Energy Savings in MEP Systems - Indoor Air Quality

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Part VIII

INDOOR ENVIRONMENTAL QUALITY

8.1 Indoor Air Quality

EPA has determined that the average U.S. citizen today spends 90% of his or her time indoors, and indoor air pollution levels can be up to 96 times greater than outdoor pollution levels. This makes indoor air quality, or IAQ, one of the greatest health concerns in this country. Poor air quality can have a significant impact on workers' health and productivity.

Opportunities

IAQ problems can be caused (or avoided) at virtually any stage in the design, construction, and operation of any facility. During *building design*, such issues as roof overhangs (to keep out rain), location of outside air inlet ports, glazing specifications (relative to potential condensation and mold growth), formaldehyde content of cabinetry, and entryway design to hold down tracked-in pollutants all can influence IAQ. During *construction*, such issues as wall system detailing to keep out wind-driven rain and practices to remove VOCs released from new building materials will affect IAQ. During *operation and maintenance*, such issues as the choice of cleaning agents, regulation of tobacco smoking, and maintenance of filters in air handlers affect IAQ.

Facility managers should not wait to address IAQ risks until problems arise. Become proactive in identifying and solving potential problems *before* they occur. Involve workers in the solution and take their complaints about IAQ seriously. Consider IAQ when renovating spaces, maintaining HVAC and other equipment, or contracting for janitorial services.

Technical Information

The three concepts below are often used to describe IAQ problems:

- **Sick building syndrome** (SBS) is a condition in which a significant number of building occupants (sometimes defined as at least 20%) display symptoms of illness for an extended period of time, and the source of these illnesses cannot be positively identified.
- **Building-related illness** (BRI) refers to symptoms of a diagnosable illness that can be attributed directly to a defined IAQ pollution source.
- **Multiple chemical sensitivity** (MCS) is a condition in which a person is sensitive to a number of chemicals, all at very low concentrations. This condition is not well understood but is often attributed to high levels of exposure to certain chemicals.

Other IAQ problems do not clearly fall into these three categories, however. Asthma and allergies (including allergic rhinitis—hay fever), for example, are very common and can be medically diagnosed, but there are many triggers, which vary widely from person to person; as a result, the source of particular triggers is not always easily identified.

IAQ SOURCES

Many factors can cause—or contribute to—IAQ problems. Sometimes it is a *combination* of different factors that causes problems—though any one of those factors, by itself, does not cause problems. Among these potential factors are the following:

Biological contaminants—including molds, bacteria, and dust mites—can result from roof leaks, water vapor entry from basements, inadequate drainage around buildings, leaking pipes, condensation from air-conditioning equipment, and the pests in a building (rodents, insects, etc.). Relative humidity that consistently exceeds 50% should be avoided. Bioaerosols emitted from certain organisms are recognized as a very significant problem. Some molds are particularly toxic, such as *Stachybotrys atra*, which has been implicated in infant deaths in Ohio.

Volatile organic compounds, or VOCs, can cause IAQ problems, particularly in new (or newly remodeled) buildings. Common sources of VOCs are paints, carpeting (especially carpet backings and adhesives), furnishings, and chemicals (such as solvents and cleaning agents).

Combustion by-products can create hazardous conditions if allowed to enter or accumulate in a building. Improper ventilation, inoperative or undersized exhaust fans, poor placement of ventilation air supply ports, and improper pressurization of the building can all lead to a buildup of combustion gases.

Particulates from a number of sources can cause IAQ problems. These include fiber shedding from fiberglass or mineral-wool insulation, ductboard, and mineral-fiber acoustic ceiling tiles; heavy metals and other compounds tracked into a building by employees or visitors; and soot from combustion devices.

CONTROLLING IAQ PROBLEMS

Avoiding or minimizing IAQ problems involves a seven-part strategy:

1. **Keep the building dry**—this is arguably the most important strategy, especially in quite humid regions of the country.

2. **Keep the building clean and pest-free**—for example, install a track-off system to capture particulates that might enter from outdoors.
3. **Avoid potential contaminant sources**—for example, particleboard and MDF products that offgas formaldehyde, adhesives, solvent-based cleaning agents, and sources of combustion gases.
4. **Reduce unplanned airflows**—these can result from unbalanced HVAC systems, the stack effect, or depressurization in buildings; and they can enable air pollutants to enter from outdoors (combustion gases, pollen), as well as moisture and radon or other soil gases through the floor slab or basement walls, for example.
5. **Provide exhaust ventilation** for unavoidable, strong, stationary pollution sources—these include photocopiers and laser printers in offices, cooking equipment, restrooms, and designated smoking areas.
6. **Provide filtered dilution ventilation** for people, interior finishes, and furnishings in a building—mechanical ventilation is necessary in most buildings to meet minimum ASHRAE standards.
7. **Educate designers, builders, and building occupants**—education is critical in minimizing the risk of creating IAQ problems, identifying problems as they occur, and effectively dealing with those problems.

A few specific recommendations for avoiding IAQ problems are provided in the list at right.

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A SAMPLING OF SPECIFIC MEASURES THAT PREVENT IAQ PROBLEMS

- **Air handlers** should be easy to clean and tightly sealed, have a minimum of joints and other dust catchers, and have effective filters.
- **Inspection of air handlers** should be made easier by good access doors and light- or white-colored surfaces inside the air handlers.
- **Condensate pans** inside air handlers should drain fully, and debris should be removed from the pans regularly.
- **Fresh air intakes** should be inspected to ensure that poor-quality air is not drawn into the building from "short circuits" between exhaust and air intakes or as a result of site-specific conditions such as wind. Look for standing water on the roof, bird feces or nests, and proximity to cooling towers, parking areas, waste stacks, exhaust vents, loading docks, and other nearby sources of contamination.
- **Ducts** should be easily cleaned, should be installed without interior insulation, and generally should be air-sealed; textile ducts, while not air-sealed, are the easiest to clean.
- **Floor drains** should be refilled periodically to prevent sewer gas from entering the building through dry traps.
- **Wall-to-wall carpeting** should be minimized and the use of carpet adhesives eliminated; install only products that meet the Carpet & Rug Institute IAQ standard.
- **Paints and adhesives** should contain no—or very low—VOCs. Interior painting should be done during unoccupied periods, such as weekends. Adequate "airing out" should be done to remove the majority of the VOCs from the air before re-occupancy.
- **Durable and easily cleaned building materials** should be used to eliminate the need for strong cleaning chemicals. For example, ceramic tile makes a good substitute for carpeting in entry areas and hallways.
- **Vinyl wall coverings** should not be used on interior surfaces of exterior walls where moisture from wall cavities can condense on the back of the vinyl and harbor mold.
- **"Wet" applied** and formaldehyde-containing wall coverings should be minimized.
- **Ventilation, temperature, and humidity** should comply with ASHRAE Standards 62-1989 and 55-94.
- **Isolate renovation work areas** with plastic sheeting. Tape off HVAC ductwork in renovation work areas to prevent dust and debris from entering the ducts.
- **Newly installed materials**, such as carpets and other flooring products, should be "aired out" before installation.

8.2 Controlling Soil Gases

The entry into buildings of soil gases—including, but by no means limited to, radon—is an important area of concern. The few studies that have investigated soil gas entry report that 1–20% of the outdoor air entering buildings enters from below grade. Some gases, such as radon and hydrocarbons (from fuel or chemical spills), are health and safety risks to building occupants. Others, principally water vapor, may put the building at risk or cause secondary IAQ problems such as mold growth. Controlling soil gases is an important priority to ensure a safe working or living environment. Fortunately, the strategies for keeping soil gases out are relatively easy.

Opportunities

Soil gases are very easy to control in new buildings through proper design and construction practices. Specific measures for soil gas control should be included in all new buildings, but they are especially important in areas known to have high soil radon levels, on brownfield sites, and on land previously used for agriculture. In existing buildings, dealing with soil gas problems is more difficult and more expensive—but still doable. Before investing in a soil-gas remediation program in an existing building, however, test the area carefully to determine the type and extent of the contamination.

Technical Information

In order for radon or other soil gases from an underground source to end up in a building, there must be a way for the soil gases to enter (passageways) and a driving force to bring them in. The driving force is usually a combination of differences in air pressure (airflow through the below-grade material) and differences in contaminant concentrations. Passages include pores in the soil matrix, fissures and cracks in the underlying bedrock, porous fill around buildings, and cracks and holes in the building foundation walls and floor.

The most common driving force is negative pressure in the building. Exhaust fans, the stack effect, or air-handler returns may create negative pressure in the basement or crawl space that draws air from the soil into the building. Natural systems can also be the driving force. For example, a low-pressure weather system accompanied by a heavy rain may force the soil air mass to equalize with atmospheric air through a building. Rapidly rising water tables displace a large amount of soil air, generating positive pressure in the soil around a building. Air moves easily through gravel and rock that is fractured or has been dissolved by water, so pressure differentials can move large amounts of underground air and soil gases.

UNDERSTANDING SOIL GASES

The soil air contaminants we know the most about are radon, vapors from petroleum products, gases released by other volatile compounds, gases released by anaerobic or aerobic decomposition of carbon-containing materials, and water vapor.

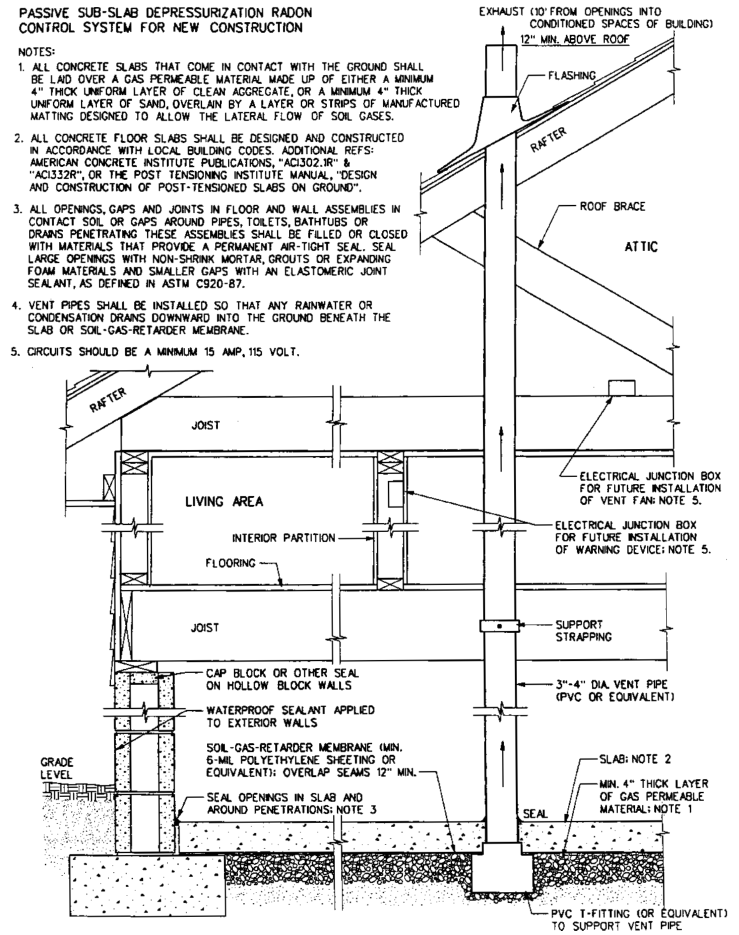
Radon is a radioactive gas released when radium, a trace element in many soils, undergoes nuclear decay. These decay products include radon and various other radioactive “daughter products” from the breakdown of radon. The only known health effect from exposure to radon and its short-lived decay products is an increased risk of lung cancer. Radon is the only carcinogen that is documented with human exposures at levels that may actually occur in buildings. It is classified by the EPA as a Group 1 (known human) carcinogen and is considered the second leading cause of lung cancer in the United States (after tobacco).

Gasoline and fuel oil are the most common sources of below-grade petroleum vapors. These hydrocarbons can get into the soil through spills, leaks, and intentional dumping. Gasoline fumes present an explosion hazard at levels of 14,000 ppm; fuel oil vapors entering a building are not generally explosive. Petroleum products contain a host of other compounds, including benzene, toluene, ethyl-benzene and xylenes (collectively referred to as BTEX). Although there are many other compounds released by petroleum products, these BTEX compounds are always present and pose substantial health risks; they can be detected very easily with portable, relatively inexpensive equipment.

Nonpetroleum VOCs disposed of underground or present in contaminated groundwater can be a big problem if they make their way into buildings. The best known example is the contamination at Love Canal in New York State. Common VOC soil gases include solvents, thinners, and de-icers—the constituents are as varied as the activities that produced them. A wide variety of short-term and long-term health effects could result from exposure to VOCs, depending on the contaminant(s) involved.

Buried materials that contain carbon are often decomposed by bacteria or fungi. Fungi most commonly digest organic matter in the presence of oxygen (aerobic decomposition), while bacteria generally operate in the absence of oxygen (anaerobic decomposition). Gases released by aerobic decomposition are primarily carbon dioxide, water vapor, and trace VOCs; the associated smell is often described as “moldy,” “musty,” or “earthy.” Compounds released by anaerobic bacterial decomposition include methane, nitrogen, hydrogen, and sulfur compounds—and the associated smell can be very bad (often described as "old socks," "locker room," "rotten food," and "sewer gases"). Landfills contain a lot of buried organic matter that decomposes anaerobically, producing methane. Methane reaches explosive concentrations at 40,000 to 150,000 ppm, depending on the temperature and oxygen content. Such explosions have occurred at landfill sites. Buildings near landfills may end up with high methane levels—rarely at explosive concentrations but often at levels where the methane and associated gases can cause "nuisance odor" and health risks.

Water vapor is not itself a contaminant, but it creates an environment that can support populations of fungi, bacteria, mites, insects, or rodents. Potentially high levels of water vapor can enter a building from the ground. Whether this water vapor becomes a problem depends on the rate at which it is being added to and removed from the building by other means. Some studies have shown that strategies to keep soil gases out of buildings can significantly reduce indoor humidity levels.



This schematic illustrates the basic operation of a soil-gas control and mitigation system for a residence. Source: EPA 402-95012, May 1995

DEALING WITH SOIL GASES

A two-prong approach is recommended: prevent soil gas entry and provide dilution ventilation air as called for by codes or professional guidelines.

Preventing soil air entry is the primary control method. It solves soil gas problems that would be impractical to solve using ventilation alone. To prevent soil air entry:

- Provide a relatively airtight foundation;
- Avoid depressurization of the building through improperly balanced exhaust fans and air-handling equipment or through the stack effect (most pronounced in tall buildings);
- Provide a highly permeable layer of material beneath the building (e.g., crushed stone) that can be easily depressurized; and
- Install a passive stack that runs from the subslab layer through the heated part of the building to the outdoors.

The last two of these steps will create a low-air-pressure zone beneath the foundation that will intercept soil air and divert it through the passive stack. In the event that the passive stack is not powerful enough to keep problem gases out of the building, the stack can be powered with an in-line fan. Detailed correctly, a very small fan can treat a large footprint. In research conducted by the EPA, a single stack using a 90-watt fan has depressurized the drainage layer beneath a 100,000-square-foot (9,300 m^2) slab.

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8.3 Controlling Biological Contaminants

Biological contaminants are particles or gases that originate with something that is—or once was—alive. Sometimes, as in the case of pathogens, the entire organism is the contaminant; in other situations the contaminant is produced by the organism—directly or indirectly. Organisms that are the source of biological contaminants may reside inside the building or outside. The contaminants may be released in the building, be tracked in on the feet of people or pets, or be carried in with infiltration or ventilation air. Biological contaminants that may cause physiological problems for people include odors, irritants, allergens, toxins, and pathogens. People in the building are not the only ones at risk. Organisms or contaminants released by them may decompose or corrode building components and damage electronic equipment.

Opportunities

Deal with existing problems first. Moisture problems are the precursor to nearly all pest, fungal, and environmental bacteria problems. If there are moisture problems in the building, these should be first on the list of priorities for correction. Mold should not be growing inside buildings. If there is mold or fungal growth, respond quickly and safely to clean it up and prevent a recurrence. The next priority is pest animals. The Executive Memorandum on "Environmentally and Economically Beneficial Practices on Federal Landscaped Grounds" (April 16, 1994) requires the use of integrated pest management, or IPM, practices when they are cost-effective and practical. Many Federal agencies developed and adopted IPM policies for their buildings and landscapes before and since this memorandum. If an IPM program is not in effect, begin to develop and implement one.

Technical Information

Living things in buildings fall into two categories: invited and uninvited. This is an important distinction, because the primary control mechanisms are quite different. The invited are the building's occupants. Contaminants released by these occupants must be controlled with personal hygiene, cleaning, filtration, and dilution by outdoor air. The uninvited biological organisms we may have to deal with, however, include the following:

- Mammals – rats, mice, bats, raccoons and skunks;
- Birds – pigeons, starlings;
- Reptiles – lizards, snakes;
- Arthropods – roaches, ants, termites, wasps, bees, carpet beetles, mites, spiders;
- Fungi – penicillium, aspergillis, cladosporium, fusarium;
- Bacteria – environmental and pathogenic; and
- Viruses – pathogenic.

The contaminants released by these organisms consist largely of the following: dander (skin or scale flakes), feces, urine, spores, hyphae, metabolites, and viable bacteria or viruses. Allergic response to alien protein in these contaminants is probably the most frequent effect encountered. The most dangerous effect is exposure to pathogens that can be passed by airborne transmission. Electronic equipment is sensitive to contaminants, especially the acidic ones found in feces and urine. Pollen is not usually lumped with biological contaminants in buildings, but it can get into buildings and commonly causes allergic responses.

Tracked-in dirt is a significant source of biological contaminants. Fungal spores are the most abundant contaminant in this category—large enough to have settled outside but small enough to become airborne for a time when disturbed indoors. Exclusion is the first line of defense for tracked-in contaminants.

The smallest biological contaminants enter by means of outdoor air. They consist primarily of fungal spores, insect parts, pollen, and metabolic gases. Generally, an especially strong outdoor source is required to cause an indoor problem, such as downwind of a composting facility or a swamp—though pollen is a seasonal problem in many areas. Contaminated outdoor air may be actively drawn in through the intakes of the ventilation system, or passively drawn in through infiltration as a result of depressurization caused by mechanical equipment, the stack effect, or wind.

CONTROLLING BIOLOGICAL CONTAMINANTS

Several strategies must be used to minimize exposure to biological contaminants while also minimizing exposure to biocides. Controlling contaminants released by organisms inside the building is accomplished using IPM methods for the animals and moisture control for the fungi and environmental bacteria.

Integrated pest management for animals consists of the following steps:

1. **Keep them out.**
   - Landscape the building to eliminate easy pest access to the building (overhanging tree branches, shrubbery in direct contact with the building, etc.).
   - Seal the exterior walls, foundations, and roofs against pest entry.
   - Seal gaps around wiring and plumbing that provide passage between food, water, and living habitat.
2. **Reduce food and water sources.**
   - Establish and enforce a food policy and a cleaning policy that minimize food scraps in the building.
   - Repair rain and plumbing leaks quickly.
   - Keep soil moisture and groundwater out of the building.
   - Prevent condensation on cool surfaces, such as windows (better-insulating glazings and edge spacers may be required).
3. **Reduce pesticide exposures.**
   - Respond to pest problems when they occur, rather than providing regular applications.
   - Select least-toxic pesticides that target the problem species.
   - Use treatment methods that target individual species and nests.
   - Avoid spraying pesticides when possible (traps and baits are preferred).

Fungal contamination should be addressed as follows:

1. **Identify problems.**
   - Determine the extent of moisture damage and fungal contamination.
   - Figure out the moisture dynamics causing the problem.
   - During the initial investigation, ensure appropriate containment and protection of workers.
2. **Dry the affected area**.
3. **Implement an effective long-term solution.**
   - Eliminate moisture sources through roof repair, flashing modification, installation of a drainage layer beneath cladding, and control of soil moisture entry.
   - Develop a long-term fungal cleanup plan.
   - Implement containment and worker protection procedures.
   - Discard materials that are not worth saving.
   - Decontaminate materials that can be saved.
   - Implement repairs and program changes to prevent a recurrence of the problem(s).
   - Tracked-in contaminants are among the simplest to control. Up to 85% of tracked-in contaminants can be caught at the entry using effective track-off mats that are cleaned daily. Vacuuming with machines that indicate when dust has been collected greatly reduces the amount of contaminants on hard-surface floors and in carpet.

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8.4 Productivity in the Workplace

Productivity involves the health, comfort, and well-being of people living and working in Federal facilities as well as how those factors affect their performance. Maximizing health and productivity through proper building design is increasingly recognized as a critical aspect of sustainability and global competitiveness. The economic impacts of productivity are much greater than commonly assumed, even among building professionals. A productivity increase of just 1% can completely offset a building's entire energy bill. Thus, while it may sometimes be difficult to defend certain green design investments (such as daylighting, natural ventilation, and passive solar heating) solely on the basis of energy savings, these investments may be easily justified when their effects on productivity are considered.

Opportunities

Human health and productivity can be maximized when the project team addresses the following issues in an integrated manner at the beginning of a project:

- Thermal comfort (HVAC design);
- Indoor air quality (interior finish materials, construction detailing, and HVAC design);
- Visual comfort (daylighting);
- Acoustic comfort (site placement and interior materials and systems);
- Ergonomic comfort (furniture selection);
- Connection to nature (windows for view, interior landscapes); and
- Potential for both privacy and networking (space configurations).

Opportunities for boosting productivity should be considered whenever significant renovation or reconfiguration is being done in a facility. Some productivity-enhancing measures can be implemented even when major modifications to the building are not being done. The widest range of strategies and most comprehensive measures to boost productivity can be incorporated into *new* buildings, especially if addressing productivity is a high priority right from the start.

Technical Information

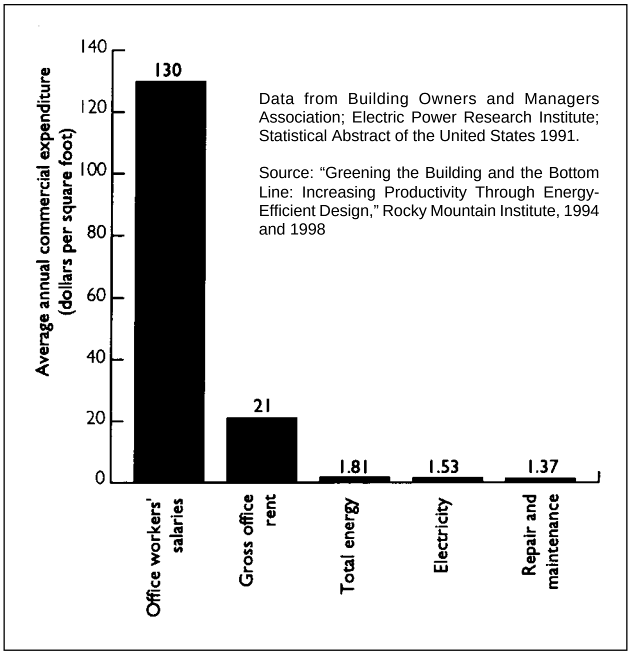
Our understanding of productivity and all the factors that influence it is still growing. Members of the integrated design team for a project should keep abreast of the latest findings regarding the productivity benefits of building design and construction strategies, such as daylighting (see box below). They should also be aware of the added benefits most such strategies offer in reducing energy consumption and improving the overall environmental performance of a building.

Daylighting and Productivity: Detailed, statistically rigorous evidence that daylighting helps boost human performance has long been claimed, but most evidence has been anecdotal or of limited statistical significance. That has changed. Two recent studies conducted by the Heschong Mahone Group of Fair Oaks, California, for Pacific Gas and Electric demonstrate that daylighting can measurably benefit productivity. One study found a dramatic improvement in sales performance in retail stores with natural daylighting; another found that elementary school students in daylit classrooms learned faster than students in rooms lit only by electric lighting (see *Section 4.1.2 – Daylighting Design*). Explanations for these results range from improved visibility and enhanced moods to better and more attentive service by employees and teachers. Studies and findings in other areas of human health and productivity are being examined at the Carnegie Mellon Center for Building Performance and Diagnostics and several other institutions.

Strategies that can maximize human health and productivity should be addressed at each stage of a project. At the outset, potential outside influences at a site should be considered, such as outdoor air quality and proximity to sources of noise (e.g., flight paths, highways, industrial facilities). These site characteristics should be taken into account in the building design to minimize negative impacts on building occupants.

High levels of ventilation, good air distribution, and thermal comfort can be addressed during design and then be specified, implemented, and ultimately tested before occupancy. Daylighting, careful selection of materials and cleaning products, contaminant isolation (to avoid noxious odors), and minimization of noise are most effectively addressed during the design phase.

Construction scheduling, detailing, and installation techniques are extremely important. In particular,



While a great deal of attention has been focused on reducing energy costs in commercial buildings, even a very small improvement in productivity can offset the entire energy bill of a facility. Some studies have found 5–15% improvements in productivity as a result of green design.

preventing construction conditions and practices that can cause wet materials and mold growth should be a high priority. Delay installing highly absorptive materials, such as fabrics and upholstery, until building products that may offgas VOCs have been in place for a while. Avoid using a building's permanent ventilation system during painting, floor finishing, carpet installation, and other procedures that may release high quantities of VOCs—because those VOCs may get into the ventilation system and then be released into the building when it is occupied.

Post-occupancy considerations, such as permanent air quality monitoring systems with feedback mechanisms and responsible O&M procedures, also play an important role in maximizing health and productivity. These should be given serious attention in the design process.

Access floors and individual controls that function well with them are good examples of design for productivity. Access floor systems provide a floor cavity that serves both as a place to run wiring and as a plenum for conditioned air delivery. An access floor greatly improves the ability to reconfigure workspaces over time (saving many thousands of dollars for a facility with a high churn rate). Access floors enhance comfort by allowing workers to individually control the diffusers that deliver conditioned air beneath the floor—the diffuser openings can be enlarged easily, for example, if the employee wants to boost airflow to keep his or her space cooler. Personal workstations with integrated environmental controls work very well with access floors. Occupancy sensors in workstations can further reduce energy use by turning equipment off when workstations are unoccupied. Individualized controls can be coordinated with natural and mechanical heating and cooling systems, daylighting, and operable windows for effective thermal, visual, and acoustic comfort.

ENVIRONMENTAL IMPLICATIONS

Several strategies that increase health and productivity have direct impacts on larger environmental considerations. For example, daylighting design with high-performance electric lighting improves occupants' performance while conserving energy. High-performance glazings specified to enhance occupants' thermal comfort also conserve energy.

Finally, human health and performance can be enhanced by avoiding materials with high levels of VOCs and other indoor pollutants. Such pollutants are commonly introduced in paints, adhesives, sealants, cleaning products, and carpeting, as well as manufactured wood products produced with medium-density fiberboard or particleboard.

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8.5 Noise Control and Privacy

Like air quality and lighting, a good acoustic environment is essential in maintaining a high level of satisfaction and morale among workers. Ideally, offices and other workspaces should be free of noise and audible information that distracts them from the tasks at hand. Additionally, acoustic privacy is necessary for some tasks. Noise and distracting sounds can come from both indoor and outdoor sources. They may be continuous and irritating, such as the buzz of magnetic ballasts, or they may be sporadic, such as an occasional loud voice. Speech is the most prolific and disruptive noise in most offices because it can be difficult to ignore.

Opportunities

Noise can be controlled most effectively, and at the least expense, if it is considered alongside other building performance parameters early in the design of a new building or renovation. During the schematic design it is possible, for example, to provide maximum separation between sources of noise and the spaces that have the greatest need for quiet. In addition, choices regarding the degree of acoustic dampening and isolation between spaces can also affect options for air distribution, lighting, and other systems. For example, indirect lighting schemes supplemented by task lighting reflect less sound than recessed troffers with plastic covers, and they may be easier to justify in a budget if their acoustic benefits are also taken into account.

In an existing facility, the impact of changes on the noise level in adjacent spaces should be considered whenever mechanical or electrical equipment is being serviced or replaced. Regular maintenance can help keep machines running quietly and efficiently.

Technical Information

Concepts important in addressing acoustical problems in buildings include the following:

- **Background noise** is needed to provide some masking of sound, but too much noise is stressful and can make it difficult to hear conversations or other communications. Noise criteria (NC) have been used to rate sources of background noise in the past. More recently, room criteria (RC) have become widespread as a rating system for overall noise levels. Studies have shown that an RC rating between 35 and 45 will usually provide speech privacy in open-plan settings, while ratings below 35 will not.
- **Speech privacy potential (SPP)** quantifies the percentage of words that can be understood from an adjacent conversation and is related to sound isolation and background noise. SPP is directly proportional to occupant satisfaction, and GSA recommends a minimum value of 60 for SPP in open offices; an SPP of 70 is considered good for closed-office plans. GSA-sponsored research for open office areas revealed that speech privacy can be improved either by increasing the sound attenuation between workstations or by increasing the background noise. Another measure of speech privacy is the articulation index (AI), which ranges from 0 (speech not at all intelligible) to 1.0 (fully intelligible).

Basic principles of sound control include these:

- Reducing noise at its source.
- Blocking noise transmission.
- Absorbing noise.
- Masking noise.
- Active noise cancellation.

Reducing noise at its source is an important first step in addressing internally generated sounds. Noise from mechanical and electrical equipment is a release of energy that is not contributing to the intended tasks, and as a result it is a symptom of inefficiency in the system. In some cases, reduced noise may be a contributing factor that can help justify the selection of higher-efficiency equipment. Air-handler noise transmission can be reduced by providing flexible connections between the air handler and ductwork and by using duct liners. Carpets are effective at preventing footfall noise from pedestrian traffic through a space.

Blocking noise transmission is achieved primarily with high-mass barriers that are rated by sound transmission class (STC). Both internally generated and exterior noises can be controlled to some extent in this way. For exterior noise, a high-mass, airtight building shell is important. Windows tend to be a weak link in this respect. Double-glazed windows are more effective with a wide space between the panes, or with sulfur hexafluoride (SF_6) gas fill. The need for noise control makes it particularly difficult to use natural ventilation or operable windows for buildings in noisy settings. Natural earth berms and other massive external barriers can also be effective at managing noise from highways or other nearby sources.

Barriers are also important to control the transmission of conversation and other indoor noises. In open office systems, partitions lower than 50 in. (1.3 m) in height are largely ineffective, while those over 70 in.

(1.8 m) are subject to diminishing returns. Minimizing spaces below dividers and at their joints is also important. In the case of full-wall partitions, airtightness is important to minimize sound leakage. In some cases it may be advisable to extend interior partitions past the suspended ceiling and up to the slab above, but such extensions complicate air distribution and other systems. One solution is use slab-to-slab partitions between adjacent offices but not between offices and corridors. Adding a foil backing to suspended ceiling tiles will also reduce the sound transmitted through the ceiling.

Absorbing noise is an essential component of any office noise-management plan. Reflective surfaces allow noises to travel over a significantly greater distance, and sound levels tend to be much higher. Absorption in ceilings, in furniture panels, on the floors, and on walls (where necessary) helps to lower noise levels and reduce the distance over which sound travels. Of these surfaces, acoustical ceilings and workstation dividers tend to be most effective at absorbing sound.

The noise reduction coefficient (NRC) is a measure of how effective a material is at absorbing sound. NRC ratings range from nearly 0 for a hard, reflective material to 1.0 for a highly absorptive material. Effective ceiling tiles should have an NRC rating close to 0.9.

Sound-masking systems artificially raise the background noise level to maintain speech privacy. Unlike older "white noise" generators, modern systems adjust sounds levels at various frequencies to meet acoustical objectives, while remaining relatively unobtrusive to occupants. The systems consist of an array of speakers that are usually located above a suspended ceiling on a 15-foot (5-meter) grid. The speakers project sound upwards so that it is reflected off the underside of the slab above. Although high-tech, such masking systems are often more cost-effective than alternative means of increasing acoustic privacy and reducing distractions. A good sound-masking system should reduce distractions as much as if the STC rating of the sound barriers was increased by 10 points.

Active noise cancellation (ANC) systems consist of microphones that receive the target noise and speakers that create an identical sound field 180 degrees out of phase with the original noise. The sound field created effectively reduces the effect of the offending noise but does not cancel it. Some ANC systems are made for use in HVAC ductwork to prevent problem noise from disturbing occupants. Active noise cancellation only works for low-frequency constant noises (such as that of generators and motors) when both the noise source and the listener are stationary. It has little or no application to office environments but may be useful in certain specialized facilities.

SOUND INTENSITY LEVELS OF TYPICAL NOISES

Sound Pressure (Pa)	Sound Intensity (W/m^2)	Decibels (dB)	Noise in the Environment
63.2	10	130	Threshold of pain
20	1	120	Near a jet aircraft at take-off
6.32	0.1	110	Riveting machine
2.0	0.10	100	Pneumatic hammer
0.632	0.001	90	
0.2	0.0001	80	Diesel truck at 50 ft (15 m) Shouting at 3 ft (1 m)
0.0632	1×10^{-5}	70	Busy office
0.02	1×10^{-6}	60	Conversational speech at 3 ft (1 m)
0.00632	1×10^{-7}	50	Quiet urban area during daytime
0.002	1×10^{-8}	40	Quiet urban area at night
0.000632	1×10^{-9}	30	Quiet suburban area at night
0.0002	1×10^{-10}	20	Quiet countryside
0.000632	1×10^{-11}	10	Human breathing
0.00002	1×10^{-12}	0	Threshold of audibility

Loudness or noise can be measured in various units. The decibel scale provides a convenient way to express this. Note that the quietest sound we can hear is one ten-trillianth ($1x10^{-13}$) as loud as the most intense noise we experience.

Adapted from: *Architectural Acoustics: Principles and Design* by Madan Mehta, Jim Johnson, and Jorge Rocafort (Prentice-Hall, Upper Saddle River, NJ, 1999)

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