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Building Systems and Indoor Environmental Quality

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This course was adapted from the “Sustainable Building Technical Manual”, which is in the public domain.

SECTION B

Buildings Systems and Indoor Environmental Quality

Designing and installing environmentally sound and energy-efficient systems have a long-term impact on the cost-effective operations of a building and on the productivity of building occupants. Chapter 12 in this section provides guidance on types of heating, ventilating, and air-conditioning (HVAC) system components that will most effectively meet design goals and also examines lighting and other electrical systems for efficiency in products and practices.

Indoor environmental quality is also reviewed, with a focus on indoor air quality (IAQ) and acoustics as two aspects that can affect building occupants' health and productivity. Chapter 13 outlines strategies to achieve good IAQ through control of contaminant sources and occupant activity and through good ventilation and building maintenance practices. Chapter 14 discusses how desired sound control levels can be reached through design practices, construction techniques, and attention to mechanical systems and surface finishes.

Building commissioning, a practice to ensure building systems are installed, operate, and are maintained to meet design goals, is discussed in Chapter 15.

CHAPTER 12

HVAC, Electrical, and Plumbing Systems

Heating, Ventilating, and Air-Conditioning

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★ SIGNIFICANCE

The amount of energy used annually by heating, ventilating, and air-conditioning (HVAC) systems typically ranges from 40 to 60 percent of the overall energy consumption in a building, depending on the building's design, the use of renewable energy strategies, climate, the building's function, and its condition. HVAC systems also affect the health and comfort of building occupants. These systems serve an essential function and are identified as problem areas more often than other occupancy issues.

HVAC system requirements increased dramatically in the twentieth century in response to changes in other design practices, such as greater use of glazing, sealed buildings, alternate envelope systems with greater thermal loads, larger building floorplates, and more extensive use of artificial lighting and occupant equipment. As a result, buildings have become more dependent on fossil-fuel energy sources instead of natural energy flows such as climate, temperature, and solar conditions.

Before the first energy crisis in the United States in the 1970s, HVAC systems in many commercial buildings were often designed to maintain comfort by simultaneously heating and cooling, with minimal regard for energy use. Additional inefficiencies caused by lighting that used two to three times the energy of modern systems, minimally insulated building envelopes, and other factors further compounded the growth in energy use. The result was excessive energy loss as heating and cooling plants were operated in "opposition" to each other during most hours when the building was occupied, regardless of climatic conditions. Systems such as constant-volume, double-duct and perimeter-induction systems were predominant and were designed primarily for comfort, not energy conservation.

After the energy crisis, design and operating practice shifted drastically. Outdoor ventilation rates were reduced to very low (and now considered unhealthy) levels, lighting levels were decreased, and building temperatures were kept at the outer limits of the comfort range. This resulted in greater occupant dissatisfaction. Since that time, advancements have led to greater precision in maintaining indoor temperature (and often humidity) and indoor air-quality levels, thus increasing the level of HVAC performance and decreasing energy use.

The goal of environmentally sound HVAC system design is to meet occupant needs through the most efficient and environmentally positive means at the lowest initial and life-cycle costs. Solutions that have evolved provide environmental comfort while accounting for climatic conditions, use of space, and building technology. These green system designs take into consideration factors such as solar orientation, floorplate depth, thermal mass, insulation, selection of architectural materials, placement and type of doors and windows, and natural ventilation.

Heating and cooling needs are affected by the performance of interrelated building systems and characteristics, including passive solar design elements such as daylighting, climate-sensitive envelope, and efficient lighting, as well as user equipment needs and other heating loads. The appropriate HVAC solution should be determined only when the full design team has thoroughly reviewed the requirements and contributing thermal loads of these interrelated systems and has carefully considered all efficiency gains possible through design strategies. The design team should also review the budgetary impact of different options. Decisions made in the pre-design phase using this integrated approach will typically lead to reduced energy requirements and lower HVAC system costs.

SUGGESTED PRACTICES AND CHECKLIST

Pre-Design Process

□ Develop a conceptual computer model that illustrates projected energy use and sources.

This conceptual model can serve as a baseline for comparison of system options. The basic framework of the model is the proposed building design, including architectural and systems information. The computer model should be “tuned” to reflect actual performance data from similar types of buildings. A local utility can be helpful in providing this information. The project team should integrate system options and “packaged” solutions. A parametric process can be used to evaluate the impact that a change in one variable would have on the remaining systems—for example, the impact that a different glazing size and type would have on heating, cooling, and lighting. The model can be used to analyze these options on a case-by-case, integrated basis. Each iteration should be reviewed for its relative energy and financial outcomes.

□ Use this suggested approach in performing the analysis.

- Explore passive solar strategies and non-energy-intensive HVAC and lighting opportunities that harness natural processes. Daylighting, natural ventilation, evaporative cooling, thermal mass coupling, energy recovery systems, and other processes may be appropriate. Free cooling directly with outside air or evaporative cooling with water may offer excellent energy-saving opportunities in certain climates.
- Consider the building envelope and integrate this with general architectural issues such as solar strategies, glazing, daylighting, and access.
- Fine-tune the proposed building footprint and orientation to maximize energy benefits.
- Recognize that thermal mass can be beneficial in providing a flywheel effect to reduce after-hours environmental conditioning and morning warm-up loads in the specific microclimate.
- Optimize the energy benefits of glazing selections, sizing, and locations for each building facade.

- Review the interaction between daylighting and artificial illumination. The benefit of reduced lighting energy needs and the resulting HVAC savings are substantial.
- Consider architectural elements such as louvers, blinds, and horizontal and vertical shades to reduce direct solar radiation into the occupied space when not desired (cooling load avoidance).
- Control the infiltration of unwanted air through window-wall detailing, sealing, and building pressurization.
- Consider increased insulation levels for various systems to reduce loss factors.
- Consider vapor barriers to reduce latent (moisture) loads.
- Reduce internal heat gains from office equipment, appliances, ambient lighting, and task lighting. Review design criteria for occupant needs, including lighting and electric power, comfort, and occupant density. Consider options to reduce the energy needs of user equipment.
- Design systems and components for ease of maintenance.
- Incorporate ventilation for healthy indoor air quality and balanced energy use.

□ **Design the HVAC system and consider potential options.**

After all systems have been optimized in the model, design the resulting HVAC system and reduce energy requirements. This will lead to lower energy and operational costs.

□ **Improve control systems by using computer software programs and sensors to operate building systems in accordance with occupancy patterns.**

□ **Develop accurate pricing.**

Prepare realistic cost estimates for all of the modeling and energy-based decisions. Make final decisions on a life-cycle cost basis, reviewing all up-front and annual operating costs.

(See also Chapter 9, “Daylighting,” Chapter 10, “Building Envelope”, and Chapter 11, “Renewable Energy,” for more information on pre-design considerations.)

HVAC Design Guidelines

□ **Define the project design criteria.**

The design criteria should reflect an understanding of the building’s use, occupancy patterns, density, passive solar opportunities, office equipment, lighting levels, comfort ranges, and specific needs. Actual operating data from similar buildings is of value in this process. When determining final criteria, the design team should build in flexibility to accept future changes in the design. The design criteria should outline a process and goals for evaluating energy efficiency, based on project economics and owner performance requirements.

□ **Use advanced design methods.**

Utilize the best design tools available to accurately size and select system components. Specify equipment that meets the calculations and do not oversize. Plan for effective ways to meet future load increases without sacrificing current energy requirements. Use computer-based analysis tools to evaluate building load, select equipment, and simulate complete system performance (such as DOE-2.1, ENERGY-10, TRNSYS, and BLAST). Annual simulations are the best tool for evaluating the complex interaction between building systems. (See “Resources” section for more information on Design Tools.)

□ **Design for part-load efficiency.**

Select equipment that remains efficient over a wide range of load conditions. Size systems to accommodate multiple stages of capacity that can be activated in sequence. Buildings operate at part-load status most of the time. Peak system loads occur infrequently and are usually caused by the simultaneous occurrence of multiple factors such as peak occupancy, temperature extremes, and use of occupant equipment. HVAC systems need to respond to various loads in order to achieve the greatest overall efficiency.

❑ **Optimize system efficiency.**

HVAC systems consists of several different types of equipment including fans, pumps, chillers/compressors, and heat-transfer equipment. The performance of the overall HVAC system should be optimized over that of any individual component. For example, the cooling system components should be optimized as a system, including the chiller, pumps, cooling tower, cooling coil, and distribution piping.

❑ **Design for flexibility.**

The HVAC design should provide flexibility to address future changes in the building and its functions and use over time. Planning for change includes factoring in potential new users.

Control Systems

❑ **Design a building-management control system.**

The continued development of microprocessor-based building controls and sensors has led to a revolution in control-system applications. Individual equipment components often contain electronic intelligence and the ability to coordinate their operations with those of other system components.

- Consider the use of direct digital control (DDC) electronic systems for all functions, including central equipment control and zone-level management. This provides greater energy-efficiency capabilities, accuracy, and flexibility. Zone-level control features are important because sensors in each zone directly measure factors such as temperature, air-flow, lighting, and whether the area is occupied or unoccupied. These control features are linked to the central systems and can be used to optimize system functions.

❑ **Train building engineers to use the control system for greater comfort and efficiency.**

Proper use of the control system's remote reporting, diagnostic, and troubleshooting capabilities allows the building engineer to monitor and modify system operations for optimal energy efficiency, lighting use and HVAC performance.

❑ **Integrate the operation of all components and install a centralized computer interface throughout the project.**

Coordinate various building management functions (energy, lighting, life safety, security, elevators, etc.) by integrating occupancy sensors, daylighting control, temperature control, and ventilation levels.

❑ **Ensure that HVAC control systems include the following functions:**

- Basic features
 - a. Comfort control (temperature, humidity)
 - b. Scheduled operation (time-of-day, holiday and seasonal variations);
 - c. Sequenced modes of operation;
 - d. Alarms and system reporting; and
 - e. Lighting and daylighting integration.
- Additional capabilities
 - a. Maintenance management;
 - b. Indoor-air-quality reporting;
 - c. Remote monitoring and adjustment; and
 - d. Commissioning flexibility.

Air-Delivery Systems

❑ **Use variable-air-volume systems.**

This approach reduces energy use during part-load conditions and takes advantage of each zone's operational characteristics.

❑ **Avoid reheating for zone temperature control.**

Consider a dedicated-perimeter heating system and the use of room return air for heating to minimize outdoor-air reheat penalty.

- ❑ **Reduce duct-system pressure losses.**

The amount of fan energy used to distribute air throughout a building is significant. Most ductwork sizing does not generally take into account the distribution system as a whole. However, computer-based programs for sizing ductwork are becoming widespread. These programs facilitate improved analysis that can reduce energy losses. A good design should strategically locate balancing dampers to improve energy efficiency. The use of round or flat oval ductwork will reduce energy losses and minimize acoustical radiated noise.
- ❑ **Reduce duct leakage and thermal losses by specifying low-leakage sealing methods and good insulation.**
- ❑ **Consider proper air distribution to deliver conditioned air to the occupied space.**

Optimal selection and location of air diffusers will save energy and improve comfort control. Select diffusers with high induction ratios, low pressure drop, and good partial-flow performance.
- ❑ **Use low-face velocity coils and filters.**

Reducing velocity across coils and filters will reduce the amount of energy lost through each component. It also will allow more efficient fan selection, and reduce noise attenuation needs.
- ❑ **Use cold-air systems.**

Consider a design that supplies air at lower temperatures to reduce airflow requirements and fan energy usage. This offers additional benefits of lower indoor air humidity and potentially higher room temperatures.
- ❑ **Design equipment and ductwork with smooth internal surfaces.**

This will minimize the collection of dust and microbial growth. Be sure to provide adequate access for inspection and cleaning.

Central Equipment

- ❑ **Evaluate chiller selection.**

Chiller options are routinely evaluated on larger projects but often are overlooked as a component of smaller, packaged equipment. High-performance chiller equipment is available in all sizes. Integrated controls that work with other HVAC components to increase operating flexibility are also available. Open-drive compressors eliminate one source of loss by not rejecting the compressor motor heat into the refrigerant flow. The energy and cost savings associated with converting or retrofitting outdated chillers that contain environmentally harmful refrigerant should be assessed. The use of evaporative cooling equipment should be considered for greater efficiency.
- ❑ **Evaluate a multiple-chiller system with units of varying size.**

Most installations with a chiller plant should have multiple chillers of different sizes. An alternative is to provide variable-speed drives for improved chiller operation during part-load conditions. This approach allows the most efficient chiller operation for low loads.
- ❑ **Consider desiccant dehumidification.**

These systems are effective where latent loads are significant, such as in humid climates or low-humidity spaces. Adsorbent enthalpy wheels (which use exhaust air to dehumidify or to cool supply air) or heat-regenerated enthalpy wheels can significantly reduce electrical power needs for refrigerant-based dehumidification. (See also Chapter 11, "Renewable Energy.")
- ❑ **Consider absorption cooling.**

This approach typically changes the energy source from electricity to gas and can reduce energy costs; however, it is not likely to reduce energy use inside the building. Although not as efficient as electrically driven chillers, absorption chillers permit the use of a lower cost fuel. A heat source, such as steam, natural gas, or high-temperature waste heat, usually drives the absorption refrigeration process. Direct-fired gas equipment can also be selected to provide hot water for building heating needs in addition to chilled water.

❑ **Consider thermal energy storage.**

The heating and cooling loads of a building vary on a daily and seasonal basis. Thermal energy storage (TES) makes it possible to manage a building's utility usage, or conduct "load management." A TES system generates and stores thermal energy on a daily, weekly, or longer basis. It can shift the use of more expensive peak utility energy to less expensive off-peak time periods. Ice banks and stratified chilled water are the most common examples.

❑ **Evaluate hydronic pumping systems.**

Primary and secondary pumping systems with variable-speed drives are worth consideration because of their effects on part-load energy use. Pressure losses in piping can be reduced by selecting pipe sizes with a lower pressure drop factor. The design should optimize total head loss with a minimum of flow-balancing controls. New systems that use hydronic system additives to reduce system friction losses and associated pumping energy are being developed.

❑ **Evaluate heat exchangers.**

Select heat exchangers with low approach temperatures and reduced pressure drops.

❑ **Consider other heating-system equipment and enhancements.**

It is advisable to use condensing boilers, match output temperatures to the load, use temperature reset strategies, and select equipment with good part-load ability. Specify multiple, staged operations wherever possible.

❑ **Evaluate heat-recovery options.**

Where simultaneous heating and cooling loads occur, evaluate the use of heat-recovery chillers. High ventilation loads benefit from air-to-air heat-recovery systems for both sensible (i.e., direct heating or cooling requirements) and latent loads.

Efficiency-Enhancement Options within HVAC Components

❑ **Consider additional improvements to energy efficiency.**

- High-efficiency motors are suggested for all applications because of their energy savings capabilities, longer life, and reduced maintenance costs. Motors should be of the proper size to avoid the inefficiencies of oversized equipment.
- Variable-speed drives have advanced significantly over recent years. They offer a proven means of substantially reducing the energy used by fans, chillers, and pumps under part-load conditions. Electronic drives are considered the best option; drive controller and motor selection are also important considerations.
- Mechanical drive efficiency can be improved to reduce losses in the power transmitted from a motor to the motor-driven equipment. Consider direct-drive equipment options and review actual loss factors on belt- or gear-driven equipment.
- Direct digital control (DDC) systems offer greater accuracy, flexibility, and operator interface than pneumatic systems. Use sensors that have the greatest accuracy to improve energy efficiency and performance.
- Advanced control strategies using DDC systems include system optimization, dynamic system control, integrated lighting and HVAC control, and variable-air-volume (VAV) box airflow tracking.

❑ **Undertake independent system testing, adjustment, and balancing to improve efficiencies and comfort.**

Building Commissioning

- ❑ **Use the commissioning process (see Chapter 15, “Building Commissioning”) to ensure that HVAC operations meet expectations.**

Energy-saving features often have not met the design predictions in actual operation. The process of building “commissioning”—documenting that a completed building meets the original design intent and the owner’s objectives—has evolved to reduce or eliminate this shortfall. Commissioning activities should begin at the inception of design and continue through completion of construction and occupancy. Commissioning should be tailored to each project. The process is governed by a commissioning plan that defines performance-test requirements, responsibilities, schedules, and documentation. The level of detail involved in commissioning depends on the project’s complexity.

Balancing Energy and Indoor Air Quality

Energy efficiency and indoor air quality (IAQ) can be closely linked through integrated design strategies for ventilation systems. (See Chapter 13, “Indoor Air Quality,” and Chapter 16, “Materials,” for more information on reducing pollutant sources.) To balance energy efficiency and indoor air quality needs, consider the following:

- ❑ **Begin the design process with the goal of maximizing IAQ performance and energy efficiency.**

Project goals and performance guidelines for both areas are needed.

- ❑ **Include dedicated ventilation systems.**

With dedicated and controlled ventilation air fans and dampers and/or dedicated ventilation distribution, the quantity of air can be regulated, measured, and documented. This provides greater certainty that acceptable air ventilation is maintained. Ventilation air can be separately conditioned for improved energy efficiency.

- ❑ **Consider heat-recovery options.**

High ventilation loads benefit from air-to-air heat-recovery systems for both sensible and latent loads. Air that is exhausted from the building can be used to precondition air entering the building, thus reducing energy needs (however, care should be taken not to reintroduce exhaust air into the supply airstream). Run-around hydronic loops and heat pipes are two solutions that improve energy efficiency.

- ❑ **Reduce pollutants.**

Install separate exhaust systems in areas with high indoor air pollution sources such as kitchens, janitorial closets, photocopier areas, and office equipment rooms.

- ❑ **Institute ventilation demand strategies.**

Regulate quantities of ventilation air based on specific occupancy needs. For example, sensors that detect occupancy, carbon dioxide, and volatile organic compounds (VOCs) can be used to monitor occupant loads and provide greater fresh-air intake. Consider air cleaning with high-efficiency filtration.

- ❑ **Consider diffuser selection.**

Provide proper air distribution to deliver conditioned air to the occupants’ work areas. The selection and location of diffusers can save energy and improve operation of the HVAC system control. Select diffusers with high induction ratios, low pressure drop, and good partial-flow performance. Locate diffusers for proper airflow, not on the basis of a simplistic pattern. Coordinate the layout with furniture and partitions.

- ❑ **Consider underfloor air distribution.**

Once the solution only for computer rooms, displacement ventilation is gaining acceptance for other building spaces, particularly in milder, low-humidity climates. Underfloor air systems can operate at higher supply-air temperatures with much lower fan energy requirements. IAQ is improved because of greater quantities of ventilation air and uniformity of distribution.

❑ **Perform a pre-occupancy flushout.**

The building controls can be programmed to initiate the flushing of a building with outside air prior to occupancy. This reduces indoor pollutants and pre-cools the space with night-time air. Running the HVAC system with a higher or continuous supply of fresh air is also beneficial during initial occupancy after construction.

❑ **Consider the use of evaporative cooling equipment.**

Primarily in dry climates, greater use of outdoor air can translate into improved effectiveness for direct or indirect evaporative cooling equipment, reducing mechanical refrigeration needs. However, proper maintenance is essential to prevent IAQ problems caused by microbial contamination. (See also Chapter 11, “Renewable Energy.”)

Renovation and Retrofit Issues

HVAC system renovations are initiated for a variety of reasons. It is important to consider all of the following issues during this process:

❑ **Consider chlorofluorocarbon (CFC) changeout.**

Retrofits offer an opportunity to replace or convert an existing refrigeration system to one that uses an environmentally benign refrigerant.

❑ **Replace outdated systems or components.**

Existing HVAC systems may be at the end of their expected life.

❑ **Address and correct past problems with ventilation and indoor air quality.**

(See Chapter 13, “Indoor Air Quality,” and Chapter 21, “Operations and Maintenance”).

❑ **Re-size components to current requirements.**

Existing system components may be oversized, especially after efficiency improvements are made to other systems (e.g., lighting reductions). The retrofit process allows system components to be matched to actual loads with a corresponding efficiency gain.

❑ **Improve occupant comfort.**

An assessment of occupant issues related to temperature control and ventilation levels can lead to renovations that improve comfort levels and productivity.

❑ **Eliminate code deficiencies.**

Upgrade components to comply with changes in building codes or comply voluntarily with current codes.

❑ **Install new building-control system.**

Control-system technology is far more advanced than it was several years ago. Modern systems can be used to manage multiple buildings, alarms, and zones. The purchase and installation costs of such systems may be justified based on energy savings and better indoor air quality.

Lighting

★ SIGNIFICANCE

Artificial lighting constitutes 20 to 30 percent of all energy use in a commercial building and approximately one-fifth of all electrical energy use in the United States.¹ Reductions in energy use can be achieved with natural daylighting, advanced lighting technology, and efficient lighting design.

Artificial light has been generally overused in most buildings. Current building codes mandate a maximum lighting power density of 1.5 to 2.5 watts per square foot. Nevertheless, a lighting power density of 0.65 to 1.2 watts per square foot can be achieved while still providing a fully functional, well-lit space. With additional improvements from control systems that reduce usage during periods of non-occupancy, the use

of daylighting, and light-level maintenance and tuning control, energy savings of more than 50 percent are possible. Because reduced lighting generates less heat, HVAC cooling requirements are lowered as well.²

Daylighting, a standard design goal for all but the last 50 years, is often overlooked in today's design practice (see Chapter 9, "Daylighting"). Green building design guidelines should encourage the maximum use of natural light, supplemented by artificial systems as needed. Increased daylighting levels are now required by many building energy codes. The design team should be aware of basic options and methods for integrating effective daylighting with the control of artificial lighting performance. This demands close coordination and support among all members of the design team.

Building form, orientation, and envelope design play key roles in effective daylighting integration and should be considered by the design team in the pre-design phase. Computerized modeling and visualization tools can aid in quantitative and qualitative evaluation. Utilization of reflected light is another important factor in efficient and effective lighting. As much as 30 percent of light in most office environments comes from light reflected off walls, ceilings, tables, and other furniture. The use of bright colors and highly reflective surfaces on walls, ceilings, and furniture can play a major role in energy savings.

SUGGESTED PRACTICES AND CHECKLIST

Lighting Design Guidelines

- ❑ **Include the entire design team in the design of building massing, orientation, and envelope to achieve greater daylighting contribution.**
Understand and take advantage of the specific daylighting characteristics at the building site (see Chapter 9, "Daylighting").
- ❑ **Incorporate the most energy-efficient technology for lamps, fixtures, and control equipment.**
- ❑ **Consider all lighting functions (including the ambient system, task lights, emergency and 24-hour lighting, exterior lights, exit lights, and public-area lighting).**
- ❑ **Use sophisticated design analysis, including computer simulation, for system design.**
Computer design tools such as the LUMEN MICRO, ADELIN, SUPERLITE, and RADIANCE programs are useful for avoiding the conventional practice of overlighting spaces. (See Chapter 9, "Daylighting" for more information on Design Tools.)
- ❑ **Consider using the guidelines of the Illuminating Engineering Society (IES).**
Avoid the use of outdated, higher light-level standards. The IES guidelines provide specific target illumination levels for various visual tasks. Criteria should include illumination levels and luminance ratios since uniformity plays an important part in perceived lighting adequacy. Some variation of light is helpful for providing occupant comfort and more accurately reflects actual outside daylight conditions.
- ❑ **Design for specific visual tasks.**
Typical lighting methodologies often do not tailor the lighting criteria and the resulting system to the visual task. With the visual display terminal (VDT) becoming standard in all building types, lower ambient lighting levels are gaining greater acceptance. Some professionals believe that overlighting VDT office environments causes visual fatigue because of the excessive contrast between the VDT and surrounding environment, resulting in lower productivity and long-term health problems.
- ❑ **Consider task-lighting systems that reduce general overhead light levels.**
Provide supplemental task illumination only in required areas, with higher light levels only at the focal point of the visual task rather than throughout the entire space.

❑ **Match the quality of light to the visual task lighting requirement.**

The quality is more important than the quantity of light delivered to the visual task. A high-quality lighting solution requires less light to yield the same visual performance. Light quality involves the following factors:

- Luminance ratio limits;
- Veiling reflections (reflection of light source in visual task);
- Reflected glare;
- Shadows;
- Color; and
- Intensity.

For example, indirect lighting systems that reflect light off the ceiling can produce a low level of uniform, low-glare light that is sufficient for VDT lighting needs, with energy-saving results.

❑ **Improve lighting design and energy efficiency by performing several key activities in the early phases of architectural space planning.**

- Coordinate the lighting plan (reflected ceiling plan) with furniture layout. Areas such as walkways or service spaces can “borrow” light from adjacent work areas.
- Coordinate daylighting to be available in spaces such as walkways, lounges, and areas intended for recreation and other public uses where the variation of color, intensity, and direction of light are desirable. In other spaces such as offices and conference rooms where lighting quality is important for performance of visual tasks, daylighting needs to be controlled properly for brightness and direction of light.
- Where possible, group occupants with similar work schedules together. This allows lighting in other areas to be turned off during unoccupied periods.

❑ **Improve room-cavity optics.**

The use of smooth, high-reflectance surfaces can greatly improve the efficiency of natural and artificial lighting. For example, use:

- Light- or neutral-colored surfaces to improve reflected light;
- Fine-fissured ceiling tiles with a smooth, reflective surface;
- Light shelves for introduction and control of natural light; and
- Low office partitions to avoid shadows and dark zones.

Lighting Fixtures and Lamps

❑ **Specify efficient lamps for the intended use.**

Choices in lamps have greatly expanded during the recent revolution in lamp technology to include:

- T8 fluorescent lamps;
- Compact fluorescent lamps;
- Lower-wattage, high-color-rendering HID lamps;
- Compact reflector HID lamps (such as PAR30 and PAR38);
- Halogen lamps with infrared reflectors; and
- Sulfur bulbs.

❑ **Use electronic ballasts.**

One of the biggest improvements in fluorescent lighting efficiency over the past few years has been the introduction of reliable electronic ballasts, which are 10 to 20 percent more efficient than the most efficient magnetic-coil-type ballast. Electronic ballasts energize lamp phosphors at a higher frequency which eliminates flicker and offers better light quality while using less energy. Selecting electronic ballasts with the appropriate capacity of light output (known as the “ballast factor”) makes it possible to match light output from fixtures and lamps to the specific design requirement. Dimmable ballasts (stepped and continuously dimming) provide a significant increase in efficiency when used in conjunction with the control opportunities discussed below. The latest ballasts have substantially reduced induced harmonics, one of their previous drawbacks, and high power factors. The use of electronic ballasts with HID lamps has been found to limit the color shift often inherent in HIDs and standard magnetic ballasts.

□ **Improve optical control.**

Construction and retrofit projects can take advantage of new improvements in optical control by providing more light for the visual task and reducing glare or spilled light while also enhancing energy efficiency. Reflectors within the fixture that direct and control light into the space are now computer-designed and optimized for better efficiency and control. Louver-finish options are also available for visual comfort and integration into a VDT-intensive area. Specifying fluorescent fixtures with heat extraction over the lamp cavity also improves fixture efficiency by allowing the lamp to operate at a cooler temperature and produce more light output.

Lighting Controls

□ **Provide effective lighting control.**

Among the greatest benefits of energy-efficient lighting are those resulting from effective lighting control. The most basic function is time-of-day control to turn lights on and off. In addition:

- Use occupancy sensors to detect when occupants are present in a space and to turn off lights when the space is unoccupied. Studies have shown that this results in a potential energy savings of more than 60 percent, depending on type of occupancy. Recent project experience indicates that occupancy sensors are less costly to install than programmable-control or dual-level manual switching.³
- Incorporate daylighting control strategies. Every building should provide the means to control the electric lighting system in response to natural light from all envelope sources. Dimmable and stepped daylighting controls are two options that take advantage of the latest technology. Continuously dimmed control systems have the highest level of energy savings and user acceptance. They also offer additional energy-saving operational strategies but have greater initial cost than stepped daylighting controls (see Chapter 9, “Daylighting”).
- Incorporate lumen-maintenance controls that use photocells to continuously dim ballasts to maintain desired illumination levels and adjust lamp output in response to variable outputs. Lumen output from light fixtures and lamps will be reduced over the course of their operating lives because of factors such as inherent lamp lumen depreciation and dirt accumulation on the fixture. Controlling light fixture energy, and thus light output, overcome these factors to achieve energy savings.
- Incorporate light-level tuning. Develop light-fixture layouts according to the layout of workstations or illumination criteria. This is preferable to the practice of designing fixture layouts for visual appeal, uniformity, and standardization of lamps. Dimmable ballasts allow lighting levels to be dimmed or “tuned” to the desired light levels, reducing energy use accordingly.

Additional Lighting Considerations

□ **Use efficient exit signs.**

Modern exit signs use only one to six watts, compared to 40 watts for older signs. The energy savings can be sizable given the large quantity of exits and the need for continuous operation of exit signs.

□ **Consider improved task-lighting products.**

Inefficient incandescent and under-counter strip fluorescent fixtures are outdated when compared to the products now available on the market, such as 15-watt compact fluorescent task lights. Issues such as luminance ratios (critical in VDT environments), veiling reflectance glare, and asymmetrical light distribution are important factors for task lighting. High-performance task lights, compact fluorescent sources, asymmetric reflectors, and electronic ballasts should be specified. These measures can reduce energy use by more than 50 percent. Some task lights are available with occupancy sensors

Renovation and Retrofit Issues

□ Convert existing light fixtures.

Consider all design-related issues such as appropriate light level and quality, architectural and furniture layout, and room cavity optics, as well as replacement and proper disposal of older ballasts containing polychlorinated biphenyls (PCBs). If major renovations are planned (such as new roofs and replacement windows), also consider daylighting improvements.

Electrical Power Systems

★ SIGNIFICANCE

Office technology, including telecommunication devices, personal computers, networks, copiers, printers, and other equipment that has revolutionized the workplace in the last 10 years, together with appliances such as refrigerators and dishwashers, makes up the fastest-growing energy load within a building. The consumption of energy to run these devices can be comparable to that of a building's mechanical or lighting systems. The design and management team should advise building users of the energy impact of efficient office equipment and appliances. The latest equipment offers energy reductions of more than 75 percent.⁴

Local area networks (LANs) and peer-to-peer computing create significant energy loads within a building because they create a demand for 24-hour operation. In addition, it is estimated that office computers consume over 26 billion kilowatt-hours of electricity annually, costing over \$2 billion; this may increase five-fold in the next decade. Decentralized information processing also demands increased HVAC support. LAN rooms, telephone closets, and even some general office areas need to maintain 24-hour "computer-room" cooling and humidity requirements year-round, further increasing energy demands and costs.⁵

The indirect environmental costs of energy consumption associated with office equipment include the release of significant amounts of carbon dioxide, sulfur dioxide, and nitrogen oxide into the atmosphere each year. Office automation and telecommunications systems have led to a dramatic increase in the volume of CFCs in the workplace to meet the demands of distributed, packaged air conditioners and halon fire-protection systems.

Office technology contributes to "electromagnetic pollution" in the workplace, an issue that is beginning to generate increased research and public concern. Radio-frequency emissions from electronic devices and their interconnecting cables can cause mutual interference. Radio frequencies associated with microwave and satellite dishes, cellular telephones, and two-way radios may be harmful to building occupants, but additional research is required before a consensus in the scientific community can be achieved.

The electrical-power distribution system should deliver power reliably and efficiently throughout a building. Losses result in wasted heat energy. Measures that reduce loss and match power distribution to the various electrical loads in the building should be considered. Electrical loads may also degrade power quality and introduce wasteful harmonics or change power factors.

SUGGESTED PRACTICES AND CHECKLIST

Design Considerations

Specify energy-efficient office equipment.

The U.S. Environmental Protection Agency (EPA) and the electronics industry are working to cut the power consumption of desktop computers by 50 percent by the year 2000 through the Energy Star program. The program encourages the use of special features to put personal computers, printers, and copy machines into a low-energy “sleep” mode when idle. In addition, energy-saving computer chips, originally developed for laptop computer applications, will be used in desktop machines. Look for the Energy Star label when making equipment purchases. The EPA also publishes a list of energy-efficient retrofit kits for older computer equipment.

Specify energy-efficient appliances.

Many energy-efficient and environmentally sound appliance alternatives now exist. New refrigerators consume less than one-half the energy of older models. In addition, some are CFC-free. Dishwashers that use less than one-half of the water and energy consumed by older models are also available.

Consider higher system voltages.

Less energy is lost in distribution systems with higher system voltages. This factor is often ignored in an effort to minimize initial construction costs. The long-term impact of lower voltages typically is not quantified.

Improve power factor.

Power factor is the ratio of active power to apparent power. The electrical load may shift the phased relationship between electric current and voltage, thereby altering the power factor. These shifts are often caused by large motors. Poor power factor results in increased distribution and motor losses that require additional energy. Use motor selection, proper motor sizing, and corrective equipment (such as capacitor banks) appropriately.

Use K-rated transformers.

K-rated transformers better accommodate electric power irregularities or harmonics. They can be used when tenant equipment (such as personal computers) introduces harmonics on the power system. These devices accept the harmonics without a reduction in system rating or efficiency.

Size conductors correctly.

Selecting conductors of the proper size can reduce voltage drop and power losses and should be considered, particularly for more concentrated loads. Neutral leg current flow, associated with equipment that has switched power supplies, should be addressed in design.

Renovation and Retrofit Issues

Optimize energy use of current equipment and specify more efficient systems with future equipment procurement.

Retrofit computers with shut-off devices.

Some users believe that turning off equipment can *shorten* its lifetime; however, equipment manufacturers have stated otherwise. Low-cost devices that sense periods of inactivity can automatically turn off computer equipment after a set period of time. These individual computer devices can be set to turn off a computer’s central processing unit (CPU) and monitor separately. These devices have been shown to be extremely cost-effective, with payback periods of around one year.

Plumbing Systems

★ SIGNIFICANCE

Water use in buildings has two environmental impacts: (1) the direct use of water, a limited resource; and (2) the expenditure of energy used in water pumping, purification, treatment, and heating. This section considers the energy-use aspects associated with water usage within a building, including pumping and hot-water heating (see also Chapter 11, “Renewable Energy”). Other chapters discuss additional water-use strategies, such as gray-water systems and landscape irrigation (for example, see Chapter 6, “Water Issues”).

The overall amount of energy used to pump, treat, and heat water can approach 10 percent of a utility company’s output. The primary areas where improvement is possible are: (1) more efficient water generation and end-use devices, (2) reduced storage losses in hot-water equipment, (3) reduced piping and pumping losses, and (4) reduction in hot-water temperatures to provide the minimum acceptable temperature for intended use.

👉 SUGGESTED PRACTICES AND CHECKLIST

Hot-Water Heating

❑ **Consider hot-water heating options.**

Analyze and specify efficient equipment options. Heat pumps, heat recovery processes, tankless water heaters, and combination space heating-water heating systems are options that can improve efficiency significantly.

❑ **Reduce hot-water system standby losses.**

Losses from distribution piping and hot-water storage tanks can be more than 30 percent of heating energy input. Tank insulation, anti-convection valves and heat traps, as well as smaller heaters with high recovery rates, can reduce these loss factors.

❑ **Evaluate system configuration.**

Consider the benefits of localized hot-water equipment versus centralized equipment by evaluating the types of loads served. Localized heating equipment options for small isolated loads may include electric heat-tracing devices which use a linear-resistance heating element wrapped around the piping.

❑ **Reduce hot-water service temperatures.**

Confirm the lowest hot-water temperature needed for the usage or equipment. Lowering the hot-water supply temperature reduces initial heating-energy and system losses. This approach should be limited to a minimum water temperature so as not to allow growth of harmful bacteria in piping.

❑ **Install hot-water system controls.**

Appropriate controls optimize energy use. Time-of-day equipment scheduling is a basic function; the use of certain applications may benefit from temperature optimization features.

❑ **Consider solar hot-water heating**

Consider solar systems based on building type, hot-water needs, and solar conditions at project site (see Chapter 11, “Renewable Energy”).

Water-Pumping Systems

❑ **Use low-flow plumbing fixtures.**

Low-flow fixtures may seem to be a water conservation method, but they also save energy because they reduce pumping energy and water heating. Products are available for a wide range of applications and have become standard in many areas.

❑ Use water-booster pumps.

Use packaged pumping systems with staged pump operation to better serve part-load flow conditions, such as after hours. Systems can include a pressurized tank to further reduce pump cycling and improve efficiency.

❑ Prepare an efficient plumbing system layout.

Prepare an efficient design for the layout of pumping and piping distribution, including:

- Simple, short piping runs with minimum offsets and pressure control stations;
- Stacking of water services in multi-story buildings;
- Gravity flow of effluent from buildings without mechanical sump pumps; and
- Calculation of minimum pressure requirements for distribution and booster pumps if necessary.

Utility Company Rebates and Assistance

★ SIGNIFICANCE

Over the past decade, utility companies across the country have developed both technical and financial programs to help their customers understand and implement energy-efficiency measures. These programs have garnered substantial customer awareness and response. With deregulation however, the utility industry is now beginning a radical restructuring of customer-service access that is expected to change the nature of utility involvement in promoting energy efficiency.

The industry now considers energy-efficiency issues for buildings under the broader concept of demand-side management (DSM), which encompasses all methods available to customers to reduce, modify, or control the use of energy. Utilities first became interested in DSM issues because of their desire to control peak utility supply requirements or to shift energy service to time periods most beneficial to their generation or transmission systems. Interest in actually reducing customer energy use came only after public utility commissions (PUCs), which regulate investor-owned utilities, identified the need to initiate more aggressive programs. By giving the utilities an economic return on efficiency investments, the PUCs developed the financial mechanism to reward utilities for promoting efficiency gains. In turn, the utilities have marketed energy efficiency to customers and created programs that offer incentives to install efficient systems.

The future of DSM programs will be driven by the future of utility deregulation, although the direction of change is uncertain. Deregulation effects power generation and distribution as well as energy costs. “Retail wheeling,” an element of deregulation, allows the customer to negotiate with competing utilities to obtain service and select the most economical alternative regardless of geographical location. The loss of customers by a local utility could result in higher rates for remaining customers.

👉 SUGGESTED PRACTICES AND CHECKLIST

❑ Obtain input from utilities early in the design process.

The design team should meet with the designated account representative to learn about current and future design and financial incentive programs, including rebates or loans.

❑ Seek out utility resources and design assistance.

Some utility companies have recognized that additional assistance in the form of educational or technical offerings can be valuable to both the building owner and design professional. Offerings may include:

- Early project review by a utility-sponsored design group to solicit ideas on daylighting contributions and reduced HVAC requirements and to involve the group in creation of computer-based energy models for the project;

- Energy learning centers with classroom and library facilities; and
- Technical seminars on specific issues provided for general information.

❑ **Institute rebate documentation and verification measures with utility.**

Verification of system performance at construction completion may be needed for more complex efficiency measures or custom rebate applications. Utilities are interested in seeing that design-efficiency objectives are realized in operation and are beginning to offer rebate incentives for building commissioning.

❑ **Assess the impact of deregulation.**

Track current energy use and estimate the potential exposure to energy cost increases. Project any plans for building expansion and related modifications and their anticipated energy usage; consider energy-efficiency options as an alternative to increased supply needs.

→ RESOURCES

American Society of Heating, Refrigerating, and Air-Conditioning Engineers. *HVAC Applications*. Atlanta: ASHRAE, 1995.

_____. *HVAC Systems and Equipment*. Atlanta: ASHRAE, 1992.

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Series of technical handbooks considered the most comprehensive HVAC reference available. These handbooks introduce design issues and provide extensive technical documentation for engineering purposes. ASHRAE is responsible for the development of practice standards for specific issues such as ventilation and energy. ASHRAE also publishes a monthly journal, which includes technical articles on a variety of topics, including energy efficiency.

Bobenhausen, William. *Simplified Design of HVAC Systems*. New York: John Wiley & Sons, Inc., 1994.

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Part of a series of technical handbooks and other references that are essential in the understanding of natural and artificial lighting systems. They are published by the leading professional society for lighting design.

Institute of Electrical and Electronics Engineers. *Electric Power Systems in Commercial Buildings—Grey Book*. IEEE Standard 241-1990. New York: Institute of Electrical and Electronics Engineers, 1991. A general reference in the design of electrical power distribution.

Lovins, Amory B., Brady Bancroft, Michael Shepard, and Robert Bishop. *State of the Art: Water Heating*. Snowmass, Colo.: Rocky Mountain Institute, 1991. An excellent resource for energy-efficient design, including background on efficiency issues and discussion of potential future developments across the spectrum of commercial/institutional energy use issues.

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- Lovins, Amory B., and Robert Sardinsky. *State of the Art: Lighting*. Snowmass, Colo.: Rocky Mountain Institute, 1990.
- Pilgrim, William L., and Richard E. Stonis. *Designing the Automated Office*. New York: Whitney Library of Design, 1984. Contains a good overview of design issues and related energy-efficiency topics in office design.
- Rea, Mark S., ed. *Lighting Handbook: Reference & Application*. New York: Illuminating Engineering Society of North America, 1993.

DESIGN TOOLS

PASSIVE SOLAR DESIGN

- BLAST*. Calculates building loads, analyzes solar feasibility, predicts life-cycle costs, and helps select the optimal HVAC system for a building. Developed by Civil Engineering Research Laboratories, U.S. Army. Contact: University of Illinois, (800) UI BLAST
- ENERGY-10, Low-Rise Building Design* (Design manual and software). Windows-environment program for small commercial buildings allowing early design evaluation of 16 energy-saving strategies including daylighting. Developed by National Renewable Energy Laboratory (NREL), Passive Solar Industries Council (PSIC), U.S. Department of Energy (DOE), and Lawrence Berkeley National Laboratory (LBNL). Contact: Blaine Collison at PSIC, (202) 628-7400.
- SERI-RES* (also known as *SUNCODE*). Useful for residential and small commercial buildings to analyze passive solar design and thermal performance. Developed by NREL and Ecotope Group. Contact: Ron Judkoff at NREL, (303) 275-3000.
- TRNSYS*. Modular FORTRAN-based transient simulation code that allows for simulation of any thermal energy system, particularly solar thermal, building, and HVAC systems. Developed by the Solar Energy Laboratory, University of Wisconsin. Contact: TRNSYS Coordinator, (608) 263-1589.

ENERGY-EFFICIENT DESIGN

- BLAST*. See Passive Solar Design. Contact: University of Illinois, (800) UI BLAST
- DOE-2*. Calculates energy use and life-cycle costs of design options. Includes building envelope, HVAC systems, and daylighting analysis package. DOE Version 2.1E available for MS-DOS and Windows (386 and 486) and UNIX workstations. Developed by LBNL. Contact: Fred Winkleman, (510) 486-4925.
- ENERGY-10, Low-Rise Building Design*. See Passive Solar Design. Contact: Blaine Collison at PSIC, (202) 628-7400.
- TRNSYS*. See Passive Solar Design. Contact: TRNSYS Coordinator, (608) 263-1589.

DAYLIGHTING DESIGN

- ADELINE*. Advanced integrated lighting design and analysis package, incorporating DXF input capability, SCRIBE MODELLER, PLINK, SUPERLIGHT, SUPERLINK, and RADIANCE, for detailed and advanced analysis of complex buildings. Available for MS-DOS 486 platforms. Developed by LBNL. Contact: Steve Selkowitz, (510) 486-5064.
- RADIANCE*. Lighting and daylighting modeling tool for performing accurate photorealistic lighting simulation. Available for UNIX workstations. Developed by LBNL. Contact: Charles Erlich, (510) 486-7916.
- SUPERLITE 2.0*. Daylighting analysis tool. Available for MS-DOS 386 and 486. Developed by LBNL. Contact: Rob Hitchcock, (510) 486-4154.

NOTES

- 1 Armory B. Lovins and Robert Sardinsky, *State of the Art: Lighting* (Snowmass, Colo.: Rocky Mountain Institute, 1990).
- 2 Paul Beck, "Pushing the Energy Envelope," *Consulting-Specifying Engineer* 18, no. 6 (1995).
- 3 Electric Power Research Institute (EPRI), "High-Efficiency Electric Technology Fact Sheet" (Palo Alto: EPRI, 1994).
- 4 Mark Ledbetter and Loretta A. Smith, "Guide to Energy-Efficient Office Equipment" (Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE), 1993).
- 5 Ledbetter and Smith, "Guide to Energy-Efficient Office Equipment."

CHAPTER 13

Indoor Air Quality

★ SIGNIFICANCE

With potentially hundreds of different contaminants present in indoor air, identifying indoor air quality (IAQ) problems and developing solutions is extremely difficult.¹ The study of indoor air quality is a relatively recent endeavor. Although much is known about the health effects of poor design and ways to overcome them through good design, a tremendous amount of research is needed in this complicated field. Over the past few years, several entities have undertaken considerable efforts to further the research and science in this area, including government agencies such as the U.S. Environmental Protection Agency (EPA), National Institute of Standards and Technology (NIST), National Institute of Occupational Safety and Health (NIOSH), and Occupational Safety and Health Administration (OSHA), and professional societies such as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and American Society for Testing and Materials (ASTM). The results of such activities will lead to more definitive IAQ practices, standards, and performance targets.

In the absence of such information and industry consensus, this chapter attempts to provide guidance on general industry practices for improved IAQ. These suggested practices should be updated and refined by the professional as more information becomes readily available.

The quality of indoor air results from the interaction of many complex factors (*Figure 1*), each contributing different effects.² The ways in which these factors contribute to IAQ may be summarized as follows:

■ **Construction materials, furnishings, and equipment.**

These items may emit odor, particles, and volatile organic compounds (VOCs), and adsorb and desorb VOCs. Individual VOCs from a specific material may combine with VOCs from other materials to form new chemicals. VOCs and particulates can cause health problems for occupants upon inhalation or exposure. In the presence of adequate heat and moisture, some materials provide nutrients that support the growth of molds and bacteria, which produce microbial volatile organic compounds (MVOCs).³

Author
Anthony Bernheim

These organisms can affect occupants adversely if fungal spores containing mycotoxins and allergens or the MVOCs are inhaled. A great deal of research remains to be done to identify individual metabolic gases, their odors, the microbes that produce them, and the human response to molds and fungi.

■ **Building envelope.**

The envelope controls the infiltration of outside air and moisture, and may include operable or inoperable windows.

■ **Ventilation systems.**

Acoustical materials in heating, ventilating, and air-conditioning (HVAC) systems may contribute to indoor air pollution in the same way as construction materials, mentioned above. Ventilation systems also control the distribution, quantity, temperature, and humidity of air.

■ **Maintenance.**

Lack of maintenance allows dirt, dust, mold, odors, and particles to increase. The use of high-VOC cleaning agents pollutes air.

■ **Occupants.**

The number of occupants and the amount of equipment contribute to indoor air pollution. People and pets are major sources of microorganisms and airborne allergens in indoor environments.⁴ Occupant activities also can pollute the air.

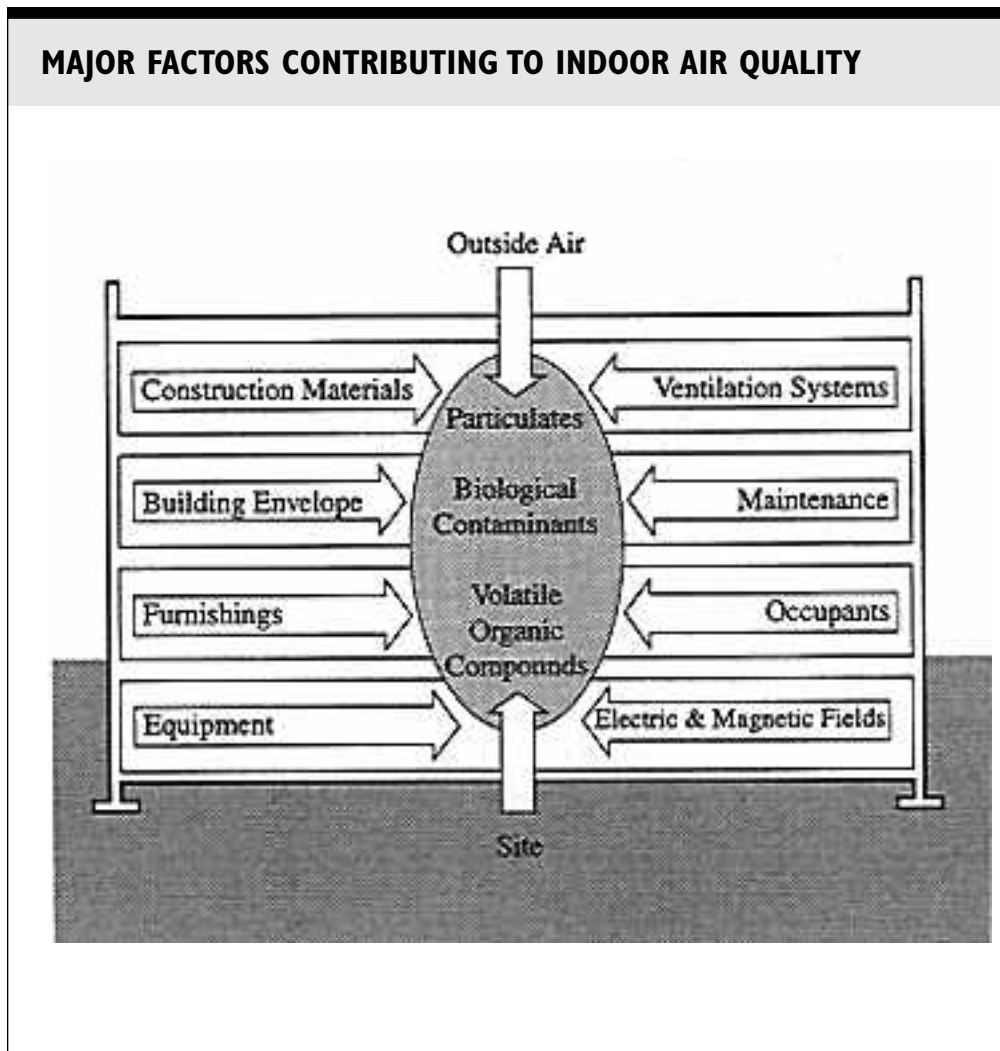


Figure 1

■ **Electric and magnetic fields (EMF).**

The possible health effects of electric and magnetic fields generated by power lines and electric appliances are not well understood at this time. There is considerable debate regarding possible health effects of these sources.⁵ More research is required.

Poor indoor air quality can cause human illness, which in turn may result in increased liability and expense for building owners, operators, design professionals, and insurance companies. It can also lead to lost productivity of building occupants, resulting in economic losses to employers.⁶ In the long term, these costs may exceed the additional initial cost, if any, of environmentally sound design in both new construction and renovation. Health problems that can result from poor indoor air quality may be short-term to long-term, and range from minor irritations to life-threatening illnesses. They are classified as follows:

■ **Sick-Building Syndrome (SBS)**

SBS describes a collection of symptoms experienced by building occupants that are generally short-term and may disappear after the individuals leave the building. The most common symptoms are sore throat, fatigue, lethargy, dizziness, lack of concentration, respiratory irritation, headaches, eye irritation, sinus congestion, dryness of the skin (face or hands), and other cold, influenza, and allergy type symptoms.⁷

■ **Building-Related Illnesses (BRI).**

BRI are more serious than SBS conditions and are clinically verifiable diseases that can be attributed to a specific source or pollutant within a building. Examples include cancer and Legionnaires' disease.⁸

■ **Multiple Chemical Sensitivities (MCS).**

More research is needed to fully understand these complex illnesses. The initial symptoms of MCS are generally acquired during an identifiable exposure to specific VOCs. While these symptoms may be observed to affect more than one body organ system, they can recur and disappear in response to exposure to the stimuli (VOCs). Exposure to low levels of chemicals of diverse structural classes can produce symptoms. However, no standard test of the organ system function explaining the symptoms is currently available.⁹

 **SUGGESTED PRACTICES AND CHECKLIST**

General Approaches to IAQ

□ **Employ an integrated approach.**

Even though current building codes are relatively silent on IAQ issues, a number of principles and practices have been developed to promote good IAQ designs that require a coordinated approach to building design. To achieve this goal, employ an organized and integrated approach that involves the building's owner, operator, design professionals, contractor, and tenants.

□ **Practice "prudent avoidance."**

In cases where research is not definitive, which involves most cases at this time, a recommended alternative is to practice "prudent avoidance" of specific materials and systems that have been proven to contribute to IAQ problems. A "prudent avoidance" strategy means limiting the building occupants' exposure to these materials and systems when this can be accomplished at a reasonable cost and with reasonable effort.

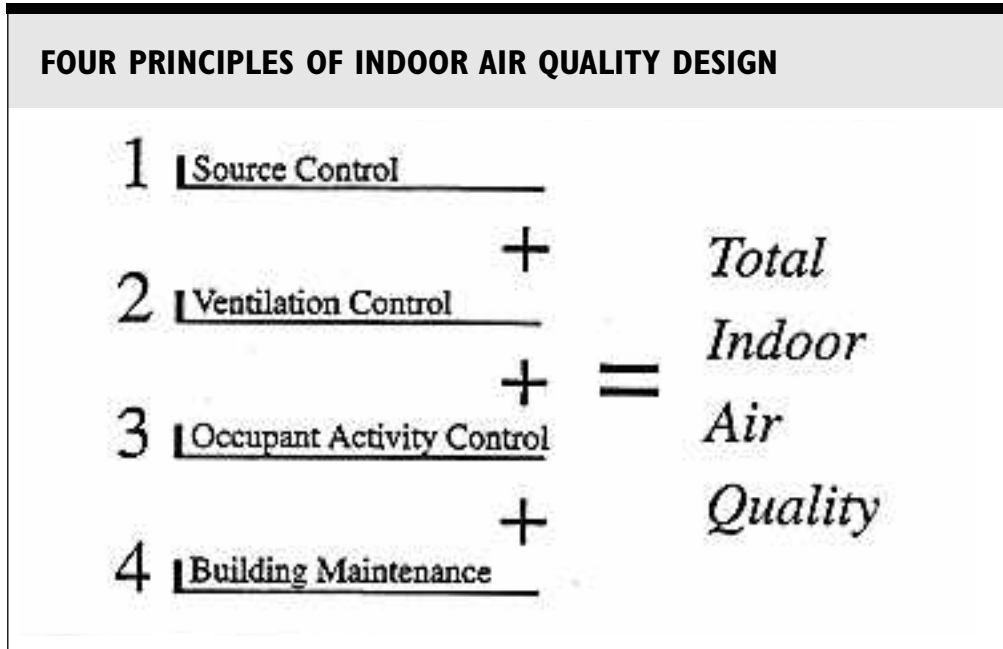
□ **Evaluate the costs and benefits of all strategies.**

This analysis should include an understanding of initial and life-cycle costs weighed against the potential IAQ benefits such as reduced health risk, increased productivity gains, the associated economic benefits, and the long-term benefits to society, which at this time are somewhat difficult to determine and quantify.

Design Principles

Design for improved indoor air quality involves four interrelated principles (*Figure 2*) that should be implemented as a whole: source control, ventilation control, occupant activity control, and building maintenance.

Figure 2



Source Control

There are many sources of potentially harmful air contaminants in buildings (*Figure 3*). Contaminants may originate indoors, outdoors, from occupants, and from within the mechanical system of the building. VOCs and MVOCs may be emitted into the air from building materials, products, equipment, and furniture.¹⁰ Pollutant sources can be controlled, reduced, or eliminated to produce a healthier indoor environment. Strategies for source control are listed below.

- Set source-control priorities that are feasible within the project budget, project schedule, and available technology.**

Priority materials for source control are materials that will be prevalent in the building and are the most highly volatile (that is, they emit odors, releasing irritating and potentially toxic chemicals to the air, or may be susceptible to microbial growth). Identify and evaluate the priority materials, equipment, and furniture for use on the project.

- Establish the building owner's and occupants' criteria and guidelines for improved IAQ.**

- Request Material Safety Data Sheets (MSDSs) for priority materials from product manufacturers.**

OSHA regulations stipulate that product manufacturers must provide MSDSs with information on chemical identification, hazardous ingredients, physical/chemical characteristics, fire/explosion hazard data, reactivity data, health hazard data, spill and leak procedures, special protection information, and special precautions. However, MSDSs provide limited IAQ information, in part because the regulations do not require the identification of proprietary information or chemicals. Therefore, MSDSs should not be relied upon as the sole source of IAQ information, although they may provide the first level of information on potential IAQ concerns for some materials. In many cases, they may be the only source of information because "acceptable" third-party emissions testing information is not readily available.

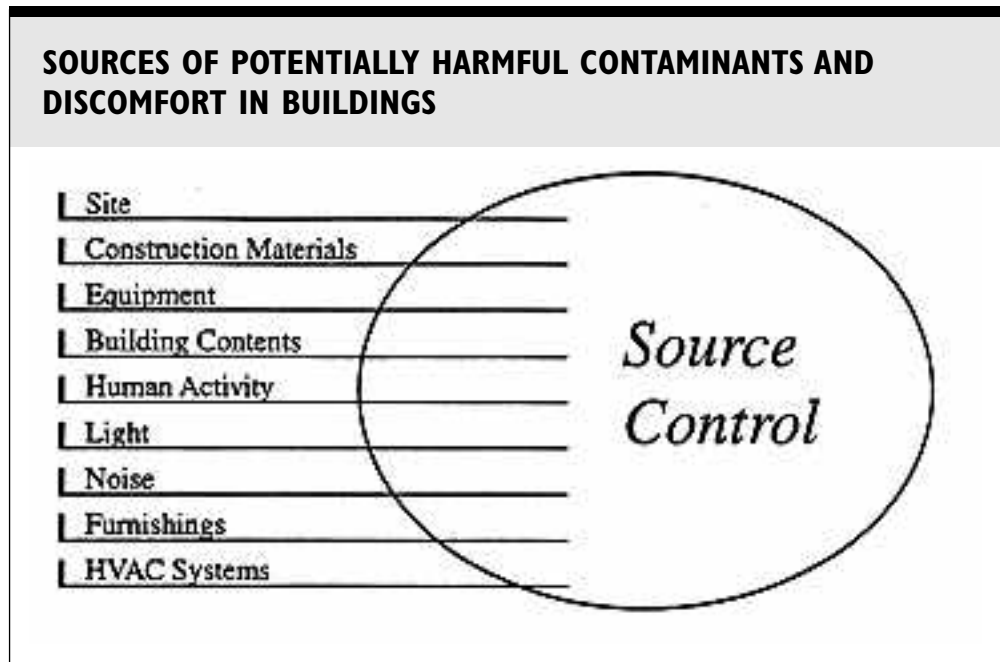


Figure 3

When chemicals or hazardous materials are identified in MSDSs, refer to the *Hazardous Chemicals Desk Reference* and existing regulations and guidance for information about their health effects and toxicity.¹¹ (For additional information regarding the interpretation of MSDSs, see Chapter 16, “Materials.”)

□ **Perform the following steps to evaluate the materials, products, and furniture in terms of their VOC contribution to indoor air:**

- Establish acceptable limits for total volatile organic compounds (TVOCs) and individual VOCs for the project. These limits should be based on regulatory requirements, guidelines, known health effects, and the professional advice of an IAQ specialist.

At the time of publication of this manual, there are no laws or codes setting acceptable levels of overall TVOC concentrations for general indoor environments or TVOC and VOC emissions from materials, products, and furniture. Some of the uncertainty associated with emissions from materials is caused by lack of standardized testing procedures and inconsistency of data reported in the literature. ASTM has developed a general guidance standard for emission testing, however it is not specific for materials. Further research and development is needed to advance the state of the art to the point where reliable emissions data based on consensus standards are available.

- Request emissions test data from the manufacturer for each priority material, product, and furniture item. The data should be based on predetermined and agreed upon chamber test methods, from the manufacturer. Reports from chamber tests should include the following information:
 - a. Clear definition of the materials and their origin, age, and history.
 - b. Clear specification of the test methods, conditions, and parameters.
 - c. Emission rates for TVOCs and individual VOCs as a function of time.
 - d. Identification of hazardous VOCs and chemicals that are listed in any of the following internationally recognized regulatory and guidance chemical lists:
 1. California Environmental Protection Agency, Air Resources Board (ARB), list of Toxic Air Contaminants (California Air Toxics);¹²
 2. California Health and Welfare Agency, Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65), which lists chemicals known to cause cancer and reproductive toxicity;¹³

3. International Agency on Research of Cancer (IARC), which classifies chemicals that are carcinogenic to humans;¹⁴
4. National Toxicology Program, which lists chemicals known to be carcinogenic,¹⁵ and
5. *Chemical Cross Index, Chemical List of Lists*, which shows listed hazardous chemicals regulated by various state and federal agencies and is published by the California Environmental Protection Agency.¹⁶

□ **Evaluate the emissions test data.**

Prepare a simple graph of TVOC and individual VOC data as shown in *Figure 4*. For each IAQ priority material, multiply the emission factor by the area of the product found in the building to determine the total emission rate and plot micrograms of emissions per hour ($\mu\text{g}/\text{hr}$). In general, review these graphs to understand the emissions from a material, product, or furniture item over time. If an increase in the emission rate is indicated, additional investigation may be warranted.

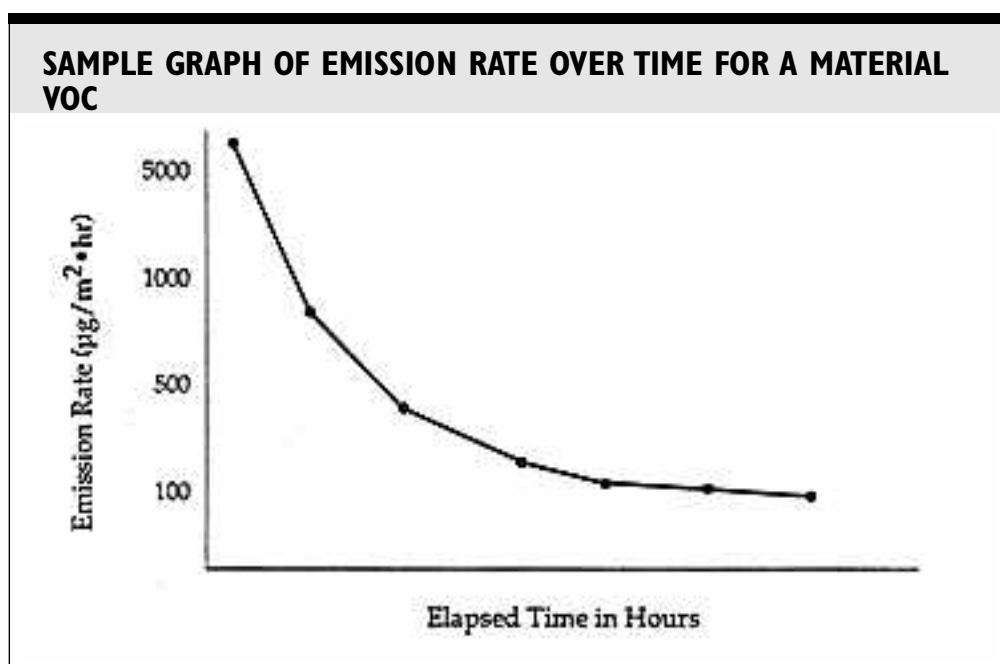


Figure 4

It is necessary to interpret these emission rates in terms of expected room concentrations of the contaminant of interest. This is not necessarily a simple conversion and needs to be done accurately and carefully. Factors such as room air exchanges (ventilation rates), concentration of contaminants in the exchange air, and the time dependence of the emission rates are essential in this determination. To the degree possible, these projected concentrations should then be compared with target concentrations for acceptable IAQ.

- Determine the emission factor and rate of the product VOCs to use as a potential indication of health concerns that may be associated with the use of the product.
- Where hazardous VOCs and chemicals are identified by the manufacturer, check the regulatory and guidance lists for the level of hazard (e.g.: “probably not carcinogenic,” “possibly carcinogenic,” “probably carcinogenic,” and “known carcinogen”).
- Prepare a chart to tabulate the hazard information for each material, product, or furniture item as indicated in *Figure 5*. It should be noted that the mere presence of such chemicals is not adequate evidence that they might or might not cause a hazardous exposure condition in a building. In any given situation, it is not always certain whether building occupants are actually exposed to emitted VOCs and, if there is exposure, whether this presents a risk to human health.

SAMPLE CHART FOR PRODUCT HAZARDOUS VOC/CHEMICAL IDENTIFICATION

Material, Product, Furniture

VOC/Chemical	Regulatory and Guidance List				
	Cal Air Toxics	CA. Prop. 65	IARC	NTP	Other Lists
Formaldehyde	*	*	*	*	
Toluene	*		*		
Styrene (Monomer)	*	*			

* indicates level of hazards, interpolated from the lists

Figure 5

Furthermore, the IAQ community is currently engaged in discussions about standards and quality control for chamber testing. Until these standards are developed, agreed upon, and implemented, review test result data with care and with the understanding that the data from different laboratories and from different equipment may not produce equivalent results.

- Determine the odor characteristics of the priority material, product, or furniture item. While odors may indicate a health-related IAQ problem, not all odors present a health risk. Nevertheless, be cautious initially about specifying products that emit strong odors, as they may indicate a potential and perceptual IAQ problem.

□ Based on the above information, determine if the priority material item is:

- Acceptable—that is, it meets the project criteria for odor and contaminant concentration, as discussed above; the TVOC and individual VOC concentrations are not hazardous, based on regulatory and guidance lists; and the material will not significantly contribute to MVOC emissions.
- Acceptable in a specific location or condition only.
- Acceptable with modifications by the material manufacturer.
- Acceptable only when temporary construction ventilation is provided during installation.
- Unacceptable—that is, none of the above criteria can be satisfied or, because of insufficient information, “prudent avoidance” is appropriate.

□ Take steps to control the MVOC contribution to the indoor air from materials, products, and furniture.

Since moisture and condensation allow molds and bacteria to start growing on the surface of indoor materials, finishes, products, ventilation ducts, and insulation materials, the primary methods to control microbial growth are controlling the interior temperature and humidity and removing the source of potential contamination. Source control to limit MVOC may be the primary method since the research has shown that increased ventilation may only produce limited results.¹⁷ Source control can be achieved by the use of simple design and specification techniques:¹⁸

- Specify materials that are resistant to microbial growth especially in areas where moisture can support the growth of fungi.
- Encapsulate materials such as insulation that might support microbial growth.
- Require in project specifications that if any material susceptible to microbial growth becomes wet during the construction phase, that material should be carefully removed from the construction site to prevent further contamination of the indoor air.

- Clean air shafts, occupied areas of new construction, and all finish materials with high-efficiency particulate air (HEPA) vacuum equipment prior to occupancy to remove dust and debris.
- Carefully design the exterior wall envelope to control moisture by locating the moisture barrier appropriately. In warm, humid climates, the vapor retarder should be installed in the external portion of the envelope; in cold climates, the vapor barrier should be on the side of the building facing the occupied space.

❑ **Consider a building flush-out.**

In certain circumstances where high-emitting materials are used, where there are legitimate reasons to remove high emissions from other sources, or where temporary construction ventilation is insufficient, consider a building “flush-out” to reduce possible contamination.¹⁹ This involves running the mechanical system with tempered 100 percent outside air for an extended period of time after construction completion and prior to occupancy. Care should be taken, however, with regard to humidity and microbial growth. A building flush-out should be carefully considered and weighed against the additional costs and delays involved. A “bake-out,” which is the introduction of extraordinary heating to the space prior to occupancy, may damage building materials and cause other problems, and therefore is not recommended. Also, research shows that VOC levels after a bake-out may be higher than before the bake-out.²⁰

❑ **In remodeling projects, test for and remove known hazardous materials such as asbestos,²¹ lead, polychlorinated biphenyls (PCBs), and fungal contamination.**

- Ensure that any removal of hazardous materials is performed by specially licensed contractors under approved and carefully controlled conditions.
- Remove microbially contaminated materials using specially trained contractors who use negatively pressurized, isolated work zones. Extreme care should be taken to remove all microbial growth from the building. In some limited cases, treatment may be considered in lieu of removal, however, it has been shown that treated dead fungi may still present a health hazard and cause allergic reactions.²²

Ventilation Control

Ventilation control involves many systems that need to be designed and modified as necessary to provide energy efficiency and adequate ventilation for building occupants (Figure 6). Proper control prevents parts of the ventilation system from becoming sources of biological contamination.²³ The best strategy for improved IAQ is to implement source-control strategies and then combine them with ventilation control. Ventilation control alone may not always solve IAQ problems, as it cannot necessarily remove an IAQ problem source.²⁴ Strategies for ventilation control are as follows:

❑ **Review the building occupants’ use needs and programmatic requirements and the energy conservation code requirements to determine whether fixed or operable windows will be provided.**

Where operable windows are selected, most energy-conservation codes require additional controls for the HVAC system.

❑ **Evaluate the HVAC system and develop the design criteria in accordance with applicable codes and ASHRAE standards to:**

- Provide adequate ventilation for the building population;
- Eliminate sources of, and growth locations for, microbial contamination; and
- Facilitate maintainability and cleanability of the HVAC system.

❑ **Consider use of the following interrelated HVAC strategies:**

- Locate outdoor-air intakes away from sources of contamination such as cooling towers,²⁵ plumbing vents, loading docks, parking areas, relief-air louvers, and dedicated exhausts from contaminated spaces such as toilets and copy rooms.
- Protect outdoor-air intakes from bird pollution with screens and bird guards.
- Locate airflow monitoring devices on the outdoor-air and return-air side of the air-handling unit.

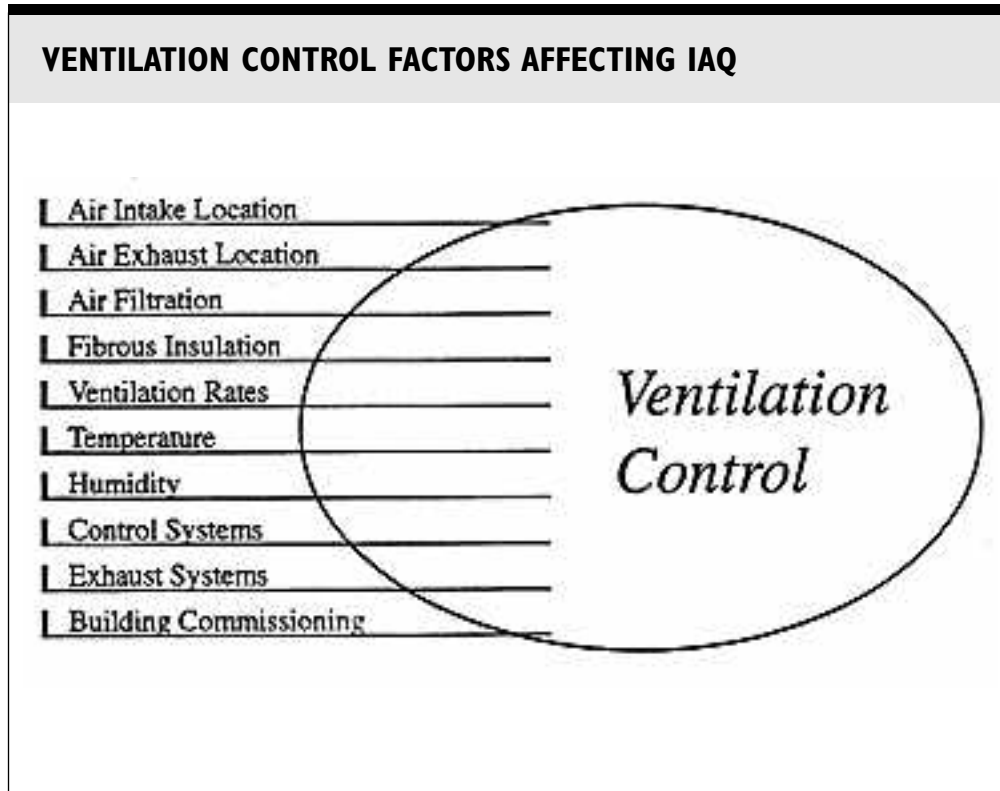


Figure 6

dling system. These devices monitor and regulate the amount of outdoor and recirculated air needed to provide minimum ventilation rates and adequate air quality.

- Install a high-efficiency air filtration system to remove particles of airborne dust from the outside air prior to distribution through the building’s HVAC system. The filtration system should consist of two filters. The second or final filter should be 85 or 95 percent efficient or should be a HEPA filter.
- Either encapsulate fibrous acoustical insulation that is located inside the air-handling units, ducts, and variable-air-volume (VAV) boxes, or remove any exposed insulation. These fibers tends to trap dirt that provides a rich nutrient base for microbes.
- Design the HVAC system to provide adequate ventilation and appropriate temperature and humidity for human comfort in accordance with building codes and ASHRAE standards and guidelines.²⁶ Within certain limits only, increased ventilation may reduce the prevalence of MVOCs in indoor air.²⁷
- Carefully design the HVAC system controls to allow the building operator to respond quickly to comfort problems and ventilation deficiencies by providing a building-control system with local controls (override switches and timers) where possible.
- Consider the use of an outdoor-air-economizer system. An air-economizer system enables the building operator to use the energy management system to vary the quantity of outside air brought into the building above minimum ventilation levels. This outside air can be used to maintain the required inside air temperature without use of the refrigeration cycle or recirculated air. With the refrigeration equipment turned off, energy is saved. The higher rate of outside air also improves ventilation conditions. Care should be taken with regard to humidity buildup.
- Install dedicated local-air exhaust systems vented to the outside, separate from the general exhaust system, in spaces that house specific contaminant sources, such as kitchens, janitorial closets, bathrooms, and copy rooms. Similarly, consider the viability of separate HVAC systems in buildings that support multiple uses.
- Consider the use of positive building pressurization in warm, humid climates to limit the infiltration of moist, hot outside air into the building interior. This will

reduce the exposure of the interior materials and finishes to moisture, inhibiting growth of molds and fungi on their surfaces.²⁸

- Design the HVAC system installations with adequate access for inspections and regular housekeeping, maintenance, and cleaning.
- Design the air-distribution system for maximum ventilation effectiveness by ensuring the proper location and performance of the air-supply and return diffusers, so that sufficient air is delivered to occupants.²⁹
- Arrange for independent professional testing, adjustment, and balancing of the HVAC system to assure proper operation for occupant comfort.
- Implement a building-commissioning program to ensure good IAQ and energy efficiency as described in the ASHRAE guidelines.³⁰ (See Chapter 15, “Building Commissioning,” for a detailed description of the three-step process.)
- Implement an operations and maintenance plan for the HVAC equipment. (See the section on “Building Maintenance” below and Chapter 21, “Building Operations and Maintenance.”)

(See also Chapter 12, “HVAC, Electrical, and Plumbing Systems,” for additional information.)

Occupant Activity Control

Some indoor air quality problems can occur when the interior thermal load (heat) generated by the occupants, their activities, and their equipment exceeds the HVAC system’s capacity to control the heating and cooling to ventilate the space. For example, if the HVAC system in a room is designed to provide adequate ventilation for three occupants and three personal computers, and there are actually six occupants and six computers in the room, the HVAC system may not be able to provide sufficient ventilation to cool the room and dissipate all environmental pollutants. Occupant activities may also generate odor and may cause VOCs to be released into the air. People and pets also produce microorganisms and allergens in the indoor air. Possible strategies for occupant activity control are listed below:

- **Implement a building commissioning program similar to the three-step commissioning process (see Chapter 15, “Building Commissioning”).**

Design the HVAC system capacity to provide sufficient outside air for the projected building population and the anticipated heat-producing equipment. Prepare the HVAC system design documentation and design criteria accordingly. These documents, provided to the building operators, specify the maximum building population and permissible equipment designated by the design parameters of the HVAC systems.

- **Consider the use of carbon dioxide (CO₂) and VOC sensors in the occupied spaces.**
These monitors should be linked to the building or energy-management-system computer, which can be used to regulate the quantity of outside air needed to ventilate the building based on actual occupant-load conditions.
- **Implement a no-smoking rule from the commencement of construction through the life of the building.**
Note that some cities have local ordinances that regulate smoking in occupied buildings. (See also Chapter 15, “Building Commissioning,” for more information.)

Building Maintenance

Air quality in poorly maintained buildings can deteriorate quickly. Materials, products, furniture, and HVAC systems need regular maintenance, cleaning, and inspections to ensure that they function as designed and to prevent indoor contaminants from developing in these locations. Other potential problems result from the use of pesticides, microbial growth caused by moisture within the building, and the emission of sewer gas where floor drains are concealed. Strategies for building maintenance are discussed below.

- **Select easy-to-maintain building materials and systems.**

For example, stone floors with metal-grate entry mats are easier to clean than carpets at building entrances.

- ❑ **Implement an integrated pest management program using only pre-authorized and non-hazardous chemicals that do not violate the integrity of building IAQ.**
Use chemicals only when there is a problem, not for scheduled preventive maintenance (see Chapter 7, “Site Materials and Equipment”).
 - ❑ **Select low-emitting, environmentally friendly cleaning agents for use in regular maintenance (see Chapter 22, “Housekeeping and Custodial Practices”).**
 - ❑ **Prepare project specifications with appropriate warranties and, where appropriate, with extended maintenance contracts (see Chapter 17, “Specifications”).**
 - ❑ **Institute a tenant policy for IAQ practices, including a no-smoking rule.**
 - ❑ **Adopt specific procedures for building operators to notify tenants when hazardous chemicals are used.**
 - ❑ **Prepare an IAQ plan to be administered by the building IAQ manager. The plan should include the following:**
 - The building commissioning design documentation with a description of the building and its systems, the function and occupancy of each individual room or space, the normal operating hours, and any known contaminants and hazards;
 - Schematic drawings of the building systems indicating equipment types, their locations, and their maintenance and inspection points;
 - Locations of system manuals and commissioning reports, as-built drawings, water-treatment logs, inspection reports, and training manuals;
 - Performance criteria and operating setpoints for each operating unit, including domestic water system and normal humidity levels;
 - Sequence of operations for equipment and systems along with seasonal startup and shutdown procedures;
 - Daily operating schedules of all systems;
 - Preventive-maintenance and inspection schedules for equipment;
 - Test-and-balance report and airflow rates listed by area;
 - Required outdoor-air rates and building pressurization requirements;
 - Building IAQ inspection checklists;
 - Equipment maintenance checklists;
 - Procedure for documenting and responding to occupant complaints; and
 - IAQ documentation.
 - ❑ **Prepare a maintenance plan with a schedule and budget for the HVAC systems, building materials, and furniture. The maintenance plan should include the following:**
 - HVAC Systems:
 - a. Maintain water treatment at cooling towers;
 - b. Change filters;
 - c. Lubricate dampers;
 - d. Eliminate standing water and excessive moisture;
 - e. Clean condensate pan; and
 - f. Clean coils and supply-air ducts.
 - Carpets:
 - a. Clean with vacuum cleaners equipped with HEPA filters.
 - b. Deep clean carpets periodically using water-extraction to remove particulates and contaminants that have accumulated at the base layer of the carpet.
 - Chairs:
 - a. Clean and vacuum regularly.
 - Office Systems:
 - a. Clean regularly.
 - Other Finish Materials:
 - a. Inspect regularly for microbial growth and remove material or finish if fungus is found.
- (See also Chapter 21, “Building Operations and Maintenance,” and Chapter 22, “Housekeeping and Custodial Practices.”)

- ❑ **Develop and provide the building operators with complete operations and maintenance manuals and a plan for appropriate system operation training.**
(See Chapter 15, "Building Commissioning," for additional information.)
 - ❑ **After the tenants have occupied a new or remodeled building, implement post-occupancy building commissioning and flush out the building as necessary to fine-tune the building systems under normal operating conditions.**
 - ❑ **Develop a plan to provide post-occupancy building commissioning on a regular basis every few years.**
(See Chapter 15, "Building Commissioning," for additional information.)
- (See also Chapter 12, "HVAC, Electrical, and Plumbing Systems," and Chapter 21, "Building Operations and Maintenance," for additional information.)

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CHAPTER 14

Acoustics

★ SIGNIFICANCE

Acoustics have a significant impact upon the overall indoor environmental quality of modern buildings and the amount of noise emission or pollution discharged to the outdoors. The levels of background noise, privacy, and separation between particular types of spaces have important implications for the work environment of building occupants. Commercial facilities would be well served by a careful review of acoustical considerations and their effects on occupant productivity.

In open office spaces, for instance, background noise that is too loud or has tonal qualities can distract occupants and reduce productivity. Other types of office spaces such as executive suites, conference rooms, and boardrooms have particular privacy requirements. Machine-rooms and other noise-producing facilities should be isolated from areas where privacy is required. There are numerous standards for acoustic quality in traditional building spaces and in specialty areas such as sound and production rooms, where acoustics is a high priority.

At the start of a project, the design team should work with the buildings' users to establish requirements for background noise levels, sound isolation, and speech privacy to ensure that sufficient levels are afforded to all spaces. Incorporating acoustic considerations into the design of a project at the planning phase can result in significant benefits and can avert costly, and possibly difficult, corrective measures later on. For example, by carefully locating internal spaces at the start of the project, the designer can reduce the need for high-sound-rated construction to mitigate noise problems. In certain noise-sensitive areas, and particularly in renovations, white noise and active noise systems may provide additional solutions.

Surface finishes are also important in the acoustic environment and can influence the character of the space as significantly as color or shape. Selecting the correct balance between hard, acoustically reflective materials and soft, absorptive ones facilitates the projection of speech to intended areas and prevents echoes or the excessive buildup of unwanted sound in other areas.

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Outdoor sound emissions must also be considered. In manufacturing areas, the operation of equipment that exceeds ambient noise levels can affect adjacent residential areas. The criteria for noise emission to the external environment are based on existing environmental conditions. In rural areas, for instance, background noise levels during the quietest periods of the day or night may drop to 35 or 40 dB(A). (dB(A) is a measure that represents a single-figure decibel weighted to the A-scale, which simulates the response of the human ear to different sound frequencies.)¹ In urban areas, the level is unlikely to drop below 50 to 55 dB(A) at night and 60 to 65 dB(A) during the day. If the jurisdictional authority has not prescribed a limit on noise emissions, the designer should establish a level consistent with existing ambient noise levels at property lines or neighboring buildings.

Building designers should also be aware of applicable local and federal limits on noise levels in certain types of workplaces. For example, Occupational Safety and Health Administration (OSHA) guidelines restrict various sound levels to prevent long-term hearing damage among workers who occupy a given area for extended periods of time.

SUGGESTED PRACTICES AND CHECKLIST

Planning Issues

Identify local zoning codes regarding noise and determine requirements for the project's adherence to such codes.

Determine the impacts of proposed building systems on surrounding areas and ambient conditions.

Minimize or reduce noise pollution generated by the building by assessing any noise-producing elements and their relationship to neighboring properties. Truck docks that operate 24 hours a day directly adjacent to residences will undoubtedly be cause for complaints. Central cooling towers and louvers from fan systems that direct noise toward nearby residences will require attenuation treatments.

Consider how the noise level from external sources around the building will affect occupants.

Noise intrusion from adjacent activities and other external sources like airports can have a significant impact on building occupants and require special mitigation. For example, structures built near airports are typically required to have high-performance glazing systems. Wide-air-space glazing systems and laminated insulating units offer better performance than standard insulating glass.

Acoustic Criteria

Select the appropriate criteria for evaluating noise levels.

Noise criteria (NC) are commonly used to rate interior noise levels of general office spaces. (NC numbers represent a series of curves of octave-band sound pressure levels.)² *Table 1* presents a list of typical NC values for various office spaces that can be a guide in establishing appropriate criteria for background noise.

Obtain the sound transmission class rating between spaces.

The "barrier" performance of materials used in general building construction is expressed by a sound transmission class (STC) rating.³ By obtaining STC ratings from wall and ceiling manufacturers for various construction materials, an acoustical engineer can project the overall STC rating of the combination of all elements separating two spaces. For example, if the wall between two offices is composed of multiple layers of gypsum board on metal studs and is erected up to the lay-in acoustical ceiling, the performance of that ceiling would dominate the barrier performance, or overall STC rating, between the two spaces.

RECOMMENDED DESIGN CRITERIA FOR BACKGROUND NOISE FROM HVAC, ELECTRICAL, PLUMBING, AND ELEVATOR EQUIPMENT

Type of office space	Noise criteria
Studios	NC-20 to 25
Boardrooms, teleconferencing rooms	NC-25 to 30
Conference rooms	NC-30 to 35
Private offices, apartments	NC-35
Lobbies, toilets, corridors, computer terminal rooms, retail spaces	NC-40
Storage, locker rooms, laboratories without fume hoods	NC-45
Kitchens, laundry, computer rooms	NC-50
Garages, laboratories with fume hoods	NC-55+

Table 1

Calculate the speech privacy potential factor.

Speech privacy potential (SPP) is a parameter that quantifies the privacy for a given room. Table 2 identifies SPPs for natural human voice levels and applies a subjective definition to each rating. The table shows the various degrees of privacy and allows the end-user to select the appropriate criteria. The use of speaker phones and other voice amplification systems requires special consideration.

To calculate the SPP factor, arithmetically add the background noise level in a given space (its NC level) to the level of separation required between adjacent spaces (the STC rating). For example, if a private office had an NC-35 background noise level from HVAC systems and a total separation from its neighbor of STC-40, the SPP rating would be 75. Using Table 2 to determine if this level is acceptable for the spaces being analyzed, adjustments can be made by either increasing the wall/ceiling performance (STC rating) with high performance structures or increasing the background noise level (NC rating). (See the section below on “White Noise.”)

DEGREES OF SPEECH PRIVACY FOR CLOSED-PLAN OFFICES

Speech Privacy Rating	Speech Privacy Potential (SPP)	Description of Privacy
Total privacy	85	Shouting is only barely audible.
Highly confidential	80	Normal voice levels are not audible. Raised voices are barely audible but not intelligible.
Excellent	75	Normal voice levels are barely audible. Raised voices are audible but mostly unintelligible.
Good	70	Normal voices are audible but unintelligible most of the time. Raised voices are partially intelligible.
Fair	65	Normal voices are audible and intelligible some of the time. Raised voices are intelligible.
Poor	60	Normal voices are audible and intelligible most of the time.
None	Less than 60	No speech privacy.

Table 2

Architectural Issues

Locate noise-sensitive areas away from noise-producing elements.

Careful “stacking” or placement of building elements can prevent costly mitigative changes later. The location of building spaces also has implications for the treatments required to provide adequate separation. Avoid locating sensitive spaces like executive office areas, studio-type environments, and meeting facilities immediately adjacent to noise-producing areas. Noise-producing elements include mechanical equipment rooms, fitness centers, production or manufacturing facilities, kitchen or food prepara-

tion areas, laboratories, gymnasiums, and music practice spaces. Data centers, storage rooms, mailrooms, and other less-sensitive spaces are more suitably placed adjacent to equipment rooms.

❑ **Evaluate slab construction between floors.**

Typical slab construction in modern buildings will usually provide adequate airborne noise separation. Thicker slabs are generally required if machinery rooms or other noise-producing spaces vertically adjoin other areas. Minimum slab constructions of six or eight inches are typically used in such cases. When evaluating the slab construction for a building:

- Determine if slab construction will serve as an adequate sound barrier.
- Evaluate the slab proposed for mechanical equipment rooms and machinery areas.
- Recommend an alternative slab where increased separation is necessary.

❑ **Consider the acoustic benefits of drywall construction.**

Generally, internal wall structures are constructed of gypsum board installed on both sides of metal studs. The level of acoustic performance varies depending upon the number of layers of drywall placed on each side of the metal stud and the thickness of insulation used in the cavity. The choice of full-height or non-full-height partition constructions also has a major bearing on the level of privacy afforded and the STC rating. Typically, monolithic drywall constructions provide a performance level of approximately STC-30 to 35 between adjacent offices when erected only to the ceiling line.⁴ Full-height structures between offices can increase performance levels to between STC-40 and 50 or more, depending on whether single- or double-layer drywall is used. Double-layer construction is typically installed in conference rooms and executive spaces to afford maximum privacy and separation.

❑ **Select appropriate partitions to achieve the required speech privacy rating between spaces and separation from HVAC equipment areas.**

Determine which areas require increased separation, based on whether they are noise-sensitive or noise-producing. Consider the typical partitions proposed for use in each area. Recommend alternative partitions for noise-sensitive areas or noise-producing areas, as appropriate.

❑ **Use constructed or natural screens to reduce the impact of noise from external sources.**

Constructed barriers, such as the screen walls typically seen along highways, can offer significant shielding and acoustical attenuation. Natural earth berms can also serve this purpose, but other natural barriers such as vegetation and trees do not have significant acoustic screening effects.

Surface Finishes

❑ **Consider acoustical properties when selecting surface finishes.**

Determine how selected finishes will affect sound travel and reverberation within building spaces. Request acoustical information and standards from the product manufacturer. Surface finishes can be modified to meet acoustic demands.

❑ **Perform product reviews and analyses to assess safety and environmental factors.**

Consider the recycling potential and environmental friendliness of finishes. In addition, choose products that satisfy requirements for flame retardancy and smoke spread.

❑ **Confirm that acoustic material selections meet the project's environmental criteria.**

(See Chapter 2, "Selecting Environmentally and Economically Balanced Building Materials," and Chapter 16, "Materials.")

❑ **Test materials as specified in American Society for Testing and Materials (ASTM) acoustic standards.**

Before selecting acoustic materials, test them according to ASTM test standards to identify their actual performance and limitations and to assess their suitability for the intended purpose.

- ❑ **In highly sound-sensitive areas, perform a full analysis of room geometry, volume, and surface finishes to predict reverberation time.**

This type of analysis is necessary in boardrooms, auditoriums, and similar spaces to identify measures that attain the desired reverberation time. Where natural speech projection is of importance, such as in classrooms and lecture halls, strategic placement of suitably reflective surfaces enhances speech projection to the rear of the facility.
- ❑ **Use acoustical ceiling products and carpeted floors.**

Sounds generated by general office functions are typically controlled by acoustical ceiling products and carpeted floors. More critical spaces such as conference rooms and audio-visual facilities require acoustical wall treatment.
- ❑ **Determine when additional acoustical treatments are needed to increase sound absorption within a given spaces, and in those cases, consider using:**
 - Acoustical ceiling tiles;
 - Fabric-wrapped wall panels; and
 - Spray-on acoustical treatments.
- ❑ **Select appropriate ceiling tiles based on ceiling sound transmission class rating.**

Ceiling materials are specified according to their level of “softness” to absorb sound in a given space and according to their barrier properties as denoted by their ceiling sound transmission class (CSTC) rating. The higher the CSTC value, the greater the material’s ability to prevent sound transmission. Typical mineral-fiber ceilings are rated CSTC-35 to 39, while fiberglass systems are rated at the lower performance level of CSTC-20 to 25.
- ❑ **Avoid using acoustic materials that may adversely affect indoor air quality.**

Some sound insulation products can absorb dust and other substances that may later be emitted. These substances can become airborne and move through the HVAC system, potentially becoming a health hazard. The use of encapsulating products to address this problem may interfere with acoustic performance. (See Chapter 13, “Indoor Air Quality,” for more information on materials and IAQ).

Mechanical Issues

- ❑ **Determine what mechanical equipment has been selected for the structure, for example:**
 - Cooling tower;
 - Chillers;
 - Air-handling units;
 - Exhaust fans;
 - Heat pumps;
 - Fan coil units; and
 - Variable-air-volume boxes.
- ❑ **Consider what manufacturers report as the sound power and pressure levels for the selected models.**
- ❑ **Determine whether a mock-up test of specific project conditions is necessary to predict actual noise levels or to test new, previously untested equipment.**
- ❑ **Determine whether the equipment is suitable for the usage from an acoustic standpoint.**
- ❑ **Determine if noise levels of mechanical equipment meet the project’s acoustical criteria.**
- ❑ **Recommend improvements to acoustic conditions related to the mechanical equipment, if necessary, such as the following:**
 - Relocate the equipment to a less sensitive space;
 - Install or increase lining within the ductwork;
 - Include sound attenuators (silencers) within the system; or
 - Re-select a given piece of equipment.

White Noise

□ **Consider a white noise or sound-masking system to maintain a constant level of speech privacy.**

If office spaces are very quiet (less than NC-35 to 40 in prime speech frequencies), conversations are readily audible to adjacent occupants, especially in open-plan offices. This, in turn, reduces concentration and interferes with productivity. A white noise system ensures a constant background noise level to maintain speech privacy. In these systems an evenly distributed array of speakers concealed above the ceiling artificially raises the background noise level in the space. The sound is unobtrusive to occupants and is similar to that of an HVAC system. Central white sound systems for large offices incorporate amplifiers and equalizers that can adjust the spectrum shape of sound and intensity levels to best suit the objectives. Smaller systems use individual speaker cans with inboard amplification and equalization facilities. White noise systems are typically designed to provide an even background noise in the range of NC-38 to 42, depending upon whether a cellular or open-plan office arrangement is used.

Active Noise Control

□ **Consider using newly developing active noise-control systems.**

Active noise-control systems are currently being developed for ducted HVAC systems, but to date their use is limited. Active noise cancellation (ANC), used in today's systems, employs a series of microphones to detect the noise occurring in the airstream of an HVAC duct. A speaker creates an identical noise sound field 180 degrees out of phase from the original sound waves processed in the controller. The result is a sound field reduced (not actually canceled) through the interaction of primary and actively controlled secondary sound sources. Currently, economic considerations limit the application of ANC to frequencies of 500 Hz and lower because passive noise methods (such as sound attenuators and acoustical duct lining) are effective and more cost-efficient at higher frequencies.

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¹ American Society for Heating, Refrigerating, and Air-Conditioning Engineers, "Sound and Vibration," chap. 7 in *1993 ASHRAE Handbook: Fundamentals* (Atlanta: ASHRAE, 1993), 7.9.

² ASHRAE, *ASHRAE Handbook*, 7.9.

³ Cyril M. Harris, *Handbook of Acoustical Measurements and Noise Control* (New York: McGraw-Hill, 1991), 2.15, 31.3.

⁴ Harris, *Handbook*, 31.15.

CHAPTER 15

Building Commissioning

★ SIGNIFICANCE

In recent years, most new buildings have been equipped with increasingly sophisticated heating, ventilating, and air-conditioning (HVAC) systems, energy conservation equipment, lighting systems, security systems, and mechanized sun control devices that rely on electronic control. However, in many buildings, some of these systems and design features have not performed as expected. This can result in energy-efficiency losses, occupant complaints about indoor air quality, high operating costs, and increased liability for building owners, operators, employers, and design professionals.

Building commissioning was developed in response to these concerns. Commissioning involves examining and approving (or withholding approval of) building systems to verify aspects of the building design, ensure that the building is constructed in accordance with the contract documents, and verify that the building and its systems function as intended. The process helps to integrate and organize the design, construction, operations, and maintenance of a building's systems.¹

Commissioning is commonly performed when building systems are constructed or installed and, preferably, once again 12 months after occupants have been using the building and all systems have been operating for a while. However, a good commissioning process actually begins during the design phase with agreement on how the design criteria will be verified and documented during the post-construction and post-occupancy assessments. Recommissioning on an annual basis is also advantageous as a means of ensuring the proper functioning and upkeep of building systems throughout their useful lives. Given its importance and many potential benefits, commissioning is becoming part of good standard practice for the industry.

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Benefits of Building Commissioning

- The building-commissioning process provides for testing and verification of building systems to ensure that they perform as designed and meet expectations for energy consumption and costs.
- The contractor commissioning activities and documentation ensure that systems are installed as designed, thereby reducing the occurrence of problems at the project's completion and over the life of the building.
- The building-commissioning process is used to discover deficiencies in the building and its systems before occupancy. It is more cost-effective to correct any deficiencies (both in design and construction) at that time.
- Construction-phase and post-occupancy building commissioning improve the building systems' performance under real, live conditions, reducing the potential for user complaints.
- The building-commissioning process helps ensure the proper functioning of buildings with good indoor air quality.² (See Chapter 13, "Indoor Air Quality," for additional information.)
- Using the HVAC system design documentation as a checklist ensures that the HVAC system capacity meets the projected peak and actual thermal loads for population and equipment.³ This review reduces the need for potentially costly construction change orders, which in turn reduces construction costs and the architect's potential liability.
- The building-commissioning process provides the design team with a better understanding of the building's systems, resulting in improved design and better coordination of the construction documents.
- Recommissioning a building throughout its life on a regular, annual, or biannual, schedule ensures the proper functioning of systems on a continuing basis. By maintaining indoor air quality, building recommissioning may also reduce worker complaints and improve worker productivity.⁴ This in turn may reduce the building owner's potential liability.
- Some utility companies are exploring the possibility of providing rebates or reduced utility rates to building owners whose buildings are commissioned or recommissioned, which may provide additional savings to cover the commissioning costs.
- Professional liability insurance companies are exploring the possibility of reducing annual premiums for architects and engineers who perform building commissioning on their projects.

A good building-commissioning process requires leadership, planning, thorough documentation, and systematic implementation. For the design and construction of green buildings, the advantages are tangible. Building commissioning reduces energy consumption and promotes good indoor air quality. It can be a cost-effective method to produce these results and should be seriously considered for large projects.⁵

SUGGESTED PRACTICES AND CHECKLIST

Design and Construction Documents Phase

- Select the building systems to be covered in the commissioning process.**

In large and sophisticated buildings, many systems are integrated. Expanding commissioning activities to cover multiple systems may be desirable. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has published guidelines for commissioning HVAC systems.⁶ *Figure 1* provides a list of additional systems that should be considered for commissioning.

EXAMPLES OF SYSTEMS THAT REQUIRE COMMISSIONING				
1. Mechanical	Hot Water Heating System	3. Electrical	Emergency Generator Systems	
	Pumps		Fire Management Systems	
2. Plumbing	Electronic Steam Grid Humidifiers	4. Controls	Air Handling Equipment	
	Cooling Tower		- VAV and Constant Terminal Boxes	
	Refrigeration Machines		Air Flow Measuring Stations	
	Air Handling Equipment		Water Cooled Computer Room	
	- Fans	Terminal Boxes	A/C Units	
	- VAV and Constant Terminal Boxes	Fire Management Systems	Building Management System	
	Air Handling Services	5. Fire Management	Air Handling Equipment	
	- Air Outlets		- Fans	
	- Fire Dampers		- VAV and Constant Terminal Boxes	
	- Balancing Dampers		Air Handling Services	
	- Fire/Smoke Dampers	Fire Management Systems	Fire Management Systems	
	Air Flow Measuring Stations	6. Sprinkler	Standpipe and Sprinkler Systems	
	Tanks		7. Elevators	
	Water Cooled Computer Room			8. Audio-Visual Systems
	A/C Units			
	Control Systems			
Fire Management Systems				
Service Water Heaters				
Pumps				
Tanks				
Compressors				

Figure 1

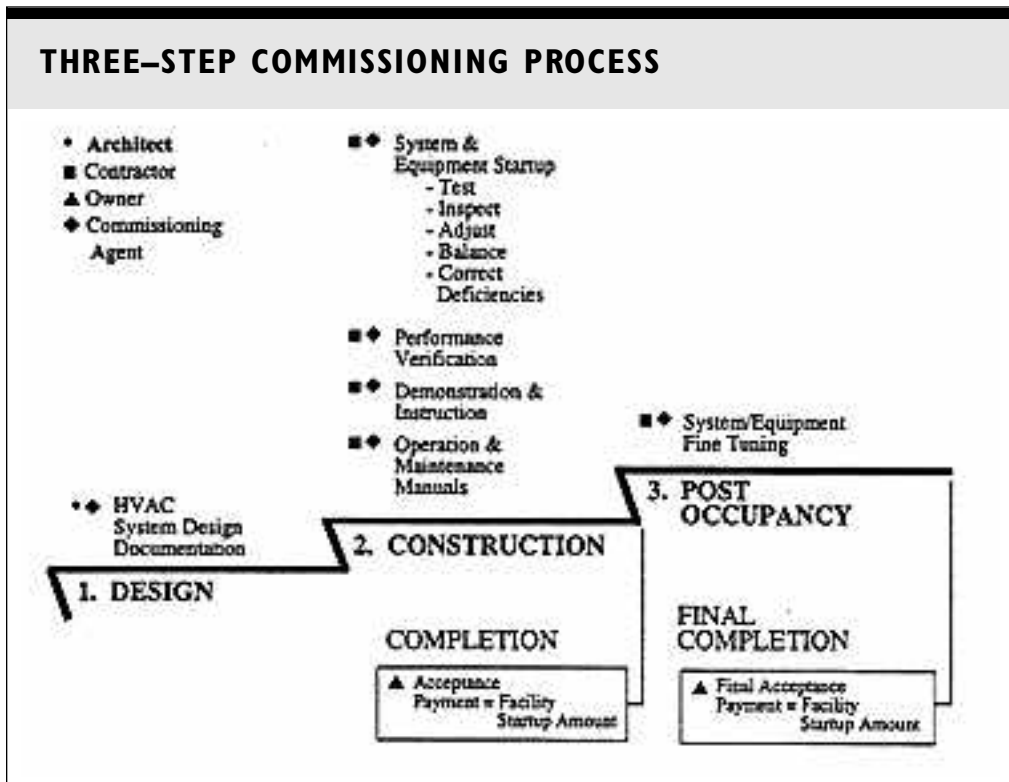


Figure 2

- **Develop a strategy to implement the building-commissioning process.**
The ASHRAE guidelines provide a good overall model. *Figure 2* illustrates a three-step commissioning process showing the suggested activities and responsibilities of team members during each step. Ensure that the commissioning strategy encompasses all of the necessary activities in each stage of the process.
- **Prepare the design documentation and design criteria for the HVAC system, including the following information:**
 - The HVAC system building-commissioning design documentation form, similar to the example shown in *Figure 3*;
 - The HVAC system design criteria; and
 - The HVAC system description.

HVAC BUILDING-COMMISSIONING DESIGN DOCUMENTATION

Room		Maximum Occupants		Equipment		Ventilation in CFM	
Number	Name	Projected	Code	Computers	Photocopy Machines	Total Air Flow	Minimum Outside Air

Figure 3

- **Use these HVAC system design documents to:**
 - Verify with the building owner or users the occupants’ anticipated building program requirements and their planned activities and equipment;
 - Verify the fire- and life-safety code requirements for the number of occupants; and
 - Verify with the mechanical engineer the ventilation requirements for the occupants and their equipment so the HVAC system is designed with sufficient capacity to provide outside air for the projected building population and the anticipated heat-producing equipment.
- **Have the design team and building operators review the documents to confirm that the building is properly designed for its intended uses.**
The building population and equipment should not be increased beyond the design limits for the HVAC system.
- **Prepare design documentation and design criteria for the other building systems to be commissioned according to the format used for the HVAC system.**
- **Prepare specifications to describe the commissioning process.**
The commissioning process should be described in the Division 1 sections of Construction Specification Institute (CSI) documents (see “Specifications,” Chapter 17, for additional information). The Division 1 sections should also refer the user to the appropriate technical sections for additional information about each system’s commissioning details.
- **Specify facility startup amount in the commissioning section of Division 1 specifications.**
The facility startup amount is the total dollar amount that the project sponsor allocates to commissioning in the project specifications and is released to the contractor at

the successful completion of each phase of the commissioning (*Figure 2*). This facility startup amount needs to be determined prior to construction commencement and should be allocated to the general contractor for coordination and to specific subcontractors for their commissioning work.

❑ **Ensure that the commissioning process is addressed in contract documents and construction meetings.**

Contract documents should accurately reflect the process agreed upon for building commissioning. The architect should also be asked to describe the commissioning process at any pre-bid or pre-construction conferences and at pre-commissioning meetings.

❑ **Form a commissioning team and designate a commissioning authority.**

The ASHRAE guidelines define the commissioning authority as the qualified person, company, or agency that will plan and carry out the overall commissioning process.⁷ There are many options as to who should be selected to serve this role, including the design professional, the contractor, the building owner, or a commissioning consultant/agent. It is often useful to form a commissioning team that works together to commission the building as illustrated in *Figure 4*. In this situation, the role of commissioning authority is divided among various members of the commissioning team, with specific members taking the lead in each phase of the project. Another approach is to consider hiring an independent commissioning agent to ensure that the commissioning is performed adequately.

Construction Phase

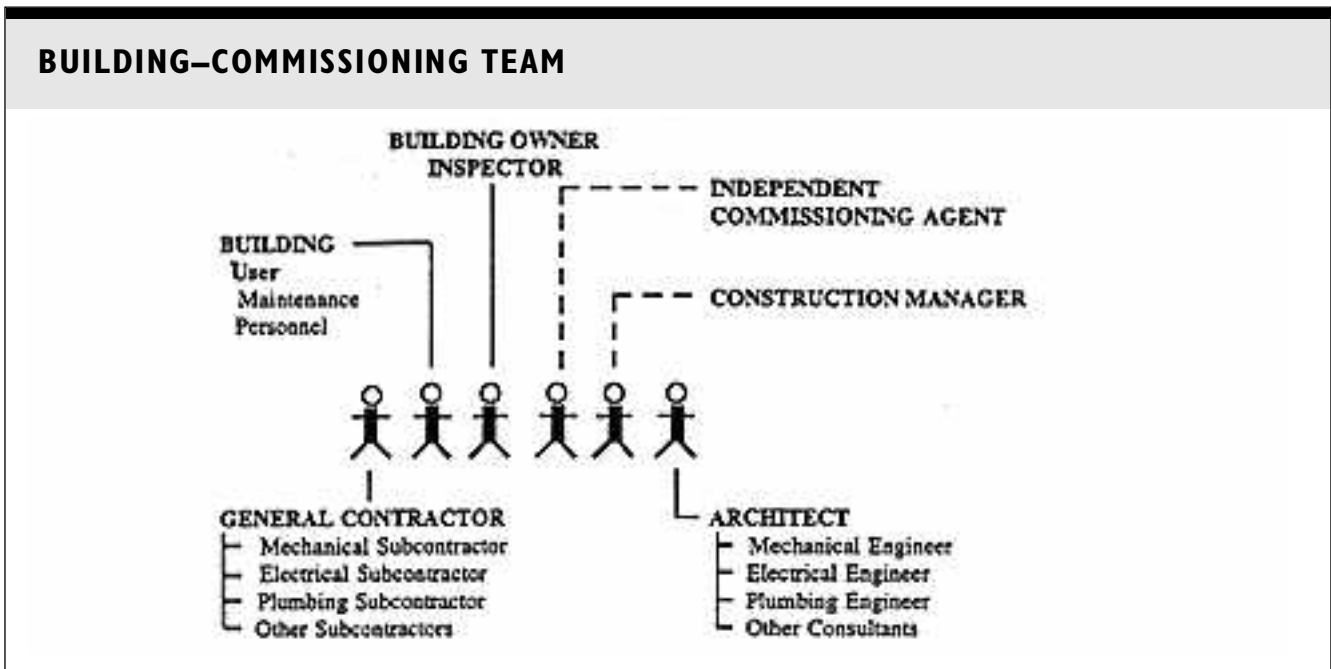
❑ **Involve the design team in monitoring the construction commissioning process.**

During the construction phase, the contractor plays the major role in performing the building commissioning. However, the design team should also be involved in monitoring the building-commissioning process. Since this is a relatively new process, “partnering” or team building may be required to ensure success.⁸ The benefit of partnering is that it establishes a forum for alternative dispute resolution so that building-equipment and system problems can be resolved quickly in “real time.”

❑ **Conduct pre-commissioning workshops and commissioning progress meetings.**

Workshops and progress meetings are useful in ensuring that all building-commissioning issues are properly addressed. Attendees should include members of the commissioning team.

Figure 4



❑ **Observe that construction is in accordance with the contract documents.**

The architect should monitor commissioning process, meetings, and workshops to ensure that this construction process is generally performed in accordance with contract documents. Ultimate responsibility for full-time observation rests with the owner's field representatives.

❑ **Perform systems and equipment startup.**

In this phase, the contractor should start the operation of building systems and equipment so they may be tested, inspected, adjusted, balanced, and corrected if necessary.

❑ **Demonstrate operations and conduct training.**

Training seminars and on-site "hands-on" training should be conducted for the building operators. The contractor should provide the systems and equipment operations and maintenance manuals.

❑ **Recommend acceptance of the work and payment of the facility startup amount.**

The architect and consulting engineers should review the work prior to acceptance.

❑ **Prepare the commissioning report.**

When the commissioning process is complete, the commissioning agent should issue a commissioning report to the owner, including the following information:

- Building description, including size, location, and use;
- Team members and responsibilities;
- The final project design documents and the commissioning plan and specification;
- A written and/or schematic description of each project system including architectural, mechanical, and electrical systems included in the project;
- A summary of system performances relative to the design intent;
- Completed pre-functional checklists;
- Completed functional checklists;
- All approval, non-compliance, and cost-tracking forms; and
- The manuals for each system, which should include the following information:
 - a. System design intent;
 - b. System description;
 - c. As-built drawing;
 - d. Specifications and approved submittals;
 - e. Emergency shutdown and operational procedures;
 - f. Test-and-balance and other testing reports;
 - g. Startup and verification checklists and reports;
 - h. Operations and maintenance manuals;
 - i. Material safety data sheets (MSDSs), and chemical disposal requirements; and
 - j. Training documents and programs.

Post Occupancy Phase

❑ **Conduct fine-tuning of building systems and equipment after one year.**

This phase of the commissioning activity should occur after the building is occupied and operating under normal and planned conditions for approximately 12 months. Fine-tuning is an extremely important part of the commissioning activity and provides the opportunity to solve any building problems identified through the owner's detailed surveys and environmental analysis. During the first 12 months, the building operators should record the conditions in the building and attempt to adjust the systems where needed. If they are unable to control the systems to sufficiently resolve malfunctions, the contractor should return to fine-tune the systems and equipment.

❑ **Recommission buildings throughout their life on a regular schedule, possibly every one to two years.**

Recommissioning is an opportunity to ensure that all systems and equipment are performing as intended and that the building occupants and activities conform to the HVAC system design documentation. (See Chapter 21, "Building Operations and Maintenance," for additional discussion.)

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