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CHAPTER SEVEN

Indoor Environmental Quality

7.1 GENERAL OVERVIEW

Indoor Environmental Quality (IEQ) is essentially described as the conditions inside the building, which typically includes air quality, and access to daylight, views, pleasant acoustic conditions, and occupant control over lighting and thermal comfort. And it is not surprising to learn that poor IEQ has become one of the major concerns we face today not only in the home, but also in education facilities and the workplace. IEQ can lead to poor health, learning difficulties, and productivity problems. This is particularly worrying since the majority of us spend most of our time indoors (especially in the United States); it is not surprising therefore that we should expect our indoor environment to be healthy and free from the plethora of hazardous pollutants. Indoor pollution is found to exist under many diverse conditions from dust and bacterial buildup in ductwork to second-hand smoke and the off-gassing of paint solvents, all of which are potential health hazards.

Studies by the American College of Allergies show that roughly 50% of all illness is aggravated or caused by polluted indoor air (Fig. 7.1). Moreover, cases of building-related illness (BRI) and sick building syndrome (SBS) continue to rise. In fact, recent studies point to the presence of more than 900 possible contaminants, from thousands of different sources, in a given indoor environment. It is not surprising therefore that 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 well-being. This heightened public awareness has led to a sudden surge of building occupants demanding compensation for their illnesses. Especially in today’s increasingly litigious society, they add another factor to be addressed—protecting their investment from liability due to air-quality issues. Moreover, tenants are not only suing building owners, but some are also architects, engineers, and others involved in the building’s construction.
This has induced building owners to shift the blame by making claims against the consultant, the contractor, and others involved in the facility’s construction. But 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 led to everyone associated with a project being blamed when the inside air of a building appears to be the cause of its occupants becoming sick. This is causing great concern among design professionals because it can ultimately result in a loss of reputation, as well as cost time and financial losses.

Because of 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. Furthermore, 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 facilities managers. Schools, health

![Figure 7.1 Percentage of buildings with inappropriate concentration of contaminants. Source: HBI Database.](image-url)
care facilities, and general office buildings can benefit from measuring many of the environmental conditions and use 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 indoor environments.

### 7.1.1 Causes of Indoor Pollution

Poor indoor air quality is usually the result of sources that release gases or particles into the air. Inadequate ventilation is generally considered the single most common cause of pollutant buildup (Fig. 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 (Fig. 7.2b). But despite fundamental improvements in air filter technology, too many buildings continue to persist in relying on inefficient filters, or continue to be negligent in the maintenance of acceptable filters.

There are several factors that can trigger an investigation into indoor air quality contamination including the presence of biological growth (mold),

![Figure 7.2](image-url) *(a) Inadequate Ventilation is the single most common cause of pollutant buildup. (b) Inefficient filtration is the second most important factor in the cause of indoor pollution. Source: HBI Database.*
unusual odors, adverse health concerns of occupants, and a variety of other symptoms or observations, such as respiratory problems, headaches, nausea, irritation of eyes, nose, or throat, fatigue, etc. 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. IEQ and energy efficiency may be classified into three basic categories: (1) Comfort and ventilation, (2) Air cleanliness, and (3) 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 (VOCs), carbon dioxide (CO₂), carbon monoxide (CO), and airborne particulates. Unfortunately, until recently, there has been insignificant federal legislation controlling indoor air quality. This has changed with the adoption of the new International Green Construction Code (IGCC) in the United States. Also, several engineering societies such as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) have established guidelines which have been generally accepted by designers as minimum air design requirements for commercial buildings. ASHRAE has established two procedures for determining minimum acceptable ventilation rates. They are:

- The Ventilation Rate Procedure. This stipulates a minimum ventilation rate based on space functions within a specified building type and is based on respiration rates resulting from occupants’ activities.
- The Indoor Air Quality Procedure (this 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, 7 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 outside air of the potentially contaminated building.

### 7.1.2 Sick Building Syndrome

SBS describes a range of symptoms thought to be linked to spending time in a particular building, most often a workplace, but for which no specific cause can be established. Thus, SBS is when building occupants sometimes
complain of symptoms that do not appear to fit the pattern of any specific illness and which are difficult to trace to any specific source. This has been labeled SBS and is a fairly recent phenomenon. The term is used to describe situations in which building occupants experience acute health and discomfort effects that appear to be caused by time spent in a building, but often no specific illness or cause can be identified. These complaints may be localized in a particular room or zone, or may be widespread throughout the building. Research has identified the factors and symptoms that impact SBS. They include:

- thermal discomfort
- psychological stress
- noise
- headaches and dizziness
- nausea (feeling sick)
- aches and pains
- fatigue (extreme tiredness)
- shortness of breath or chest tightness
- eye and throat irritation
- irritated, blocked, or runny nose
- skin irritation (skin rashes, dry itchy skin)

It is worth noting that there are various measures that can be taken at work to help prevent the symptoms of SBS, such as:

- Open windows to avoid getting too hot
- Organize and prioritize the workload to help prevent stress
- Take regular screen breaks of a few minutes (if you use a computer) for every hour that you are sitting at your desk
- Go outside for some fresh air and a walk during lunchtime and break time
- Exercise regularly, eat healthily foods and maintain good posture.

The Environmental Protection Agency’s (EPA) Indoor Air Quality Website contains pertinent information regarding strategies for identifying the causes of SBS as well as finding possible solutions to the problem. According to industry IAQ standards, SBS is diagnosed if significantly more than 20% of a building’s occupants complain of adverse health effects such as headaches, eye irritation, fatigue and dizziness, etc., over a period of two weeks or more, but without a clinically diagnosable disease being identified, and the SBS symptoms disappear or are diminished when the complainant leaves the building.
7.1.3 Building-Related Illness

BRIs on the other hand are defined as a heterogeneous group of disorders whose etiology is linked to the environment of essentially modern air-tight buildings. These are typically characterized by features such as sealed windows, and dependence on heating, ventilation, and air-conditioning systems for air circulation. BRIs usually appear in nonindustrial office buildings, but it is also found in apartment buildings, single-family homes, schools, and libraries. There are two categories of BRIs, specific or non-specific. Diagnosis is based on history of exposure and clinical findings, and treatment is generally supportive.

Specific BRIs are those for which a link between building-related exposure and illness is proved. Typical examples include:

- *Legionella* infection
- Occupational asthma
- Inhalational fever
- Hypersensitivity pneumonitis

Unlike SBS, the causes of BRIs can be determined and are typically related to allergic reactions and infections. 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 VOCs) 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 7, 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 health care costs. The report suggests that by just having healthier and more efficient indoor environments, these costs could be reduced by 10–30%. 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, and
- Improve the psychological and social aspects of space.

The current marketplace shows that many of the building products used 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). 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. General 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.

The Insurance Information Institute (III) reports a dramatic increase in IAQ-related lawsuits within the United States and that there are currently thousands of IAQ-related cases pending. This follows several lawsuits with large damage awards particularly relating to mold that have been won in recent years by building occupants suffering from health problems linked to chemicals off-gassed from building materials, that is setting legal precedents across the country. Among the primary reasons for the dramatic increase in mold claims include:

- More energy-efficient buildings with less fresh air infiltration
- Health-related issues
- Changes in building materials such as particle board, oversight board, and “synthetic stucco” or Exterior Insulation Finish Systems
- Lawyers’ awareness of billions won in bad faith or personal injury litigation
- Mold exposure scientifically linked to adverse health effects

Because of this and 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 FACTORS THAT AFFECT IEQ

USGBC says “IEQ encompasses the conditions inside a building—air quality, lighting, thermal conditions, ergonomics—and their effects on occupants or residents.” According to a report on IEQ released in July 2005, there are a growing number of people suffering from 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 (http://ieq.nibs.org/). 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 IEQ and occupants’ health and well-being. The adverse effects to building occupants caused by poor air quality and lighting levels, the growth of molds and bacteria, off-gassing of chemicals from building materials can be significant. One of the chief characteristics of sustainable design is to support the well-being 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, providing adequate access to daylight and views, and providing for optimum comfort through control of lighting, temperature levels, and humidity.

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

Asbestos
This 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 (Table 7.1). Yet, though banned in certain products and uses, this mineral continues to pose a significant health threat. High concentrations of airborne asbestos can occur during demolition and after asbestos-containing materials are disturbed by cutting, sanding, and other activities. 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.
The EPA and US Consumer Product Safety Commission have also banned several asbestos products. But asbestos-containing material became more of a high-profile public concern after federal legislation known as Asbestos Hazard Emergency Response Act was enacted in 1987. Today, asbestos can still be found in older homes, in pipe and furnace insulation materials, asbestos shingles, millboard, textured paints and other coating materials, and floor tiles. Asbestos is considered the most widely recognized environmentally regulated material during building evaluations.

**Health Hazards:** 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, work shop, laundry, etc.), the risk increases. Increased levels of exposure to airborne

| Table 7.1 Partial list of materials that may contain asbestos |
|---------------------------------------------------------------|
| **Sample asbestos-containing material list**                   |
| 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/tabletops |
| 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 | Subflooring 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.
asbestos fibers will cause disease. When these fibers get into the air, they may be inhaled and remain and accumulate in the lung tissue, where they can cause substantial health problems including lung cancer, mesothelioma (a cancer that attacks 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 (Thus, it could be at least 10 years or more before asbestosis occurs, or several decades before symptoms of cancer emerge), the result and, thus, the risk are well established.

**Radon**

Radon is a natural colorless (at ordinary temperatures), odorless, tasteless, radioactive soil gas, i.e., that is emitted from the soil as a carcinogenic by-product of the radioactive decay of radium-226. Radon is the heaviest known gas (atomic number 86) and is often found associated with uranium ores. Radon also exists as a dissolved gas in some spring waters (e.g., those at Hot Springs, Arkansas, USA). The by-product can, however, cling to dust particles which 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, sump wells, etc., in building spaces coming in close contact with uranium-rich soil. Vent fans and exhaust fans also facilitate to 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 buildup, which is why adequate ventilation is necessary to prevent the gas 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 of radon 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 one building to another. Radon levels are typically at their highest during the coolest part of the day when pressure differentials are at their greatest.
High concentration of radon in the air 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 would be highly recommended. Generally speaking, high radon concentrations are more likely to exist where there are large rock masses, such as in mountainous regions. The United States EPA recommends that buildings should be tested every few years to assess the safety of radon levels.

**Radon Mitigation:** Everything being equal, elevated radon levels should not necessarily deter investors from purchasing a property, as the problem can usually be easily 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 should be used. The EPA has published several brochures and instructional aides 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 retrofit it later. Also, EPA studies suggest that elevated radon levels are more likely to exist in energy-efficient buildings than otherwise. 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.

**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. However, the real threat is not so much from the radon gas itself but from the products that it produces such as lead, bismuth, and polonium when it decays. The risk is greatest for people with diminished lung capacity, asthma sufferers, and smokers, and so on. And although energy-efficient construction may save energy bills, it may also increase occupants’ exposure to radon and other indoor air pollutants.

**Radon Testing Methods:** There are many methods that can be used for Radon testing. For short-term testing, consultants typically use electro-ionization chambers which generally last about a week. The chambers method work 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. Thus fortunately, Radon detection devices are commercially available, and the short-term radon test devices used for screening purposes are generally inexpensive, and sometimes free.

**Lead**

Lead is a highly toxic metal found in products including paint, ceramics, pipes, solders, gasoline, batteries, and cosmetics. Since 1980, federal and state regulatory standards have helped to minimize or eliminate the amount of lead in consumer products and occupational settings. In fact, for several decades, lead has been known to be a harmful environmental pollutant and in late 1991, the Secretary of the Department of Health and Human Services described lead as the “*number one environmental threat to the health of children in the United States.*” There are many ways in which humans may get exposed to lead: as mineral particles in ambient air, drinking water, food, contaminated soil, deteriorating paint, and dust. Lead is a heavy metal and 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 of the lead in use today is inorganic lead, which enters the body when an individual breathes (inhales) or swallows (ingestion) lead particles or dust once it has settled. Lead dust or particles cannot penetrate the skin unless the skin is broken. Organic lead, however, such as the type used in gasoline can penetrate the skin.

**Lead Levels in the Indoor Environment:** Because of its widespread use and the nature of individual uses, lead has for some time been known to be a common contaminant of interior environments. For centuries, lead compounds like 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 their use more viable particularly in exterior white paints.

The most common sources of lead exposure in the United States today consist mainly of old lead-based paint found in older homes, and old piping, contaminated soil, household dust, drinking water, lead crystal, and lead-glazed pottery. One of Lead-based paint’s main characteristics is that it can
begin to flake and peel as it ages, and can also become airborne, or ingested which can lead to serious health problems; this is of grave concern since 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. Because of potentially serious health hazards and negative publicity, lead content was gradually reduced until it was banned altogether in 1978 (in the United States). In commercial buildings, lead was used primarily as a paint preservative.

Although lead piping has sometimes been used in older buildings, it was not legally required to be replaced, which is why it can create a health hazard because the piping is frequently found to be deteriorating and leaching into the building’s drinking water. In some buildings, lead solder has also been used in copper pipes installation, but in most jurisdictions, this procedure has now been banned due to water contamination resulting from the deterioration of the solder. 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.

**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 system, 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. Effects of lead poisoning depend largely on dose exposure. Contact with lead-contaminated dust is the primary method in which most children are exposed to harmful levels of lead. Pregnant women, infants, and children are more vulnerable to lead exposure than adults because lead is more easily absorbed into growing bodies, and the tissues of small children are more sensitive to the damaging effects of lead. In adults, high lead levels have many adverse effects, including causing kidney damage, digestive problems, high blood pressure, headaches, diminishing memory and concentration, mood changes, nerve disorders, sleep disturbances, and muscle
or joint pain. Likewise, lead can seriously impact the ability of both men and women to bear healthy children.

**Lead Paint Testing**: Various testing methods and procedures can be used to identify 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 it is expensive, and should only be used by trained professionals.

**Combustion-Generated Contaminates**
Combustion (burning) by-products are essentially gases and tiny particles that are created by the incomplete burning of fuels. And there are many combustion by-products including, fine particulate matter, carbon monoxide (CO), nitrogen oxides, and tobacco smoke. These fuels (such as natural gas, propane, kerosene, fuel oil, coal, coke, charcoal, wood, and 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 contaminates and combustion were complete, emissions would have been limited to carbon dioxide (CO$_2$), water vapor (H$_2$O), and high-temperature reaction products formed from atmospheric nitrogen (NO$_x$) and oxygen (O$_2$). Sources of combustion-generated pollutants in indoor environments are many and include wood heaters and woodstoves, furnaces, gas ranges, fireplaces, and car exhaust (in an attached garage). Other combustion-generated contaminates include respirable particles, aldehydes such as formaldehyde (HCHO) and acetaldehyde, as well as a number of 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.

**Carbon Dioxide**
Carbon Dioxide 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 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, and so on.

**Carbon Monoxide**

**Carbon Monoxide** is an odorless, colorless, lighter than air, nonirritating gas that interferes with the delivery of oxygen throughout the body and which can kill you. CO is the leading cause of poisoning deaths in the United States and occurs when there is incomplete combustion of carbon-containing material such as coal, wood, natural gas, kerosene, gasoline, charcoal, fuel oil, fabrics, and plastics. CO can build up indoors and poison people and animals who breathe it. CO is typically found in fumes produced any time fuel is burned in cars or trucks, small engines, stoves, lanterns, grills, fireplaces, gas ranges, or furnaces. And the fact that CO cannot be seen, smelled, or tasted makes it especially dangerous because one is not aware of being poisoned. Moreover, doctors frequently misdiagnose CO poisoning. The most common indicators of CO poisoning are headache, dizziness, weakness, chest pain, upset stomach, vomiting, and confusion. CO symptoms are frequently described as “flu-like.” Breathing in a large quantity of CO can cause unconsciousness or death. And persons who are sleeping or drunk can die from CO poisoning before they have symptoms. Particularly at risk for CO poisoning are infants, the elderly, and persons with chronic heart disease, anemia, or breathing problems.

**Testing methods for Carbon Monoxide:** The only reliable method currently used to test for the presence of carbon monoxide is an electronic device known as a carbon monoxide alarm. In the home, CO detectors should be placed in areas where the family spends most of its time such as the family room, bedroom, or kitchen, but placed far enough away from obvious and predictable sources of CO, such as a gas stove, to avoid false alarms.

**Nitrogen Dioxide**

Nitrogen Dioxide (NO$_2$) 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. Documented evidence also indicates that
high concentrations or continued exposure to low levels of nitrogen dioxide increases the likelihood of respiratory problems. Because nitrogen dioxide is relatively insoluble 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. Likewise, documented evidence from animal studies shows that repeated exposures to elevated nitrogen dioxide levels may lead, or contribute, to the development of lung diseases such as emphysema. Excessive exposure can cause problems such as wheezing, coughing, colds, flu, and bronchitis and can also have significant impacts on people with asthma because it can cause more frequent and more intense attacks. People at particular risk from exposure to nitrogen dioxide include children with asthma and older people with heart disease or other respiratory diseases. 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.

Organic Contaminants—Aldehydes, VOCs/Semivolatile Organic Compounds, Pesticides

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. The main organic compounds include VOCs, the very volatile organic compounds (V VOCs), semivolatile organic compounds (SVOCs), and particulate organic materials (POMs). POMs may comprise components of airborne or surface dusts. Organic compounds often pose serious indoor contamination problems and include the aldehydes, VOCs/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 chlorine and fluorine containing). VOC concentration levels are generally higher in indoor environments than in outdoor air.

In recent years, we have witnessed a steady increase in the number of identified VOCs. 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 extensive sources. VOCs pose many health hazards such as being potent narcotics that cause a depression in the central nervous
system and others can cause eye, nose, and throat irritation; headaches; loss of coordination; nausea; and damage to the liver, kidneys, and central nervous system (Fig. 7.3). A number of these chemicals are suspected or known to cause cancer in humans.

**Formaldehyde**

Formaldehyde (HCHO), also known as urea-methanal, is a colorless, pungent-smelling gas, and one of the more common VOCs found indoors and which is an important chemical used widely by industry to manufacture building materials and numerous household products. Additionally, it is a nontransparent thermosetting resin or plastic, made from urea and formaldehyde heated in the presence of a base. It is also a by-product of combustion and certain other natural processes and thus, may be present in substantial concentrations both indoors and outdoors. On condensing, it forms a liquid with a high vapor pressure, and due to its high reactivity, it rapidly polymerizes with itself to form paraformaldehyde. Formaldehyde, by itself or in combination with other chemicals, serves a number of purposes in manufactured products such as a component of glues and adhesives, and as a preservative in some paints and coating products.

Some of the attributes of urea-formaldehyde (UF) resin include high tensile strength, flexural modulus, and heat distortion temperature, low water absorption, mold shrinkage, high surface hardness, and volume resistance. 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), plywood, finish coatings (acid-cured), textile treatments, as well as in the production of UF...
foam insulation (UFFI). However, most people are unaware that formaldehyde is given off by materials other than UFFI. Certain types of pressed wood products (composition board—e.g., MDF, paneling, etc.), carpeting, and other material can be formaldehyde sources. Many of these products use a UF-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.

**Health Risks**: 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 to formaldehyde can cause chemical hypersensitivity and provides an accelerating factor in the development of chronic bronchitis and pulmonary emphysema. This has caused considerable concerns about the risks of cancer and bronchial health impacts from formaldehyde. These concerns and several market factors are driving major changes in the composition and technology of these resins. In addition, significant pressure from the green building movement through market selection and certification programs, plus emissions regulations from the California Air Resources Board, has moved manufacturers to seek new ways to reduce formaldehyde emissions or eliminate formaldehyde entirely from formulas. It should be noted that upon condensing, HCHO 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.

**Polychlorinated Biphenyls**
Polychlorinated Biphenyls (PCBs) are oils used primarily as a coolant in electrical transformers. Although production and sale of PCB was banned by the 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 PCB. PCBs may also be found in light ballasts and elevator hydraulic fluids. PCBs are a suspected carcinogen, but if properly sealed or contained, they do not pose a hazard.

**Hydrocarbons**
Hydrocarbons are a class of organic chemical compounds consisting only of the elements hydrogen (H) and carbon (C) and are a colorless, flammable, toxic liquid. They are cardinal to our modern way of life and its quality and
being one of the Earth’s most important energy resources. Hydrocarbons are the principal constituents of petroleum, 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.

Many of the symptoms associated with exposure to aliphatic hydrocarbons may include watery eyes, nausea vomiting, dizziness, weakness, 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. Benzene is found in most hydrocarbons and is considered to be one of the more serious contaminants and is known to cause leukemia. Air quality tests may be necessary as well as tests for contaminants in the soil around the foundation.

Pesticides

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 and as such are unique contaminants of indoor environments. Studies show that approximately 16 million Americans are sensitive to pesticides, because 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, miscarriages, genetic damage, decreased fertility, liver damage, thyroid disorders, diabetes, neuropathy, still births, decreased sperm counts, asthma, and other autoimmune disorders (lupus, etc.).

Pesticides are carefully regulated by the Federal Government, in cooperation with the States, 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 pesticide products that are available in the marketplace including some of the most widely used over the past 60 years that are persistent and have become globally distributed.

According to the EPA, “The process of registering a pesticide is a scientific, legal, and administrative procedure through which we examine the ingredients of the pesticide; the particular site or crop where it is to be used; the amount, frequency, and timing of its use; and storage and disposal
practices. In evaluating a pesticide registration application, we assess a wide variety of potential human health and environmental effects associated with use of the product. The company that wants to produce the pesticide must provide data from studies that comply with our testing guidelines.”

The EPA also states that “Potential human risks range from short-term toxicity to long-term effects such as cancer and reproductive system disorders.” These include aldrin, chlordane, dichlorodiphenyltrichloroethane, 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 threaten our ecosystem. The EPA regulates “pesticides under broad authority granted in two major statutes, the Federal Insecticide, Fungicide, and Rodenticide Act and the Federal Food, Drug, and Cosmetic Act. These laws have been amended by the Food Quality Protection Act and the Pesticide Registration Improvement Act.”

### Biological Contaminants

Mold and mildew, viruses, bacteria, and exposures to mite, insect, and animal allergens are biological pollutants arising from various sources such as microbiological contamination (e.g., fungi, bacteria, viruses), mites, pollens, and the remains and dropping of pests such as cockroaches. Of particular concern are those biological contaminants that cause immunological sensitization manifested as chronic allergic rhinitis, asthma, and hypersensitivity pneumonitis. Pollutants of biological origin can also significantly impact indoor air quality and cause infectious disease through airborne transmission.

One of the major contributors to poor indoor air quality, mold growth, and unhealthy buildings is the presence of moisture, but by controlling the relative humidity (RH) 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 as well as contaminated central HVAC systems which can then distribute these contaminants through the building.

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

**Mold and Mildew**

Mold and Mildew are forms 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 are thousands of species of molds which include pathogens, saprotrophs, aquatic species, and thermophiles. Molds are part of the natural environment growing on dead organic matter and are present everywhere in nature; their presence is only visible to the unaided eye when mold colonies grow (Table 7.2).

Different mold species will vary enormously in their tolerance to temperature and humidity extremes. The key to controlling indoor mold

| 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, toxic pneumonitis infection |
| *Cladosporium herbarum* | Moist window-sills, wood                     | Allergens            | Asthma, allergy                          |
| *Penicillium chrysogenum* | Damp wallpaper, behind paint                | Mycotoxins           | Unknown                                  |
| *Penicillium expansum*  | Damp wallpaper                               | VOCs, Mycotoxins     | Unknown                                  |
| *Stachybotrys chartarum* (attra) | Heavily wetted carpet, gypsum board | Mycotoxins           | Dermatitis, mucosal irritation, immunosuppression |

VOCs, volatile organic compounds.
Source: California Department of Health Services, Environmental Health Investigations Branch.
growth is to control moisture content, and the temperatures of all surfaces, including interstitial surfaces within walls. Mold generally needs a temperature range between 40°F and 100°F to grow, and maintaining RH levels between 30% and 60% will help control mold and many of these known biological contaminants. Winter humidification and summer dehumidification controls/modules can supplement central HVAC systems when climate excesses require additional conditioning measures.

Exposure to fungus in indoor air settings has emerged as a significant health problem of great concern in both residential environments as well as in workplace settings. Fungi are primitive plants that lack chlorophyll and therefore feed on organic matter that they digest externally and absorb or must live as parasites. True fungi include yeast, mold, mildew, rust, smut, and mushrooms. When mold spores land on a damp spot indoors, they can grow and start digesting whatever they are growing on.

Four vital elements are needed for mold to grow, they are: viable spores, a nutrient source (organic matter like wood products, carpet, and drywall), moisture, and warmth. The mere presence of humid air in itself is not necessarily conducive to fostering mold growth, except where air has an RH level at or above 80% 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 the things they grow on. Likewise by removing any of the four essential growth elements, the growth process is inhibited or nonexistent.

To execute a mold remediation project, the first step requires determining the root cause of the mold growth. The next step is to evaluate the order of magnitude of the mold growth, which 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. Toxic molds and fungi are a significant source of airborne VOCs that create IAQ problems as can be seen in Fig. 7.4. Toxicity can arise from inhalation or skin contact with toxigenic molds. 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.
Bacteria and Viruses

Many millions of people around the globe suffer daily from viral infections of varying degrees of severity and at immense cost to the economy including the costs for medical treatment of infected people, costs of lost income due to inability to work, and costs of decreased productivity of those who are infected. 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, and parainfluenza viruses; whereas viruses responsible for gastrointestinal infections include rotavirus, astrovirus, Norwalk–like viruses. Some of these infections like the common cold are very widely spread but are not severe, while infections like influenza are relatively more serious.

Figure 7.4  (a) Example of mold on a ceiling that is growing out of control which can be found in damp buildings. (b) Example of mold on a wall that has grown out of control. (c) Example of an extreme case of toxic mold growth in the process of being treated. Courtesy: Applied Forensic Engineering, LLC. (a) Source: mold-kill.com.
While bacteria cause bacterial infections, viruses cause viral infections. And while antibiotic drugs usually kill bacteria, they are not effective against viruses. Examples of infections caused by bacteria include strep throat, tuberculosis, and urinary tract infections. Common diseases caused by viruses include chicken pox, AIDS, and common colds. In some cases, it may be difficult to determine whether a bacterium or a virus is causing a person’s symptoms. Many ailments such as pneumonia, meningitis, and diarrhea can be caused by either type of microbe.

Bacteria and viruses are minute in size and readily become airborne and remain suspended in air for hours which makes them a cause of considerable concern due to their ability to transmit infectious diseases. While there are many methods for the infection to spread, 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 (also known as query fever), which is a bacterial infection caused by the bacteria *Coxiella burnetii*, is another emerging infectious disease among US soldiers serving in Iraq.

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 their biological properties. Bacterial aerosols have also been found to be a means to transmit a number of major diseases as shown in Table 7.3 below:

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

- The type of virus and potential health effects it causes
- Mode of exit from the body

| Disease                        | Causal organism          |
|-------------------------------|--------------------------|
| Tuberculosis                  | *Mycobacterium tuberculosis* |
| Pneumonia                     | *Mycoplasma pneumoniae*   |
| Diphtheria                    | *Corynebacterium diphtheriae* |
| Anthrax                       | *Bacillus anthracis*      |
| Legionnaires’ disease         | *Legionella pneumophila*  |
| Meningococcal meningitis      | *Neisseria meningitidis*  |
| Respiratory infections        | *Pseudomonas aeruginosa*  |
| Wound infections              | *Staphylococcus aureus*   |
• 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 building 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 derived from infected individuals. A number of infectious viral diseases and associated causal viruses transmitted through air are shown below in Table 7.4.

### Rodent, Insect, and Animal Allergens

The Illinois Department of Public Health, a typical large city in the United States says it annually receives more than 10,000 complaints about rodent problems and performs tens of thousands of rodent control inspections and baiting services. Effective measures need be taken to prevent entry by 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. 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 pests presenting a serious health concern to a building’s occupants, they also distract from a facility’s appearance and value.

#### Rats

Large communities of rats exist today within and beneath cities, traveling unnoticed from one building to another, along sewers and utility lines. Each

| Disease        | Virus/bacteria type |
|----------------|---------------------|
| Influenza      | Orthomyxovirus      |
| Cold           | Coronavirus          |
| Measles        | Paramyxovirus       |
| Rubella        | Togavirus           |
| Chicken pox    | Herpes virus        |
| Respiratory infection | Adenovirus          |
A 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-foot to 150-foot radius of the nest, while mice usually have a much smaller range, living within a 10-foot to 30-foot radius of the nest (Fig. 7.5). In places where all their needs (food, water, shelter) are met, rodents have smaller territories.

**Insects**

Today, more than 900,000 species of insects have been identified and additional species are being identified everyday. 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 allergens and are commonly implicated as contributors to SBS in urban housing and facilities with poor sanitation. Most of the allergens from cockroaches come from the insect’s discarded skins (Fig. 7.6). As the skins disintegrate over time, they become airborne and are inhaled. Cockroaches have been reported to spread at least 33 kinds of bacteria, 6 kinds of parasitic worms, and at least 7 other kinds of human pathogens.

**Mites:** Mites are microscope bugs that thrive on the constant supply of shed human skin cells (commonly called dander) that accumulate on carpeting, drapes, furniture coverings, and bedding (Fig. 7.7). The proteins in that 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. It is estimated that up to 15% of people are allergic to dust mites which due to their very small size
(250–300 μm 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 10× magnification. Dust mites have eight hairy legs, no eyes or antennae, and a mouthpart group in front of the body (resembles head) and a tough, translucent shell. Dust mites have multiple developmental stages, commencing with an egg, then developing into larva, followed by several nymph stages, and finally the adult. They also 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 flakes). Humans generally shed about 1/5 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.

**Ants**: Ants are found throughout the United States, although species found in different regions of the country vary. 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 (Fig. 7.8). Worldwide, there are more than 12,000 species, but of these, only a limited number actually cause problems. Among the more common ant species in the United States are the Argentine, Odorous House, Carpenter, Fire, Pavement, and Pharaoh Ants. Destructive ant species include fire and carpenter ants. Fire ants are vicious, unrelenting predators and have a powerful, painful sting. More than 32 deaths in the United States have been attributed to severe allergic reactions to fire ant stings. Ant infestations are more likely to occur in single-family dwellings, because colonies usually nest outdoors and will only come inside in search of food or water.
Termites: Although there are more than 2000 species of termites across the world, only 50 or so of those species are found within the United States. Termites live in colonies; this means they live and work together to gather food and raise their young (larvae). 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 telltale signs termites usually provide such as small holes in wood, straw-shaped mud tubes, crumbling drywall, termite insect wings, and sagging doors or floors (Fig. 7.9).

Animal Allergens
Allergens are produced by many mammalian and avian species and 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, although pollens, ragweed, and a variety of other allergens can find their way indoors from the outdoors. 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.

7.2.2 General Steps to Reducing Pollutant Exposure
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 their 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. 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 (there are numerous addenda to this standard; visit https://www.ashrae.org/standards-research--technology/standards--guidelines) 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 7.3.5 of this chapter.

Indoor air pollution is currently ranked among the top four environmental risks in America by the EPA, which 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.

**Investigating Indoor Air Quality**

Indoor Air Quality (IAQ) investigations provide evaluations of air quality in both public and commercial buildings. Indoor air quality is defined by the depiction of concentrations of pollutants and thermal conditions that may negatively affect the health, comfort, and performance of a building’s occupants. Thus, the procedure for investigating 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 namely:
• A building’s occupants
• A building’s HVAC system
• Possible pollutant pathways
• Possible sources of contamination

7.2.3 Thermal Comfort

Defining thermal comfort is somewhat elusive other than it is a state of well-being and involves temperature, humidity, and air movement among other things. Wikipedia says, “Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation (ANSI/ASHRAE Standard 55).” Often heard complaints facility managers get from building occupants is that their office space is either too cold or too hot. Studies show that people of 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 not an easy matter. 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% of the building occupants are expected to express satisfaction.” This is the goal outlined by the ASHRAE in the industry’s gold standard of comfort—Standard 55, Thermal Environmental Conditions for Human Occupancy. ASHRAE Standard 55 also specifies what thermal conditions are deemed likely to be comfortable to occupants.

As previously mentioned, employee health and productivity are greatly influenced by the quality of the indoor environment. 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. 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 well-being 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.
Below are a number of relevant standards, codes, and guidelines (check websites for latest updates):

- ASHRAE Standard 62-1999: Ventilation for Acceptable Air Quality
- ASHRAE 129-1997: Measuring Air-Change Effectiveness
- South Coast Rule #1168, South Coast Air Quality Management District
- Regulation 8, Rule 51, of 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 VOCs from Office Building Construction Materials
- Carpet and Rug Institute Green Label Indoor Air Quality Test Program

7.2.4 Noise Pollution

Much research has been conducted on noise pollution which is considered to be 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 federal EPA 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. And although good engineering design can mitigate noise pollution levels to some extent, it is frequently not to acceptable levels, particularly if a significant number of individual sources combine to create a cumulative impact. Nevertheless, humans, whether tenants or building occupants have a basic right to live in environments that are relatively free from the intrusion of noise pollution, even though this may not always be possible.

Defining Noise

Noise can be defined as a form and level of environmental sound that is generally considered likely to annoy. The City of Berkeley’s Planning and Development Department on the other hand defines sound as pressure variations in air or water which can be perceived by human hearing and 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 use of a unit of measurement called a decibel (dB). On the dB scale, the zero represents the lowest sound level that a healthy, unimpaired human ear can detect. Sound levels in dBs are calculated on a logarithmic basis. Thus, an increase of 10 dB represents a 10-fold increase in acoustic energy, and a 20 dB increase is 100 times more intense \((10 \times 10)\), etc. The human ear likewise responds logarithmically, and each 10-dB increase in sound level is perceived as approximately a doubling of loudness.

**Impact of Noise**

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 be undesirable. For example, 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). There is therefore the introduction of a value judgment among people 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.

**Health Effects**

Wikipedia points out 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 like after an explosion. 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 which 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 8 h. 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 that may further lead to undesirable stress-related behavior, increase workplace accident rates or in many cases, stimulate aggression and other antisocial behaviors when they are exposed to chronically excessive noise.

Major Sources of Noise
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

Cities in the United States currently can only adopt noise exposure standards for noise levels emanating from trucks, trains, or planes and then not permit land uses to be developed in areas with 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 streets that impact noise generation. 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 by reducing the noise level at the source, increasing the distance between the source and the receiver, and place an appropriate obstruction (e.g., a wall) between the noise source and the receiver.

A noise wall may sometimes be 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 with noise walls we have both a positive side, the ability to reduce the noise exposure to affected persons, and a negative side, that is 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 from receivers, it may also block beautiful views of trees, parks, and water, and may also give drivers a claustrophobia feeling of being surrounded by massive walls.
7.2.5 Daylighting and the Daylight Factor

The sun has been our principal source of light and heat for millions of years, and we have become almost totally dependent on it for our health and survival. The world and, in particular, the sustainable design movement is now returning to nature because of its increasing concern with global warming, carbon emissions, and sustainable design, and has started to take positive steps to increase its 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, the new IgCC and now has increased recognition in California’s Title 24 energy code. According to Craig DiLouie of the Lighting Controls Association daylighting is defined as “the use of daylight as a primary source of illumination to support human activity in a space.” Direct sunlight is a 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 (Fig. 7.10).

Figure 7.10 The three major types of energy flows that occur through windows: (1) Nonsolar heat losses and gains in the form of conduction, convection, and radiation (2) solar heat gains in the form of radiation and (3) airflow, both intentional as ventilation and unintentional as infiltration. Source: US DOE.
Assessing the daylight quality in a room traditionally consisted of a manual average daylight factor (DF) calculation, or based on a computerized version of the manual method. The term “average DF” is sometimes construed to be the average DF on all surfaces, whereas the output from most computer-based calculations reflect average DF calculations derived from a series of points on the working plane. 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 lighting and electrical lighting calculations and also take into account an evaluation of the thermal impact on window design. Table 7.5 lists recommended illumination levels for various locations and functions.

Daylight availability in a room is normally expressed by a measure commonly called the DF. Chris Croly, a building services engineering associate with BDP Dublin and Martin Lupton, a director with BDP Lighting, however, state that, “The calculation of daylight factor 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 factor or lux levels corresponding to a particular static external condition.” They define DF 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

| Area                              | Foot-candles |
|-----------------------------------|--------------|
| Building surrounds                | 1            |
| Parking area                      | 5            |
| Exterior entrance                 | 5            |
| Exterior shipping area            | 20           |
| Exterior loading platforms        | 20           |
| Office corridors and stairways    | 20           |
| Elevators and escalators         | 20           |
| Reception rooms                   | 30           |
| Reading or writing areas          | 70           |
| General office work areas         | 100          |
| Accounting/bookkeeping areas      | 150          |
| Detailed drafting areas           | 200          |
in percent. The higher the DF, the more natural light that is available in the room. The impact of direct sunlight to 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 \( E_{in} \) represents the inside illuminance at a fixed point and \( E_{ext} \) represents the outside horizontal illuminance under an overcast (Commission Internationale de l’Eclairage (CIE) sky) or uniform sky, as defined by the CIE.

**Daylighting Strategies**

Research over the years clearly demonstrates that effective daylighting saves energy and improves the quality of the visual environment, while reducing operating costs and enhancing 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, offsetting any savings achieved by reduced lighting loads. Some architectural/design firms known for their sustainable design inclinations like HOK and Gensler design the majority of their buildings to be internally load-dominated, meaning the buildings need to be cooled for most of the year. Strategies for improved daylighting include 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 will involve the integration of several key disciplines including architectural, mechanical, electrical, and lighting. As with sustainable design in general, an integrated design approach is needed where team members are brought into the design process early to ensure that daylighting concepts and strategies are satisfactorily implemented throughout the project (Fig. 7.11).

The application of innovative and advanced daylighting strategies and systems can significantly enhance the quality of light in an indoor environment as well as improve 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 significantly reducing the total building energy costs.

Note that when light hits a surface, part of the light is reflected back. This reflection normally takes the form of diffused (nondirectional) and is dependent on the object’s reflection. The reflection of the outside ground
is typically in the order of 0.2% or 20%. This means that in addition to the
direct sunlight and skylight components, there also exists an indirect com-
ponent which can make a significant contribution to the lighting inside a
building, especially since the light reflected off the ground will hit the ceil-
ing thus adding to its brightness.

**Daylighting and Visual Comfort**

Designing for natural light has for many years been a challenge that design-
ers often face, due to 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 BRIs and
SBS. Gregg Ander, FAIA says that “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.”
Designers should adopt practical design strategies for sustainable daylighting
design that will increase visual comfort by applying three primary techniques.
These are basic lighting approaches that reflect the strategies of sustainability
and thus support the larger ecological goal. These strategies are:

- **Architectonic**: What has made daylighting design so difficult until
  recently 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 do not have this capability or the budget for it.

- **Environmental**: using the natural forces that impact design, resource, and energy conservation.
- **Human Factors**: the impact on people and their experience. 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.

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% higher on standardized tests than students in the same school district but whose classrooms had less natural light. This appears to confirm what many educationalists 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 of 108 stores that were part of a large retail chain. The stores were all one storey 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%—even though the design and operation of all the store sites was remarkably uniform, except for the presence of skylights in some of the stores. The study showed that all other things being equal, an average nonskylit store in the chain would likely increase their sales by an average of about 40% just by adding skylights, even though the design and operation of all the store sites was remarkably uniform, except for the presence of skylights.

Technology is moving at such a rapid pace and architects are now increasingly specifying high-performance glass with spectrally selective coatings that only allows 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 then hits a solid surface, it is absorbed and reradiated into the space as heat.

Combining daylighting with efficient electric lighting strategies can provide substantial energy savings. The building’s planning module can often give indications on how best to organize the lighting. In any case, the lighting system must correlate to the various systems in place including structural, curtain wall system, ceiling system, and furniture system. Likewise, initial lighting costs may rise when designing for sustainability and implementing energy-efficient strategies. These energy-saving designs may require items like dimmable ballasts, photocells, and occupancy sensors, all of which are not typically covered in most traditional project budgets (Fig. 7.12). However, these items would normally be included if an integrated design approach was employed and where daylight strategies were appropriately employed at an early phase of the project’s design.

Figure 7.12 Schematic diagram of a room utilizing a photoelectric dimming system. The ceiling-mounted photosensor reads both electric light and daylight within the space and adjusts the electric lighting as required to maintain the design level of total lighting. Source: Ernest Orlando Lawrence Berkeley National Laboratory.
Daylight has many positive attributes, the main one being enhancing 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 link indoor spaces with the outdoors for the building occupants. However, natural light also has its negatives such as glare, overheating, variability, and privacy issues. It is left to the designer therefore to find ways to increase the positive aspects of using natural light in buildings, while at the same time reducing the negative. Addressing glare requires 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 alternative sources of light.

In recent years, the implementation of daylighting strategies at an early stage of a building design has become vital for the success of the building's lighting strategy. This is because previously simple tools that can predict the performance of advanced daylighting strategies were not available to the designer. The data output from their 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, yet avoiding glare.

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 associated with them 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 daylight zones to be extended from a conventional 10–15 ft (3.0 to 4.6 m) depth to a 20 ft (6.1 m) or even 30 ft (9.1 m) depth from the window wall.
• The increased use of low-reflectance, higher brightness flat-screen LCD monitors, has allowed architects to employ design solutions that involve increasing daylight and 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.

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, skylight, and other shading systems (Fig. 7.13). Some owners are being driven by the financial and competitive pressure of powerful market forces 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 associated with their use. The following are significant potential risks associated with highly glazed façades:

• Increased sun penetration and excessive brightness levels that exceed good practice may cause or heighten visual discomfort.
• Adequate tools may not always be available to reliably predict thermal and optical performance of components and systems, and to assess environmental quality.

Figure 7.13 A rule of thumb for daylight penetration with typical depth and ceiling height is 1.5 times head height for standard windows, 1.5 to 2.0 times head height with light shelf, for south facing windows under direct sunlight. Source: Ernest Orlando Lawrence Berkeley Laboratory.
• Buildings utilizing transparent glazing generally use greater cooling loads and cooling energy, which has the potential for thermal discomfort (Fig. 7.14).
• Increased cost of automated shading systems and purchasing lighting controls utilizing dimming ballasts and difficulty in commissioning systems after installation.
• Technical difficulty and high cost of reliably integrating dimmable lighting and shading controls with each other and with building automation systems to ensure effective operation over time.
• 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.

Large glazed spaces in work areas (as distinct from corridors, lobbies, etc.) require much better sun and glare control to reap potential benefits and minimize possible risks. Appropriate solutions must be delivered by systems that can rapidly respond to exterior climate and interior needs. One of the challenges facing manufacturers is how to provide such needed increased functionality at lower cost and lower risk to owners. Due to various advantages and disadvantages, lighting consultants often recommend the use of switching for spaces with nonstationary tasks such as corridors, and continuous dimming for spaces where users perform stationary tasks,

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**Figure 7.14** Graphic of various cooling load sources. *Source: Ernest Orlando Lawrence Berkeley Laboratory.*

such as offices. It has been shown that daylight harvesting using continuous dimming equipment automatically controlled by a photosensor, can generate 30–40% savings in lighting energy consumption, thereby significantly reducing operating costs.

**Shades and Shade Controls**

The greatest benefit of harvesting daylight can be achieved implementing a shading strategy that is tailored to the building in question. 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 (Fig. 7.15). 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% of the solar heat gain. Shades and shade control strategy is based on the perception that occupants of commercial buildings typically prefer natural light to electric light, and the shade system goals would normally include maximizing use of natural light within a glare free environment, while avoiding direct solar radiation on occupants through interception of sunlight penetration. Such a strategy may also include facilitating occupant connectivity with the outdoors through increased glazing and external views.

![Figure 7.15](image-url) A venetian-blind system at a Berkeley Lab office building is equipped with a “virtual instrument” panel for IBECs control of blinds settings. **Courtesy: HPCBS.**
7.2.6 Views

Research over the years has shown that windows providing daylight and ample views can dramatically affect building occupants’ mental alertness, productivity, and psychological well-being. David Hobstetter, 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 well-being.” Though some educators opine 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 plain concrete walls. Another revealing study noted that computer programmers with views spent 15% more time on their primary task, while workers without views spent 15% more time talking on the phone or to one another.

Building occupants generally relish contact with the outside world, even if only through a windowpane, and landscapes not surprisingly are preferred to cityscapes, and in many countries around the world, views, whether high-rise or otherwise, are normally considered mere perks. Moreover, some researchers contend 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% to 12% faster than colleagues without views. Workers with better views also reported better health conditions and feelings of well-being, while their counterparts reported higher fatigue.”

Researchers have also 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, maintenance facilities, and storage facilities such as warehouses.
7.3 VENTILATION AND FILTRATION

In ancient times, buildings whether a Babylonian palace, an Egyptian temple or a Roman castle, were ventilated naturally using either “badgeer/malqaf” (wind shafts/towers) or some other innovative method (Fig. 7.16) since mechanical systems did not exist at the time. Andy Walker of the National Renewable Energy Laboratory says, “Wind towers, often topped

![Figure 7.16](image-url)  
*Different types of traditional wind catchers.*

Figure 7.16 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.
with fabric sails that direct wind into the building, are a common feature in historic Arabic architecture, and are known as ‘malqafs.’ 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 IEQ. 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. In today’s polluted environment, inadequate ventilation is one of the main culprits that cause increased indoor pollutant levels by not bringing in enough outdoor air to dilute emissions from indoor sources and by not removing these indoor air pollutants to the exterior.

### 7.3.1 Ventilation and Ductwork

Appropriate 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 a prerequisite to ensuring healthy air quality, occupant comfort, and energy efficiency. Sufficient air supply and movement can be tested and analyzed to determine 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 airflow and potential 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 surprising that to date, we lack Federal standards for air filter performance. Air cleaning filters are designed to remove pollutants from indoor air, to improve the indoor environment and breathe cleaner air. Proper filtration removes dirt, dust, and debris from the air you breathe and reduces pollen and other allergens, which can cause asthmatic attacks and allergic reactions. Filters awarded the *High-Efficiency Particulate Air* accolade has to satisfy certain standards of efficiency such as those set by the United States
Department of Energy (DOE). To qualify as HEPA by government standards, an air filter must remove $99.97\%$ of all particles greater than $0.3\,\mu m$ from the air that passes through. A filter that is qualified as HEPA is superior to those unqualified, but is also subject to interior classifications. And although 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.

The marketplace is currently flooded with various types of air filters including mechanical filters, electronic filters, hybrid filters, gas phase, and ozone generators—some of which 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. Filters are often rated according to the Minimum Efficiency Reporting Value (MERV), which is a filter rating system devised by the ASHRAE to standardize and simplify filter efficiency ratings for the public. In the MERV rating system, the higher the rating, the higher the efficiency of the air filter; thus a MERV 12 filter will remove smaller particles from the air than a MERV 8 filter. Before making a determination on the most appropriate filter for a project or home, adequate research is required (see ANSI/AHRI Standard 680 (I-P)-2009).

### 7.3.3 Air Purification

Pollutants are released more or less continuously from many sources, such as building materials, furnishings, and household products like air fresheners. Some sources, related to activities carried out in the home or workplace, release pollutants intermittently. These include smoking, the use of unvented or malfunctioning stoves, furnaces, or space heaters, the use of solvents in cleaning and hobby activities, the use of paint strippers in redecorating activities, and the use of cleaning products and pesticides. High pollutant concentrations can remain in the air for extended periods after some of these activities cease if appropriate action is not taken. While air filtration removes particulate, air purification is required to remove the things a filter fails to, 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 one
way to address these potential problems is through air purification on a regular basis. These concerns have encouraged the use of air purifiers that are intended to relieve allergy symptoms, fight pollution, eradicate airborne pollutants, remove unwanted smells, and eliminate germs.

7.3.4 Amount of Ventilation

There are various means for outdoor air to enter and leave a building 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 by wind. When insufficient outdoor air enters a home, pollutants can accumulate to elevated levels 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 a room, such as bathrooms and kitchen, 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 rising pollutant levels should be expected.

Residents or occupants are occasionally 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 one 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 in a downloadable PDF format.
7.3.5 Ventilation Improvements

Increasing the amount of outdoor air coming indoors is another approach to lowering the concentrations of indoor air pollutants. 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 increases the outdoor ventilation rate. In residents, 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 like painting, paint stripping, or heating with kerosene heaters. Such activities should preferably be executed outdoors whenever possible. The following design recommendations can help achieve better ventilation in buildings:

- Naturally ventilated buildings should preferably be narrow, as it is difficult to distribute fresh air to all areas of a wide building using natural ventilation. The maximum width that one may expect to ventilate naturally is estimated at 45 ft. Consequently, buildings that rely on natural ventilation typically have an articulated floor plan. Use of mechanical cooling is recommended in hot, humid climates.
- Occupants should be able to operate window openings.
- The use of fan-assisted cooling strategies should be considered. Employing ceiling and whole-building fans can provide up to 9°F effective temperature drop costing about one-tenth the electrical energy consumption of mechanical air-conditioning systems.
- Decide whether an open- or closed-building ventilation approach potentially offers the best results (A closed-building approach is more appropriate 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).
- Maximize wind-induced ventilation by siting the ridge of a building perpendicular to the summer winds. Also, buildings should be sited where summer wind obstructions are minimal. A windbreak of evergreen trees may also be useful to mitigate cold winter winds that tend to come predominantly from the north.
- When possible, provide ventilation to the attic space as this greatly reduces heat transfer to conditioned rooms below. In buildings with
attics, ventilating the attic space greatly reduces heat transfer to conditioned rooms below. Ventilated attics have been found to be approximately 30°F cooler than unventilated attics.

**Air Cleaners**

Air cleaners come in a variety of types and sizes 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. The effectiveness of an air cleaner 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. The fact needs noting that 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. All being said, the long-term performance of any air cleaner depends to a large extent on maintaining it in accordance with 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 reduce 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 of pollution.

**Ventilation Systems**

Most large commercial buildings have mechanical ventilation systems that are typically designed and operated to heat and cool the air, as well as to draw in and circulate outdoor air. However, 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 adequate 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 to reach 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 kitchens and bathrooms.

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.” For Mechanically Ventilated Spaces designers should refer to ASHRAE Standard 55-1992, Addenda 1995 “Thermal Environmental Conditions for Human Occupancy.”

RELEVANT CODES AND STANDARDS.

- Energy Policy Act of 2005 (PDF 1.9 MB, 550 pages)
- Naturally ventilated buildings should be designed to provide thermal comfort, to achieve adequate moisture and contaminant removal, and to meet or exceed Government Energy Conservation Performance Standards.
- Standards for building thermal comfort have been defined by ASHRAE 55.
- Standards for adequate ventilation rates and contaminant levels are found in ASHRAE 62
- Additional standards effecting ventilation practice have been developed by:
  - American Conference of Governmental Industrial Hygienists (ACGIH)
  - ACGIH: provides threshold limit values for chemical substances and physical agents and biological exposure indices.
- OSHA
- OSHA (1989), Air Contaminants: examines Air Contaminants—Permissible Exposure limits (Title 29, Code of Federal Regulations, Part 1910.1000).
- Federal energy standards: The US DOE has updated 10 CFR 435 to reflect the codified version of the ASHRAE/Illuminating Engineering Society of North America Standard 90.1 to be closer to the existing voluntary sector code. This new federal standard, 10 CFR 434 Energy Code for New Federal Commercial and Multi-Family High Rise Residential Buildings, is mandatory for all new federal buildings. For existing buildings, refer to ASHRAE 100 Energy Conservation in Existing Buildings. For residential buildings, the applicable standard is ASHRAE 90.2 Energy Efficient Design of Low-Rise Residential Buildings. Methodology and Procedures for Life-Cycle Cost Analysis are described in 10 CFR 436.
7.4 BUILDING MATERIALS AND FINISHES—EMITTANCE LEVELS

Although several studies have been conducted over the years to investigate the impact of pollution emitted by building materials on the indoor air quality and then relating the results to ventilation requirements, there has been a lack of systematic experiments, in which building materials are initially ranked according to their pollution strength, and then analyzing the impact on the indoor air quality when using these materials in real rooms. Such studies would allow us to quantify the extent to which using low polluting building materials would reduce the energy used for ventilation of buildings without having to compromise 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 Toxic Building Materials

The Healthy Building Network (HBN) identifies the primary building materials that are considered toxic and which have unacceptable high VOC emittance levels. Examples are given in the following subsections.

Polyvinyl Chloride

Polyvinyl chloride (PVC) and its by-products contain known carcinogens that are released as they age and release dioxin when burned. This is why HBN singled it out for elimination. Likewise because of its uniquely wide and potent range of chemical emissions throughout its life cycle including many of the target chemicals listed below. 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 potent carcinogen dioxins, vinyl chloride, ethylene dichloride, PCBs, and others. Moreover, when burned, it releases hydrochloric acid and more dioxins. It is therefore prudent to avoid products made with PVC.

Volatile Organic Compounds

As discussed earlier, VOCs consist of thousands of different chemicals, such as formaldehyde and benzene, which evaporate readily into the air. Depending on the level of exposure, they can cause dizziness, headaches, eye, nose, and throat irritation or asthma, and in some cases, can also cause
cancer, 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 in them. 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 South Coast Air Quality Management District compliant.

To minimize VOCs in 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, CRF’s Green Label Plus, SCS’s Indoor Advantage, RFCI’s FloorScore, and GreenGuard’s Children and Schools Certification Program. Try to avoid flooring that requires waxing and stripping, a process which will release more VOCs than the original material. Care should be taken to ensure that there is no added formaldehyde present in all composite wood products and insulation.

**Phthalates**

Di(2-ethylhexyl) phthalate and other phthalates have attracted considerable adverse publicity for their use in PVC medical products and in toys (although the US Congress banned six kinds of phthalates from toys 8 years ago) and concerns have been raised about their impact on the development of young children. However, phthalates are chemicals that can be found almost everywhere. They are in soaps, plastics, and even cosmetics. Phthalates are also in our foods and are 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 PVCs).

**Heavy Metals**

Even though these metals are known to be health hazards, they continue to be used for stabilizers or other additives in building materials. Lead, mercury and organotins are all known potent neurotoxins, which is 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 therefore for products that do not contain heavy metals that are health hazards.
Halogenated Flame Retardants

The use of flame retardants in many fabrics, foams, and numerous plastics is known to have saved many lives over the years. However, the halogenated flame retardants (HFRs); 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 systems. The use of products that have HFRs should be avoided.

Perfluorocarbons

Perfluorocarbons (PFCs) (sometimes referred to as fluorocarbons) are colorless and have high density, up to over twice that of water. Numerous treatments for fabric and some building materials have been based on PFCs that—like the 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 Scotchgard, Stainmaster, Teflon, and Gore-Tex, and has been linked to a range of developmental and other adverse health effects. Thus avoid all products that are treated with a PFC-based material.

7.4.2 Resources for Locating Healthy Building Materials

Because of the great diversity of materials used in the construction and manufacturing industries, it is difficult to produce a single building materials list or certification that covers all of the relevant health and environmental issues. For example, the HBN’s PVC-Free Alternatives Database (www.healthybuilding.net/pvc/alternatives.html) is a Construction Specifications Institute–prepared listing of PVC-free alternatives for a wide range of building materials. The following list should be useful:

Green Seal-Certified Products: Paints and coatings that meet the GreenSeal VOC (VOCs) content standards are listed; these materials do not contain certain excluded chemicals and meet typical LEED performance requirements.

EcoLogo: Is an environmental standard and certification mark founded in 1988 by the Government of Canada and 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 eco-label, as defined by the International
Organization for Standardization (ISO) and has been successfully audited by the Global EcoLabelling Network as meeting ISO 14024 standards for eco-labeling. Products EcoLogo certifies include carpet, adhesives, and paint.

**CHPS (Collaborative for High Performance Schools) Low-Emitting Materials:** CHPS 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 ([www.chps.net/manual/lem_table.htm](http://www.chps.net/manual/lem_table.htm)).

**Green Label Plus:** This basically confirms 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 just needs to look for the Green Label Plus logo as this 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 (see [www.scscertified.com/iaq/floorscore_1.html](http://www.scscertified.com/iaq/floorscore_1.html)).

**GreenGuard for Children and Schools:** Air Quality Sciences certifies for GreenGuard that furniture and indoor finishes meet 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.

**BFRs/HFRs and perfluorochemicals (PFCs):** Although no listings are yet screened for these emerging problem chemicals, all halogen-based
flame retardants are likely to be problematic. Flame retardants are added to plastics, particularly fabrics and foams. PBDEs are the most widely used.

### 7.5 IEQ BEST PRACTICES

An overview of the new International Green Construction Codes clearly reaffirms that IEQ is a critical component of sustainable buildings. Ventilation, thermal comfort, air quality, and access to daylight and views are all important factors that play a pivotal role in determining IEQ.

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 IEQ Project as a first step in implementing an action plan. The NIBS issued a project report on IEQ released in July 2005 which 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, and fragrances, and others products. This condition is known as MCS. The range and severity of these reactions are very varied. In addition, the Access Board received numerous complaints from other people who report adverse reactions from exposures to electrical devices and frequencies, a condition referred to as electromagnetic sensitivity (EMS).

The Access Board responded to these concerns by sponsoring a study on ways to tackle the problem of IEQ for persons with MCS and EMS as well as for the general population. In conducting this study for the Board, the NIBS brought together a number of interested parties to explore the relevant issues and to develop an appropriate action plan. The report includes among other things, recommendations on improving IEQ that addresses building products, materials, ventilation, and maintenance issues.

The following are some of the steps and best practices that can be applied to ensure good IEQ (portions of this list are excerpted from “Indoor Environmental Quality” Harvard University Campus Services):

- Conduct a faculty-wide IEQ survey/inspection of the facility, noting odors, unsanitary conditions, visible mold growth, staining, presence of moisture in inappropriate places, poorly maintained filters, personal air cleaners, hazardous chemicals, uneven temperatures, blocked vents.
- Determine operating schedule and design parameters for 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 well-being of building occupants. Maintain complete and up-to-date ventilation system records.

- Ensure that appropriate Preventive Maintenance 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, 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 ft 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 VOCs. This particularly applies to paints, sealants, adhesives, carpet and flooring, furniture, and composite wood products and insulation.

- Monitor Carbon Dioxide (CO$_2$), and install carbon dioxide and airflow 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%) 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, materials storage and use, and trash disposal.
A process for complaint procedures should be established and IEQ complaints promptly respond to.

Discuss with occupants how they can participate in maintaining acceptable IEQ.

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

Construction IAQ Management Plan should be in place so that during construction, materials are protected from moisture damage and control particulates through the use of air filters.

There are also a number of suggested IEQ-related recommendations that tenants should follow to ensure that all building occupants maintain a healthy indoor environment. These include:

- The use of air handlers during construction must be accompanied by the use of filtration media with a MERV of eight at each return grill as determined by ASHRAE 52.2-1999.
- Replace all filtration media immediately prior to occupancy; conduct when possible, a minimum 2-week flush out with new filtration media with 100% outside air after construction is completed and prior to occupancy of the affected space.
- Contractors to notify Property Manager 48 h prior to commencement of any work which 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. Also, 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 UF resins.
- Contractors should provide protection and barricades where needed to ensure personnel safety and should comply with OSHA at a minimum.

Finally, it should be remembered that the air quality of a building is one of the most important factors in maintaining employee productivity and health. Toward this end, IEQ monitoring will help minimize tenant complaints of BRI and SBS, and a cohesive proactive IEQ monitoring program
is a powerful tool that can be used to achieve this goal. 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.

The following are some relevant standards, codes, and guidelines:

- ASHRAE Standard 62-1999: Ventilation for Acceptable Indoor Air Quality
- ASHRAE 129-1997: Measuring Air-Change Effectiveness
- IgCC
- South Coast Rule #1168, South Coast Air Quality Management District
- Regulation 8, Rule 51 of 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 VOCs from Office Building Construction Materials
- Carpet and Rug Institute Green Label Indoor Air Quality Test Program.