CHAPTER 1

HVAC SYSTEM ANALYSIS AND SELECTION

AN HVAC SYSTEM maintains desired environmental conditions in a space. In almost every application, a myriad of options are available to the design engineer to satisfy this basic goal. In the selection and combination of these options, the design engineer must consider all criteria defined here to achieve the functional requirements associated with the goal.

HVAC systems are categorized by the method used to control heating, ventilation, and air conditioning in the conditioned area. This chapter addresses the procedures associated with selecting the appropriate system for a given application. It also describes and defines the design concepts and characteristics of basic HVAC systems. Chapters 2 through 5 of this volume describe specific systems and their attributes, based on their heating and cooling medium and commonly used variations.

SELECTING A SYSTEM

The design engineer is responsible for considering various systems and recommending one or two that will satisfy the goal and perform as desired. It is imperative that the design engineer and the owner collaborate on identifying and rating the criteria associated with the design goal. Some criteria that may be considered are

- Temperature, humidity, and space pressure requirements
- Capacity requirements
- Redundancy
- Spatial requirements
- First cost
- Operating cost
- Maintenance cost
- Reliability
- Flexibility
- Life cycle analysis

Because these factors are interrelated, the owner and design engineer must consider how these criteria affect each other. The relative importance of factors, such as these, differs with different owners and often changes from one project to another for the same owner. For example, typical concerns of owners include first cost compared to operating cost, the extent and frequency of maintenance and whether that maintenance requires entering the occupied space, the expected frequency of failure of a system, the impact of a failure, and the time required to correct the failure. Each of these concerns has a different priority, depending on the owner's goals.

Additional Goals

In addition to the primary goal to provide the desired environment, the design engineer must be aware of and account for other goals the owner may require. These goals may include

- Supporting a process, such as the operation of computer equipment
- Promoting a germ-free environment
- Increasing sales
- Increasing net rental income
- Increasing the salability of a property

The owner can only make appropriate value judgments if the design engineer provides complete information on the advantages and disadvantages of each option. Just as the owner does not usually know the relative advantages and disadvantages of different systems, the design engineer rarely knows all the owner's financial and functional goals. Hence, the owner must be involved in the selection of a system.

System Constraints

Once the goal criteria and additional goal options are listed, many constraints must be determined and documented. These constraints may include

- Performance limitations (i.e., temperature, humidity, and space pressure)
- Available capacity
- Available space
- Availability utility source
- Building architecture
- Construction budget

Few projects allow detailed quantitative evaluation of all alternatives. Common sense, historical data, and subjective experience can be used to narrow choices to one or two potential systems.

Heating and air conditioning loads often contribute to the constraints, narrowing the choice to systems that will fit in the available space and be compatible with the building architecture. Chapter 29 of the *ASHRAE Handbook—Fundamentals* describes methods used to determine the size and characteristics of the heating and air conditioning loads. By establishing the capacity requirement the size of equipment can be determined, and the choice may be narrowed to those systems that work well on projects within a size range.

Loads vary over time due to the time of day/night, changes in the weather, occupancy, activities, and solar exposure. Each space with a different use and/or exposure may require a different control zone to maintain space comfort. Some areas with special requirements may need individual systems. The extent of zoning, the degree of control required in each zone, and the space required for individual zones also narrow the system choices.

No matter how efficiently a particular system operates or how economical it is to install, it can only be considered if it (1) maintains the desired building space environment within an acceptable tolerance under all conditions and occupant activities and (2) physically fits into the building without being objectionable.

Cooling and humidity control are often the basis of sizing HVAC components and subsystems, but the system may also be

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determined based on the ventilation criteria. For example, if large quantities of outside air are required for ventilation or to replace air exhausted from the building, only systems that transport large air volumes need to be considered.

Effective delivery of heat to an area may be an equally important factor in the selection. A distribution system that offers high efficiency and comfort for cooling may be a poor choice for heating. This performance compromise may be small for one application in one climate, but may be unacceptable in another that has more stringent heating requirements.

HVAC systems and the associated distribution systems often **occupy a significant amount of space**. Major components may also require special support from the structure. The size and appearance of terminal devices (i.e., diffusers, fan-coil units, radiant panels, etc.) have an affect on the architectural design because they are visible in the occupied space.

Other architectural factors that limit the selection of some systems include

- Acceptable noise levels in the occupied space
- Space available to house equipment and its location relative to the occupied space
- Space available for horizontal and/or vertical distribution pipes and ducts
- Acceptability of components visible in the occupied space.

Construction budget constraints can also influence the choice of HVAC systems. Based on historical data, some systems may be economically out of reach for an owner's building program.

Narrowing the Choices

Chapters 2 through 5 cover building air distribution, in-room terminal systems, central cooling and heating, and decentralized cooling and heating. Each chapter briefly summarizes the positive and negative features of various systems. One or two systems that best satisfy the project goal can usually be identified by comparing the criteria, other factors and constraints, and their relative importance. In making subjective choices, notes should be kept on all systems considered and the reasons for eliminating those that are unacceptable.

Each selection may require combining a primary system with a secondary system (or distribution system). The **primary system** converts energy from fuel or electricity into a heating and/or cooling media. The **secondary system** delivers heating, ventilation, and/or cooling to the occupied space. The two systems, to a great extent, are independent, so several secondary systems may work with a particular primary system. In some cases, however, only one secondary system may be suitable for a particular primary system.

Once subjective analysis has identified one or two HVAC systems (sometimes only one choice may remain), detailed quantitative evaluations must be made. All systems considered should provide satisfactory performance to meet the owner's essential goals. The design engineer should provide the owner with specific data on each system to make an informed choice. The following chapters in the ASHRAE Handbooks should be consulted to help narrow the choices:

- Chapter 8, *ASHRAE Handbook—Fundamentals* covers physiological principles, comfort, and health.
- Chapter 31, *ASHRAE Handbook—Fundamentals* covers methods for estimating annual energy costs.
- Chapter 35, *ASHRAE Handbook—Applications* covers methods for energy management.
- Chapter 36, *ASHRAE Handbook—Applications* covers owning and operating cost.
- Chapter 38, *ASHRAE Handbook—Applications* covers mechanical maintenance.
- Chapter 47, *ASHRAE Handbook—Applications* covers sound and vibration control.

Selection Report

As the last step of selection, the design engineer should prepare a summary report that addresses the following:

- The goal
- Criteria for selection
- Important factors
- Other goals

A brief outline of each of the final selections should be provided. In addition, those HVAC systems deemed inappropriate should be noted as having been considered but not applicable to meet the owner's primary HVAC goal.

Table 1 Sample HVAC System Selection Matrix (0 to 10 Score)

Goal: Furnish and install an HVAC system that provides moderate space temperature control with minimum humidity control at an operating budget of 70,000 Btu/h per square foot per year				
Categories	**System #1**	**System #2**	**System #3**	**Remarks**
1. Criteria for Selection: • 75°F space temperature with ±3°F control during occupied cycle • 20% relative humidity with ± 5% rh control during heating season. • First cost • Equipment life cycle				
2. Important Factors: • First class office space stature • Individual tenant utility metering				
3. Other Goals: • Engineered smoke control system • ASHRAE *Standard* 62 ventilation rates • Direct digital control building automation				
4. System Constraints: • No equipment on the first floor • No exterior louvers below the perimeter windows				
5. Other Constraints: • No perimeter finned tube radiation				
TOTAL SCORE				

The report should include an HVAC system selection matrix that identifies the one or two suggested HVAC system (primary and secondary when applicable) selections, system constraints, and other constraints. In completing this matrix assessment, the engineer should have the owner's input to the analysis. This input can also be applied as weighted multipliers.

Many grading methods are used to complete an analytical matrix analysis. Probably the simplest grading method is to rate each item Excellent/Very Good/Good/Fair/Poor. A numerical rating system such as 0 to 10, with 10 equal to Excellent and 0 equal to Poor, can provide a quantitative result. The HVAC system with the highest numerical value then becomes the recommended HVAC system to accomplish the goal.

The system selection report should include a summary that provides an overview followed by a more detailed account of the HVAC system analysis and system selection. This summary should highlight the key points and findings that led to the recommendation(s). The analysis should refer to the system selection matrix (such as in Table 1) and the reasons for scoring.

A more detailed analysis, beginning with the owner's goal, should immediately following the summary. With each HVAC system considered, the design engineer should note the criteria associated with each selection. Issues such as close temperature and humidity control may eliminate some HVAC systems from being considered. System constraints and other constraints, noted with each analysis, should continue to eliminate HVAC systems. Advantages and disadvantages of each system should be noted with the scoring from the HVAC system selection matrix. This process should reduce the HVAC selection to one or two optimum choices to present to the owner. Examples of installations for other owners should be included with this report to endorse the design engineer's final recommendation.This third party endorsement allows the owner to inquire about the success of these other HVAC systems.

HVAC SYSTEMS AND EQUIPMENT

HVAC systems may be central or decentralized. In addressing the primary equipment location, the design engineer may locate this equipment in a **central** plant (either inside or outside the building) and distribute the air and/or water for HVAC needs from this plant. The other option is to **decentralize** the equipment, with the primary equipment located throughout the building, on the building, or adjacent to the building.

Central System Features

Some of the criteria associated with this concept are as follows:

Temperature, humidity, and space pressure requirements. A central system may be able to fulfill any or all of these design parameters.

Capacity requirements. A central system usually allows the design engineer to consider HVAC diversity factors that reduce the installed equipment capacity. In turn, this offers some attractive first cost and operating cost benefits.

Redundancy. A central system can accommodate standby equipment of equal size or of a preferred size that decentralized configurations may have trouble accommodating.

Spatial requirements. The equipment room for a central system is normally located outside the conditioned area—in a basement, penthouse, service area, or adjacent to or remote from the building. A disadvantage with this approach may be the additional cost to furnish and install secondary equipment for the air and/or water distribution. A second consideration is the access and physical constraints throughout the building to furnish and install this secondary distribution network of ducts and/or pipes.

First cost. A central system may not be the least costly when compared to decentralized HVAC systems. Historically, central system equipment has a longer equipment service life to compensate for this shortcoming. Thus, a life cycle cost analysis is very important when evaluating central versus decentralized systems.

Operating cost. A central system usually has the advantage of larger, more energy efficient primary equipment when compared to decentralized system equipment.

Maintenance cost. The equipment room for a central system provides the benefit of maintaining its HVAC equipment away from the occupants in an appropriate service work environment. Access to the building occupant workspace is not required, thus eliminating disruption to the space environment, product, or process. Another advantage may be that because of its larger capacity, there is less HVAC equipment to service.

Reliability. Central system equipment can be an attractive benefit when considering its long service life.

Flexibility. Redundancy can be a benefit when selecting standby equipment that provides an alternative source of HVAC or backup.

Among the largest central systems are those HVAC plants serving groups of large buildings. These plants provide improved diversity and generally operate more efficiently with lower maintenance costs than individual central plants. The economics of these larger central systems require extensive analysis. The utility analysis considers multiple fuels and may also include gas and steam turbine-driven equipment. Multiple types of primary equipment using multiple fuels and types of HVAC generating equipment (i.e., centrifugal and absorption chillers) may be installed in combination in one plant. Chapter 12, Chapter 13, and Chapter 14 provide design details for central plants.

Decentralized System Features

Some of the criteria associated with this concept are as follows:

Temperature, humidity, and space pressure requirements. A decentralized system may be able to fulfill any or all of these design parameters.

Capacity requirements. A decentralized system usually requires each piece of equipment to be sized for the maximum capacity. Depending on the type and location of the equipment, decentralized systems cannot take as much benefit of equipment sizing diversity when compared to the central system diversity factor potential.

Redundancy. A decentralized system may not have the benefit of backup or standby equipment. This limitation may need review.

Space requirements. A decentralized system may or may not have an equipment room. Due to the space restrictions imposed on the design engineer or architect, equipment may be located on the roof and/or the ground adjacent to the building.

First cost. A decentralized system probably has the best first cost benefit. This feature can be enhanced by phasing in the purchase of decentralized equipment on an as-needed basis (i.e., purchasing equipment as the building is being leased/occupied).

Operating cost. A decentralized system can emphasize this as a benefit when strategically starting and stopping multiple pieces of equipment. When comparing energy consumption based on peak energy draw, decentralized equipment may not be as attractive when compared to larger, more energy efficient central equipment.

Maintenance cost. A decentralized system can emphasize this as a benefit when equipment is conveniently located and the equipment size and associated components (i.e., filters) are standardized. When equipment is located on a roof, maintainability may be difficult because it is difficult to access during bad weather.

Reliability. A decentralized system historically has reliable equipment, although the estimated equipment service life may be less than that of centralized equipment.

Flexibility. A decentralized system may be very flexible because it may be placed in numerous locations.

Primary Equipment

The type of central and decentralized equipment selected for large buildings depends on a well-organized HVAC analysis and selection report. The choice of primary equipment and components depends on factors presented in the selection report with such factors as those presented in the section on Selecting a System. Primary HVAC equipment includes heating equipment, air and water delivery equipment, and refrigeration equipment.

Many HVAC designs recover internal heat from lights, people, and equipment to reduce the size of the heating plant. In large buildings with core areas that require cooling while perimeter areas require heating, one of several heat reclaim systems can heat the perimeter to save energy. Chapter 8 describes some heat recovery arrangements, Chapter 33 describes solar energy equipment, and Chapter 44 introduces air-to-air energy recovery. In the *ASHRAE Handbook—Applications*, Chapter 35 covers energy management and Chapter 40 covers building energy monitoring.

The search for energy savings has extended to **cogeneration** or total energy systems, in which on-site power generation has been added to the HVAC project. The economics of this function is determined by gas and electric rate differentials and by the ratio of electric to heating demands for the project. In these systems, waste heat from generators can be transferred to the HVAC equipment (i.e., to drive the turbines of centrifugal compressors, to serve an absorption chiller, etc.). Chapter 7 covers cogeneration or total energy systems.

Thermal storage is another energy savings concept, which provides the possibility of off-peak generation of air conditioning with chilled water or ice. Thermal storage of hot water can be used in heating. Many electric utilities impose severe charges for peak summer power use or offer incentives for off-peak use. The storage capacity installed to level the summer load may also be available for use in winter, thus making heat reclaim a viable option. Chapter 34 of the *ASHRAE Handbook—Applications* has more information on thermal storage.

With ice storage, colder supply air can be provided than that available from a conventional air conditioning. This colder air allows the use of smaller fans and ducts, which reduces first cost and operating cost that can offset the energy cost required to make ice. Similarly, the greater water temperature difference from hot water thermal storage allows smaller pumps and pipe to be used.

Heating Equipment

Steam boilers or hot water boilers are the primary means of heating a space. These boilers are (1) used both for heating and process heating; (2) manufactured to produce high or low pressure; and (3) fired with coal, oil, electricity, gas, and sometimes, waste material. Low-pressure boilers are rated for a working pressure of either 15 or 30 psig for steam and 160 psig for water, with a temperature limit of 250°F. Package boilers, with all components and controls assembled as a unit, are available. Electrode or resistance-type electric boilers that generate either steam or hot water are also available. Chapter 27 has further information.

Where steam or hot water is supplied from a central plant, as on university campuses and in downtown areas of large cities, the utility service entering the building must conform to the utility's standards. The utility provider should be contacted at the system analysis and selection phase of the project to determine availability, cost, and the specific requirements of the service.

When the primary heating equipment is selected, the fuels considered must ensure maximum efficiency. Chapter 26 discusses the design, selection, and operation of the burners for different types of primary heating equipment. Chapter 18 of the *ASHRAE Handbook—Fundamentals* describes types of fuel, fuel properties, and proper combustion factors.

Air Delivery Equipment

Primary air delivery equipment for HVAC systems are classified as packaged equipment, manufactured and custom manufactured equipment, or field fabricated equipment. Most ventilation equipment for large systems use centrifugal or axial fans; however, plug or plenum fans are becoming more popular. Centrifugal fans are frequently used in packaged and manufactured HVAC equipment. Axial fans are more often part of a custom unit or a field-fabricated unit. Both types of fans can be used as industrial process and high-pressure blowers. Chapter 18 describes fans, and Chapters 16 through 25 provide information about ventilation components.

Refrigeration Equipment

The section on Refrigeration Equipment in Chapter 4 summarizes the primary refrigeration equipment for HVAC systems designed to maintain desired environmental conditions in a space.

SPACE REQUIREMENTS

In the initial phase of a building's design, the engineer seldom has sufficient information to render the HVAC design. As noted in the section on Space Requirements in Chapter 4, the final design is usually a compromise between what the engineer recommends and what the architect can accommodate. At other times, final design and space requirements may be dictated by the building owner who may have a preference for a central or decentralized system. The following paragraphs discuss some of these requirements.

Equipment Rooms

The total mechanical and electrical space requirements range between 4 and 9% of the gross building area with most buildings falling within the 6 to 9% range. These ranges include space for HVAC, electrical, plumbing, and fire protection equipment. These percentages also include vertical shaft space for mechanical and electrical equipment.

Most facilities should be centrally located to (1) minimize long duct, pipe, and conduit runs and sizes; (2) simplify shaft layouts; and (3) centralize maintenance and operation. A central location also reduces pump and fan motor power, which reduces building operating costs. But, for many reasons, not all the mechanical and electrical facilities can be centrally located in the building. In any case, the equipment should be kept together whenever possible to minimize space requirements, centralize maintenance and operation, and simplify the electrical system.

Equipment rooms generally require clear ceiling height ranging from 10 to 18 ft, depending on equipment sizes and the complexity of air and/or water distribution.

The main electrical transformer and switchgear rooms should be located as close to the incoming electrical service as practical. If there is an emergency generator, it should be located considering (1) proximity to emergency electrical loads and sources of combustion and cooling air and fuel, (2) ease of properly venting exhaust gases to the outdoors, and (3) provisions for noise control.

HVAC Facilities

The heating equipment room houses the boiler(s) and may also house a boiler feed unit, chemical treatment equipment, pumps, heat exchangers, pressure-reducing equipment, control air compressors, and miscellaneous equipment. The refrigeration equipment room houses the chiller(s) and may also house chilled water and condenser water pumps, heat exchangers, air-conditioning equipment, control air compressors, and miscellaneous equipment. The design of these rooms needs to consider (1) the size and weight of the equipment; (2) installation and replacement when locating and arranging the room to accept this large equipment; and (3) applicable regulations relative to combustion air and ventilation air criteria.

In addition, ASHRAE *Standard* 15, Safety Code for Mechanical Refrigeration should be consulted for special equipment room requirements.

Most air-conditioned buildings require a cooling tower or condenser unit. If the cooling tower or air-cooled or water-cooled condenser is located on the ground, it should be at least 100 ft away from the building (1) to reduce tower noise in the building, (2) to keep discharge air and moisture carry-over from fogging the building's windows and discoloring the facade of the building, and (3) to keep discharge air and moisture carry-over from contaminating outdoor air being introduced into the building. Cooling towers should be kept the same distance from parking lots to avoid staining car finishes with water treatment chemicals. Chapter 35 and Chapter 36 have further information on this equipment.

It is often economical to locate the heating plant and/or refrigeration plant at an intermediate floor or on the roof. The electrical service and structural costs are higher, but these may be offset by reduced costs for heating piping, condenser and chilled water piping, energy consumption, and a chimney through the building. Also, the initial cost of equipment may be less because the operating pressure is lower.

Applicable regulations relative to both gas and fuel oil systems must be followed. Gas fuel may be more desirable than fuel oil. Fuel oil storage has specific environmental and safety concerns. In addition, the cost of oil leak detection and prevention may be substantial. Oil pumping presents added design and operating problems.

Energy recovery systems can reduce the size of the heating plant and/or refrigeration plant. Well-insulated buildings and electric and gas utility rate structures may encourage the design engineer to consider several energy conservation concepts such as limiting demand, free cooling and thermal storage.

Fan Rooms

The fan rooms house the HVAC fan equipment and may include other miscellaneous equipment. The room must have space for removal of the fan shaft and coil. Installation, replacement, and maintenance of this equipment should be considered when locating and arranging the room.

Fan rooms may be placed in a basement that has an airway for intake of outdoor air. In this situation the placement of air intake louver(s) is a concern because of debris from leaves and snow may fill the area. Also, if parking areas are close to the building, the quality of outdoor air may be compromised.

Fan rooms on the second floor and above, have easier access for outdoor air, exhaust air, and equipment replacement. The number of fan rooms required depends largely on the total floor area and whether the HVAC system is centralized or decentralized. Buildings with large floor areas may have multiple decentralized fan rooms on each floor or a large central fan unit serving the entire area. High-rise buildings may also opt for decentralized fan rooms for each floor; or they may have a more central concept with one fan room serving the lower 10 to 20 floors, one serving the middle floors of the building, and one at the roof serving the top floors.

Life safety is a very important factor in fan room location. Chapter 52 of the *ASHRAE Handbook—Applications* discusses fire and smoke management. In addition, state and local codes have additional fire and smoke detection and damper criteria.

Vertical Shafts

Vertical shafts provide space for air distribution and water and steam (pipe) distribution. Air distribution includes HVAC supply air, return air, and exhaust air ductwork. If the shaft is used as a return air plenum, close coordination with the architect is necessary to insure that the shaft is airtight. Pipe distribution includes hot water, chilled water, condenser water, and steam supply and condensate return. Other mechanical and electrical distribution found in vertical shafts are electric conduits/closets, telephone cabling/closets, plumbing piping, fire protection piping, pneumatic tubes, and conveyers.

Vertical shafts should be clear of stairs and elevators on at least two sides to permit access to ducts, pipes, and conduit that enter and exit the shaft while allowing maximum headroom at the ceiling. In general, duct shafts having an aspect ratio of 2:1 to 4:1 are easier to develop than large square shafts. The rectangular shape also makes it easier to go from the equipment in the fan rooms to the shafts.

In multistory buildings a vertical distribution system with minimal horizontal branch ductwork is desirable because it is (1) usually less costly; (2) easier to balance; (3) creates less conflict with pipes, beams, and lights; and (4) enables the architect to design lower floor-to-floor heights. These advantages also hold for vertical water and steam pipe distribution systems.

The number of shafts is a function of building size and shape. In larger buildings, it is usually more economical in cost and space to have several small shafts rather than one large shaft. Separate HVAC supply air, return air, and exhaust air duct shafts may be desired to reduce the number of duct crossovers. The same can be said for steam supply and condensate return pipe shafts because the pipe must be pitched in the direction of flow. From 10% to 15% additional shaft space should be allowed for future expansion and modifications. This additional space may also reduce the initial installation cost.

Equipment Access

Properly designed mechanical and electrical equipment rooms must allow for the movement of large, heavy equipment in, out, and through the building. Equipment replacement and maintenance can be very costly if access is not planned properly.

Because systems vary greatly, it is difficult to estimate space requirements for refrigeration and boiler rooms without making block layouts of the system selected. Block layouts allow the engineer to develop the most efficient arrangement of the equipment with adequate access and serviceability. Block layouts can also be used in preliminary discussions with the owner and architect. Only then can the engineer obtain verification of the estimates and provide a workable and economical design.

AIR DISTRIBUTION

Ductwork should deliver conditioned air to an area as directly, quietly, and economically as possible. Structural features of the building generally require some compromise and often limit the depth of the space available for ducts. Chapter 9 discusses air distribution design for small heating and cooling systems. Chapter 34 of the *ASHRAE Handbook—Fundamentals* discusses space air distribution and duct design.

The designer must coordinate duct design with the structure as well as other mechanical, electrical, and communication systems. In commercially developed projects, a great effort is made to reduce floor-to-floor dimensions. The resultant decrease in the available interstitial space for ductwork is a major design challenge. In institutional buildings, higher floor-to-floor heights are required due to the sophistication and complexity of the mechanical, electrical, and communication distribution systems.

Air Terminal Units

In some instances, such as in low velocity, all-air systems, the air may enter from the supply air ductwork directly into the conditioned space through a grille or diffuser. In medium and high velocity air systems, an intermediate device normally controls air volume, reduces duct pressure, or both. Various devices are available, including (1) a fan-powered terminal unit, which uses an integral fan to accomplish the mixing rather than depending on the induction principle; (2) a variable air volume (VAV) terminal unit, which varies the amount of air delivered to the space (this air may be delivered to low-pressure ductwork and then to the space, or the terminal may contain an integral air diffuser); (3) an all-air induction terminal unit, which controls the volume of primary air, induces return air, and distributes the mixture through low-velocity ductwork to the space; and (4) an air-water induction terminal, which includes a coil in the induced airstream. Chapter 17 has more information about air terminal units.

Insulation

In new construction and renovation upgrade projects, HVAC supply air ductwork should be insulated in accordance with energy code requirements. ASHRAE *Standard* 90.1, Section 9.4, and Chapter 34 of the *ASHRAE Handbook—Fundamentals* have more information about insulation and the calculation methods.

Ceiling Plenums

Frequently, the space between the suspended ceiling and the floor slab above it is used as a return air plenum to reduce the distribution ductwork. Refer to existing regulations before using this approach in new construction or a renovation because most codes prohibit combustible material in a ceiling return air plenum.

Some ceiling plenum applications with lay-in panels do not work well where high-rise elevators or the stack effect of a high-rise building create a negative pressure. If the plenum leaks to the low-pressure area, the tiles may lift and drop out when the outside door is opened and closed.

Raised floors with a plenum space directly below are another way to provide horizontal air distribution and/or a return air plenum.

The return air temperature in a return air plenum directly below a roof deck is substantially higher during the air conditioning season than in a ducted return. This can be an advantage to the occupied space below because the heat gain to the space is reduced. Conversely, return air plenums directly below a roof deck have substantially lower return air temperatures during the heating season than a ducted return and may require supplemental heat in the plenum.

PIPING

Piping should deliver refrigerant, hot water, chilled water, condenser water, condensate drains, fuel oil, gas, steam, and condensate to and from HVAC equipment as directly, quietly, and economically as possible. Structural features of the building generally require mechanical and electrical coordination to accommodate pipe pitch, draining of low points in the system, and venting of high point in the system. Chapter 35 of the *ASHRAE Handbook—Fundamentals* covers pipe distribution and pipe design.

Pipe Systems

HVAC piping systems can be divided into two parts; (1) the piping in the central plant equipment room and (2) the piping required to deliver refrigerant, hot water, chilled water, condenser water, condensate drain, fuel oil, gas supply, steam supply, and condensate return to and from HVAC and process equipment throughout the building. Chapters 10 through 14 discuss piping for various heating and cooling systems. Chapters 1 through 4 and 32 of the *ASHRAE Handbook—Refrigeration* discuss refrigerant piping practices.

The major piping in the central plant equipment room includes refrigerant, hot water, chilled water, condenser water, condensate drains, fuel oil, gas supply, steam supply, and condensate return connections.

Insulation

In new construction and renovation upgrade projects, HVAC piping may or may not be insulated based on existing code criteria. ASHRAE *Standard* 90.1 and Chapters 25 and 35 of the *ASHRAE Handbook—Fundamentals* have information regarding insulation and the calculation methods**.**

SYSTEM MANAGEMENT

System management is an important factor in choosing the optimum HVAC system. It can be as simple as a time clock to start and stop the equipment or as sophisticated as a computerized facility management software system serving large centralized HVAC multiple systems, decentralized HVAC systems, a large campus, etc.

Automatic Controls

Basic HVAC system management is available in electric, pneumatic, or electronic temperature control systems. Depending on the application, the design engineer may recommend a simple and basic management strategy as a cost-effective solution to an owner's heating, ventilation, and refrigeration needs. Chapter 46 of the *ASHRAE Handbook—Applications* and Chapter 15 of the *ASHRAE Handbook—Fundamentals* discuss automatic control in more detail.

The next level of HVAC system management is direct digital control either with or without pneumatic control damper and valve actuators. This automatic control enhancement may include energy monitoring and energy management software. The configuration may also be accessible by the building manager via telephone modem to a remote computer at an off-site location. Chapter 41 of the *ASHRAE Handbook—Applications* covers building operating dynamics.

Using computer technology and associated software the design engineer and the building manager can provide complete facility management. This comprehensive building management system may include HVAC system control, energy management, operation and maintenance management, fire alarm system control, and other reporting and trending software. This system may also be integrated and accessible from the owner's information technology computer network and the Internet.

System Management Interface

Today, system management includes the purchasing of automatic controls that come prepackaged and prewired on the HVAC equipment. In the analysis and selection of a system, the design engineer needs to include the merits of purchasing prepackaged automation versus traditional building automation systems. Current HVAC controls and their capabilities need to be compatible with other new and existing automatic controls. Chapter 39 of the *ASHRAE Handbook—Applications* discusses computer applications and ASHRAE *Standard* 135 discusses interfacing building automation systems.

Other interfaces to be considered include the interface and compatibility of other mechanical and electric control and management systems. Building systems, such as the fire alarm, medical gas systems, and communication systems are just three of the management interfaces that an owner may want to work in unison with the HVAC control system. Predictive and preventive maintenance using computerized maintenance management software (CMMS) also enhances the management and should be considered.

STANDARDS

ASHRAE *Standard* 15-1994. Safety code for mechanical refrigeration.

ASHRAE/IESNA *Standard* 90.1-1999. Energy efficient design of new buildings except low-rise residential buildings.

ASHRAE *Standard* 135-1995. BACnet—A data communication protocol for building automation and control networks.