Mechanical Systems

OVERVIEW
The main purposes of mechanical systems are to provide thermal comfort and to maintain good indoor air quality (IAQ). These conditions are essential for a quality, high-performance building. Mechanical systems are also one of the largest energy consumers in buildings, and relatively small improvements in design or equipment selection can mean large long-term savings in energy expenditures over the life cycle of the system.

The choice and design of mechanical systems can affect many other high-performance goals as well. Water-cooled air conditioning equipment is generally more efficient than air-cooled equipment, but it increases water consumption and maintenance. Mechanical systems are also the major source of outside air ventilation in most buildings, making their operation and maintenance mission critical for IAQ. The acoustic environment of building spaces can be adversely affected by noise created by the movement of air through ducts and air diffusers, and from the operation of mechanical equipment. Proper design, installation, and operation of mechanical systems and controls minimizes these potential impacts.

INTEGRATED DESIGN
To achieve a high-performance design, it is very important to integrate the mechanical systems with the building envelope, lighting system, and other equipment. Integrated design creates opportunities for greater comfort, lower first costs, easier equipment maintenance, and lower operating costs. It is sometimes difficult to recognize integrated design opportunities. Electrical, mechanical, and envelope systems are designed and specified by different disciplines and communications between the disciplines is limited. It is critically important to understand and define the project goals during pre-design and to establish a process of effective communication between design disciplines. It is equally important that the mechanical system designer participate in making early architectural design decisions. An extra investment in up-front design can easily pay for itself in improved efficiency and may also lead to reduced construction cost.

The interactions between systems may be obvious or they may be subtle. Some of the ways in which high performance can be achieved through integrated design are:

- Selection of light-colored finishes for systems furniture can reduce the lighting power required to achieve a certain illuminance level by as much as 25%, resulting in reduced cooling load and downsized air systems.
- Under-floor air distribution allows flexibility for renovations and access for future power and communication needs. Under-floor systems require significant architectural coordination.
- Attention to the radiant temperature of surfaces through careful envelope design reduces heating and cooling energy requirements. This is especially true of windows, where an extra investment in window performance may eliminate the need for a separate perimeter heating system in some cases.
- Using a central heating and chilled water plant opens opportunities for solar thermal or geo-exchange sources for heating or cooling and permits consideration of thermal energy storage for managing peak electric demand.
- Integration of mechanical system controls and lighting occupancy sensor controls can reduce operating costs for both systems.
- Careful attention to shading, the locations of windows, glazing types, placement and type of landscaping, roof colors, building thermal mass, and enhanced natural ventilation may eliminate the need for cooling for some buildings in many parts of the United States.
- Natural ventilation can eliminate the need for ductwork, allowing higher ceilings and more...
opportunities for daylighting.

- Supply air temperature affects the airflow required for cooling or heating which in turn affects duct size and the space required for ducts. Advantages are smaller ducts, potentially higher ceilings or reduced floor-to-floor height, and better moisture control. Disadvantages are a need for more duct insulation, less efficient cooling, and reduced economizer use.

A mechanical system maintains comfort by offsetting heat losses and gains from the building envelope, occupants, lights, and equipment. Most mechanical systems are unable to provide heating and cooling to the exact local sources of the losses and gains, so local temperatures in the space can become too hot or too cold and comfort issues arise. Better building envelope thermal performance reduces the hot spots and cold spots and enables the mechanical system to provide more uniform space conditions. Comfort can be further improved by separating sedentary spaces from the building perimeter by “buffer” spaces such as circulation zones, which have less stringent comfort requirements. A buffer space strategy is an excellent example of an integrated design challenge because its implementation requires creative space planning to maintain efficient use of floor space and to capture daylighting benefits. By reducing building envelope loads and locating spaces near the building perimeter that have less stringent comfort requirements, the mechanical system can be downsized and also significantly simplified, resulting in cost savings that might not be achievable without attention to space planning and envelope design.

THERMAL COMFORT

Thermal comfort is affected by air temperature, humidity, air velocity, and mean radiant temperature (MRT). However, non-environmental factors such as clothing, gender, age, and metabolic activity also affect thermal comfort. It is important to understand that comfort is not an absolute condition, but a set of conditions (temperature, humidity, air speed, etc.) that a majority of persons find acceptable. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) comfort standard (Standard 55) is based on satisfying four out of five, or 80%, of the occupants.

Air temperature or dry-bulb temperature is measured with a normal thermometer, and most people are comfortable between 70–76ºF. However, an individual’s preferred temperature is higher in the summer and lower in the winter, mostly because of differences between summer and winter clothing.

The relative humidity range for human comfort is 20–60%. The moisture content of air can also be expressed as the wet-bulb temperature, humidity ratio, or dewpoint temperature. When the human body is overheated, perspiration forms on the surface of the skin, and as the moisture evaporates the body is cooled. Relative humidity levels above 60% slow evaporation from the skin resulting in less cooling and more discomfort, especially at elevated metabolic rates and higher temperatures. People are more tolerant of higher temperatures when relative humidity levels are low. For activities with higher metabolic rates than deskwork, relative humidity levels below 50% are absolutely necessary to maintain comfort. For some climates, these humidity requirements can be satisfied all or part of the time using natural ventilation, but in relatively humid climates, mechanical cooling will be required. Discomfort calls to building operation staff are typically more related to excessive humidity than they are to higher dry-bulb temperatures.

Relative humidity levels above 70% can result in the growth of mold and mildew spores. Even after humidity levels have been reduced below this level, mold and mildew growth may continue abated only in proportion to the reduction in humidity. Mold and mildew are not killed until the relative humidity is reduced below 30% for an extended period of time, or the growth is treated with biocide. See the Building Envelope chapter for more information on mold.

1 MRT is the temperature of an imaginary enclosure where the radiant heat transfer from a human body equals the radiant heat transfer to the actual non-uniform temperature surfaces of an enclosure.

2 Women generally prefer temperatures about 1° warmer.

3 Persons over 40 generally prefer temperatures about 1° warmer.
Ceiling fans, circulation fans, or operable windows can provide air movement, and such air movement up to a limit of about 200 ft/minute increases the upper temperature limit of comfort by about two degrees. Air speeds higher than about 200 ft/minute should be avoided because they can create drafts and be annoying (see Table M-1). Also, at higher levels of relative humidity, the evaporative effect of increased air speed is reduced, resulting in a lesser improvement in comfort.

<table>
<thead>
<tr>
<th>Air Velocity</th>
<th>Probable Impact</th>
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<tbody>
<tr>
<td>Up to 50 ft/minute</td>
<td>Unnoticed.</td>
</tr>
<tr>
<td>50 to 100 ft/minute</td>
<td>Pleasant.</td>
</tr>
<tr>
<td>100 to 200 ft/minute</td>
<td>Generally pleasant, but causes a constant awareness of air movement.</td>
</tr>
<tr>
<td>200 to 300 ft/minute</td>
<td>From slightly drafty to annoyingly drafty.</td>
</tr>
<tr>
<td>Above 300 ft/minute</td>
<td>Requires corrective measures if work and health are to be kept in high efficiency.</td>
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The temperature of the surfaces surrounding a person (walls, ceiling, floor, and windows) affect the MRT, and MRT is especially important on hot and cold days. Caves have a low MRT, which makes them comfortable even when the air temperature is high. Conversely, rooms with heated floors have a high MRT and are comfortable, although the air temperature may be cooler.

Research has shown that occupants in naturally ventilated buildings are comfortable for a wider range of thermal conditions than in buildings that have continuous mechanical cooling. Part of the difference in comfort expectations is due to behavioral adaptations: occupants in naturally ventilated buildings wear appropriate clothing and open windows to adjust air speeds. However, some of the difference is due to physiological factors. The human body’s thermal expectations actually change through the course of a year, possibly because of a combination of higher levels of perceived control (occupants can open and close windows) and a greater diversity of thermal experiences in the building. In many climates, maintaining a narrowly defined, constant temperature range is unnecessary and expensive. However, in humid climates, the physical rate of evaporation of skin perspiration may limit the range of allowable temperature excursions.

Using an adaptive model of thermal comfort allows buildings to be designed and operated to both optimize thermal comfort and reduce energy use (see Figure M-1). ASHRAE *Standard 55-2004* has more information about the adaptive model of thermal comfort.
POTENTIAL FOR NATURAL VENTILATION
Natural ventilation is an effective and energy-efficient way to provide outside air for ventilation and to provide cooling in many climates. While it may not totally replace air conditioning and mechanical ventilation in many climates, it can reduce the need for air conditioning during certain times of the spring and fall. In the winter, the challenge is to temper the cold ventilation air as it is brought into the building. In the summer, humidity is a challenge in the eastern United States (climate region A, see Figure M-2).

In most climates, natural ventilation is a useful strategy only during the spring and fall. When any significant number of operable windows are used, the building as a system must be carefully designed to minimize glare and heat gain from the sun shining in through the glass and to maintain a safe and secure facility while still allowing air to enter and escape. Use of ventilation in the off-hours must be approached very carefully as the humidity load from unconditioned nighttime air can lead to moisture problems in some climates and can result in additional energy use to remove the moisture. This is especially important if some areas of the facility are mechanically cooled or have exposed cold surfaces that might be below the dewpoint of the nighttime air.

Another limitation to the effectiveness of natural ventilation is building shape and the adjacency of occupants to the window wall. For larger floor plate buildings with workstations inboard of the perimeter zone, providing adequate ventilation and cooling through natural ventilation to these inboard areas may result in discomfort or inconvenience in the perimeter zones through which ventilation must flow. In dense urban areas, dirty outside air may present problems. Finally, the transition from operation with natural ventilation to operation with mechanical ventilation for cooling or heating must be rigorously controlled, or the naturally ventilated building may use far more energy than a sealed building. The issue is not necessarily that the open windows interfere with the pressure balance of the mechanical system, but that the open windows admit excessive outside air that must be conditioned to achieve comfort in the space.

ENVIRONMENTAL CONSIDERATIONS
The mechanical system affects energy usage, acoustic comfort, the life of building materials, and indoor environmental quality. Proper mechanical performance enhances worker productivity and occupant health. However, poor design or installation detracts from productivity and can contribute to illness. Other environmental considerations are relevant, such as efficient use of materials, conservation of water, use
of materials that can be readily recycled, and avoidance of ozone-depleting refrigerants. A well-designed building with integrated building systems will significantly reduce the requirements for hot and cold air distribution. High performance buildings can result in energy savings as well as simpler and smaller equipment.4

Mechanical strategies and considerations for improved environmental performance include:

- Specifying low-toxicity (water-based) mastic to seal ducts, or in cases where round ducts are used, specify internal gasketed duct joint systems so that duct sealants are not needed (this is good practice, though not required).
- Selecting durable long-life equipment with hinged access doors that allow for equipment service and that can be easily refurbished.
- Eliminating equipment that uses chlorofluorocarbon (CFC) refrigerants and carefully considering equipment that use hydrochlorofluorocarbon (HCFC) refrigerants.5
- Evaluating the environmental trade-offs between energy-efficient evaporative heat rejection and water consumption. Alternatives to potable water usage for evaporative heat rejection include ground and groundwater heat sinks, surface water heat sinks, and alternative sources of evaporative makeup water. The environmental impact of each alternative should be carefully weighed.
- Recycling metal components of mechanical systems. Suggest recycling equipment at the end of its life cycle. In addition, metal components of mechanical equipment typically include recycled content, although data are not readily available as to the amount.
- Selecting environmentally friendly materials using benign materials (i.e., fasteners instead of solvent glues). Considering renewable energy sources (i.e., solar hot water systems).
- Providing easy access for cleaning and repair, enhancing long-term ability to provide good IAQ and thermal comfort.


5 Given the high efficiency purge systems and rigorous refrigerant management protocols currently in place, the inherent energy efficiency of R-123 over R-134 may represent a significant environmental benefit.
In addition to general energy simulation programs, many useful tools for optimizing mechanical design exist. Heating and cooling load calculation programs are widely available from equipment manufacturers and commercial vendors. Other programs integrate with CAD software and aid the design of piping and...
duct systems. Many of these tools also have cost estimating capabilities, which are very helpful in design optimization and budget review.

Computational fluid dynamics (CFD) software can help in studies of natural and mechanical ventilation and is very useful in creative integration of mechanical and architectural design. CFD analysis is expensive and requires special expertise that many engineering offices do not have. The procedure is very powerful, however, and should be considered for projects that are incorporating unconventional air diffusion strategies, especially those that rely upon thermal stratification and buoyant flow for comfort maintenance. Examples of such strategies include radiant cooling, displacement ventilation, and convectively driven natural ventilation. Some manufacturers of air distribution equipment offer CFD analysis as a service.

**CONTROLS**

Good controls are absolutely essential to achieving comfort and efficient operation. Automatic control of multiple pieces of mechanical equipment and other systems may be integrated using computerized systems known variously as direct digital controls (DDC), energy management systems (EMS), energy management and control systems (EMCS), building management systems (BMS), building automation systems (BAS), etc. The added expense and complexity may be justified by the equipment optimization and increased convenience of maintenance possible with such a system.