in conjunction with collaborative efforts to remove the source.

The EPA does not currently recommend using air cleaners to reduce levels of radon and its decay products. The effectiveness of these devices is questionable because they only partially remove the radon decay products and do not diminish the amount of radon entering the home. EPA is planning to undertake additional research on whether air cleaners are or could become a viable means of reducing the health risk from radon.

For most indoor-air-quality problems, source control is the most effective solution. The EPA issued “Ozone Generators that are Sold as Air Cleaners” to provide accurate information regarding the use of ozone-generating devices in indoor-occupied spaces. This information is based on the most credible scientific evidence currently available. The document explains what air-duct cleaning is, offers guidance to help consumers decide whether to have the service performed, and provides useful information on choosing a duct cleaner, determining if duct cleaning was done correctly, and how to prevent contamination of air ducts.

### 7.3.7 Ventilation Systems

Mechanical ventilation systems in large commercial buildings are normally designed and operated to heat and cool the air as well as to draw in and circulate outdoor air.
On the other hand, ventilation systems themselves can be a source of indoor pollution and contribute to indoor-air problems if they are poorly designed, operated, or maintained. They can sometimes spread harmful biological contaminants that have steadily multiplied in cooling towers, humidifiers, dehumidifiers, air conditioners, or inside surfaces of ventilation ducts. For example, problems arise when, in an effort to save energy, ventilation systems are incorrectly programmed and bring in inadequate amounts of outdoor air. Other examples of inadequate ventilation occur when the air supply and return vents within a space are blocked or placed in a manner that prevents the outdoor air from reaching the breathing zone of building occupants. Improper location of outdoor-air intake vents can also bring in contaminated air, particularly from automobile and truck exhaust, fumes from dumpsters, boiler emissions, or air vented from bathrooms and kitchens.

For mechanically ventilated spaces designers should refer to ASHRAE Standard 55-1992, Addenda 1995, “Thermal Environmental Conditions for Human Occupancy.” For naturally ventilated spaces, refer to California High Performance Schools (CHPS) Best Practices Manual Appendix C, “A Field Based Thermal Comfort Standard for Naturally Ventilated Buildings.”

7.4 Building Materials and Finishes Emittance Levels

Several studies over the years have investigated the impact of pollution emitted by building materials on indoor-air quality and related it to ventilation requirements. However, there has been a lack of systematic experiments in which building materials are initially ranked according to their pollution strength and the impact on the indoor-air quality of using these materials in real rooms analyzed. Such studies would allow us to quantify the extent to which using low-polluting building materials would reduce the energy needed for ventilation of buildings without compromising indoor-air quality. One of the primary objectives of an ongoing research project is to quantify this energy-saving potential based on the effects on the perceived air quality.

7.4.1 Unhealthy Building Materials

Healthy Building Network (HBN) identifies the primary toxic building materials that have unacceptably high VOC emittance levels.

HBN singled out polyvinyl chloride, or vinyl, for elimination because of its uniquely wide and potent range of chemical emissions throughout its life cycle. It is virtually the only material that requires phthalate plasticizers, frequently includes heavy metals, and emits large amounts of VOCs. In addition, during manufacture it produces a large quantity of highly toxic chemicals including dioxins (the most potent carcinogens measured), vinyl chloride, ethylene dichloride, and PCBs, among others. Moreover, when burned at the end of its useful life, whether in an incinerator or landfill fire, it
releases hydrochloric acid and more dioxins. It is therefore prudent if not imperative to avoid products made with PVC.

Volatile organic compounds (VOCs) essentially consist of thousands of different chemicals, such as formaldehyde and benzene, that evaporate readily into the air. Depending on the level of exposure, they can cause dizziness; headaches; eye, nose, and throat irritation; asthma; and in some case, cancer; they induce longer-term damage to the liver, kidney, and nervous system, and stimulate higher sensitivity to other chemicals.

When dealing with wet products such as paints, adhesives, and other coatings, ensure that the products contain no or low VOC. Look for the Green Seal when using certified paints or paints with less than 20 g/l VOCs. For adhesives and coatings make sure they are SCAQMD (South Coast Air Quality Management District)-compliant.

For flooring and carpet, wall covering, ceiling tiles, and furniture, it is advisable to use only CA 01350-compliant products. A number of programs currently use the CA 01350 testing protocol to measure the actual levels of individual VOCs emitted from the material and compare it to allowable levels set by the state of California. These include CHPS, CRI’s Green Label Plus, SCS’s Indoor Advantage, RFCI’s FloorScore, and GreenGuard’s Schools and Children. Try to avoid flooring that requires waxing and stripping, processes that will release more VOCs than the original material.

Ensure that all composite wood products and insulation have no added formaldehyde. The CA 01350 program has set limits on formaldehyde emissions; however, for these products there are options that completely exclude the presence of formaldehyde.

DEHP and other phthalates have attracted considerable adverse publicity for their use in PVC medical products and in toys, and concerns have been raised about their impact on the development of young children. Phthalates are, however, also used widely in flexible PVC building materials and have been linked to bronchial irritation and asthma. It is important therefore to avoid using products with phthalates (including PVC).

Even though heavy metals are known to be hazardous to your health, they continue to be used for stabilizers or other additives in building materials. Lead, mercury, and organotins are all known potent neurotoxins that are particularly damaging to the brains of fetuses and growing children. Cadmium is a carcinogen and can cause a variety of kidney, lung, and other damage. Look for products that do not contain heavy metals.

The use of halogenated flame retardants (HFRs) in many fabrics, foams, and plastics is known to have saved many lives over the years. However, these retardants, including PBDEs and other brominated flame retardants (BFRs), have been found to disrupt thyroid and estrogen hormones, which can cause developmental effects such as permanent changes to the brain and to the reproductive system. Being persistent and bioaccumulative, they are rapidly accumulating to dangerous levels in humans and have now become the subject of an increasing number of bans and phaseouts. Avoid all products that use halogenated flame retardants.

Numerous treatments for fabric and some building materials have been based on perfluorocarbons (PFCs) that – like HFRs – are characteristically highly persistent and
bioaccumulative and hence are concentrating at alarming levels in humans. PFOA is a major component of treatment products such as Scotchguard, Stainmaster, Teflon, and Gore-Tex and has been linked to a range of developmental and other adverse health effects. Avoid all products that are treated with a PFC-based material.

Here is a checklist for healthy materials:

- Avoid PVC (polyvinyl chloride, vinyl)
- Low or no VOC (volatile organic compounds)
- CA 01350-compliant
- Ensure no added formaldehyde
- Ensure no phthalates or heavy metals (lead, mercury, cadmium, organotins) are used
- Ensure no HFRs (PBDEs, BFRs, and other halogenated flame retardants) are used
- Ensure no PFCs (perfluorocarbons) are present

### 7.4.2 Resources for Locating Healthy Building Materials

Because of the great diversity of materials used in the construction and manufacturing industries, we are unable to produce a single building-materials list or certification that covers all of the relevant health and environmental issues. For example, we find that of the various programs listed below that certify products to meet the CA 01350 VOC-emissions standards, none also screen for phthalates and flame retardants, and you will find many PVC/vinyl products on those lists. Furthermore, some 01350 VOC programs are managed by trade associations. It is prudent to always ask to see the actual lab certification of 01350 VOC emissions when first screening a material and ask about PVC/vinyl, heavy metals, HFRs, and PFCs.

HBN PVC Alternatives Database is a CSI-prepared listing of PVC-free alternatives for a wide range of different building materials. Website: [www.healthybuilding.net/pvc/alternatives.html](http://www.healthybuilding.net/pvc/alternatives.html).

Paints and coatings that meet the GreenSeal VOC content standards are listed in the Green Seal Certified Products list; these materials do not contain certain excluded chemicals and meet typical LEED™ performance requirements.

EcoLogo is an environmental standard and certification mark. EcoLogo was founded in 1988 by the Government of Canada and is now recognized internationally. The EcoLogo Program provides customers – public, corporate, and consumer – with assurance that the products and services bearing the logo meet stringent standards of environmental leadership. The EcoLogo Program is a Type I ecolabel as defined by the International Organization for Standardization (ISO) and is one of two such programs in North America that have been successfully audited by the Global EcoLabeling Network (GEN) as meeting ISO 14024 standards for ecolabeling. Among the products EcoLogo certifies are carpet, paint, and adhesives.

CHPS (Collaborative for High Performance Schools) maintains a table listing products that have been certified by the manufacturer and an independent laboratory to meet the CHPS Low-Emitting Materials criteria, Section 01350, for use in typical classrooms. Certified materials include adhesives, sealants, concrete sealers, acoustical ceilings, wall panels, wood flooring, composite wood boards, resilient flooring, and
carpet. Note: This list also includes paint listings, but CA 01350 is not yet a replacement for low VOC screening. The website is: www.chps.net/manual/lem_table.htm.

The GreenLabel Plus designation means that the Carpet and Rug Institute (a trade association) assures customers that approved carpet products meet stringent requirements for low chemical emissions and furthermore certifies that these carpets and adhesives meet CA 01350 VOC requirements. Thus any architect, interior designer, government specifier, or facility administrator who is committed to using green-building products can assume that the Green Label Plus logo signifies that the carpet product has been tested and certified by an independent laboratory and meets stringent criteria for low emissions.

FloorScore Scientific Certification Systems certifies for the Resilient Floor Covering Institute (a trade association) that resilient flooring meets CA 01350 VOC requirements. Website is: www.scscertified.com/iaq/floorscore_1.html.

Air Quality Sciences certifies for GreenGuard that furniture and indoor finishes meet the lower of CA 01350 VOC or 1/100 of TLV. The GreenGuard Environmental Institute (GEI) has formulated performance-based standards to define goods with low chemical and particle emissions for use indoors; these primarily include building materials, interior furnishings, furniture, cleaning and maintenance products, electronic equipment, and personal-care products. The standard establishes certification procedures including test methods, allowable emissions levels, product-sample collection and handling, testing type and frequency, and program-application processes and acceptance. GEI now certifies products across multiple industries.

No listings are yet screened for BFRs, HFRs, or PFCs. The flame retardants are added to plastics, particularly fabrics and foams. PBDEs are the most widely used. All halogen-based flame retardants, however, are likely to be problematic.

7.5 Best Practices for IEQ

Indoor environmental quality is a critical component of sustainable buildings. As we have already seen, numerous documented studies have confirmed the effect of the indoor environment on the health and productivity of building occupants. Ventilation, thermal comfort, air quality, and access to daylight and views are all important factors that play a significant role in determining indoor environmental quality.

The Architectural and Transportation Barriers Compliance Board (Access Board), which is an independent federal agency devoted to accessibility for people with disabilities, contracted with the National Institute of Building Sciences (NIBS) to establish an Indoor Environmental Quality Project as a first step in implementing an action plan. NIBS issued a project report on indoor environmental quality in July 2005 that revealed that a growing number of people in the United States suffer a range of debilitating physical reactions caused by exposures to everyday materials and chemicals found in building products, floor coverings, cleaning products, fragrances, and others products. This condition is known as multiple chemical sensitivity (MCS). The
range and severity of these reactions are varied. In addition, the Access Board received numerous complaints from other people who reported adverse reactions from exposures to electrical devices and frequencies, a condition referred to as electromagnetic sensitivity (EMS).

In response to these concerns, the Access Board sponsored a study on ways to tackle the problem of indoor environmental quality for persons with MCS and EMS as well as for the general population. In conducting this study for the Board, NIBS brought together a number of interested parties to explore the relevant issues and to develop an appropriate action plan. While the focus of the project was on commercial and public buildings, many of the issues addressed and recommendations offered can also be applied to residential settings. The report includes, among other things, recommendations on improving indoor environmental quality that address building products, materials, ventilation, and maintenance.

A steering committee was established for the project, which included representation from MCS and EMS organizations, experts on indoor environmental quality, and representatives from the building industry. Committee members examined various methods and strategies for collecting and disseminating information, focusing on specific areas, increasing awareness of relevant issues, encouraging extended project participation, identifying potential partners for further study and outreach, and developing practical recommendations for best practices.

Below are some of the steps and best practices that can be applied to ensure good IEQ:

- Conduct a facility-wide IEQ survey/inspection, noting odors, unsanitary conditions, visible mold growth, staining, presence of moisture in inappropriate places, poorly maintained filters, personal air cleaners, hazardous chemicals, uneven temperatures, and blocked vents.
- Determine operating schedule and design parameters for the HVAC system and ensure adequate fresh air is provided to prevent the development of indoor-air-quality problems and to contribute to the comfort and wellbeing of building occupants. Maintain complete and up-to-date ventilation-system records.
- Ensure that appropriate preventive maintenance (PM) is performed on HVAC system including but not limited to outside-air intakes, inside of air-handling unit, distribution dampers, air filters, heating and cooling coils, fan motor and belts, air-distribution ducts and VAV boxes, air humidification and controls, and cooling towers.
- Manage and review processes with potentially significant pollution sources such as renovation and remodeling, painting, shipping and receiving, pest control, and smoking. Ensure adequate controls are instituted on all renovation and construction projects and evaluate control impacts on IEQ.
- Control environmental tobacco smoke by prohibiting smoking within buildings or near building entrances. Designate outdoor smoking areas at least 25 feet from openings serving occupied spaces and air intakes.
- Control moisture inside buildings to inhibit mold growth, particularly in basements. Dehumidify when necessary and respond promptly to floods, leaks, and spills. Use of porous materials in basements should be monitored and restricted whenever possible.
- When mold growth is evidenced, immediate action should be taken to remediate.
Choose low-emitting materials with minimal or no volatile organic compounds. This particularly applies to paints, sealants, adhesives, carpet and flooring, furniture, composite wood products, and insulation.

Monitor carbon dioxide (CO₂), and install carbon-dioxide and air-flow sensors in order to provide occupants with adequate fresh air when required.

To maintain occupants’ thermal comfort, include adjustable features such as thermostats or operable windows.

Window size, location, and glass type should be selected to provide adequate daylight levels in each space.

Window sizes and positions in walls should be designed to take advantage of outward views and have high visible transmittance rates (greater than 50 percent) to ensure maximum outward visibility.

Incorporate design strategies that maximize daylight and views for building occupants’ visual comfort.

Educate cleaning staff regarding use of appropriate methods and products, cleaning schedules, material storage and use, and trash disposal.

A process for complaint procedures should be established and IEQ complaints promptly responded to.

Discuss with occupants how they can participate in maintaining acceptable indoor environmental quality.

Permanent entryway systems such as grilles or grates should be installed to prevent occupant-borne contaminants from entering the building.

A construction IAQ management plan should be in place so that during construction materials are protected from moisture damage and particulates controlled through the use of air filters.

There are a number of suggested IEQ-related recommendations that tenants should follow to ensure that a healthy indoor environment is maintained for all building occupants:

- The use of air handlers during construction must be accompanied by the use of filtration media with a minimum efficiency reporting value (MERV) of 8 at each return grille as determined by ASHRAE 52.2-1999.
- Replace all filtration media immediately prior to occupancy, and conduct when possible a minimum two-week flush-out with new filtration media and 100 percent outside air after construction is completed and prior to occupancy of the affected space.
- Contractors should notify property manager 48 hours prior to commencement of any work that may cause objectionable noise or odors.
- Protect stored on-site materials and installed absorptive materials from moisture damage.
- All applied adhesives must meet or exceed the limits of the South Coast Air Quality Management District Rule #1168. Sealants used as fillers must meet or exceed Bay Area Air Quality Management District Reg. 8, Rule 51.
- Ensure that all paints and coatings meet or exceed the VOC and chemical component limits of GreenSeal requirements.
- Ensure that carpet systems meet or exceed the Carpet and Rug Institute Green Label Indoor Air Quality Test Program.
- Composite wood and agrifiber products should not contain any added urea-formaldehyde resins.
• Contractors should provide protection and barricades where needed to ensure personnel safety and should comply with OSHA at a minimum.

In conclusion, it should be remembered that the air quality in your building is one of the most important factors in maintaining employee productivity and health. Towards this end, IEQ monitoring will help minimize tenant complaints of building-related illnesses (BRI) and sick-building syndrome (SBS). A cohesive, proactive IEQ monitoring program is a powerful tool that can be used to achieve this goal.

It is also likely that in the coming years we will witness national and state regulations stipulating that designers, facility managers, and property owners meet specified indoor-air-quality standards. Several national and international organizations including the EPA, OSHA, ASHRAE, ASTM, USGBC, and others are currently in discussions concerning formulating new standards and updating and improving existing national indoor-air-quality standards.