HVAC
Design Guide
for
Tall Commercial Buildings

This publication was prepared under ASHRAE Research Project RP-1261,
in cooperation with TC 9.12, Tall Buildings.

ABOUT THE AUTHOR

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American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ISBN 1-931862-45-1

Library of Congress Control Number: 2003117180

1791 Tullie Circle, N.E.
Atlanta, GA 30329
www.ashrae.org

Printed in the United States of America

Cover design by Tracy Becker.

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Acknowledgments

The content of this book results from the design experience of one practitioner but has been influenced by useful suggestions during its preparation from a number of sources. It has been prepared as a research project authorized by ASHRAE.

The ASHRAE Project Monitoring Subcommittee chaired by Thomas Kroeschell and consisting of Harvey Brickman, Mark Fly, W. Ted Ritter, Peter Simmonds, and Dennis Wessel provided useful comments on both the structure and content of the text. In a similar fashion the partners of Jaros, Baum & Bolles have helped to shape the book in many significant ways through their comments on the proposed material contained in drafts they kindly reviewed. For the chapter on life safety systems, the author was the recipient of invaluable assistance through the review and suggested changes received from William A. Webb of Performance Technology Consulting, Ltd. The details on structural interface with the HVAC systems are the result of material provided by John J. Cryan of Severud Associates. Similarly, the acoustical material included in the book results from discussions with Patricia Scanlon of Cerami & Associates,Inc.

The word processing efforts by Gregory Babb and the development of drawings by Clive Webster, both of Jaros, Baum & Bolles, are gratefully acknowledged.

The ASHRAE person who edited and prepared the published version of this design guide is Erin S. Howard.

Chapter 1
Introduction

Tall commercial office buildings have existed for more than 100 years. While their origin occurred in the United States in the closing years of the 19th century, they are a design concept that today finds application in every corner of the globe. The tall commercial office building only became possible through the invention of the elevator safety braking system by Elisha Graves Otis in 1853. The earliest examples of the tall building phenomenon can be found in New York City and Chicago. It was the concentration of economic activities, the availability of the developed infrastructure that would support business enterprises, and the limited building sites in the centralized business areas of these cities that originally gave rise to tall office buildings. Because of the growth in population and the expansion of the economy in multiple cities, the tall commercial office building exists today in every city in the world.

The design of any tall building is the result of the collaborative effort of owners, architects, structural engineers, mechanical and electrical engineers, and other specialized engineers and consultants. This design guide is focused on the efforts of the designers of the heating, ventilating, and air-conditioning (HVAC) systems, but it also addresses the importance of the design team and their collective efforts and concerns that are the critical elements in determining the ultimate solutions to the project needs.

Every building is a product of its location, the time during which the building is designed and erected, and the specific client for whom the building is being constructed. A building is constructed of multiple commercially available products, but in its completed state, there may well be differences in how these products are assembled. Accordingly, every building will usually differ in many ways from other buildings regardless of apparent similarities.

This guide addresses HVAC design issues for tall commercial office buildings, but the matters discussed and the recommendations and comments that are developed, with various modifications, frequently can be applied to other project types within the built environment. This is particularly true of matters discussed in the "General Overview" section of this chapter. It is necessary to cover these matters, however, in order to lay the groundwork for matters discussed subsequently in this design guide, many of which are more exclusively applicable to the tall commercial office building.

1.1 GENERAL OVERVIEW

It is clear that the design of mechanical and electrical systems for large commercial office buildings is a continually evolving art form that progressively responds to the local market's economic and political concerns, the space utilization needs and requirements of the specific user who will occupy the building, and the geographic location within which the building is being constructed.

The techniques and design alternatives for the tall commercial office building—because of its size, location in major urban areas, and typically sophisticated group of owners, and occupants—require a particularly intense response from the architects and engineering designers. The HVAC design engineer, as a significant element in the design team, must complete his or her designs with due consideration of first cost, operating expense for the completed building, the present and future needs of the building occupants, as well as environmental issues and the conservation of energy, regardless of source, in the completed project. The architectural profession responds to the same pressures but, in addition, is subject to the requirement to create buildings that are attractive to the public at large, the real estate industry, and, most importantly, the owner of the building.

The purpose of mechanical and electrical systems in commercial office buildings has not changed, in any fundamental sense, over the history of the construction of buildings utilized for such occupancy. Clearly, the primary purpose of these systems was, and is, to provide space in the building that will permit the occupants to conduct their business in a productive, comfortable, and safe atmosphere. There has, however, been a change that fundamentally altered the means of satisfying this continuing set of basic requirements. This fundamental change took place in much of the United States starting in the 1950s and in much of Europe some 20 odd years later. This was the introduction of air conditioning. Prior to World War II, there were virtually no fully air-conditioned commercial office buildings in most of the United States. Since then, virtually all buildings have been so designed. The introduction and wide usage of air conditioning in tall commercial office buildings fundamentally altered and expanded the role of the heating, ventilating, and air-conditioning engineering design professional. A primary purpose of this design guide is to outline the details of this altered and expanded role as it presently exists.

The provision of air conditioning also had a major impact on the architectural design and space usage of large commercial buildings in that each space no longer needed to be contiguous to a window or means of providing natural ventilation. This change permitted the design of large floor plates that allowed spaces 40, 50, and more feet from an exterior wall to be gainfully occupied by desks and workers and even to include interior private offices. The effect of this on architectural designs cannot be overstated. It was dramatic and meaningful.

Beyond the import of the advent of air conditioning, a series of smaller but equally significant changes have been effected in the past several decades that have significantly modified the basis of the design of air-conditioning systems for the tall commercial office building.

These include the following:

- The evolution of energy-conserving building designs that consume significantly less energy than buildings constructed in the not too distant past, up to and including the early 1980s.
- Expanding and changing zoning and building codes, which have impacted the architectural designs of buildings, the internal energy systems that can be employed in buildings, and the enlarged life safety systems mandated to protect both the occupants and the contents of the building.
- The changing real estate market, particularly in the area of developer buildings, as contrasted with owner-occupied buildings, in that potential tenants have become more knowledgeable and demanding with regard to the various proposed solutions capable of meeting their perceived needs.
- The altered utilization of buildings, largely driven by the development and the extensive deployment in buildings of distributed intelligence in the form of the personal computer and alternative telecommunication systems.

- The availability of new or modified air-conditioning designs and the commercially manufactured equipment to permit an altered response to the needs of buildings.
- Finally, and of major impact, the recognition of the design profession that buildings must respond to environmental and green building concerns including, but not limited to, energy conservation as an end unto itself, indoor air quality, sustainable design considerations, and new technology that will better address the global environment of both the present and the future.

This is a significant list of altered perceptions and design requirements to which the design community must respond. Nowhere is it of greater import than to the HVAC design professionals who are responsible for the documents that define the basis of the installations that are provided for any large commercial office building. How that response is determined and framed is a matter that must be given the full focus of the intellect of the HVAC designer of tall buildings regardless of the location of the building.

1.2 THE TALL BUILDING DEFINED

Various definitions have been put forth for a tall building. In a sense, none is needed inasmuch as any person looking at a building of twenty or more stories will accept the fact that the structure is a tall building. This perceived definition, however, is not of value in an architectural and engineering field where the building codes themselves will alter the design requirements if the building exceeds a stipulated height. Accordingly, a more precise definition is necessary.

The ASHRAE Technical Committee for Tall Buildings, TC 9.12, has defined a tall building as one whose height is greater than 300 feet (91 m). This is a viable definition that can be used in a discussion of the tall building and the design concerns that become apparent with such a building.

The Council on Tall Buildings and Urban Habitat (CTBUH) defines a tall building as one in which the “tallness” strongly influences planning design or use. This definition, while vague, captures the essence of the problem with which we will be concerned in this design guide.

The General Services Administration (GSA) sponsored the “International Conference on Fire Safety in High-Rise Buildings” in Warrenton, Virginia, on April 12, 1971. That conference arrived at a more complex and more flexible definition that is appropriate. It stated:

> A high-rise building is one in which emergency evacuation is not practical and in which fires must be fought internally because of height.

Building codes throughout the United States vary widely and fall into two general categories: (1) model codes, which are developed by model code associations and are applicable in large geographic areas of the United States, and (2) local codes, which are specific to a particular geographic area (e.g., the Chicago Building Code, the Los Angeles Building Code, or the Building Code of the City of New York). Every local jurisdiction has either adapted one of the model codes or has developed its own, which is frequently based on one of the model codes.

The associations that have developed the traditional model codes and their regions of application are as follows.

- Building Officials and Code Administrators (BOCA), which is applicable in the Northeast.
- Southern Building Codes Congress (SBCC), which is applicable in the Southeast.
- International Conference of Building Officials (ICBO), which is applicable in the West.

Recently these three code associations have integrated their efforts and have issued a single unified national code. The integrated association is the International Code Council (ICC) whose code will be called the International Building Code (IBC). A second unified national code has been developed by the National Fire Protection Association (NFPA). It is called NFPA 5000. The adoption of either of these unified codes is a work in progress with expanding success in various jurisdictions and states at this time.

The relevance of these codes to this design guide is that they all invoke specific design requirements as a result of their definition of a tall building. This includes all codes, not just the model codes. The design of any building must respond to the requirements of the code that is applicable for the building and to the interpretation of that code by the local authority having jurisdiction over the project. All codes affect the design of any building in that they will mandate specific design responses to environmental conditions, such as solar heat gain, building envelope thermal opaqueness, air transport efficiency criteria, pipe and duct insulation performance, etc. They also will detail the project's seismic requirements for all building equipment with specific emphasis on life safety equipment, including the need for restraint of the sprinkler piping, emergency generators, and fire pumps. The codes address the tall commercial building in detail regarding smoke management needs and the venting of elevator shafts. Many of these matters are discussed in more detail in later chapters of this design guide.

1.3 REAL ESTATE CONSIDERATIONS

Every building that is designed and constructed must respond to real estate considerations if the project is to be a successful venture. These considerations include ownership issues as well as matters that are more appropriately a concern of the usage to which the building will be subjected. While of import in all buildings, the matters are of even greater import in the tall commercial office building due to the size of the building and the need for it to meet the requirements of its occupants. It is difficult to fundamentally alter a large building, such as any tall commercial building, after it is finished and available for use by occupants. So the building usage and the performance criteria to meet the needs of that usage will always need definition when the building is being designed. An example of the information that would be included in the detailing of the design criteria for a project is included in chapter 3, "The Design Process."

An initial real estate consideration that must be recognized and dealt with is the nature of the ownership of the building. The ownership entity for whom a building is being constructed falls into several distinct categories. These categories may overlap, but in general they do not. There is more than a single ownership category and the alternative categories may well affect the design solutions developed for any project.

Many tall commercial office buildings are corporate headquarters that are developed within a program for the project that is prepared, typically, by the architect and owner with significant input from a real estate consulting firm retained by the owner. The developed program will establish the specific requirements for the design team regarding the building program. For example, will the building contain a data center? If so how large and with what potential for expansion? What dining facilities are to be included? Are there executive dining area requirements that are separate from the general employee dining? Are the telecommunication requirements and possible technology vendors established? What areas beyond the data center will be operating on an extended time schedule or on a 24/7 basis? The answer to these and similar programmatic questions will have direct impact on the HVAC solutions that will be developed for the project, but there are other significant issues that will also have a major affect on the final design solution.

For example, it is not unusual for a corporation anticipating growth to meet the future needs by one of two means. The first is to build a building that is larger than presently needed by a given amount, lease the extra space for given periods to other business firms not related to the developing corporate owner, and, as the need for expansion develops, move into the overbuilt space as it becomes available with the expiration of leases to the other outside commercial tenants.

The second means of providing for future corporate growth is to design the building to allow for future building expansion. This is frequently not a viable alternative for a tall commercial building. Tall buildings are, almost always, built in our major cities on constricted sites that are fully utilized at the time of the construction. Moreover, the height and size of the building is typically built to the maximum dimensions allowed by the local zoning board in the geographical entity within which the building is to be erected. This, short of a zoning code modification, restricts the use of the expansion option for the tall commercial office building in an urban location.

There are isolated cases where a corporate headquarters has been built with the first phase of the project completed to meet a present need of the corporation but with the structure designed to handle in a second phase additional floors above the original number that were constructed. This solution is rare and can be expensive in that roof-located equipment on the top of the original set of floors presents costly and logistically difficult relocation problems that will tend to preclude this approach. The necessary relocation equipment includes cooling towers, general and toilet exhaust fans, elevator machine rooms, and any other roof-located equipment such as emergency generators or dry coolers for data center or telecommunication equipment.

Moving beyond the corporate headquarters, tall commercial office buildings will usually be erected by developers. Developers, however, are not all the same. At least three types exist.

The first is a developer who erects a building for a specific single user. The building will be a “build-to-suit” building that does not substantively differ from the corporate headquarters in that a very specific program must be prepared by the staff of the occupying user, the architect, and the real estate advisors providing a detailed definition of the tenant’s exact requirements. The needs and requirements of the occupying user must be fully defined in any contract, as any modification of these needs and requirements that may develop during the actual design and construction of a build-to-suit building can result in substantial, unanticipated costs to the occupying user.

The other two types of developers are largely a function of their ownership intention with regard to the building when it is completed. There are developers who historically plan and build for long-term ownership of their buildings. Many of these portfolio owners own and keep all of their developed properties, passing them on to future generations of their family or successor corporations.

Alternatively, there are developers who construct a building with the expressed intent to dispose of the building in a varying period of time after the building is completed. These can be short-term owners. The time they retain ownership is rarely defined and, more often than not, is controlled by the fluctuations in the price of real estate in the local market within which the building is located. Obviously, a fully rented building with high rents will obtain a higher purchase price than one partially leased at low rents—the exception, of course, being if the leases are due to expire and the rental prices for space in the geographic area within which the building has been built are increasing; then the building will obtain a substantially greater price than would be the case with a fully rented building at modest rents with long-term lease commitments or where the rental market is soft and increased revenue cannot be anticipated from the property.

In large part, the reaction of a developer to specific real estate issues in the design of large commercial office buildings will be affected by the developer category from the alternatives just outlined (i.e., developer of a build-to-suit building for a single user, developer with long-term ownership intentions, or developer with short-term ownership intentions). A partial summary of these real estate issues is as follows:

- Market forces, which include prospective tenant perceptions and expectations.
- The developer's target market (e.g., financial services sector, general corporate market, unknown and unspecified business entities, etc.).
- Large multi-floor tenant occupiers vs. multi-tenanted single-floor occupants.
- Core to exterior wall dimension requirement to meet the needs of prospective tenants.
- Clear ceiling height desired on each office floor.
- Code-mandated building height or building massing limitation.
- Overtime building usage.
- Available alternative energy sources and their costs.
- Allowable utility metering arrangements.
- Green building issues.

This list is, in general, self-explanatory and, in part, beyond the scope of this design guide. Several of these issues are discussed in detail in other chapters (e.g., large multi-floor tenant occupiers vs. multi-tenanted single-floor occupancy, overtime building usage, available energy sources and their costs, and allowable utility metering arrangements). There are several listed matters for consideration that would usually be architectural design matters but that are also impacted by the HVAC design solutions and therefore warrant discussion in this introductory chapter.

1.4 ARCHITECTURAL CONSIDERATIONS

While clearly the architect must respond to many of the real estate considerations just outlined, there are architectural concerns to which the architect must respond that require input from other members of the design team but are primarily architectural in nature. These certainly include aesthetic considerations, such as the location of louver areas on the exterior of the building, which can modify the appearance of the building, or the inclusion of a large atrium. The architect must also address a request to include a below-grade parking area, the provision of a significant retail area on the lowest level of the building or the inclusion of rental apartments or condominiums in the project. Any of these possibilities would raise a whole host of HVAC requirements as well as alter the electrical, plumbing, and vertical transportation system details for the project. They would affect the mechanical design and the very massing of the structure as well as the resultant limitation on possible locations for mechanical and electrical space. Several of these matters are discussed subsequently in this design guide, but two other architectural considerations require discussion at this juncture. These are the design of the core areas and the determination of the project's floor-to-floor height and the impact of the resolution of both matters on the building's cost as well as the architectural and HVAC designs.

1.4.1 Core Design

The architectural design of the core areas of any building is much more difficult than might appear at first glance. The core design is extremely critical from the perspective of being organized in a manner that meets the needs of the occupants while also simplifying the provision of mechanical and electrical services to the occupied floor. But often the needs of the occupant of the floor are not established when the core is being defined and organized by the architect and the consulting engineers. Moreover, the cost of the core and its content can be substantial. Finally, the configuration of the core impacts the usable area on a given floor and the resultant rent for that floor, so it should be arranged in the tightest area possible, resulting in the most efficient possible use of the floor.

1.4.1.1 Core Location

Most tall commercial buildings are designed with a center core that provides maximum flexibility in the architectural subdivision of the floor. This is particularly true in the case of a multi-tenanted floor. In addition, use of a center core has the potential to improve the distribution of air-conditioning ducts, since they can be extended to the floor from both sides of the core. This both reduces their size and shortens their length.

The center core also offers structural advantages, with the stiff core providing a means to resist wind loads. A center core can also simplify the construction of the building in that it forms a central spine for the building with radial construction being added in all four directions, which can be accomplished more efficiently than if construction options were more limited.

There are cases with small floors or with a building that is located against an existing building party wall where a side core will be designed for a building. As is discussed in chapter 5, "Central Mechanical Equipment Room vs. Floor-by-Floor Fan Rooms," this can offer opportunities for introducing outside air directly to the floor if floor-by-floor air-conditioning units are planned for the building.

In buildings with very large floor plates, multiple cores may be necessary to reduce the travel distance to stairs or toilets. A cost disadvantage of multiple cores is the potential need for additional elevators, although this is not always necessary.

1.4.1.2 Core Components

As a minimum, the core must incorporate the following entities:

- Fire stairs.
- Vertical transportation elements, which will be an arrangement of elevators and possibly escalators, including both passenger elevators and one or more service or freight elevators.
- Toilet rooms for both the male and female population and with provision to meet the Americans With Disabilities Act (ADA) requirements for both sexes.
- Electric closets.
- Communication closets for multiple telecommunication providers.
- Local fan rooms (if floor-by-floor air-conditioning equipment is the selected approach for the project) or large supply air and return air shafts (if central fan rooms are the selected approach for the project).
- Shaft space for other HVAC risers, beyond those for the local fan rooms or the supply and return ducts for the central fan rooms, such as toilet exhaust, general exhaust, or dedicated smoke exhaust risers and possibly kitchen exhaust risers.
- Space for risers for the piping of the HVAC system and plumbing system as well as riser space for electrical distribution cable and distribution cable for the building management and fire alarm systems.

The number, location, and arrangement of the stairs are architectural issues that are driven by the operative building codes that are in effect in the geographic area within which the building is being constructed. A minimum of two stairs is always required and the maximum travel distance for any occupant on a floor is defined within every building code, but the specific maximum travel distance can well vary from code to code. Moreover, for very large floor areas, there may be a need for more than two stairs to meet the maximum travel distance requirements. Although the entries to the stairs should be located as remotely from each other as possible, the project design must conform to the maximum code-defined distance from any occupied area on a floor to a stair.

The effect of the elevators on the core will involve not only the elevators that serve a given floor but also the elevator shafts that contain elevator elements that bypass the specific floor and serve floors above the floors for which the core is being designed. This would be the case in buildings in excess of approximately 15 to 20 floors where multiple banks of elevators are usually included to meet the design criteria for interval and waiting time, which is critical in the selection of the elevator system. It is noted that where multiple banks of elevators are deemed necessary to meet the needs of the building, alternative core designs must be completed where a bank of elevators serving a group of floors is eliminated beneath an elevator machine room. The details of alternative vertical transportation systems that find application in tall commercial buildings are discussed in chapter 9, "Vertical Transportation."

A second concern in the core design as a result of the use of multiple banks of elevators is that the alternative core, as it changes due to the elimination of a bank of elevators, must address the shaft locations for HVAC ductwork and piping and electrical risers with minimal—if any—offsets in these shafts. If the core is designed in a manner that requires offsets in the service risers, it must be understood that any transfers are likely to be expensive as well as consumptive of space.

Finally, the elevator system for a first-class tall commercial building will usually include service or freight elevators, which are used to move material as opposed to people, within the building. In some buildings, usually smaller in size, one of the passenger elevators can be used as a "swing car" being employed for passengers most of the time but converting to handle material on an as-needed basis. This issue is discussed in chapter 9.

The fixtures to be installed in toilet rooms are as a minimum driven by the applicable building code. The code will mandate the minimum number of fixtures (water closets, lavatories, and urinals) for each sex. In addition, the federal Americans With Disabilities Act (ADA) and the building code will address the number of toilet fixtures for the handicapped and the minimum space requirements to allow the handicapped to access the fixtures.

In any new construction, these handicapped facilities must be provided within both the male and female toilet rooms used by the general population of the building. In retrofitting, the need for handicapped toilet compliance in an existing building, where the original design did not address the needs of handicapped occupants and the existing toilet rooms are not sufficiently spacious to permit the legal requirements to be met within the rooms, it is permitted to address the needs in a space separated from the toilet rooms for the general population. In this case of providing a separate toilet room for the handicapped in an existing building, the room may be a unisex space used by both males and females.

The building code definition, as noted above, addresses a minimum number of each type of fixture required for males and females. These quantities are derived from the floor area of the specific floor and a defined number of males and females based on that area. For a corporate headquarters or a developer building catering to a higher level of tenancy, the number of fixtures mandated by the code is frequently increased due to the sense that the code-dictated number of fixtures is marginally insufficient for a corporate tenant. Moreover, on very large floor plates, two toilet rooms may need to be provided for each sex to limit the travel distance of any occupant to a reasonable length. This can further complicate the design being completed by the architect of the overall core required for a project and frequently results in a separate auxiliary core smaller in area and remote from the main core that will contain the added toilet room and additional stairs if they are required.

Electric closets are also a major issue in the design of a core. Their location on any floor must be such as to permit diverse routing of electric cable at the utilization voltage appropriate for the geographic location of the building to any area of the floor to meet the design criterion, in watts per square foot, that is the agreed design basis for the project. There are limits to the distance that the floor distribution cable can be extended on any given floor without a cost penalty. In general, on a floor in excess of approximately 25,000 ft^2 (2,400 m^2), more than one electric closet will be required to serve that floor. On floors smaller than 25,000 ft^2 (2,400 m^2), a second closet may still be included to meet the possible needs of the element in the corporate world who is envisaged as the occupant of the building.

The communication closet has gone through a major series of changes over the past decade. Originally the closet was called a telephone closet, but that terminology is rarely used today. The appropriate terminology is “telecommunication,” “communication,” or “information technology” closet. Traditionally, the closet contained the vertical telephone riser cables that in turn connected to telecommunication terminal blocks from which the horizontal runs on the specific floor were extended by the telephone company to the user’s phone. However, that was in a time when there was only one telephone company and no such thing as a computer. All that has changed.

Now there are multiple telecommunication companies. Corporations may each utilize four or more companies and, in a large developer building with unknown multiple tenants, provision must be made in the telecommunication risers for as many as twelve different telecommunication companies. Not all will be used on every tenant’s space, but all may be required for a multi-tenanted building. The communication risers may not be installed during construction, just the riser space and empty sleeves in the communication closet, with the empty risers being filled as specific tenants request specific telecommunication providers for their space. In a developer building currently under design in New York City, forty empty sleeves are being provided in each of two closets on every floor to meet anticipated but unknown demands from yet-to-be-determined tenants. The service for each vendor to a specific tenant on a given floor will be independently routed in each of the two closets. Moreover, in the below-grade levels, space will be needed for multiple points of entry from each telecommunication provider to allow its service to be brought to two separate service rooms from at least two different streets to ensure continuity of service under any possible emergency contingency.

A further change in telecommunication system design has occurred in that rack-mounted equipment is used to interface with the desktop data services equipment, including telephones, being used by the occupant. This requires much more space than was previously required when the telephone equipment distribution wiring terminated at terminal strips in the telephone closet. The rack space used today is typically located away from the core on the floor, which allows full front and back access (a requirement) and, just as important, provides the degree of security mandated by many tenants. This need for security is particularly true with large corporations or enterprises that serve the financial markets. They will insist that the actual telecommunication equipment be installed within their demised premises with access limited to their staff. With the arrangement outlined, even the base building operating staff will not have access to the tenant’s proprietary telecommunication switches and equipment.

A final involvement of the telecommunication closet in the core is that it is frequently used to house the fire alarm system and building management system risers and floor equipment. This is logical in that it is space on all floors, can be easily accommodated in a new building with multiple risers, and can be accessed by the owner’s operating personnel or the fire alarm or building management system maintenance people for servicing.

The need for shaft space for HVAC ductwork and piping with either central fan rooms or local floor-by-floor fan rooms and the space requirements for local floor-by-floor fan rooms are discussed in chapter 5.

All in all, the complication of the design of the core of a tall commercial office building becomes clearer when the disparate elements that must be integrated—as outlined above—are all considered. The architect is appropriately challenged to meet the goal of an efficient core (i.e., one that uses the least amount of the gross floor area). The definition of an efficient core is not simple in that the percentage of the gross area that will be used is very much a function of the size and the usage of the floor. For example, on larger floor plates, i.e., those with areas greater than 20,000 gross ft^2 (1,800 gross m^2), it is a core that often will take less than approximately 15 to 20 percent of the total

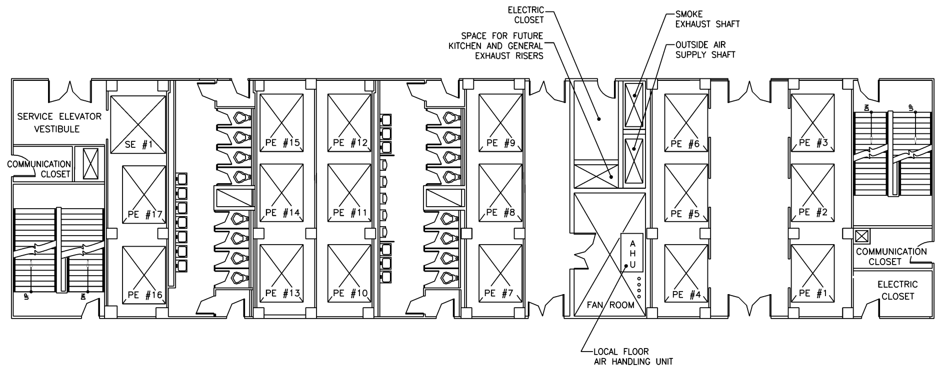


Figure 1-1.
Typical core plan.

floor area of a given floor. This core usage will be possible while still meeting the demands of travel distance to stairs, provision for and access to all vertical transportation elements, an appropriate number of toilet fixtures, and provision for mechanical and electrical services and access from these services in the core to meet the requirements of the diverse tenant occupants. There are other possible design details that would alter these approximate percentages. For example, if a floor grows beyond a certain size or has internal loads with high cooling requirements it can become necessary to add a second local floor air-handling unit and fan room, which will cause a reduction in the usable area. Moreover, on smaller floor plates, the core may take as much as 30 percent of the total floor area.

1.4.1.3 Example of Core Design

Figure 1-1 shows the several elements in a core as they might be assembled for a building. In designing a core, it is not unusual for the owner to request the architect to revise the layout as first proposed to reduce the core area to provide a larger amount of usable area on each floor. The provision of a more efficient core will become a significant benefit to the owner in his usage or leasing of the building, so the concern about its design and space needs will be of great interest to the owner.

The core in this figure is of interest in that it shows that there are three passenger elevator banks in the drawing. Passenger elevators PE1 through PE6 serve the lower stories of the building. The passenger needs for the mid-levels of the building are served by passenger elevators PE7 through PE12. The passenger needs for the uppermost building floors are served by passenger elevators PE13 through PE17. Above the floors that the low-rise bank of elevators serve, that bank is dropped, decreasing the size of the core and increasing the usable space except for the approximately two floors immediately above the floors served by the elevators, which contain the elevator machine room for the low-rise bank. Higher in the building, the mid-rise bank of elevators is dropped, further decreasing the core area. Also note the service elevator (SE1), which serves all floors from the basement to a mechanical equipment room on the uppermost level of the building. The service elevator is provided with an adequately sized vestibule to permit the movement of large office equipment, rugs, and other appurtenances from the service elevator to the floor.

The area between the mid-rise elevator banks is used for the men's toilet room, and the space between the high-rise elevators and service car is used for the women's toilet room. This area usage increases the overall efficiency of the core but may create a relocation problem for the toilets and the stairs as well as for piping, ductwork, and other mechanical and electrical services as the low-rise and mid-rise elevator banks are eliminated.

The project for which this core is shown employed local floor-by-floor fan rooms. The floor for which the core is shown could contain a packaged chilled water or a direct expansion air-handling unit.

The selection of local fan room or central fan rooms is discussed in detail in chapter 5. It is noted here that the local fan room solution will use more space on the individual floor, thereby affecting the core design, but will usually need less space in the overall building when the reduction of the double-height central mechanical equipment room required in the alternative solution for the large air-conditioning supply systems is taken into consideration.

1.4.2 Floor-to-Floor Height

The second issue that fundamentally involves the architectural design of the building is the floor-to-floor height. The overall cost of a tall building is affected by the floor-to-floor height of the individual floors. A small difference in this height, when multiplied by the number of floors and the area of the perimeter length of the building, will result in an increase in the area that must be added to the exterior skin of the building. The exterior skin of the building can cost in excess of \$100 per ft^2 (\$1,100 per m^2). In addition to the increase in the cost of the skin, an increase in the floor-to-floor height will increase the length of the vertical structural elements as well as all of the building's other vertical elements, such as shaft enclosures, HVAC, plumbing, electrical power distribution and telecommunication risers, elevator components, stairs, and the length of the interior partitions. Accordingly, a small reduction in the floor-to-floor height in a tall building can be a matter of import when the overall cost of the building is being determined. In addition, where zoning regulations exist that limit the bulk and height of a building, a small increase in the vertical dimension of each floor may result in fewer floors in the developed building.

The final floor-to-floor height of the office occupancy floors of any building will involve decisions by the owner, architect, structural engineer, and both the HVAC and electrical engineers. All will influence the ultimate determination of this key dimension. The discussions below on floor-to-floor height are concerned with normal office floor occupancy areas. Floors in the building that contain data centers, dining facilities, or other areas with special needs require separate consideration beyond those discussed below. The import of the several deciding entities on the office floor-to-floor dimensions is discussed in the following paragraphs.

1.4.2.1 The Owner's Involvement

The owner will make judgments on many of the issues discussed in this section that will influence the floor-to-floor height of the building, but the owner will be the primary entity in determining whether to include in the design a raised floor for the general office occupancy areas of the project.

The single most important change in the needs of occupants of buildings in the past decade has been the development of the electronic workplace. The need to satisfy the expanding and continually changing electronic needs in the tall commercial building has forced consideration of the inclusion of a raised floor to handle the horizontal distribution of both power wiring and information technology cabling, which includes both the telecommunication cabling and any interconnection of personal computers, printers, and the like. Typically the raised floors in general office occupancies will be between 4 and 6 inches (100-150 mm) above the concrete slab when the raised floor is used exclusively for the distribution of power wiring and information technology cabling. Floor tiles are included above the slab to provide the walking surface in the office space, which in turn are covered by carpet tiles of the same size as the floor tiles. The carpet tiles and then the floor tiles can easily be lifted to provide the needed access to allow modification of the wire and cable as changes evolve in the needs of tenants.

The application of raised floors for general occupancy office areas has largely been limited to corporate headquarters or owner-occupied buildings but is finding its way into developer buildings where the developer is looking for a competitive advantage in an attempt to lease the building. For projects in Europe, a raised floor is a standard aspect of most building projects, regardless of whether the building is being constructed for owner occupancy or unspecified and unknown tenants.

Raised floors in the United States, as a function of the specific tile that is used, will cost between \$6 and \$10 per ft^2 (\$64 and \$110 per m^2). One cost benefit that accrues to projects using a raised floor exclusively for wire and cable distribution is that neither the wire nor the cable installed within the raised floor cavity need be plenum rated or installed in conduit. As noted in chapter 4, “Systems,” in the discussion of underfloor air distribution systems, this cost benefit cannot be obtained on a project using the raised floor as a plenum for air distribution. Nonetheless, the application of raised floors with under-the-floor air-conditioning distribution systems is becoming more common with the increased use of raised floors.

Regardless of the type of air-conditioning system used on a project, it is expected that the use of raised floors in the United States will be increasing in the future because they can provide substantial occupant savings in the completed building as the information technology cabling and power wiring modifications develop on an ongoing basis for any tenant in any given project. The cost of the occupant changes or churn over the life of a building is significant in that changes occur with frequency. The use of a raised floor allows the relocation of electric outlets and information technology connections at a relatively low cost when compared to the cost of these relocations without a raised floor. There is, however, a housekeeping cost that must be understood. This involves the removal of information technology cabling and power wiring when they are abandoned due to ongoing changes in the requirements of the occupants. This mandates the need for maintaining accurate records of the installed cable and wire on any given floor. The importance of requirement for accurate installation records and the removal of abandoned cable and wiring cannot be overstated.

What should be understood at this juncture is that the inclusion of a raised floor must be viewed as an issue in the floor-to-floor height of the building. In and of itself, the inclusion of the raised floor will increase the floor-to-floor height, but the integration of a raised floor with an underfloor air-conditioning distribution system may minimize, if not eliminate, the increase in the floor-to-floor height for a given project.

1.4.2.2 The Architect’s Involvement

The architect’s primary concern with the floor-to-floor height of a building results from the concern the architect has with the floor-to-ceiling clear height on the occupied floors of the project. The architect, with the active involvement of the owner, will determine this dimension in an effort to provide space that, in their judgment, is aesthetically attractive. While tall commercial office buildings have been designed to provide different ceiling heights, the most common values are between 8 ft 6 in. (2.6 m) and 9 ft 0 in. (2.75 m). On floors with an area of more than approximately 30,000 ft^2 (2,700 m^2) with longer lease spans from the exterior wall to the core elements, the higher ceiling height of 9 ft 0 in. (2.75 m) is often provided in that an 8 ft 6 in. (2.6 m) ceiling provides space that is too low and not visually pleasing to the occupants. This is particularly true on floors that are of open floor design with minimal partitioning, where a lower floor-to-ceiling height can create a more restricted feeling to the occupants. Moreover, in corporate headquarters buildings, the ceiling height will almost always have a minimum height of 9 ft 0 in. (2.75 m) or more.

Once the floor-to-ceiling height has been determined and the decision to include or not include a raised floor has been made, the floor-to-floor height largely falls to the joint coordination efforts of the structural engineer and the HVAC design engineer.

1.4.2.3 Structural Coordination

The structural engineer must select the structural design and floor slab system for a project with the active involvement of the mechanical, electrical, and fire protection (sprinkler) members of the design team, since the structural systems must be fully integrated with the ductwork, the HVAC piping (if any), the lighting, the electrical distribution system, and the sprinkler piping. This integration of the structural, mechanical, and electrical designs will determine the space requirements between the top of the ceiling and the bottom of the structural slab of the floor above, which will be the starting point of the next floor.

Most, not all, tall commercial buildings in the United States utilize a steel structure rather than one that employs reinforced concrete construction. The reasons for the use of steel are:

- Careful scheduling of the contractors will allow structural steel to be designed and ordered in advance of the final completion of architectural and mechanical, electrical, and plumbing designs. This would be a fast-track process of construction. Fast tracking will permit the steel to be erected as soon as the foundations are complete with a resultant reduction in the total construction time of the building.
- Structural steel construction is more readily and economically adapted to the long-span column-free space that is desired by interior space designers and occupants, thus allowing for more flexible space designs and, in the case of a developer building, potentially, an increase in the building's marketability.
- Structural steel construction provides the flexibility to alter the capacity or configuration of the structure to handle changes in the loading by reframing or reinforcing the structural steel so that future occupant requirements may be accommodated. Such changes could be required by the introduction of floor-to-floor communicating stairs, elevators, dumbwaiters, or by the necessity to increase the load capacity of portions of a floor to support compact files, libraries, telecommunications equipment, or mainframe computer components.
- Structural steel will result in a lighter construction than would be the case with reinforced concrete construction. This will effect savings in the cost of the foundations. The reduction in weight will also lower the seismic forces that the building will experience.
- The temporary shoring of a concrete floor for some time after its casting is not required in structural steel construction. This will allow the other construction trades to commence their work earlier.

The structural engineer designs the floor for the dead loads of the building (the self-weight of the structure, partitions, floor finishes, ceilings, mechanical and electrical equipment, etc.) and code-prescribed live loads. Additionally, the girders and beams that frame from column to column are usually designed to resist the lateral loads from the wind or the seismic forces that are imposed on a building. The floor must be designed so that code-mandated allowable stresses are not exceeded (strength) and vibrations or deflections are not excessive (serviceability).

The structural design of the building core presents challenges to the structural engineer in that the core is usually designed to resist a large part of the wind and seismic forces to which the building will be exposed. This design requirement can be achieved by introducing bracing or deep girders or a combination of bracing and girders between columns at the edge of the core. This is where the supply and return ductwork leave or enter the shaft or the local floor-by-floor fan room. It is also the location where the ducts are at their maximum dimension and where extra height will be required for fire dampers where they exit a rated shaft.

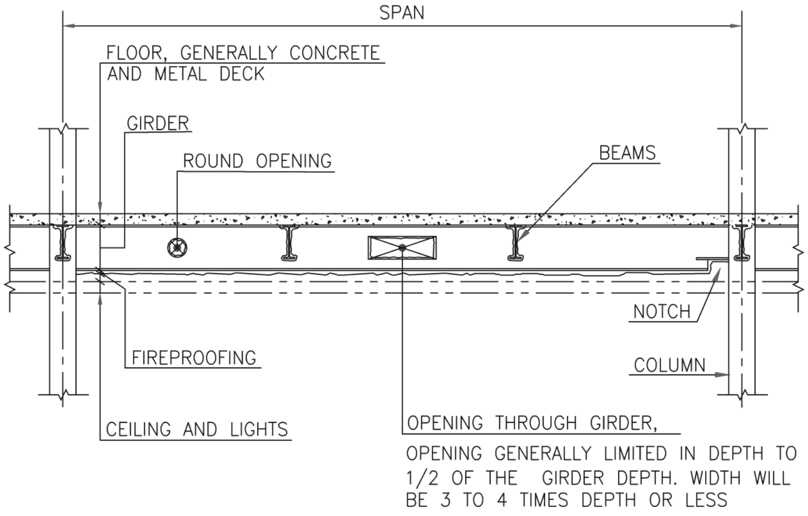
If the structural engineer were concerned only with structural criteria, the floor members would have an optimal depth that would constitute a design that was the least costly while providing the required strength and serviceability for the project. As a design reality, however, the structural engineer must work with the other design team members to ensure the optimum overall solution for the project. This collective effort will result in a design that will produce a cavity between the ceiling and the slab of the floor above that will minimize the floor-to-floor height to a point that is appropriate for the project. The design process for this space will involve compromises by both the architectural and several engineering disciplines. All parties must focus on the goal of reducing the vertical dimension of the ceiling cavity to its lowest possible dimension.

The collective effort must start early in the design process and must be continuous since the decisions that are made will affect the ongoing design results of the several disciplines. Moreover, an early start and continuity of effort is even more critical if the project is being subjected to fast-track construction because the structural steel may well be in fabrication before the HVAC designs are completed.

The HVAC design engineer can, in conjunction with the architect and the design of the core elements, start by locating the supply and return air shafts (in the case of a central air-conditioning supply system solution) or the local fan room (in the case of a floor-by-floor air-conditioning supply system solution) at a location where the distribution of the mechanical and electrical elements that are installed in the project are able to be extended to the occupied floor in the smallest vertical dimension when integrated with the structure. The HVAC engineer can also design the ductwork to have the highest possible aspect ratio, which may nominally increase the cost of the ductwork but will also result in a shallower duct that can more readily be accommodated in the structural design.

There are several alternative approaches that can be taken in an integrated design by the involved architectural and engineering professionals.

- The structural engineer can determine the shallowest depth of beams and girders that will satisfy the strength and serviceability requirements. The HVAC designer will then utilize ductwork, possibly with a greater aspect ratio, and pass the ductwork and other mechanical and electrical services between the fireproofing on the bottom of the steel framing and the top of the ceiling. This is a very common solution.
- The structural engineer can leave the girders at their optimum depth or make them deeper than required while providing strategically located openings in the webs of the structural members (near the center of the span) or notches near the ends of the members. Moreover, it is possible to provide small round holes in the structural element to allow the passing of small mechanical or electrical elements through the steel. Examples of these alternatives are shown in Figure 1-2. The utilization of any of these approaches will result in the ductwork and structure occupying, in essence, the same vertical space.
- A further possibility is shown in Figure 1-3. This approach will necessitate that the structural engineer provide a stub girder system, where the girders are dropped so that beams can be supported by bearing on the top flange of the girder. This alternative creates a void within which ductwork and other crossover services can go over the girder's top flange and beneath the concrete floor.
- It is also possible to modify the location of the intermediate girders to create a useable void as is shown in Figure 1-4. In Figure 1-4a the girder is upset into the floor above and in Figure 1-4b the girder is lowered into the floor below. Either approach requires the involvement of the architect since both these solutions will result in projections of the beam into the shaft or fan room, which may create interferences requiring careful coordination and a possible decrease in future flexibility. Where the girder is lowered to create a void above it, the approach is further limited in that it cannot be lowered to the point that it would be lower than the height of any door located beneath it in the floor below.
- A final approach involving the mutual efforts of the structural and HVAC design engineers is shown in Figure 1-5. This approach involves the use of V-shaped bracing that will be framed between the columns. The bracing provides support for the



NOTES:

1. IN GENERAL RECTANGULAR OPENINGS LIMITED IN SIZE NEAR THE CENTER OF THE SPAN WILL NOT REQUIRE REINFORCING.
2. RECTANGULAR OPENINGS LOCATED BETWEEN THE COLUMN AND FIRST BEAM IN GENERAL WILL REQUIRE REINFORCING.
3. ROUND OPENINGS 8" (200MM) IN DIAMETER OR LESS CAN USUALLY BE LOCATED ANYWHERE WITHOUT REINFORCING.
4. NOTCHES MUST ALWAYS BE AT THE END OF GIRDERS, WILL BE LIMITED IN SIZE AND USUALLY ARE REINFORCED. IF POSSIBLE NOTCHES SHOULD BE AVOIDED.
5. REINFORCED OPENINGS AND NOTCHES SHOULD BE FABRICATED IN THE STEEL FABRICATOR'S SHOP. OPENINGS CUT IN THE FIELD WILL BE RESTRICTED IN SIZE.

Figure 1-2. Structural steel openings for ducts and other services.

Courtesy Severud Associates.

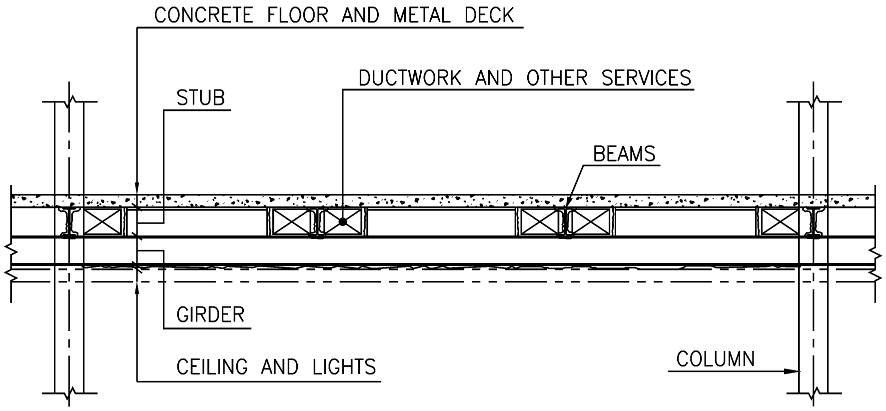
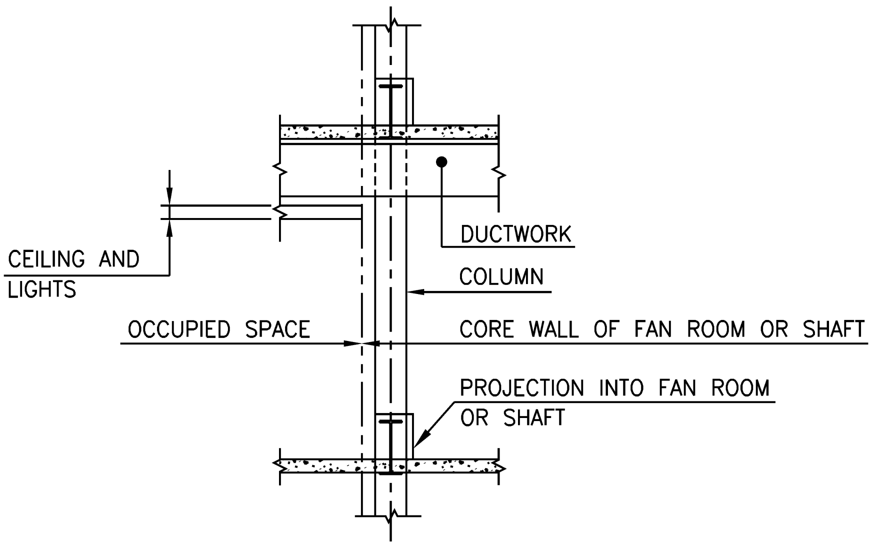
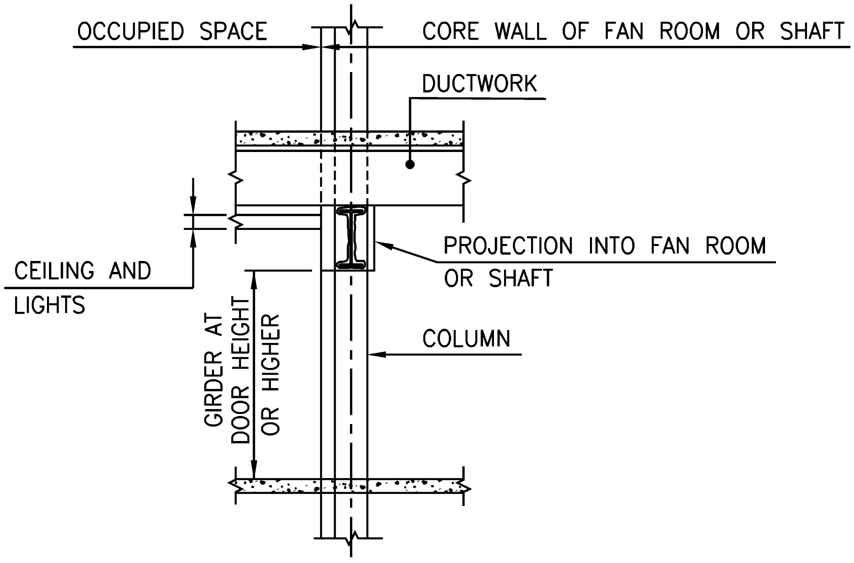


Figure 1-3. Stub girder structural void for ducts and other services.

Courtesy Severud Associates.



(a) Girder upset into the floor above



(b) Girder lowered into the floor below

Courtesy Severud Associates.

Figure 1-4. Relocated girder location openings for ducts and other services.

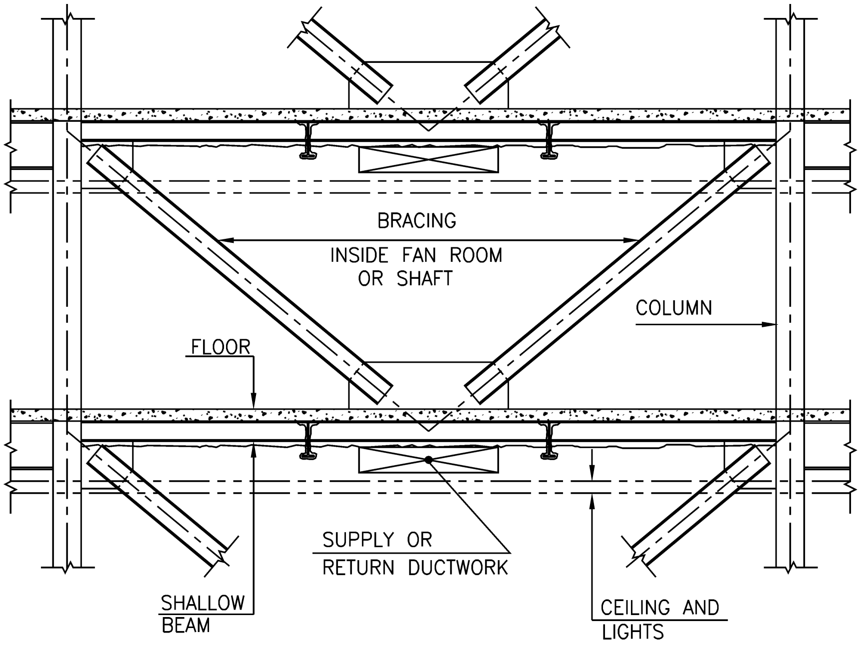


Figure 1-5. Bracing created void for ducts and other services.

Courtesy Severud Associates.

girder while creating a void for the ductwork. The girder size will reduce in depth since its bending moment will be 25 percent less than the moment of a girder without the brace as a support. The bracing sizes and connections and their costs will be greater than would be the case if the bracing were used for lateral support only.

Other means of minimizing the floor-to-floor height that involve the structural engineer and the HVAC engineer have been tried with varying success. The possible means of integrating the structure and the mechanical, electrical, and plumbing services is an important challenge to the designers that must be addressed collectively because the ultimate integrated design will have an economic effect on the total project cost beyond the specific engineering discipline installed cost. The goal of the design team, therefore, must be to provide the most cost-effective integration of the structural system and the mechanical and electrical systems.

A final approach that has been used is to lower the ceiling around the core, inasmuch as this will frequently be used as a circulation corridor when the interior spaces are laid out and an 8 ft 0 in. (2.45 m) ceiling height, the width of a possible corridor at that location, will not be considered obtrusive.

1.4.2.4 Alternative Ductwork Designs

A further means of reducing the vertical height of ductwork, the ceiling void, and the floor-to-floor height is to utilize multiple points of duct entry to the floor from the core. This can be arranged only with the active participation of the architect, since the ability to make this arrangement will involve other core areas.

With floor-by-floor air-conditioning system alternatives, it is best achieved by placing the local floor fan room at the end of the core, which will provide a minimum of two and as many as three entry points for the supply and return ducts. If the local fan room cannot be located at the end of the core, it is useful to be able to extend the ductwork from the local fan room in a direction both above and below the core.

Beyond these duct arrangements and their integration with the structural systems, the choice of the HVAC system itself can have a significant effect on the overall HVAC system integration with the structural system because the use of fan coil units for the exterior zone of a building will result in smaller ducts being required than if an all-air system were to be provided for that zone. This is discussed in chapter 4.

A final consideration is that with a central fan room solution, the limitation on the number of vertical supply and return ducts is greatly expanded. A recently completed project in Europe is a good example. The building, which was a large expansion of an existing building, provides a dramatic example of this design technique. The existing building was not air conditioned and had 3.3 m (10 ft 10 in.) floor-to-floor heights with 2.60 m (8 ft 6 in.) floor-to-ceiling heights. The request was to provide floor integration so that a person walking from the existing building to the expansion area would neither step up nor step down. To satisfy the need for flexible power and information technology cable distribution, a 125 mm (5 in.) raised floor was also to be included. These requests were accommodated by the use of two HVAC design details and one detail that involved the ultimate architectural layout of the interior of each floor. The first HVAC detail involved multiple duct drops from the central mechanical equipment room to the occupied floor and routing the floor supply ducts between the lighting fixtures. The second was to include fan coil units on the exterior wall to reduce the volume of air required on each floor. The lighting fixtures, while shallow, were located beneath structural members, creating a limitation on the location of partitions and the resultant space layouts. The ceiling void with this arrangement was 300 mm (12 in.). The architectural limitation in the final constructed building was that the ceiling could not be modified, so partitioning on the floor lacked total flexibility, but in an owner-occupied building, this constraint was acceptable.

1.4.2.5 Effect of Lighting Systems

One development that has taken place recently is the availability of lighting fixtures for office illumination that provide an acceptable level of illumination of 55 to 65 foot-candles of lighting but are only 5 in. (125 mm) to 5 ½ in. (138 mm) deep. When integrated with the ceiling system, the overall height of both elements will be approximately 5 ½ in. (138 mm) deep. These lower-height fixtures are a help in the routing of both the ductwork and sprinkler piping within a given ceiling cavity.

It should be stressed that, contrary to the project in Europe just discussed, the ductwork and lighting fixtures should not be in the same plane since the interior design of the floor is not known at the time the project is being designed and, even if it were known, it would change periodically over the life of the building. When these changes occur, it will usually be necessary to move the lighting fixtures and the air distribution devices, but the major distribution ductwork, short of a significant increase in air-conditioning capacity requirements, will remain in place.

1.4.2.6 Conclusions Concerning Floor-to-Floor Height

The floor-to-floor height required to meet the needs of a tall commercial office building with general office occupancy can usually be effected with a floor-to-floor height of 12 ft 6 in. (3.8 m) to 13 ft 6 in. (4.1 m). This floor-to-floor height is achieved, for example, with the dimensions shown in Figure 1-6. The space from the bottom of the ceiling to the top of the slab of the floor above is 4 ft 0 in. (1.2 m). This 4 ft 0 in. (1.2 m) space would contain the lighting fixtures, ducts, sprinkler piping, and structural

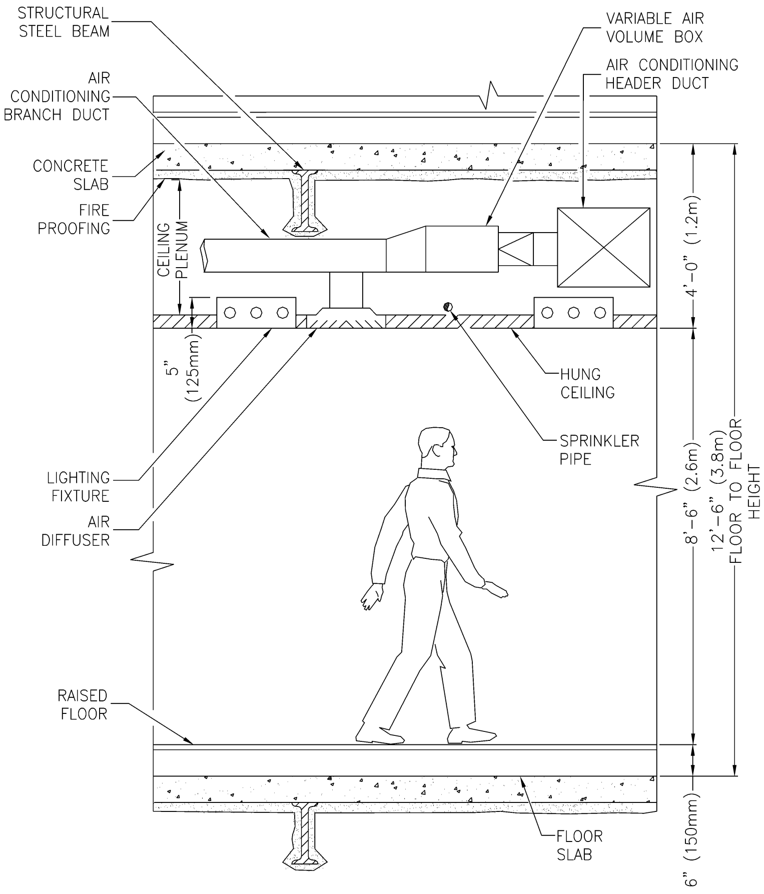


Figure 1-6. Typical section through an office floor.

steel system supporting the slab. An increase (or decrease) in any of the elements shown in this figure will result in an increase (or decrease) in the floor-to-floor height.

These conclusions do not include special areas in a building such as data centers, trading floors, or dining facilities. A data center or trading floor will require a raised floor of as much as 24 in. (600 mm.) to 30 in. (750 mm.). Trading floors are normally open, partitionless spaces and very much call for a floor-to-ceiling height in excess of 9 ft 0 in. (2.75 m) to allow line-of-sight communication between traders in various areas of the floor.

This brief overview is intended to highlight the issues involved in determining the floor-to-floor height, a significant determination that has a major impact on the building cost due to the effect it has on the area and cost of the exterior wall of the building and the other vertical elements in the building. Accordingly, the entire design team must focus considerable effort on the reduction of the floor-to-floor height to a practical minimum for any tall commercial office building.

Chapter 2

Stack Effect

A condition that exists in tall buildings at the times when the outside temperature is significantly lower than the temperature of the spaces in the building is called *stack effect*. Stack effect is the phenomenon in which a tall building in cold weather acts as a chimney with a natural convection of air entering at the lower floors of the building, flowing through the building, and exiting from the upper floors. The cause of stack effect is the difference in density between the cold, denser air outside the building and the warm, less dense air inside the building. The pressure differential that is created by the stack effect is directly proportional to the building height as well as to the temperature differential that exists between the warm temperature inside the building and the cold temperature outside the building.

When the temperature outside the building is warmer than the temperature inside the building, the stack effect phenomenon is reversed. This means that in very warm climates, air will enter the building at the upper floors, flow through the building, and exit at the lower floors. This downward flow of air is known as *reverse stack effect*. The cause of reverse stack effect is the same in that it is caused by the differences in density between the air in the building and the air outside the building, but in this case the heavier, denser air is inside the building.

While reverse stack effect would seem to be a problem in tall buildings in warm climates, this is usually not the case. The reason is that the difference in temperatures inside and outside the building and the resultant difference in density in warm climates is significantly less than the difference in temperatures inside and outside the building in very cold climates. Accordingly, this chapter will focus its discussions on the problems that develop due to the stack effect phenomenon in cold climates.

2.1 THEORETICAL DISCUSSION OF STACK EFFECT

For a theoretical discussion of stack effect, reference should be made to the current volume of the *ASHRAE Handbook—Fundamentals*. The ASHRAE discussion allows the calculation of the theoretical total stack effect for alternative temperature differences between the building and the area outside the building. It also points out that there is a neutral pressure level (NPL) in any building. This is the point at which the interior and exterior pressures are equal for a specific building at a given temperature differential. The location of the neutral pressure level in any building is governed by the actual building, the permeability of its exterior wall, the internal partitions, as well as the construction and permeability of stairs and the shafts, including the elevator shafts and shafts for ducts and pipes, that are provided in the building. Also influencing the neutral pressure level are the air-conditioning systems themselves, with exhaust systems tending to raise the neutral pressure level in the building (thereby increasing the portion of

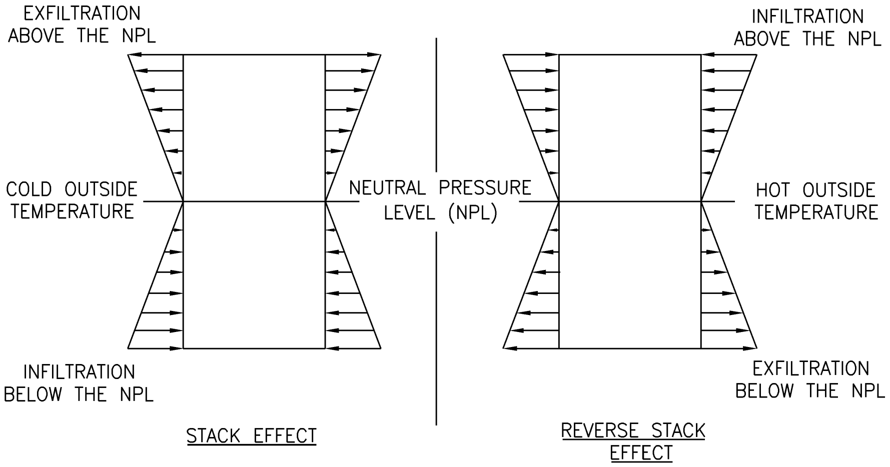


Figure 2-1. Airflow due to stack effect and reverse stack effect.

the total pressure differential experienced at the base of the building) and any excess of outside air over exhaust air in supply air-conditioning systems tending to lower the neutral pressure level in the building (thereby decreasing the portion of the total pressure differential experienced at the base of the building).

Figure 2-1 diagrammatically depicts the flow of air into and out of a building when the outside temperature is cold (stack effect) and when the outside temperature is hot (reverse stack effect). Not shown is the movement of air up or down within the building that occurs as a function of the stack effect condition or the reverse stack effect condition. The neutral pressure level is the point in the building elevation where air neither enters nor leaves the building. The vertical movement of the air within the building will occur in the shafts and stairs as well as any other openings that exist at the slab edge or in vertical piping sleeves at various locations that are less than perfectly sealed.

The figure also indicates that the movement of air into and out of the building increases as the distance from the neutral pressure level increases.

It is possible to calculate the total theoretical pressure differential that exists in a building of a given height and at various differences in temperature between the air inside the building and the air outside the building.

The theoretical stack effect pressure gradient for alternative temperature differences and building heights, as calculated using the equation in the *2003 ASHRAE Handbook—Applications*, is shown in Figure 2-2. The diagram is intended to provide the potential maximum differentials that can occur—and they are significant—but these plotted values are based on a building with no internal subdivisions in the form of slabs and partitions. The plot, therefore, includes no provisions for resistance to the flow of air within the building. Further, the permeability of the outside wall will influence the values on the diagram and, as noted earlier, the operation of the building's air-handling systems and fans will affect this theoretical value as will the wind effect. Accordingly, the diagram should be considered one that will point to the possible magnitude of the problem and should not be viewed as an actual set of values for any building. The actual stack effect in any building, as well as the location of the neutral pressure level, is difficult, if not in a practical sense impossible, to determine, but it does exist; it can be troublesome, and its possible effects must be recognized in the design documentation for a project.

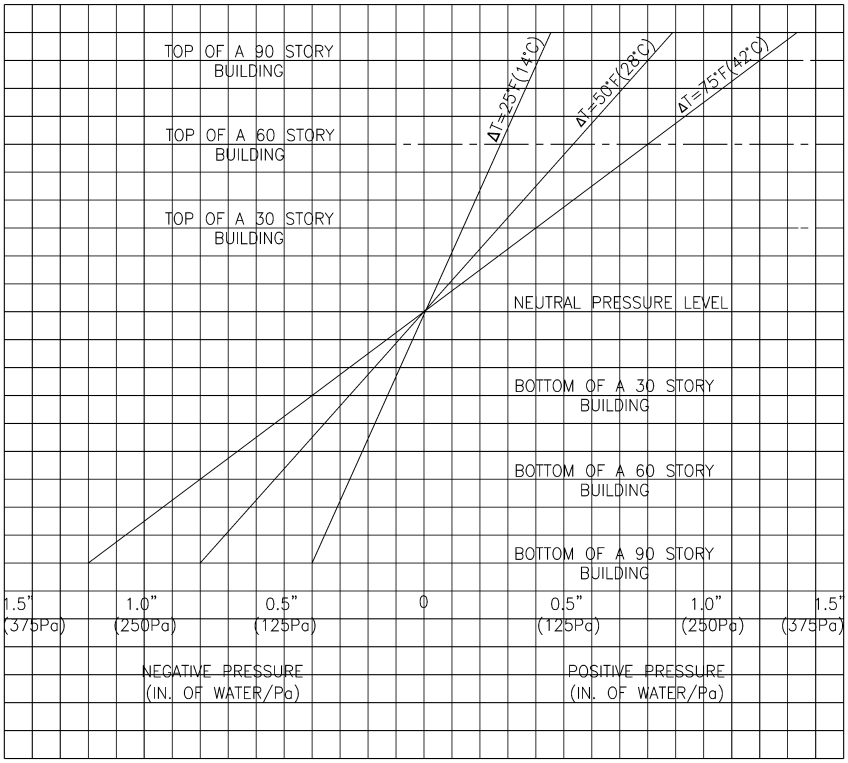


Figure 2-2. Theoretical stack effect pressure gradient for various building heights at alternative temperature differences.

NOTES:

1. ΔT EQUALS TEMPERATURE DIFFERENCES BETWEEN CONDITION INSIDE AND OUTSIDE THE BUILDING.
2. FLOOR TO FLOOR HEIGHT FOR ALTERNATIVE BUILDINGS IS ASSUMED TO BE 13'-0"(4.0m).

2.2 PRACTICAL CONSIDERATIONS OF STACK EFFECT

The existence of stack effect in tall commercial buildings has often presented major problems. The problems most frequently manifest themselves in difficulty getting elevator doors to close and in difficulty heating lower levels of the building. The elevator doors' failure to close properly is due to the pressure differential across the doors, which, in turn, causes the door to bind in its guideway to the degree that the closing mechanism for the elevator doors does not generate sufficient force to overcome the binding effect. The heating problems are due to the substantial influx of cold air through the doors at the entrance level itself and across the outside wall of the building due to the permeability of the wall being higher than the design requirement of the specification for the wall. The heating problem can be so severe as to freeze the water in sprinkler system piping, and in cooling coils, if the chilled water is not circulated. The National Association of Architectural Metal Manufacturers specifies a maximum leakage per unit of exterior wall area of 0.06 cfm/ft^2 (300 cm^3/m^2) at a pressure difference of 0.30 in. of water (75 Pa) exclusive of leakage through operable windows. This type of criterion, even when contained within a project specification, is not always met in actual construction, thereby causing potential operational problems.

Two actual examples, while extreme in nature, will allow a better perception of the degree to which stack effect can cause major problems in a building in cold climates.

A very tall commercial building in Chicago was partially occupied in September of a given year. At the time the building was usefully occupied on its lower floors, the top of the building was still under construction and open to atmosphere. Only the lowest thirty percent of the building was occupied, but there were few operating problems as the construction of the top portion of the building continued into the fall. Major problems only occurred when winter hit the area and temperatures 20°F (–7°C) and below were experienced. At this time, the neutral pressure level in the building, due to the openings at the top, was raised substantially above the midpoint. (In a practical sense, the neutral pressure level was at the roof and the entire theoretical pressure differential was experienced at the entrance level.) The result was collapsing revolving doors, an inability to close elevator doors, and total failure in the provision of heat for the entrance levels of the building. Additional heated outdoor air was introduced at the entrance level, stairs were sealed at the point where occupancy stopped, and the construction at the top of the building was expedited to obtain closure of that portion of the building. By midwinter, these efforts minimized the problems to allow more conventional usage of the occupied lower floors.

Another problem developed in a 64-story building in New York City that was built in part over a major transportation hub with a direct open connection from the building to the transportation hub itself. The transportation hub, through the means of train tunnels entering and leaving the hub and the multiple doors that open and close as train passengers enter the center, is effectively open to atmosphere. With large volumes of outside air entering the train hub and being able to directly pass to the connected office building, the result on cold winter days was such that the elevator doors would not close and comfort conditions could not be maintained in the lobby areas of the office building.

The resolution of the problem in this building was to provide a glass enclosure with revolving doors between the office building lobby and the escalators that allowed individuals to enter the train station. The practical closure of the openings to the train station solved the elevator door and heating problems, while the construction of the closure in glass allowed the visually desired sense of opening to continue to exist.

2.3 MEANS TO MINIMIZE STACK EFFECT

Fortunately there are steps that can and should be taken in the design process to minimize the potential problems that will develop through stack effect. The necessary steps must be taken by both the architect and the HVAC design engineer. The steps that can be taken involve minimizing the air leakage into or out of the building. While it is not possible to completely seal any building, through consideration of the normal points at which outside air can and does enter and move vertically through the building, the problem can be mitigated.

The points at which outside air will infiltrate a building include the entry doors to the building as well as doors that open to truck docks, any outside air intake or exhaust louvers that are provided in the building, overhangs in the construction with light fixtures that are located immediately above the ground level and are not properly sealed against leakage or provided with heat, and any possible small fissures in the exterior wall itself. Internally, the building will allow the passage of air through the fire stairs, elevator shafts, mechanical shafts for ducts and piping, and any other vertical penetrations that exist at the edge of the floor slab at the exterior wall or for pipes. All these are candidates for careful review to ensure, to the degree possible, that a tight exterior wall is constructed, closure of all shafts is provided, and the sealing of all penetrations is provided. Vestibules or air locks can be provided for loading docks, with good door seals on the doors to and from the loading dock.

The entry doors for tall buildings in cold climates should always be revolving doors. Doors of this type are important in that they are balanced with equal pressure in opposite directions on the panels on either side of the central pivot, making their operation relatively simple with no special effort being required to have them turn. They also provide closure at all times due to the gasketing that is included in a quality revolving door.

Two-door vestibules with adequate heat will work for the loading dock, assuming the doors are properly spaced to allow them to be operated independently, with one of the two doors to the vestibule always being closed, and sufficient heat is provided in the space between the doors. If properly spaced, the simultaneous opening of both doors on either side of the vestibule can be controlled. However, two-door vestibules have proven inadequate for personnel entry since, with large numbers of people entering the building at various times, both doors will be open simultaneously and significant quantities of air can enter the building. In projects where two-door vestibules have been tried in cold climates for tall buildings, there have inevitably been problems. It is strongly recommended that revolving doors be used at all points of personnel entry.

To control possible airflow into the elevator shaft, the inclusion of doors at the entry to the elevator banks should be considered. This creates an elevator vestibule on each floor that will minimize the flow through elevator doors that open on any given floor.

It is possible, and will have beneficial effect, if stairs are interrupted with doors with good seals, to minimize the flow of air vertically through the buildings. This is particularly true of fire stairs that would run the height of the building. These entry doors to fire stairs should be provided with good door and sill gaskets. As is discussed in chapter 9, “Vertical Transportation,” the elevator shafts are a problem because an air opening may be required at the top of the elevator shaft. All shafts, however, can be sealed in their vertical faces to minimize airflow into the shaft that would travel vertically in the shaft to the openings at its top.

The last key item is to ensure a tight exterior wall through specification, proper testing, and the hiring of a proper contractor to erect the wall.

All of the above discussions involve the architect and the trades for which the architect is responsible. The HVAC designer must include mechanical air-conditioning and ventilating systems that supply more outside air than they exhaust. This is true of all systems where, to ensure pressurization, a full air balance should be used for the entire building with a minimum of five percent more outside air than the combination of spill and exhaust air being provided at all operating conditions. In addition, it is good design, and often required by code for smoke control reasons, to have a separate system for the entrance lobby. Although not always required, this system, if provided, can be designed to operate in extreme winter outside air conditions with 100 percent outside air. Under these circumstances, this air will be used to pressurize the building lobby, which is a point of extreme vulnerability in the overall efforts to minimize the harmful impact of stack effect.

Chapter 3

The Design Process

The preceding chapters discuss real estate and technical problems that are of significant import in the tall commercial building. The chapters that follow are concerned with the systems and details of those systems that find application in the tall building as well as specific technical issues that may not be unique to the tall building but may well have special considerations that must be understood and responded to in the HVAC designs for that type of project.

For any tall commercial building, multiple alternative solutions are possible and the selected approach for one project may not be appropriate on the next project. The selected design will differ with the project, its usage, location, and owner. Only through analysis and an iterative process that examines the real estate needs of a building and the proposed architectural design can the most appropriate solution be selected by the HVAC engineer. Even after the selection of a solution, the design must be completed through a process or series of steps that are well established and that will permit reviews of the evolving design by the owner to allow discussions of possible modification of the design to better meet the perceived needs of the goals of the project.

The process followed in the design of the tall commercial building does not differ in any significant detail from the design process employed in most other commercial or institutional projects. The steps in the design process for any of these projects will usually be consistent with the services that are rendered on the project by the architect. This recognizes that the architect is usually the leader of the design team and the steps in the design process are those that have been standardized and are followed by most architects. Other members of the design team, including the structural engineer as well as the HVAC, electrical, plumbing, and fire protection engineers, while frequently independent practitioners, will function, in large part, in response to the efforts of the architect.

There are, of course, in the United States, integrated offices that consist of architects and the several engineering disciplines functioning under a single ownership. The inclusion of all the design team members in a single office does not significantly alter the relationship that must be developed among the several design groups during both the design and the construction phases of the project.

3.1 PROJECT PHASES

The design and construction of any project will be completed in a series of phases. The phases can differ from project to project or in different geographic areas of the United States, but frequently they will be as established by the American Institute of Architects in their Standard Form of Agreement Between Owner and Architect (AIA Document B141). The use of this document, or a modified version of the agreement, establishes the design process for a project. It states that the basic services of both the architect and the design team will be completed in the following phases:

- Schematic design phase
- Design development phase
- Construction document phase
- Bidding or negotiation phase
- Construction phase

The efforts in each of these phases by the HVAC engineer require amplification to allow an understanding of what is occurring in the phase and to allow a proper implementation of the design process.

3.1.1 Alternative Processes

Before discussing each phase under the AIA Standard Form of Agreement, it is important to understand that other procedures can be followed. These can be procedures developed by a specific owner or developer or one that has found application in different geographical locations. In addition, the Engineers Joint Contract Document Committee (EJCDC) has prepared a family of contract documents that can be used by engineering firms. The EJCDC documents are issued and published jointly by the American Council of Engineering Companies (ACEC), the National Society of Professional Engineers (NSPE), and the American Society of Civil Engineers (ASCE). Included in their documents is an agreement titled “A Standard Form of Coordinated Multi-Prime Design Agreement Between Owner and Design Professional for Construction Projects.” This agreement has a series of phases that differ by title and function from those in AIA Document B141 but that could be used by design engineers for commercial and institutional projects—but with significant inconvenience if the owner is dealing with the architect under the AIA agreement. The EJCDC contracts have therefore found their widest usage in civil engineering projects such as bridges and road construction.

In accordance with the conventional design procedures and phases as defined in the AIA document, our discussion will focus on the design phases used by architectural firms as the design process to be utilized by the mechanical and electrical engineering design offices. The effort in each of these phases requires some amplification to allow an understanding of what is occurring in the phase and to allow a proper implementation of the design process.

3.1.2 Schematic Design Phase

At the commencement of the schematic design phase, the design objectives and scope of the project should be reviewed with the owner or developer. In an owner-occupied building or build-to-suit project, a full design program should have been established detailing the requirements of all of the facets of the project. This programmatic definition was discussed in chapter 1.

A developer building will usually be less fully defined, and it will be necessary for the HVAC engineer to provide a basis of the design that will be included on the design documents for the project. With an owner-occupied build-to-suit or developer building, an early step is to provide a “Project HVAC Design Criteria and System Description” for review and acceptance.

In the owner-occupied or build-to-suit building, it will establish the design criteria for the several functions requested in the owner’s program and define the systems that will be provided to meet these requests.

In the developer building, the same information will be provided but frequently with limited knowledge of the tenants who will settle in the building. The developer may provide a description of the type of tenants expected to take space in the building.

This could include the type of businesses, the space needs of individual tenants, and the like. The information provided will allow the HVAC engineer to define any special features that are proposed for the project. These could include supplementary condenser water systems, telecommunication design features, and the like.

While acknowledging that different projects will have alternative solutions, a typical Design Criteria and System Description document is included as an appendix to this chapter. The Appendix provides design criteria and a system selection to allow an understanding of the type of information and the detail of that information that will be provided at this early stage to the owner, the architect, and the other members of the design team. A complementary set of information will be developed for the electrical, plumbing, and fire protection trades, which, when combined with the Heating, Ventilating and Air-Conditioning Design Criteria and System Description, will provide to ownership an early description of the total design of the mechanical, electrical, plumbing, and fire protection trades for review, possible modification, and ultimate acceptance.

The design criteria will be tailored to the project and its location, and they will be critical in determining the design capabilities necessary for the building. The electric cooling load from lighting and small power should be stated not only for office, retail, and lobby spaces, but for any required computer space, a trading floor, an auditorium, or any of the other special spaces that find their way into office buildings.

The lighting loads in office spaces have diminished recently and today will not exceed 2.0 W per net ft^2 (22 W per net m^2) and frequently will be as low as the 1.5 W per net ft^2 (16 W per net m^2) shown in the enclosed design criteria. The small power component for most office spaces will usually not be less than 2.0 W per net ft^2 (22 W per net m^2) and can be as much as 4.0 W per net ft^2 (40 W per net m^2). The difference will be in the expectation of the concentration of personal computers, printers, and the like (and the possible tenants who will occupy the project). A corporate headquarters will usually meet the higher small power electric load, and a developer building, which may well be intended for a less sophisticated occupancy, will gravitate to the lesser loads.

The point of this is that the Design Criteria and System Description will establish a standard of capacity and solution that will be reviewed by ownership and accepted at a very early step in the design process. The document will also establish the systemic solutions that will be reflected on the schematic design drawings. These drawings will, at a minimum, include block layouts showing location and space requirements of equipment, shaft sizes, and distribution arrangements of all systems. The capacities of major equipment for each system will be provided, with the understanding that the capacities and arrangement of the systems may be modified as the various elements in the project evolve and are more fully defined. Finally an outline specification will be included establishing a standard for the equipment required for the project with a sufficient level of detail to allow a budget estimate to be completed for the project.

In total, the product of the schematic design documents will contain sufficient information to allow an understanding of the solutions proposed for the project and to permit a preliminary construction cost estimate to be developed for the owner. The HVAC documentation and cost will be combined with the other design team members' documents and their budget costs to provide to the owner a reasonable estimate of the design approaches being proposed for the project as well as their scope and expected cost.

3.1.3 Design Development Phase

The schematic design documents, after review by the owner, will be approved. The approval can be total or it can include requested changes or modifications to the schematic design package. Based on this approval, the HVAC engineer will prepare design development documentation. This documentation will go beyond the schematic drawings in detail, will confirm or revise system capacities, and, in general, will be a more fully developed set of drawings. The documents will include a more detailed specification and include matters only briefly addressed in the schematic drawings.

At the time that the design development documentation is being completed, a written interdisciplinary description of the fire protection plan for the project will frequently be completed by the design team. The material included will be in sufficient detail to permit a review of the design team proposals for the project and to allow the governmental agencies to provide discussion and comments on the submitted plan. The governmental agencies will usually include both the building and fire departments. The material that is submitted will usually include as a minimum the following:

- A definition of the applicable building code used in the design.
- Physical data on the project that would provide the name of the owner, the legal location of the project as detailed on city maps, the building area, the number of floors in the building and their specific usage (e.g., retail space, entry level, office floors, mechanical floors, etc.). The building height, gross area, and occupancy classification will typically also be provided.
- The architect will provide physical data on the project that will include the points of entry to the building, the elevator configuration and the means of egress from the building, and the fire rating of shaft walls and other spaces in the building.
- The structural engineer will provide a brief description of the structural system and slab construction, including the necessary fireproofing protection for both the structural steel elements and the slab.
- The mechanical, electrical, and fire protection engineers will provide full details of the life safety system and equipment that is to be provided for the project. The normal facets of the life safety system are discussed in chapter 10, “Life Safety Systems.” The information provided will include the necessary details of the central fire command center, the fire alarm system, the communication systems, the sprinkler and fire stand pipe system, the elevator recall system, the emergency/standby power system, and the means of smoke control in the design.

The entire design team will use this fire protection plan and the necessary drawings that are included for clarification to obtain the necessary governmental approval for the project.

An updated budget will also be prepared based on the design development documentation that will confirm or modify the previous project cost estimates. The project costs and documents will again be subjected to review by the owner who will approve the documents or request changes to specific details.

3.1.4 Construction Document Phase

The approved design development documents, when provided with any requested modifications of these documents by the owner, will allow the design team to complete the construction documents. These include fully coordinated HVAC drawings and a full specification that will, in conjunction with the plans and specifications prepared by the other disciplines, allow the project to be bid and contracts to be awarded to several subcontractors.

This requires that all mechanical equipment rooms be fully designed and coordinated with other trades. In addition, all shaft requirements, riser diagrams, and piping and ductwork must be shown. Full schedules are necessary that will provide the size and capacities of all equipment necessary for the project. In short, the documentation will provide all the information needed by contractors to construct the project.

3.1.5 Bidding or Negotiation Phase

After release of the documentation to contractors, the architect and engineers will assist the owner, as needed, in the negotiation with contractors. This may require attending meetings with the contractors to answer questions or responding to written questions submitted by the contractors on design details.

The engineers may be requested to analyze the bids prepared by the contractors and evaluate the details of the contractors' proposals. This phase of the design process will be completed when the contracts are awarded for the project.

3.1.6 Construction Phase

The construction phase commences with the award of a contract for the project and usually ends with the issuance by the owner of a certificate of completion or a similar document.

This phase is almost always twice as long as the previous four project phases combined. It will find the engineer performing multiple functions. These include a review of shop drawings and product data on equipment being supplied for the project, approval of contractor drawings of the installation, replying to contractors' questions on design details of the work included in the design documentation, and periodic visits to observe the installation and prepare lists on points of discrepancy in the completed work by the contractor. Frequently the engineer will be requested to approve the contractor's invoices for completed work.

At the project completion, the design team, including the HVAC engineer, will be asked to assist and determine the date or dates of substantial completion by the contractor. These are critical dates, as they usually establish the time when warranties by the contractor and equipment manufacturer are started.

In general, during the construction phase, the HVAC engineer performs multiple tasks to expedite and assist the construction process and to ensure that the design intent is respected in the completed installation.

APPENDIX TO CHAPTER 3
HEATING, VENTILATING, AND AIR-CONDITIONING DESIGN CRITERIA AND SYSTEM DESCRIPTION FOR A MULTITENANTED OFFICE BUILDING

1. GENERAL

a. The entire installation will comply with all applicable governmental codes and local regulations.

2. DESIGN CRITERIA

a. Temperature and Humidity Conditions

1) Outside Design Conditions

a) Winter 0°F (–18°C) dry-bulb

b) Summer 95°F (35°C) dry-bulb
75°F (24°C) wet-bulb

2) Inside Design Conditions

a) Heating

All occupied spaces	72°F (22°C) dry-bulb maximum*
Storage and Mechanical/ Electrical Equipment Areas	65°F (18°C) dry-bulb
Elevator Machine Rooms	65°F (18°C) dry-bulb

* No humidification will be provided.

b) Cooling

All Occupied Spaces	75°F (24°C) dry-bulb ± 2°F (1°C) 50% R.H. max. ±5%
Storage/Mechanical Areas	Ventilated only
Electrical Equipment Rooms	Ventilated or air Conditioned to 85°F (30°C) dry-bulb minimum
Elevator Machine Rooms	Air conditioned to 80°F (27°C) dry-bulb minimum

b. Internal Heat Loads

1) Office Spaces

Lighting	1.5 W/net ft^2 (16 W/net m^2)
Small Power	2.5 W/net ft^2 (27 W/net m^2)
People	1 person/100 net ft^2 (9.3 net m^2)

2) Retail Spaces

Lighting and Small Power	17 W/net ft^2 (180 W/net m^2)
People	1 person/50 net ft^2 (4.6 net m^2)

3) Lobby Spaces

Lighting and Small Power	10 W/net ft^2 (100 W/net m^2)
People	1 person/100 net ft^2 (9.3 net m^2)

c. Minimum Outside Air Quantity

1) Office Spaces

20 cfm (9.44 Lps)/person.

2) Retail Spaces

20 cfm (9.44 Lps)/person with a 50% occupancy diversity factor applied to the population.

d. Acoustical Design Criteria

1) Office Spaces

Noise levels will conform to a noise criteria of NC35 except that within 10 feet (3 m) of the local floor fan room, NC40 will result.

2) Retail Spaces

Noise levels will conform to NC35 subject to a review of the tenant architectural and engineering design details

3. SPECIAL DESIGN FOR SUPPLEMENTARY COOLING

a. In addition to the capacity to handle the above cooling loads, as well as the cooling needs of the building facade, the condenser water delivered to each office floor will have the capacity to provide an additional 2 W/net ft^2 (22 W/net m^2) to be used by each tenant for supplemental cooling loads. Tenants utilizing this capacity will provide their own air-handling units and extend the condenser water from valved connections provided in the local fan room.

4. AIR-CONDITIONING SYSTEMS

a. Office Floors

1) The air-conditioning systems will be all-air variable air volume type. Supply air will originate from condenser water cooled, direct expansion (DX) packaged air-conditioning units located on each floor in a local floor fan room. Each unit will be factory-assembled medium pressure, variable air volume, arranged in a draw-through configuration, utilizing plenum type or mixed-flow type fans with variable-speed control, complete with all necessary compressors, prefilters, filters, fan discharge and return air smoke dampers, automatic louver dampers, direct expansion and condenser water economizer cooling coils, discharge plenum, acoustic treatment, insulation, motors, and variable-speed drive with radio noise filter reduction, motor acoustic noise reduction filter, a.c. reactor to suppress harmonics generated by the variable-speed drive system, motor controllers, ductwork, and smoke detectors. Each system will be designed to operate with a water-side economizer cycle, which will provide free cooling when the systems are operating during the winter cycle. The fan systems will be capable of varying from 100% of design airflow down to 20% of design airflow, utilizing variable-speed fan motor drives. Each local fan room will be configured as follows:

a) Outside air will be supplied to each floor via a supply air riser located within each local floor fan room. The local fan room will be utilized as a mixed air chamber. A constant volume regulator (CVR) will be provided to supply minimum outside air to each fan room and a maximum outside air tap with an automatic louver damper (ALD) will be provided for each fan room to provide a means of supplying 100% outside air on a selected floor-by-floor basis for use during initial purging of volatile organic compound (VOC) out-gassing after initial fit-out construction is complete, following future fit-out construction, for periodic normal floor purging of indoor pollutants, and to assist in smoke purging and/or pressurization during and/or after a fire. The outside air system has the capability to supply 100% outside air to a minimum of three floors simultaneously.

b) Smoke exhaust risers located within the building core will provide smoke exhaust from each floor. The smoke exhaust risers will be sized to exhaust a minimum of 6 air changes per hour for the volume of the floor inclusive of the return air plenum volume from three floors simultaneously.

c) All connections into vertical duct risers will be provided with combination fire/smoke dampers, which may function as control ALDs. All ALDs and/or combination fire/smoke dampers will be UL listed and meet the requirements of UL555S and be of the low leakage type (Class II rating).

d) Each air-conditioning unit will provide a minimum available external static pressure of 2.50 in. of water (625 Pa). The minimum available static pressure at the core wall leaving the Fan Room will not be less than 1.50 in. of water (375 Pa).

e) Each unit will be provided with Class I, 20% efficiency prefilters (at 1 micron) and a 95% efficiency (at 1 micron) 12 in. (300 mm) deep rigid final filter, DX cooling coil, and a high-efficiency variable-speed motor.

    f) In addition to the particulate filtration, each unit will be provided with disposable activated carbon absorber type filters for mitigation of gaseous chemical contamination.
    g) Units will be internally lined and be selected acoustically in conjunction with the construction of fan room walls and entry doorways into fan rooms so as to limit the maximum NC immediately outside the fan rooms to NC-40.
    h) All damper actuators and valve actuators will be pneumatic. Control of units will be by factory furnished and installed DDC control panels, which, in turn, will be networked into a central DDC building automation and temperature control system for the building. All fresh air units and local floor fan rooms will be provided with smoke detection as required by code.
    i) The air quantities will be based on a room temperature minus entering room supply air temperature differential of 18°F (10°C).

b. Central Station Air-Handling Units
   1) Outside air supply systems (100% outside air) will be located in main mechanical equipment rooms (MERs). These supply systems will provide outside air to each office floor via a riser located within the local fan room. Systems will be variable-volume type equipped with Class I, 20% efficiency prefilters (at 1 micron) and 95% efficiency (at 1 micron), 12 in. (300 mm) deep rigid final filter, hot water heating coils for outside air tempering and building warm-up capability, and variable-speed motors.
   2) Central smoke exhaust fans will be provided and be connected to the smoke exhaust risers (described above) that serve the office floors. Central smoke exhaust fans will also be provided to exhaust the ground floor and basement levels.
   3) The ground floor lobby air-conditioning system will be an all-air constant volume DX system with 100% outside air capability. The system will be provided with a dedicated return air/smoke exhaust fan.

5. HEATING SYSTEMS

a. The building will be heated by finned tube heating elements within an architectural enclosure located at the base of the facade wall at each office floor. The system will be fed by supply and return loops serving water risers at the perimeter columns and will be piped in a reverse return arrangement.

6. COOLING TOWER

a. A cooling tower will be located on the roof and will consist of multiple cells, sized for the installed refrigeration tonnage of the packaged direct expansion (DX) equipment plus an allowance of 2 W/usable ft^2 (22 W/usable m^2) of additional capacity for supplementary loads on the office floors.
b. The cooling tower condenser water system will be provided with a bypass sand bed filtration system.
c. Cooling tower cells will be of the packaged, induced draft, cross-flow type with variable-speed motors. Tower cells will have stainless steel basins and sumps with hot dipped galvanized frames and noncombustible fill. Each cooling tower cell will be winterized.
d. The spare capacity for supplemental cooling needs will be distributed by means of the main secondary condenser water risers, which extend from the cooling towers located on the penthouse mechanical equipment room down to the floor-by-floor

fan rooms. Valved outlets will be provided in each floor fan room for future extensions.

e. Condenser water will be distributed to the floors by central primary and secondary condenser water pumps and plate-and-frame heat exchangers located in the penthouse mechanical equipment room. The pumps will be double-suction centrifugal type sized for the full rated capacity of the cooling towers they serve.

f. A completely automatic system of condenser water treatment will be provided for the building condenser water/cooling tower, complete with automatic feed pumps for corrosion inhibitors, dispersants, biocides, etc.

7. FUEL OIL SYSTEMS

a. Emergency Generator Plant

  1) A No. 2 fuel oil system will be provided for the building emergency generator plant. The fuel oil storage will be sufficient for full-load operation of the life safety emergency generator for a 24-hour period.

8. LIFE SAFETY SYSTEM AND SMOKE CONTROL SYSTEM

a. Dedicated smoke exhaust fans and risers (complete with fire/smoke dampers at each floor takeoff) will be utilized for smoke control by means of pressurization and exhaust, all as controlled from the smoke damper and fan switch panel located within the central fire command center.

b. The outside air supply systems will be capable of providing 100% of their capacity for floor pressurization and will be capable of being controlled from the central fire command center in a similar manner to the smoke exhaust fans described above.

c. Stair Pressurization System

  1) The two interior stair towers above grade will be designed to resist smoke infiltration. Each of the interior stair towers will be provided with a dedicated pressurization system that will draw supply air directly from atmosphere. Air will be distributed vertically from each fan system to stair discharge points located on approximately every other floor. Pressure relief ducts consisting of adjustable barometric backdraft dampers and fire dampers will be located approximately every other floor between the stair tower and the adjacent floor space. Each fan system will be controllable from the fire command center.

  2) The supply air quantities to each interior stair tower will be such as to achieve 0.10 in. of water (25 Pa) when all doors are closed and 0.05 in. of water (12.5 Pa) when any three doors are open.

9. ELEVATOR MACHINE ROOMS

a. Elevator machine rooms will be air conditioned utilizing packaged condenser water cooled units.

b. All elevator hoistways will be provided with dedicated hoistway smoke venting ducted directly from the hoistways to atmosphere. The smoke vents will be provided with fire/smoke dampers activated by smoke detectors located at the top of their respective hoistways. Each dedicated smoke vent riser will be encased in a two hour fire rated enclosure in its entirety from the hoistway to the terminus at an outside air louver.

10. MISCELLANEOUS SYSTEMS

a. Dedicated systems of ventilation and exhaust will be provided for the loading dock, emergency generator system ventilation, toilets, domestic water and fire pump rooms, electric network compartments, central mechanical rooms, etc. Packaged air-conditioning units will be provided for the electric switchgear rooms.

b. A system of products-of-combustion exhaust piping from the building emergency generators, including piping, insulation, and exhaust silencers, will be provided.

c. Unit heaters will be provided for entrance heating, truck dock areas, mechanical rooms, and miscellaneous general building support areas.

d. Core toilets on each floor will be exhausted at a ventilation rate of two cfm/ft^2 (10 Lps/m^2) via duct risers located in the building core. Supply air will be provided at a rate of one (1) cfm/ft^2 (5 Lps/m^2).

e. All base building rotating or vibrating machinery, equipment, and piping will be provided with proper vibration isolation components, including concrete inertia bases and steel spring vibration isolators as required to limit noise levels in the surrounding occupied areas in accordance with the criteria previously defined.

f. All systems will be seismically restrained in accordance with the requirements of the local applicable building code.

g. Provide testing and balancing of all hydronic, steam, and air systems.

h. Provide chemical treatment and initial water treatment for all water and steam systems.

i. Provide piping equipment and valve identification system.

j. Provide instruction to the operating personnel regarding operation and maintenance for all HVAC systems.

k. Provide factory and field testing of all major HVAC system components (i.e., chillers, air-conditioning units, etc.).

l. Provide thermometers, pressure gauges, etc., for all systems.

11. BUILDING AUTOMATION AND TEMPERATURE CONTROL SYSTEM

a. The building energy management system will be microprocessor based with distributed direct digital processing. It will incorporate the use of direct digital electronic controls for all central mechanical equipment. Local zone (VAV box) control will be direct digital control type with electric actuators. Final output to terminal devices (i.e., valves, damper operators, etc.) serving central mechanical equipment will be pneumatic. It will be completely stand-alone as a system. Each local floor-by-floor and main air-handling systems and each water system will be provided with a separate DDC unit. The automation system will provide the ability to monitor, control, and optimize the operations of all building HVAC systems and to provide the necessary interfaces to allow proper operation of the building life safety systems. The system will also include a freeze protection sequence to automatically circulate chilled water when the outdoor air temperature drops below an adjustable value.

Chapter 4

Systems

The systems that have found application in tall commercial office buildings have evolved over the past decades in response to the changes in the perceived goals of the entity that is constructing the building, the expanding needs of the potential occupants, be they a corporate end user or a leasing party, and the concerns of the owner with the availability and the cost of energy and the resultant expenditures necessary to operate the building. More recently, the import of environmental concerns, including indoor air quality and the growing challenge to provide safer buildings, has further influenced the approach that is taken in the system selected for a modern tall commercial building.

To meet the challenge of providing systems that address these major issues, the commercially available equipment and the deployment of that equipment have also gone through a period of modification in some design details over the recent past. This process of evolution will undoubtedly continue in the future, but the basic general system categories that are available today, which are discussed in this chapter, will undoubtedly continue to find wide usage in the tall commercial building. It is the technical details of the system design that have been and will be subjected to ongoing modification.

The *ASHRAE Handbook—HVAC Systems and Equipment* provides guidelines to allow a quantitative evaluation of alternative systems that should be considered in the system selection process. The *ASHRAE Handbook—Fundamentals* provides means for estimating annual energy costs, and the *ASHRAE Handbook—Applications* discusses mechanical maintenance and life-cycle costing, which may be useful in the evaluation process with regard to alternative systems.

This chapter is concerned with a general discussion of the air-conditioning systems that currently find application in tall commercial buildings. Pertinent details of the installation of these systems are covered in subsequent chapters of this design guide or in the ASHRAE Handbook references.

4.1 CONSIDERATIONS IN SYSTEM SELECTION

In a fully developed building, including the cost of the space developed for occupancy, the cost of mechanical and electrical trades (i.e., HVAC, electrical, plumbing, and fire protection) can be as much as 35 percent and will usually be in excess of 25 percent of the overall cost (exclusive of land costs) of a high-rise commercial building. In addition, as a function of the building size and the selected system and arrangement of the equipment to meet the needs of the system, the mechanical and electrical equipment and the associated shafts can consume between 7 and 10 percent of the gross building area. Moreover, the architectural design of the building's exterior and the building core is fundamentally impacted by the choice of the system to be included in the building.

All of this and the other real estate considerations discussed in chapter 1 make the HVAC system selection for any tall commercial office building one that should involve the entire building design team (i.e., the owner, architect, engineers, and the contractors) since all will share in the results of the decision.

There are alternative means of providing air conditioning for the modern high-rise office building. This statement applies to both the system selected, details of the equipment installed, and the location of the installed equipment that is required to provide the operational basis for the selected system. The determination of the appropriate HVAC system and supporting equipment for a project must, as a minimum, be responsive to the following considerations:

- Capital cost
- Initial and future occupancy requirements
- Architectural and structural restraints and objectives
- Internal and external environmental requirements
- Acceptable acoustical levels desired in occupied spaces
- Seismic requirements (when applicable)
- Energy consumption and energy source depletion
- Annual operating and maintenance cost
- Smoke and fire management

This list of points of concern and analysis does not differ in any way from the same type of list that would be prepared for a low-rise building. The alternative systems that could find application will also come from a very similar list of alternative choices, but, as noted below, the choices for the high-rise office building are probably more limited than would be the case for a low-rise project.

4.2 AIR-CONDITIONING SYSTEM ALTERNATIVES

There are a number of alternative systems that have found application in tall commercial office buildings. While the precise configurations of the systems are subject to the experience and imagination of the designing HVAC engineer, the systems that have primarily been utilized are variations of generic all-air systems and air-water systems.

Unitary refrigerant-based systems, such as through-the-wall units, have found application in conjunction with all-air systems providing conditioned ventilation air from the interior zone, but this combined solution has been limited to the retrofit of older buildings that were not air conditioned at the time of their construction and smaller low-rise projects. They are infrequently used in first-class tall commercial buildings due to the several inherent shortcomings of this type of solution. These shortcomings include a probability of higher energy use, the need for routine filter change at each unit and periodic cleaning of the cooling and condenser coils to maintain system capacity, the relatively short equipment life, the inability to cope with stack effect and the outside air flow through the unit, the generation of higher noise levels than are acceptable for first-class office space, and the failure to be able to respond to environmental concerns due to inadequate filtration, poor ventilation air control, and unacceptable space temperature variation as a result of the on-off nature of the compressor control.

Also of limited application in tall commercial buildings in the United States are panel cooling-type systems, including chilled ceiling and chilled beam systems. These systems have found application in Europe as a retrofit alternative in existing buildings that were not air conditioned at the time of their construction since it is possible to install these systems with minimal effect upon the floor-to-ceiling dimension in an existing building.

4.2.1 All-Air Variable Air Volume System

All-air variable air volume (VAV) systems in various configurations are the most commonly used solution in the tall commercial building. The conditioned air for the VAV system can be provided from a central fan room or from a local floor-by-floor air-conditioning system. These alternative means of obtaining the conditioned air are discussed in chapter 5, "Central Mechanical Equipment Room vs. Floor-by-Floor Fan Rooms." This chapter is primarily concerned with the functioning of the system, the configurations finding application, and variations that are possible in the system design.

The VAV system controls space temperature by directly varying the quantity of cold supply air with the cooling load. Previous all-air systems that found application in tall commercial buildings used a constant quantity of air and varied the temperature of the supply air by reheat or, in the case of dual-duct systems, by mixing air from a cold duct with that from a warm duct. Due to their inherently higher use of energy, these alternatives are infrequently utilized at this time in the tall commercial building.

VAV terminals or boxes are available in many configurations for application in the tall commercial building. All of the configurations will control the space temperature by varying the quantity of cold supply air as the cooling load changes in the space supplied by the terminal. For most projects, pressure-independent terminal units are recommended. The VAV terminals used can vary as a function of the details of the design being employed and the nature of the space being supplied with conditioned air.

Interior spaces that have a cooling load at all times of the year regardless of the outside air temperature can use any one of three alternative types of VAV boxes.

- *A pinch-off box that simply reduces the supply air volume directly with a reduction of the cooling load.* This type is a very commonly used terminal that finds application in commercial projects. It has the advantage of having the lowest vertical dimension of any terminal used in office buildings. It has the disadvantage that at low cooling loads, the airflow may be reduced to the point where poor air circulation in the space may result. This disadvantage can be overcome by putting a stop or minimum flow of air beyond which the terminal will not reduce the airflow. However, the setting of a minimal airflow from the terminal can result in an inability, when light loads are present, to maintain a thermostatic setting for the space.
- *A series flow fan-powered VAV terminal that maintains a constant airflow into a space by mixing the required amount of cold supply air with return air from the space.* The VAV terminal contains a small fan to deliver the constant flow air to the space. The fan mounted in the unit always operates. This can result in a reduction in the air-conditioning supply fan energy due to the VAV box losses being overcome by the unit-mounted fan. However, since the unit-mounted fan has a very low efficiency, the overall usage of energy by the system will usually be slightly larger than would be the case with a pinch-off box. The slight increase in energy usage is so insignificant, however, that it is rarely a consideration in the terminal selected for a particular project. The primary advantage of the fan-powered box is that the air flow in the space it supplies is constant at all conditions of load and the constant air flow provides excellent, consistent air distribution at all conditions of load. This is of particular import if low-temperature air, discussed below, is used to reduce the distributed air quantity and the energy necessary to distribute the system air.
- *An induction box that will reduce the supply air volume while simultaneously inducing room air to mix with the supply air, thus maintaining a constant supply air flow to the space.* These units require a higher inlet static pressure to achieve the velocities necessary to effect the induction with a concomitant increase in the supply fan energy required for the system. Moreover, operational problems have been experienced with units of this type that have limited their extensive use in large projects. While undoubtedly finding application on commercial projects, this type of terminal is not frequently the choice of many design engineers.

The exterior zone can use any of these three VAV box types, but in geographic locations requiring heat, the system must be designed with an auxiliary means of providing the necessary heat. This can be done external to the VAV terminal by either of two alternatives. In the first, hot water baseboard is installed. The flow of the hot water in the convector can be thermostatically controlled, but more frequently the temperature of the hot water is scheduled inversely with the outside air temperature to increase the amount of heat as the outside air temperature decreases. This more common arrangement eliminates the need for a control valve on the hot water baseboard units. The second alternative is to use electric baseboard on the exterior wall, which will be thermostatically controlled separately from the VAV terminal.

An approach that does not utilize baseboard hot water or electric heat is to include in either the pinch-off or the fan-powered VAV terminal a hot water or electric coil that will be energized as the space temperature continues to drop after the supply airflow has been reduced to a preset minimal flow condition that is established in the VAV box.

4.2.1.1 Low Temperature Air VAV Systems

All of the above variations can be designed utilizing conventional temperature differentials between the supply air temperature and the room temperature. These temperature differentials will be between 16°F (8.8°C) and 18°F (10°C). A number of buildings recently designed are utilizing low-temperature supply air between 48°F (8.9°C) and 50°F (10°C). This increases the temperature supply differential to approximately 28°F (16°C).

This lower temperature air can be obtained by operating the refrigeration machines with the leaving chilled water at 40°F (4.4°C). If ice storage has been included in the project as a means of reducing the electric demand load in the project, the 40°F (4.4°C) water can be provided as part of the ice storage design. The use of low-temperature air is not in and of itself an argument for ice storage, in that the obtaining of the low-temperature air can be through the use of refrigeration equipment providing lower-temperature water to obtain the cold air. If the chiller operates and supplies 40°F (4.4°C) chilled water, the operating cost of the refrigeration plant will be increased and the chiller will have to operate for a longer period of time before the economizer cycle can be used. Moreover, the use of absorption refrigeration machines may not be possible, in that they usually are not capable of providing 40°F (4.4°C) chilled water.

Of greater import is the fact that with a solution employing low-temperature supply air, there is a dramatic reduction in the quantity of air that is being delivered in the building. This reduction in the distributed air and the reduction in fan horsepower results in a saving in fan horsepower that more than offsets the additional energy utilized by the chiller. The application of this lower-temperature air mandates the use of fan-powered variable air volume terminals to avert the problem of reduced airflow at less than design loads, particularly in the interior zone of the project.

4.2.2 Air-Water Systems

Air-water systems historically have included induction systems, but today's systems usually employ fan coil units. When this solution is employed, the fan coil units are installed at the exterior of the building, the interior spaces usually being supplied by an all-air variable air volume system, and the exterior is provided with a constant volume of air. The fan coil units in a tall building that requires winter heat are usually designed with a four-pipe secondary water system. Air from the same duct system that supplies the interior space can also supply the exterior space to provide the necessary outside ventilation air, but the terminals for the exterior are usually constant-volume boxes to ensure air movement and the delivery of ventilation air to these spaces at all times.

An advantage of the air-water system will be a reduction in the required capacity of the supply air and return air systems and in the size of the distribution air ducts from those that would be required with an all-air system (including a low-temperature all-air solution) with a concomitant reduction in the space needed for the air-conditioning supply systems in the mechanical equipment room and that required for the distribution ductwork in the ceiling cavity between the ceiling with its light fixtures and the structural steel and slab of the floor above. The air-water system will, however, require space for heat exchangers and pumps to obtain the hot and cold secondary water for the fan coil units. As discussed in Chapter 1, a reduction in the depth of the ceiling cavity can offer savings in the cost of the exterior wall as well as other vertical elements in the building.

4.2.3 Underfloor Air Systems

Of more recent impact has been the consideration of underfloor air-conditioning systems where the space beneath the raised floor is used as a distribution plenum or where terminal units are installed beneath the raised floor. This would be contrasted with more traditional systems where the terminal units are installed above the ceiling. Either system, with ceiling-mounted terminals or one distributing air through the raised floor, when properly designed, will meet the comfort requirements of the occupants. The underfloor air-conditioning system typically has higher first cost than comparable overhead distribution systems due to the cost of the raised floor. The cost premium can vary as a function of design details for the project. The cost premiums can be substantially offset if the decision has been made by the owner to incorporate a raised floor for power wiring and information technology cable distribution. Without this fundamental decision, the increase in the cost of the floor itself and a possible increase in the floor-to-floor height—with the resultant premium that must be paid for the exterior wall and the extended internal shafts, piping, and stairs—may well be too great to justify the inclusion of the underfloor distribution system.

The underfloor air-conditioning system design in and of itself contains multiple variations. The distribution systems of air in the underfloor distribution systems use the principle of displacement ventilation. Designs typically are implemented with all-air systems in which air is distributed beneath the floor with the void between the slab and the raised floor serving as a supply air plenum. The conditioned air is provided at relatively elevated temperatures of approximately 60°F to 64°F (16°C to 18°C) by blending cold supply air with warm return air. This air then passes from the air-conditioned floor through floor outlets at low velocities and rises vertically to the ceiling through its own buoyancy, removing the heat of the people and office equipment as it rises. The ceiling and the space above it function as a return air plenum where the distributed air is collected and returns to the air-conditioning supply system, which can be either a central air-conditioning system or a floor-by-floor type system. The plenum above the ceiling, due to the absence of supply ductwork, can be reduced in its depth when compared to that required for an overhead distribution system.

A variation of the underfloor air-conditioning system that has found application would be one using all-air terminals or fan coil units beneath the floor in the exterior zone. The use of a thermostatically controlled terminal can be advantageous in altering the unit capacity in the exterior zone with its widely varying loads. In addition, the use of a fan coil unit, with both its ability to modify its capacity output as the load varies and with its inherently greater capacity on a percent basis when compared to an all-air terminal, may well provide a more cost-effective solution for tall commercial buildings, particularly those with larger glass elements in the exterior wall. The design using fan coil units is the same as with all-air terminal designs in that the air would be distributed through floor grilles, with the ceiling acting as a return air plenum.

As discussed in chapter 1, the fact that projects in Europe always include a raised floor for power wiring and information technology cabling has led to the wide acceptance of under-the-floor distribution systems throughout the continent. Although finding application in the United States, that application has been more limited. This limited application is probably due to the infrequent use of raised floors in the United States and the requirement under the National Electric Code in the United States, also discussed in chapter 1, that all cabling distributed in an air plenum must be installed in conduit or carry a plenum rating. Where a raised floor is used for cable distribution only, this need for conduit or plenum rated cabling is not a requirement, but once the raised floor is used for the free discharge of supply air, this requirement becomes mandatory. This can increase the cost of cabling by a substantial percent and can therefore be a significant consideration in the decision process.

It is expected that in the future there will probably be wider application of under-the-floor distribution systems using variable air volume or fan coil terminals because of the potential advantage with these systems that results from the lower cost of reconfiguring a space as the occupancy changes, since all that is required is a relocation of a floor diffuser to meet the altered space needs. This is not dissimilar to the relocation of an electrical outlet to meet a new occupant layout. The increase in the interior design layout modifications at lower cost that results from an under-the-floor distribution system is a matter worthy of full consideration by the owner and the design team.

4.3 AIR-CONDITIONING SUPPLY SYSTEM CONCLUSIONS

For the tall commercial office building, the air-handling systems that find application fall into two major categories with regard to their distribution ductwork. The first would be a central air-conditioning supply system located in a mechanical equipment room within the building that would serve multiple floors above and/or below the mechanical equipment room. The second category would be a local floor air-conditioning system that usually would serve the floor within which the equipment is located. The local floor air-conditioning systems come in two alternative configurations. The first would use air-handling units that contain chilled water coils. The second would use self-contained direct-expansion air-conditioning units. These differing approaches are discussed in detail in the next chapter.

The combination of system components and the resultant system configuration for a specific building are limited only by the imagination of the designer. As was stressed earlier, the chosen alternative is of interest and concern to the owner, architect, and other engineering consultants and, therefore, should be subjected to the scrutiny and review of the entire design team before the selection is made for a given project.

Chapter 5

Central Mechanical Equipment Room vs. Floor-by-Floor Fan Rooms

A major decision that must be made by the entire project team for a tall commercial office building is whether to meet the project needs for conditioned air through air-conditioning supply systems installed in a central mechanical equipment room serving multiple floors or by systems installed in a separate local floor fan room located on each floor supplying air only to the floor on which the system is installed. The choice from any of the three alternative schemes outlined in this chapter is one of the most fundamental decisions that must be made during the conceptual design phase. It is an issue that concerns the owner, each member of the design team, and the constructing contractors who will erect the building from the completed design documents.

It is important to the owner in that it will affect the very basis of the usage and rental of the building as well as both the first cost and the operating costs for the project. It is important to the architect because the choice will modify the building massing and appearance to the degree that the decision will result in a building that is aesthetically different as a function of the alternative chosen. It is important to the structural engineer because it will modify the structural system and slab construction—in specific areas—that will be designed for the project. It is important to the contractors in that it will influence the means and methods and construction schedule that they develop for the project. Finally, it is important to the mechanical and electrical consulting engineers as it will modify their designed product in several obvious and important ways.

The decision, therefore, is one that requires full consideration and detailed input from the entire project team, including the contractors who will be implementing the project designs. While frequently the decision is predicated on what is being done on competitive projects in the same real estate market and may reflect the bias of one or more of the deciding members of the project team, it is possible to establish points of comparison that can be discussed with relative objectivity to allow the decision to be made in a proper manner.

5.1 THE ALTERNATIVE SYSTEMS

As was outlined in chapter 4, the central fan room and the local floor-by-floor alternatives fall into the following three discrete alternatives. Before the development of a comparative analysis can be prepared, the details of each of the alternative possibilities must be discussed.

5.1.1 Alternative 1—Central Fan Room

In this alternative, the conditioned supply air for each office floor originates from multiple air-handling systems located in one or more central fan room(s), which are frequently identified as central mechanical equipment rooms (MERs). The air-handling systems can be factory-fabricated air-handling units but usually, due to the multiplicity of floors being conditioned and the resultant air quantities for the systems, they will be field-erected units. Each air-handling system, as a function of the annual temperature and humidity and building code requirements, can be provided with an outside air economizer through minimum and variable outside air dampers. The multiple systems in a given fan room can be interconnected by having supply air delivered into a common discharge header from all of the supply systems in the given fan floor.

Air from the central fan room(s) is distributed to each floor by means of vertical risers located in two-hour fire-rated shafts within the core of the building. At each floor, horizontal duct taps are made into each riser. The horizontal duct tap contains a fire damper (or a fire/smoke damper as required by the local building code) when air exits the rated shaft. In addition, frequently an automatically remotely controlled, two-position damper is provided. The two-position damper, which, as discussed in chapter 10, “Life Safety Systems,” should be rated as a smoke damper, provides capability for individual floor overtime operation and for smoke control. It will be controlled with regard to its position (i.e., open or closed) by the building management system.

Return air from each floor’s hung ceiling plenum is drawn through horizontal duct taps into vertical return air shafts for return to the central fan rooms. A second two-position, remotely controlled damper is included in the duct stab that provides the connection between the hung ceiling plenum and the return air shaft. This two-position damper, as was the case with the damper in the supply ductwork, is used for individual floor overtime operation and for smoke control. It is also positioned by the building management system.

The return air is not ducted in the shaft, so the air is carried back to the central fan room in the two-hour rated drywall shaft. In each central fan room, multiple return air fans are located that draw the return air from the return air shafts and deliver it to a headered return air duct system within the central fan room.

Where an outside air economizer is included, the return air is either returned to the supply air system or exhausted to atmosphere as a function of the relative enthalpy of the return air and the outside air being provided to the building. The quantity of outside air and the quantity of the return air being utilized by the central air-handling system or being exhausted to the atmosphere is a function of season and the resultant outdoor temperature and humidity. In those warmer geographic areas, where the systems operate on minimum outdoor air at all times, the return air is always returned to the supply air system except for morning start-up or where the fans are under a smoke control operating condition as is discussed in chapter 10.

A typical central fan room arrangement and the supply and the return air shaft arrangements are shown in Figure 5-1. This figure is for a design that includes four supply systems and four return systems, with the ducted supply air being distributed through two shafts above and below the fan apparatus. The return air is being brought to the MER in the same shaft within which the supply duct is routed, but it is not ducted in the shaft. The return air is only ducted within the mechanical equipment room. This arrangement is subject to multiple alternative configurations as a function of the experience, judgment, and analysis of the designing HVAC engineer and, of course, the actual design details of the building.

5.1.2 Alternative 2—Floor-by-Floor Fan Rooms with Chilled Water Units

The air supply for each office floor under this arrangement originates from a local floor fan room, typically located within the building core, that contains a factory-fabricated, chilled water air-handling unit complete with a cooling coil, filters, and fan. Morning heating needs at start-up in cold climates can be provided by a heating coil in the air-handling unit or a unit heater installed in the local fan room. The unit on a given floor usually only supplies the floor on which the unit is installed. Typically one unit is installed on each floor except in the case of large floor areas, e.g., those in excess of

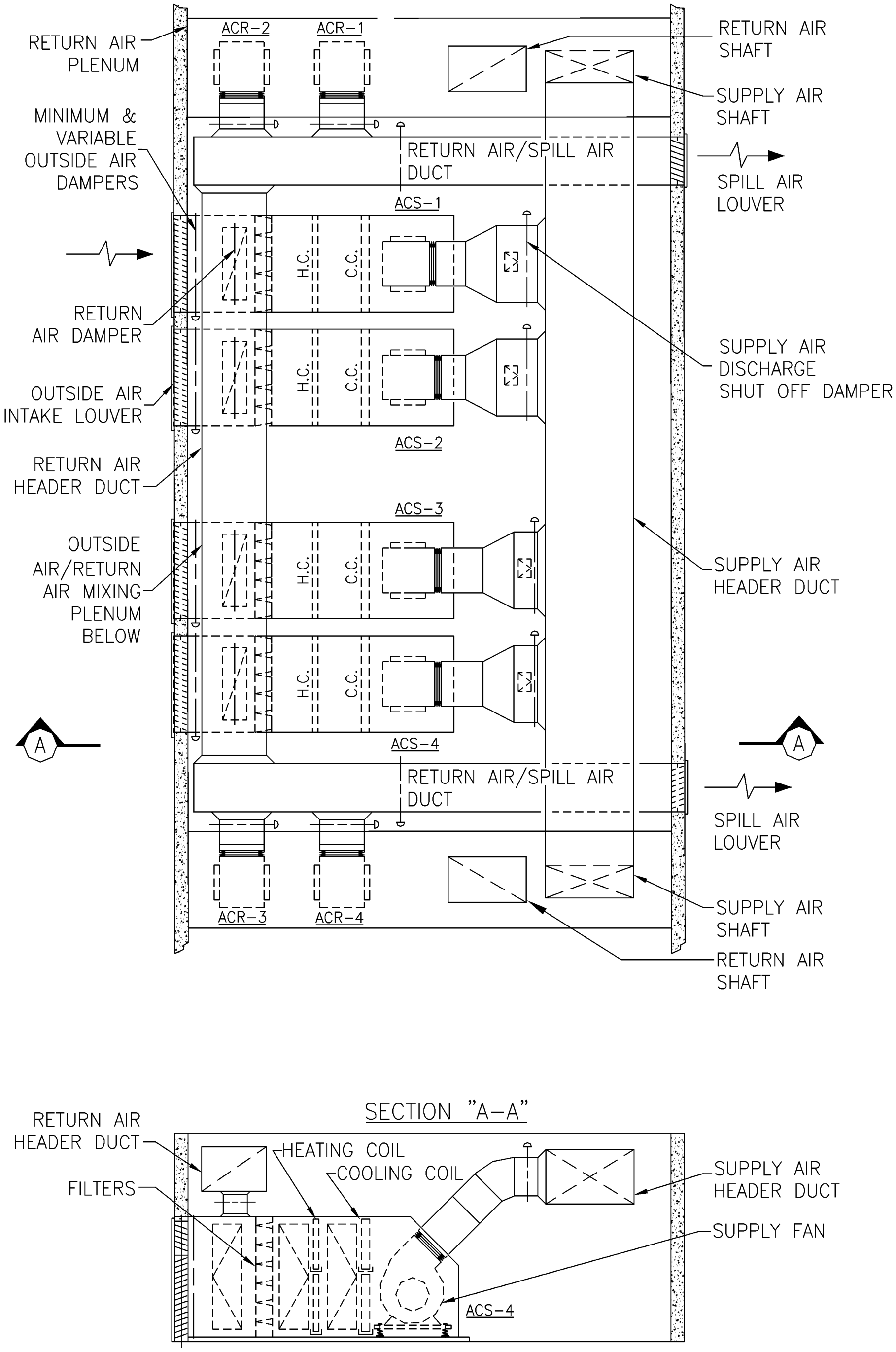


Figure 5-1.
Central fan room arrangement.

approximately 25,000 ft^2 (2,400 m^2) where more than one unit may be required to be installed. Chilled water for the cooling coil is provided by a central chilled water plant in the building sized to meet the capacity requirements of the project. The supply air fan in the air-conditioning supply system also serves as a return air fan for returning the air from the conditioned area on the floor back to the air-conditioning supply unit. The return air is ducted in the arrangements discussed in this chapter to the fan room, but the return air is not typically ducted within the fan room. Accordingly, the fan room in most cases acts as a return air plenum, and all wire and cable within the room must be plenum-rated or within conduit.

This system, regardless of geographic location and the outside air temperature and humidity variation during the year, operates on minimum outdoor air during all periods of occupancy.

The outside air for the system is provided by an air-handling unit located on the roof or in a central mechanical equipment room that provides outside air to the unit on each floor by means of a vertical air riser that is routed to each of the multiple local air-conditioning floor-by-floor air-handling units. The unit that provides outside air to the local floor-by-floor air-conditioning units as a function of the outdoor ambient conditions will usually include a cooling coil and can include a preheat coil to treat the outside air being introduced into the building.

With the air-conditioning supply systems operating on minimum outdoor air at all times, the code-mandated economizer requirement can be achieved, in periods of low wet-bulb temperature, through the use of the condenser water from the cooling tower as a means of cooling the chilled water that is supplied to the floor-by-floor air-conditioning units. This can be done by either of two approaches. The first would be to interpose a flat plate heat exchanger between the chilled water and condenser water and condenser water circuits. The second would be through injecting the condenser water directly into the chilled water system after passing the condenser water through a bypass sand filter to remove any potential fouling material from the condenser water.

The ability to use this system as a means of smoke control in the event of a fire is discussed in chapter 10.

A typical local fan room arrangement showing the supply and return air arrangement and the outside air duct provision is shown in Figure 5-2. The unit heater shown in the figure, as was noted earlier, is to provide morning heat. It can use electric energy or hot water as its heat source. The position of the several dampers that are indicated in the figure would be their operating position during the normal operating day. The position of the dampers in a smoke condition in the building is detailed in chapter 10. The arrangement shown in Figure 5-2 is frequently altered as a function of the location of the local fan room in the core and the prior experience of the designing HVAC engineer, but the equipment should be capable of installation in a space of about 250 to 450 ft^2 (24 to 42 m^2) as a function of the size of the conditioned floor and the precise capacity of the required unit. Figure 5-2 also shows the valved, capped connection of the chilled water piping to allow its extension to a location on the floor that may require the installation of supplemental air-conditioning equipment, such as information technology equipment or a small area with a concentration of data processing equipment. A full-blown data center could probably not be supported by this piped connection due to the limited volume of water that is available in this location. A major data center could only be accommodated if its needs were provided for in the original design of the piping system and the capacity of the piped system.

As shown in Figure 5-2, the walls around the local floor fan room are not rated. The vertical shaft that contains the outside air duct from the central fan room, and perhaps the smoke exhaust ducts, constitute a rated shaft. Accordingly, fire dampers are only provided at the point where ducts penetrate the shaft wall, not as they leave or enter the local floor fan room itself.

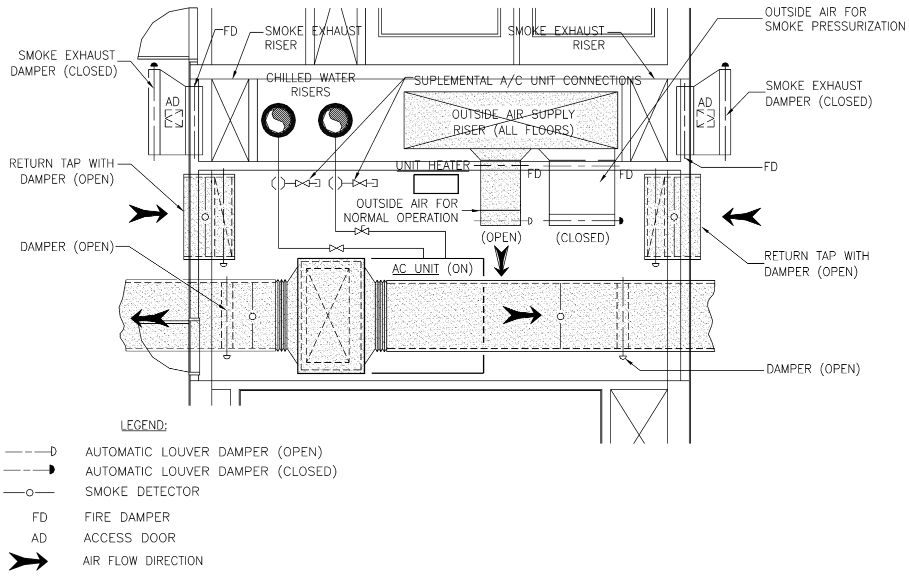


Figure 5-2. Floor-by-floor air-conditioning unit layout (normal operation).

5.1.3 Alternative 3—Floor-by-Floor Fan Rooms with Direct Expansion Units

A second variation of the floor-by-floor alternative would consist of a floor-by-floor air-conditioning supply system identical in its details to that in Alternative 2, except the package unit installed on the floor is a self-contained water-cooled direct expansion (DX) unit complete with one or more refrigeration compressors and water-cooled condensers. The heat of rejection from the compressor is handled by a condenser water system and a cooling tower. If an economizer requirement is needed due to lower geographic outdoor air temperature and humidity, it is met by a free-cooling coil that is installed in the package unit that will only operate when the condenser water being delivered to the unit is below a specified temperature of approximately 48°F (9°C). The only central equipment in this alternative is a cooling tower, condenser water pumps, and the central outside air supply unit. This unit is functionally the same as the floor-by-floor air-conditioning supply unit in Alternative 2, except it would be a direct expansion unit, obviating the need for any chilled water plant in the building.

The physical arrangement of the unit would not differ from that shown in Figure 5-2 other than that the chilled water risers shown in Figure 5-2 would be used for condenser water. One additional difference is that the unit heater will usually be electric because the electrical capacity of the unit heater can be met by the electrical needs of the refrigeration compressors, as they will not both operate simultaneously. The electrical design for the project must be provided with a control means that will prohibit the simultaneous operation of the refrigeration compressors and the electric unit heater.

5.1.4 Floor-by-Floor Units Located on an Outside Wall

There is a variation of Alternative 2 and Alternative 3 that has found application in tall commercial office buildings to a sufficient degree that it should be noted. This would be a package floor-by-floor unit solution where the unit is located on an outside wall. In this alternative the unit can be found in a core area where the building core is located on an outside wall. It can also be utilized where there is a central core, with the floor-by-floor unit being installed in a location remote from the core. This arrangement is not common in that exterior space with the usual inclusion of windows is a preferential location for office space and locating the unit on an outside wall will utilize valuable usable space.

If this alternative location of the floor-by-floor unit on an outside wall is utilized, it eliminates the need for the separate outside air unit located in a central fan room, in that outside air can be directly introduced to the floor-by-floor unit through a louver and automatic louver damper for each unit. Moreover, it may allow the use of an air-cooled condenser to handle the heat of rejection in Alternative 3. In locations requiring an economizer, that requirement with this unit location can be satisfied by the inclusion in the design of a minimum and variable air damper behind the outside air louver.

Precautions are necessary in several details of this arrangement. First, where an outside air economizer is used for either Alternative 2 or Alternative 3, care must be taken in the location of the return air spill damper to ensure that mixing of the outside air and spill air does not occur. Similar care must be taken if it is determined, in the case of Alternative 3, to use an air-cooled condenser to allow the outside air to be brought to the air-cooled condenser and to be spilled to atmosphere with no possibility of mixing the heated discharge air with either the condenser intake air or the outside air being brought into the building by the supply air-conditioning unit. This can become a complicated alternative arrangement that may necessitate the air-cooled condenser being located at a point remote from the local fan room.

5.2 POINTS OF COMPARISON OF ALTERNATIVE SCHEMES

The comparison of the three alternative systems can be made on a rational basis. The points of evaluation must be part of an overall analysis that is made at a very early stage of the project since the decision about the alternative to be utilized will impact the architectural core that is included in the project as well as significant portions of the building, including both the location and the configuration of mechanical space as required in areas other than on the typical office floors.

5.2.1 First Cost

The relative cost of the three alternatives outlined in this chapter will vary from project to project and with the geographic area within which the building is located. Moreover, the first cost analysis must include not only the mechanical system but also the electrical system and the general construction cost of the different types of spaces that are provided. There is only one way in which an accurate comparison can be made and that is to provide a developed set of schematic plans in sufficient detail to allow a cost estimate to be completed by either the contracting team retained for the project or a professional estimating service. These cost estimates should also reflect the altered total space required for each of the three considered alternative schemes. A matrix that details the comparative points of first cost comparison is provided in Table 5-1. The intent of this matrix is merely to outline points of comparison by trade; it is only through a complete cost estimate that the true comparative costs can be determined.

The capital costs for the three alternative solutions will be affected by the local construction trades and their abilities, for example, to handle the more complicated piping, sheet metal, and control systems that will be necessary in Alternative 1 with its large central mechanical equipment rooms. Both Alternatives 2 and 3 use package air-handling units in local fan rooms, which are typically repeated on each floor of a high-rise building. The installed simplicity of Alternative 3 is even greater than Alternative 2 in that there is no central refrigeration plant with a need for somewhat complex piping. Moreover, in Alternative 3, the internal wiring and control of the air-conditioning supply systems is the responsibility of the unit manufacturer, with the temperature control design responsibility of the HVAC engineer being limited to the interface between the unit and the building management system.

Project experience with large buildings, i.e., those with 20 or more stories and areas of 400,000 ft^2 (37,000 m^2) to 500,000 ft^2 (46,000 m^2), in the Northeast United States has indicated that the mechanical and electrical system costs are approximately equal

Table 5-1. First Cost Considerations

Alternative 1 Central Fan Systems Central Chilled Water	Alternative 2 Floor-by-Floor Fan Systems Central Chilled Water	Alternative 3 Floor-by-Floor DX Systems Central Cooling Tower
ISSUE—HVAC IMPACT ON COST		
• Fewer units, field erected. • More complex and expensive duct systems. • More complex field-installed controls. • Central chilled water plant.	• More units, factory-fabricated and assembled. • Simpler ductwork. • Field-installed control system. • Central chilled water plant.	• More units, factory-fabricated and assembled. • Simpler ductwork. • Factory-installed control system. • No central chilled water plant; cooling tower only.
ISSUE—BUILDING MANAGEMENT SYSTEM COSTS		
• Complex controls and interface with BMS and smoke control system.	• Controls are relatively simple but field installed. Interface with BMS and smoke control system less complex.	• Unit controls provided by manufacturer. Interface with BMS and smoke control system simple.
ISSUE—ELECTRICAL IMPACT ON COST		
• Electrical loads concentrated in central location. • Probably lowest electrical cost.	• Minor cost premium for distributed fan motors. • Probably higher electrical cost than Alternative 1.	• Additional cost for electrical distribution to local DX units. • Highest electrical cost.
ISSUE—GENERAL CONSTRUCTION COST		
• Additional gross space needed. • No separate outside air or smoke exhaust shaft.	• Additional cost of sound treatment of local floor-by-floor fan room. • Need separate outdoor air and smoke exhaust shaft.	• Additional cost of sound treatment of local floor-by-floor fan room. • Need separate outdoor air and smoke exhaust shaft.

for all three schemes. When the cost of the additional mechanical equipment room area and volume of Alternative 1 and to a lesser degree Alternative 2 is considered, Alternative 3 may have a lower first cost than either of the other alternatives. The difference, however, is not significant and consideration of other points of comparisons may result in a decision to use either Alternative 1 or Alternative 2.

On smaller buildings with fewer floors, the package DX solution of Alternative 3 will almost always be the least costly. Generally, the smaller the building and the fewer the number of floors in a building, the greater the cost advantage of Alternative 3 will become.

It must be apparent that first cost, while always important, is not the only consideration. As is discussed in chapter 1, the nature of the owner, specific needs, and the owner's perception of the market must all be reviewed to allow the owner to select the alternative that will best satisfy the owner's judgment as to which alternative best fulfills the owner's understanding of the project requirements.

Corporate headquarters, for example, will usually favor either chilled water alternative and could well lean toward Alternative 1 with central mechanical equipment rooms, since this will result in simpler maintenance, more flexible operation, and potentially longer equipment life after the building is completed. There is a further advantage in a corporate headquarters with Alternative 1 in that maintenance personnel will not need access to every floor for normal maintenance, which could be a significant advantage from the perspective of office space security.

Developer buildings, particularly those being constructed with the expectation of single floor leases, may well favor Alternative 3, which minimizes if not eliminates overtime operation by the owner's staff and eliminates the allocation of operating costs that is necessary in Alternative 1 and, to a lesser degree, in Alternative 2. This issue of the allocation of operating costs is discussed in more detail later in this chapter.

Table 5-2. Construction Schedule Impact

Alternative 1 Central Fan Systems Central Chilled Water	Alternative 2 Floor-by-floor Fan Systems Central Chilled Water	Alternative 3 Floor-by-Floor DX Systems Central Cooling Tower
ISSUE — GENERAL COMPLEXITY OF INSTALLATION		
• Central mechanical equipment room space and complex construction technology for both chiller plant and fan system locations.	• Chiller plant space is required with the need for more complex construction technology.	• Areas that contain complex construction technology are limited.
• Requires piping of a major chiller plant.	• Requires piping of a major chiller plant.	• No major chiller plant. • Cooling tower only.
• Chiller plant location critical to construction schedule.	• Chiller plant location critical to construction schedule.	• Chiller plant is not required.
• Heavier slab construction at central mechanical equipment room.	• Heavier slab construction for chiller plant only.	• Very limited special slab construction.
• Extensive complex ductwork in central mechanical equipment room.	• Limited ductwork, repetitive fan room arrangement on each floor.	• Limited ductwork, repetitive fan room arrangement on each floor.

5.2.2 Construction Schedule Impact

There is an impact on the construction schedule as a function of which alternative is selected. The issues that will affect the construction schedule are outlined in Table 5-2.

Alternative 1, with field-erected air-conditioning supply units, complex ductwork, and extensive chilled water and condenser water piping, when coupled with the fact that each mechanical equipment room in a specific building is different when compared to the mechanical equipment room from other projects, is only the beginning of the schedule concerns.

As discussed in chapter 6, “Central Heating and Cooling Plants,” the location of the chiller plant will have an impact on the overall project schedule. If located at the top of the building, which is constructed last, the large concentration of labor at that location may cause a lengthening of the overall construction schedule for the project. A similar concern will be the case if the central fan room of Alternative 1 is at the penthouse location, in that the extensive, complex ductwork will take a disproportionate amount of time to be completed with potential delays in the project schedule.

The opposite end of the scale is Alternative 3. In this Alternative, the equipment is factory fabricated and assembled, includes all of the internal control wiring, and is extremely repetitive on a floor-by-floor basis. The sheet metal sketches for the duct fabrication, the piping to the units, and both the power wiring and the building management system connections are the same on each floor and are relatively simple. The cost-related advantage of these factors will be reflected in the estimates of the alternative schemes but the impact on the project schedule can also be a matter of significance.

Alternative 2 is very close in the construction time involved to Alternative 3. There can be, however, a nominal increase in time over Alternative 3 due to the need to provide more complex piping for the chilled water plant, as well as the necessary power wiring for the plant and building management system connections for the plant and the floor-by-floor units. The increase in time, however, is not significant. Moreover, the repetitive nature of everything involved in this construction is still apparent and can be used to improve the project construction schedule if the comparison is limited to Alternative 1 and Alternative 2.

5.2.3 Owner Issues

There are other issues that should be considered in the decision process. The owner will have a strong interest in the first cost and construction schedule just discussed; a list of other matters of concern to the owner is provided in Table 5-3. The discussions under "Marketing/Electric Metering" are of special consideration in developer buildings. An issue in lease negotiations for developer buildings is the allocation of operating costs. In today's market, most, if not all, multitenanted buildings have separate electric meters for each tenant. These separate meters will cover all of the tenants' lighting and small power consumption, but the energy used to provide heating, ventilating, and air conditioning is a much more difficult issue.

For a multitenanted building and lease terms of multiple years during which the cost of energy will fluctuate as will the operating labor for the building, the problem can be quite complex.

The difficulty is most apparent in developer buildings using Alternative 1 with central fan rooms and central chilled water. For those projects, the operating energy costs are paid for by the owner and a means to pass this cost on to the several tenants is required. For example, if all tenants utilized their space from 8 a.m. to 6 p.m. on weekdays only, the problem would be relatively simple, but many professional service firms in the fields of accounting, law, architecture, and engineering typically operate on

Table 5-3. Owner Issues

Alternative 1 Central Fan Systems Central Chilled Water	**Alternative 2 Floor-by-Floor Fan Systems Central Chilled Water**	**Alternative 3 Floor-by-Floor DX Systems Central Cooling Tower**
ISSUE — MARKETING/ELECTRIC METERING		
• Tenant lights and small power can be metered directly.	• Tenant lights, small power, and fan energy can be metered directly for any floor with a single tenant. Multi-tenanted floor will require allocation of fan energy only.	• Tenant lights, small power, fan and cooling energy can all be metered for any floor with a single tenant. Multi-tenanted floors will require allocation of fan energy and cooling energy only.
• Fan energy and chiller plant energy, as well as heating energy, operating costs are allocated unless heating is by electric resistance heat.	• Chiller plant energy, as well as heating energy, operating costs are allocated unless heating is by electric resistance heat.	• Heating energy operating cost must be allocated unless heating is by electric resistance heat.
• Other common building operating costs are allocated.	• Other common building operating costs are allocated.	• Other common building operating costs are allocated.
ISSUE — OPERATING COSTS		
• For normal operating day, operating costs for all floors occupied will be lower than for Alternative 3, approximately equal to Alternative 2.	• For the summer operating day, operating costs for all floors occupied will be lower due to lower energy consumption than for Alternative 3, approximately equal to Alternative 1.	• For the summer operating day, operating costs for all floors occupied will be higher due to higher energy consumption than Alternative 1 or Alternative 2 due to less efficient DX compressors.
• Overtime operation requires the chiller plant to operate in the summer. With variable-speed fan control and headered supply and return fans, energy costs equal to Alternative 2. Operation more cumbersome. Fan and chiller plant costs must be allocated.	• Overtime operation requires the chiller plant to operate in the summer but otherwise simple. Chiller plant cost must be allocated.	• Overtime operation simplest but probably higher in cost than Alternative 1 or Alternative 2. Single-floor tenant cost for cooling tower only must be allocated.

extended schedules of overtime, which can extend into the evenings as well as weekends. To solve this problem, a relatively complex and—for the tenant—possibly expensive arrangement must be provided to allow the tenant to obtain air conditioning in periods other than the normal occupancy hours of most offices. The arrangement should include the cost of the labor and energy to operate the chilled water plant and any fans that may be required to deliver air conditioning to the tenant. Most leases include the heating cost as a landlord's cost and, since heating costs are nominal, there is a lesser problem with that component of operating cost.

One of the primary advantages of Alternative 3 is that the cost of energy for air conditioning for any single-floor tenant can be directly metered to the tenant on an electric meter. If electric heat rather than fossil fuel heat is utilized, that cost can also be placed on the tenant's meter. To express it more directly, the problem is simple and the solution straightforward with Alternative 3. Overtime operation for firms that operate on extended hours is equally simple with only the cost to operate the cooling tower and any necessary labor being subject to an allocation basis. Alternative 2 again is more complex in that the costs of operating the chilled water plant in warm weather must be allocated with only the fan energy, lighting, and small power in the local floor-by-floor fan room being on the tenant's meter.

The issue is a difficult matter, but the use of Alternative 3 with floor-by-floor DX units has achieved much of its application because it provides a solution that appeals to the landlord since the landlord can negotiate a lease with minimal concern for any need to allocate costs and appeals to the single-floor prospective tenant because the system can be operated when needed and with the knowledge that the costs to operate the system are predictable and under the tenant's control.

Moreover, since condenser water is required to operate any one unit in a project on overtime, the provision of condenser water to tenants with supplemental cooling needs for information technology rooms or a limited data center can be easily accommodated through the operation of the cooling tower and condenser water pumps to satisfy both needs.

The marketing advantage in the multitenanted developer building with Alternative 3 is clear. In owner-occupied and corporate headquarters buildings, the issue of the allocation of operating costs is not a real issue and, as a result, these buildings will more typically use either of the chilled water solutions that are part of Alternative 1 and Alternative 2.

5.2.4 Equipment Considerations

The decision concerning which of the three alternative solutions to use in any building—owner occupied or developer constructed—also must involve the nature of the equipment installed in the particular building after the building is completed. These issues are summarized in Table 5-4. These concerns require little elaboration but include the redundancy and operational flexibility, the life expectancy, and maintenance concerns of the equipment that are installed in each alternative.

The developer may well select Alternative 3 due to its marketing advantage in seeking tenants from the marketplace even though the maintenance and replacement costs may be the least with Alternative 1 and, to a degree, less with Alternative 2.

The drawback of a lesser degree of equipment redundancy with Alternative 2 and Alternative 3 is rarely considered but is a matter that warrants consideration. There is very little that can be done to mitigate the downtime that would occur if a compressor failed in a unit. Fortunately, most units can be or are provided with multiple compressors, which will result in only a partial loss of cooling. In addition, the life of DX compressors is usually quite good, and the operating experience in actual installations would indicate that, while failures do occur, this has not been a major ongoing issue. More-

Table 5-4. Equipment Issues

Alternative 1 Central Fan Systems Central Chilled Water	Alternative 2 Floor-by-Floor Fan Systems Central Chilled Water	Alternative 3 Floor-by-Floor DX Systems Central Cooling Tower
ISSUE — EQUIPMENT MAINTENANCE		
• All equipment is installed in central mechanical equipment room with centralized maintenance.	• Requires more maintenance than Alternative 1 but less than Alternative 3 due to larger number of units with filters, motors, fan drives, bearings, etc. • Chiller is installed in central mechanical equipment room, allowing centralized maintenance.	• Requires more maintenance than either Alternative 1 or Alternative 2 due to larger number of units with filters, motors, fan drives, bearings, etc., plus the compressor equipment on each floor.
ISSUE — EQUIPMENT REDUNDANCY AND FLEXIBILITY		
• Can operate in reduced mode in case of limited failure due to headered fan arrangement. Can handle changing cooling loads and/or uneven cooling loads on a floor-by-floor basis within limits. Can usually turn down system operation to supply air to a single floor.	• If unit fails, floor is without air conditioning. Cannot handle changing cooling loads or uneven cooling loads on a floor-to-floor basis without building in additional system capacity at design.	• If unit fails, floor is without air conditioning. Cannot handle changing cooling loads or uneven cooling loads on a floor-to-floor basis without building in additional system capacity at design.
ISSUE — EQUIPMENT LIFE EXPECTANCY		
• Life expectancy of equipment is in excess of 25 years.	• Life expectancy of equipment is in excess of 25 years.	• Compressor life expectancy is probably approximately 10 years. • Remainder of installation life expectancy is in excess of 25 years.

over, the availability of replacement compressor parts coupled with the infrequent failure and the relatively straightforward means of replacement have contributed to a limited concern when this alternative is considered for a project.

5.2.5 Architectural Issues

The decision to proceed with the design of a tall commercial office building based on a central mechanical equipment room or either of the alternatives outlined for the floor-by-floor fan rooms will have a significant impact upon the architectural design of the building. Table 5-5 provides an outline summary of the comparative issues involved in the architectural design. Each requires a more detailed discussion.

There is a significant change in the building massing as a function of the alternative selected. With either of the floor-by-floor alternatives, there is a lesser impact upon the architecture when compared to the central fan system alternative, since any central mechanical space will be limited in size because the conditioned air for the office floors will be developed by the local floor-by-floor air-conditioning units. The need for a more limited central fan room exists with the Alternative 2 or Alternative 3 solutions, but it is significantly less than with Alternative 1. With Alternative 1, one or more two-story-high mechanical equipment rooms will be required to contain the field-erected supply air systems and the extensive supply and return air ductwork that is extended from the supply fan to the supply air shafts and from the return air shafts to the return air fan, with the further extension to the supply air system and the spill dampers that allows the air to be expelled to atmosphere. The need for more than one double-high mechanical

Table 5-5. Architectural Issues

Alternative 1 Central Fan Systems Central Chilled Water	Alternative 2 Floor-by-Floor Fan Systems Central Chilled Water	Alternative 3 Floor-by-Floor DX Systems Central Cooling Tower
ISSUE — BUILDING MASSING IMPACT		
• Central fan rooms usually require two-story-high MER.	• Local fan room fits within floor-to-floor height of the office floor.	• Local fan room fits within floor-to-floor height of the office floor.
• Chiller plant room usually requires two-story-high MER.	• Chiller plant room usually requires two-story-high MER.	• No central chiller plant room required.
ISSUE — USABLE AREA IMPACT		
• Takes the least area per office floor.	• Takes a greater area per floor.	• Takes a greater area per floor.
• Maximum usable area per office floor.	• Less usable area per office floor than Alternative 1.	• Less usable area per office floor than Alternative 1.
ISSUE — GROSS AREA IMPACT		
• Takes more gross building area than either Alternative 2 or Alternative 3.	• Takes more gross building area than Alternative 3 but less than Alternative 1.	• Takes less gross building area than either Alternative 1 or Alternative 2.

equipment room for air-conditioning supply units and return air fans is a function of the number of floors, the area in the building, and the location of the central mechanical equipment room within the project.

One location that is frequently used for the central mechanical equipment room in a tall commercial building results from the design of the vertical transportation system. As is noted in chapter 9, “Vertical Transportation,” every high-rise office building will require multiple banks of elevators, each of which will serve separate banks of floors. The floor above the last floor served by any bank of elevators will require that an elevator machine room be provided that will contain the machinery that operates the elevator cabs in the bank. The elevator machine room can be 18 feet (5.5 m) in height (more than a single floor) and will exceed the width of the shaft that contains the elevator cab. The existence of this equipment will frequently dictate that the floor on which it is located become a mechanical equipment floor, since potential occupied space is already compromised, so the addition of multiple air-conditioning apparatus, fans, pumps, and refrigeration machines is easily accommodated. The floor can also serve well as a location for plumbing equipment.

The air distribution from any central fan room in the Alternative 1 approach is limited by the number of floors above and/or below the central mechanical equipment room, the acceptable size of the supply and return air duct shafts, and the area of the individual floors. While experience on large projects has indicated that the maximum number of floors from the central mechanical equipment room is limited to approximately 20 to 24 floors, the architecturally acceptable central mechanical equipment room location may be different as a function of the aesthetic considerations for the building, which would affect the number of floors being handled by a given central mechanical equipment room.

For example, if the central mechanical equipment room can be accommodated aesthetically in the middle of a tall building, it could theoretically be possible to satisfy the air capacity for a 40- to 48-story building with a single central mechanical equipment room for the air-conditioning supply and return systems. In a practical sense, this will frequently not be possible. Moreover, the architect (and perhaps the building owner) may well not accept a band of louvers around the middle of the building. They may well prefer that the central mechanical equipment room be located in a penthouse space immediately below the cooling tower and elevator machine rooms on the roof. If this is the case, a second central mechanical equipment room for a 40- or 44-story building would be required, again perhaps, immediately above the building entrance lobby area.

In addition, for either Alternative 1 or Alternative 2, a location must be found for the chiller plant room. As discussed in chapter 6, with the necessary design considerations, the plant can be located anywhere from a basement area of the building to a penthouse mechanical space. The clear height of the mechanical equipment room (i.e., the space below the structural steel of the floor above the mechanical equipment room and the slab of the room) that contains the refrigeration equipment can vary from 15 ft (4.6 m) to 18 ft (5.5 m) as a function of the requirements established by the dimensions necessary to install the refrigeration equipment. It must be sufficiently high to allow the relatively clean installation of the refrigeration equipment and both the chilled water and condenser water piping with all of the associated valves and fittings. No central chilled water plant or space for such a plant is required for Alternative 3.

The impact on usable area and gross building area is also affected by the alternative selected for a project. By usable area we mean the amount of area that can provide beneficial occupancy on each office floor. Clearly, the central mechanical equipment room uses less space on any office floor than either of the floor-by-floor alternatives. All that is required is shaft space, whereas in the floor-by-floor alternative, one or more fan rooms, each using between 250 ft^2 (24 m^2) and 450 ft^2 (42 m^2), is required. The variation in area is a function of the size of the unit required to support the capacity requirements of a given floor.

The double-high mechanical equipment room required for Alternative 1, particularly if considered as two floors, requires more gross building area than either of the local fan room approaches. Moreover, due to the absence of a central chilled water system, Alternative 3 will require less gross building area than Alternative 2.

This analysis of usable and gross area should be made on every project before a decision is made on the best solution to be used for a project. This is necessary as the additional usable space will be given favorable consideration by the project real estate professionals on a project. In the United States, the rentable area may or may not be affected as a function of the local rules for determining rentable area, which will differ in various areas of the United States and are substantively different for countries in Europe and East Asia, but usable area is measurable and can be differentiated for the various alternatives and will favor the central air-conditioning supply system.

The additional building gross area with the central mechanical equipment room should be factored into the building cost in that the area is a cost that must be considered in determining the project cost.

5.3 ACOUSTICS

In any project that is developed for commercial usage, an acoustical criteria should be established for the alternative types of occupancy that are expected in the building. For example, open plan office space can be designed to meet a noise criteria level of NC-40, while private and executive offices or conference rooms should be no higher than NC-35 and could be lower. The acoustical engineer on a project will set these levels, and it will be the responsibility of the HVAC designer to work with the acoustician to see that the criteria established can be achieved in the designed installation.

The selection of one of the three alternatives discussed in this chapter will have an effect on the sound treatment and the resultant acoustical level in the occupied areas of the office floors. Regardless of which of the three alternatives is ultimately selected, it is important that in addition to establishing the project acoustical standards, the actual designs be reviewed by the acoustical consultant to ensure that the desired levels can be achieved in the final construction. This presence of an acoustical consultant on the design team is advised on all projects but is particularly necessary with either of the floor-by-floor fan room alternatives for the reasons detailed below.

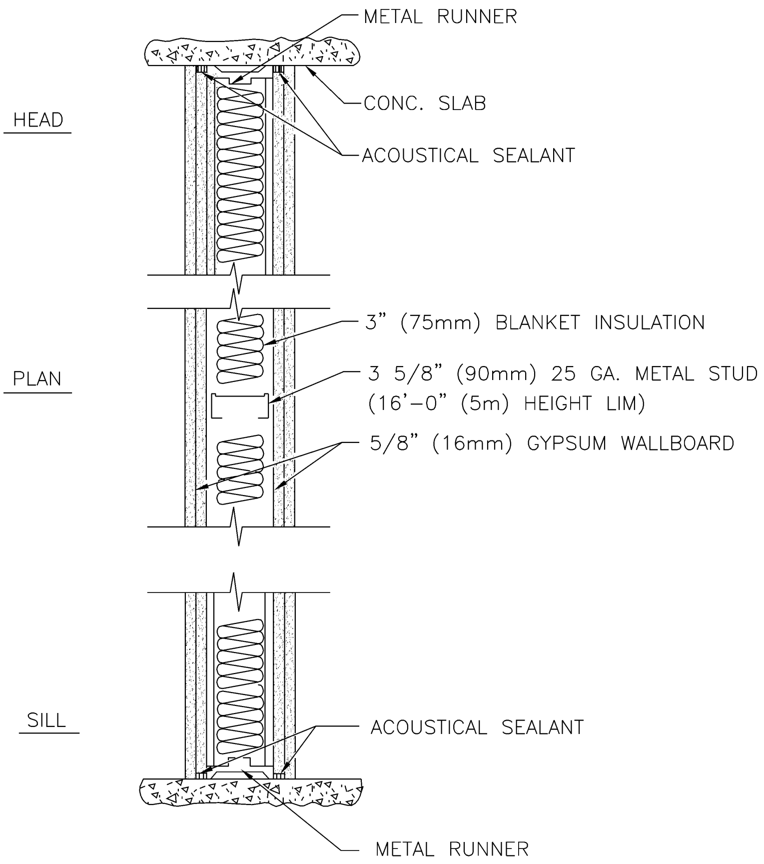


Figure 5-3. Mechanical equipment room wall construction.

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5.3.1 Acoustical Issues with Central Fan Systems

With Alternative 1, it is possible to provide a sound criteria level of NC-35 or lower in any office area as a function of the selection of the equipment that is provided for the chosen air-conditioning system, the design and acoustical attenuation means included for both the supply and return ductwork, and the selection of the air distribution equipment, including the air terminals and air diffusion devices that are included to distribute the air in the occupied space.

To provide physical separation of airborne sound transmission between the mechanical equipment room and occupied areas, the construction of slabs both at the bottom and top of the mechanical equipment room, assuming occupied floors above and below the mechanical equipment room, should be, as a minimum, 8 in. (200 mm) normal weight concrete to contain the noise that is generated by the fan equipment in the room. The type of construction used in the mechanical equipment room that contains the refrigeration equipment is discussed in chapter 6. In either case, the intent is to contain the noise that is generated by the mechanical equipment.

Spaces that are occupied by office workers that are on the same level but adjacent to the central mechanical equipment room that contains fans and similar equipment should be separated by a wall with a minimum installed STC (Sound Transmission Class) rating of 50. This can be achieved with a 6 in. (150 mm) or 8 in. (200 mm) cinder block wall or gypsum board construction that includes 3-5/8 in. (90 mm) metal stud erected slab-to-slab with batt insulation in the stud cavity and two layers of 5/8 in. (16 mm). thick gypsum board on both sides of the stud. A typical example of this construction as shown in Figure 5-3.

A further consideration with a mechanical equipment room located above grade in a building is the possibility of noise being carried along the curtain wall at the slab ending or through openings at the mechanical level and back through the glazing installed in office floors above or below the mechanical equipment room. To avert this from happening, the slab endings at the curtain wall on the mechanical level must be sealed properly and there should be no openings that are not closed along the wall of the mechanical room.

The ductwork from the central air-conditioning supply units must be treated acoustically. Typically, internal acoustic duct lining is recommended 30 ft (9 m) downstream of the air-conditioning unit. Some building owners are concerned for environmental reasons with the inclusion of duct lining. This concern may still exist even when the acoustical lining is covered with a material to minimize its fibers from being loosened by the air velocity and carried from the duct distribution system to occupied areas. In these cases, it is necessary to use sound attenuators or silencers. The best location for a sound attenuator is within the built-up air-conditioning system where the velocity of the air through the cooling coil is 500 fpm (2.5 mps) and the resultant velocity through the attenuator will be quite low. This yields a silencer selection with better attenuation in the space of 3 to 5 ft (0.9 to 1.5 m) with a lower static pressure drop. The alternative, if a sound attenuator is the project choice, is to install the silencer in the supply ductwork. The velocity in the ductwork can be 2,500 fpm (12.5 mps) or higher, but the maximum air velocity for a silencer is 1,200 fpm (6.0 mps) to minimize the static pressure drop through the attenuator. This difference in velocities will require a duct shape transition to satisfy the lower velocity requirement and attenuator cross section. The attenuator length will be between 5 and 7 ft (1.5 and 2.1 m), which does not include the duct transition requirement. The combination of the length of the attenuator and the duct transition to accommodate the attenuator will be a significant design complication.

In the central fan room alternative, return air can also be a problem in the floors closest to the central mechanical equipment room where they are in close proximity to the return fan. These several floors may require sound attenuators, acoustically lined elbows at the shaft, or an equivalent sound treatment to prevent transmission of the return fan noise back through the return air shaft to the occupied floor.

Finally, both the air-conditioning supply fans and the return fans will require external spring isolation between the fan and the concrete base on which the fan is installed, the details of which should be prepared by the projects acoustical engineer.

5.3.2 Acoustical Issues with Floor-by-Floor Fan Room Systems

The design issues with local floor-by-floor Alternatives 2 and 3 are subject to wide variation as a function of the proximity of the unit to occupied space, the unit configuration, the type of fan used, and both the supply and return duct arrangements that are possible on the project.

In general, office spaces other than those contiguous to the local fan room can achieve the NC-35 or lower noise criteria that was possible with Alternative 1. The spaces contiguous to the fan room, assuming the design considerations detailed below are respected, may well only be capable of achieving a sound criteria level of NC-40 to NC-45 for approximately 10 ft (3 m) from the local fan room wall. The precise distance of higher noise criteria levels will depend on the fan selection, the duct layout in the local fan room, and the construction of the room itself. This slightly higher noise level is usually not a major deterrent to the use of these alternatives for general office space but should be understood by the design team, especially the owner when he or she is developing a lease document with any prospective tenant.

The air-conditioning supply systems used with either local fan room alternative can be obtained in either a draw-through or blow-through configuration. These two configurations have different acoustical characteristics and, accordingly, result in different noise control requirements. At this time, virtually all projects utilize fan speed control through a variable frequency drive rather than variable inlet vanes. This improves the acoustical levels from the unit, as the possible turbulence created by the vanes is eliminated. Moreover, because the fan speed is reduced at part loads, the acoustical energy and the resultant noise level will be lower than would be the case at full fan speed. This, coupled with the fact that the system will operate at less than design conditions virtually at all times (typically 90% of the time), results in lower noise levels than might be expected if the fan operated at full speed at all times.

A unit configuration that has found application with floor-by-floor systems is a blow-through arrangement with the fan before the cooling coil, in the unit. The advantage of this configuration is that the fan heat will be removed by the cooling coil, which is located after the fan. This configuration, however, is inherently noisier on the unit return air side with a resultant noisier fan room than would be the case with a draw-through unit. This system arrangement will require treatment to allow return air to transfer back to the local floor fan room while keeping noise from escaping the fan room. The options to achieve these goals include an acoustically lined return air plenum, to allow the use of the least amount of acoustically lined return ductwork, or special return air treatment, such as an architectural return air transfer wall detailed subsequently in this chapter (see Figure 5-5).

The unit configuration most frequently used with the floor-by-floor system, however, is a draw-through unit, which eliminates any concern with fan system casing radiated or inlet noise. This type of unit also makes it possible to consider return air transfer to the local fan room with simpler return air duct connections than would be the case with a blow-through arrangement, which would require expanded acoustical treatment.

In addition to the arrangement of the unit, the type of fan used will alter the noise control specification for the project. There are three choices typically available.

Acoustically, the most desirable fan is a mixed flow fan. This fan has its loudest sound levels at higher frequencies than either of the other two alternatives. The maximum acoustical noise with the mixed flow fan is between 250 and 500 Hz. Noise in these frequencies is more easily attenuated than would be the case with the lower-frequency noise generated, for example, by centrifugal fans.

A plug fan is a second alternative. It is a quieter selection than a centrifugal fan, as it pressurizes an open plenum and is more isolated within the air-handling unit than would be the case with a centrifugal fan. The plenum with plug fans also provides a versatile design option in that the supply ducts can be distributed with multiple taps in differing directions. This can be quite advantageous, particularly where ducts will be routed from the local fan room in multiple directions off a common plenum that will provide improved sound attenuation.

The third type of fan that has been successfully employed is a centrifugal fan. The fan will require less space on its own, but the supply duct must proceed in the direction of the fan rotation with minimal deviations in that direction until the airflow is sufficiently laminar to permit a change in direction. In addition, the sound power levels from a centrifugal fan are higher than either of the other two alternatives and may require a sound attenuator in addition to acoustical lining or increased lengths of supply duct prior to penetration of the duct into the ceiling void above an occupied area.

The only acoustical difference between Alternative 2 and Alternative 3 is the compressor that is provided with Alternative 3 that is not required with Alternative 2. The problem is partially resolved in that the unit manufacturer for Alternative 3 will provide spring isolation for the compressors as an integrated part of the unit. The air-handling unit for Alternative 2 or Alternative 3 should be mounted on external springs where occupied areas are adjacent to the local fan room. The "spring on spring" condition between the internal and external isolators is not a problem, but, together, they resolve the potential noise from compressor vibration in Alternative 3. With this treatment of isolation of the compressor, the fan noise will predominate and will require the major

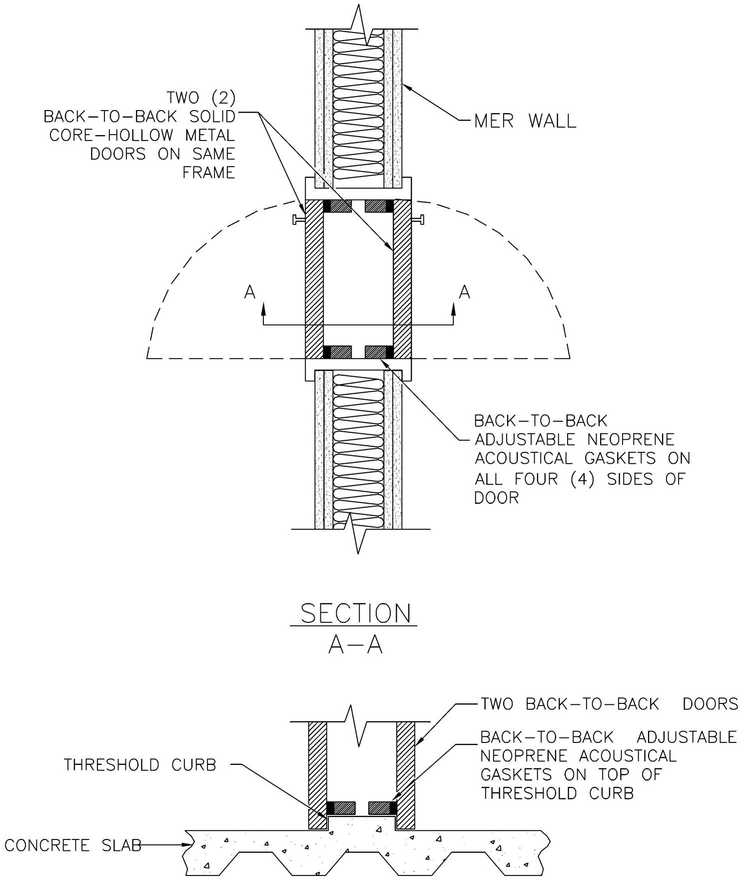

Figure 5-4. Back-to-back door arrangement for a local floor fan room.

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consideration of the designer in the effort to develop the needed acoustical design details.

The problems that remain and are common to both Alternative 2 and Alternative 3 are the construction of the partition that forms the wall adjacent to occupied space that is often contiguous to the local fan room, the construction of the door that permits access to the fan room, and the control of the airborne noise from the supply fan that can be transmitted by either the supply ductwork or the return air connection provided for the air that is recirculated on the floor.

The wall partition should be provided to achieve a minimum installed Sound Transmission Class (STC) of 50. The construction, as was the case with adjacencies on the same level as a central fan room solution, can be 6 in. (150 mm) or 8 in. (200 mm) block wall or can have the construction shown in Figure 5-3.

The detailing of the doors can differ as a function of their location with respect to occupied areas and the arrangement of the local floor-by-floor air-handling unit within the fan room. A blow-through unit, which will be acoustically louder than a draw-through unit, will require a higher acoustical rating. The options available for the door to the fan room include a core-filled hollow metal door with perimeter gasketing and automatic drop seals, back-to-back doors with threshold seals, or an acoustically rated door-and-frame assembly. An example of the detailing of the back-to-back door arrangement is shown in Figure 5-4.

To minimize airborne noise transmission through the supply duct system, it is prudent to include at least 10 ft (3 m) of a straight run of lined supply duct in the local fan room. This is before the duct penetrates into the ceiling plenum of occupied areas. This

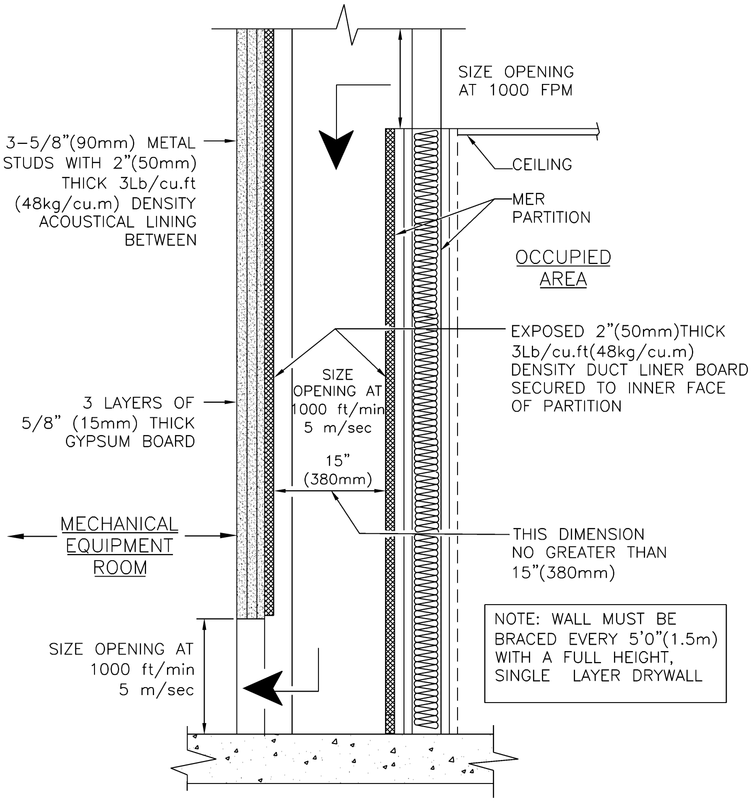

Figure 5-5. Return air transfer wall.

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is at least as important, as the unit selection for overall noise impact. Where the straight length of ductwork is more limited, then the unit selection will be more critical. This straight run of duct is important, as it will not only attenuate fan noise but also will reduce the turbulence of the air and allow the air to even out its flow in the ductwork. If possible, as a function of the space available and the fan type being utilized on the project, the splitting of the supply duct is also beneficial in that the acoustical energy will be distributed into two ducts rather than one. If the fan room and associated space will not allow the installation of two ducts in the fan room, the splitting of the single duct after it leaves the fan room can be beneficial in obtaining a reduction of the acoustical energy in the resulting pair of ducts.

The return air duct from the plenum ceiling should also be lined and have at least 12 ft (4 m) of lining. One method of achieving this goal is to bring the lined return air duct as it enters the fan room to the floor of the fan room, creating a vertical elbow from the ceiling plenum to the fan room. This lined elbow section of ductwork of approximately 9 ft (3 m) will limit the lined extension into the ceiling plenum to about 3 ft (1 m). A further alternative is that shown in Figure 5-5 where a return air transfer wall is detailed that is sufficient to eliminate the need for any return ductwork, in that air passes through a specially constructed, widened fan room wall.

Care must be taken in the duct construction for both the supply and return ducts to ensure sufficient gauge sheet metal is used to contain the low-frequency fan noise. This requirement for the use of the appropriate sheet metal gauge material is especially important where the ductwork has a high aspect ratio to allow the ducts to fit within the space constraints forced by the need to minimize the ceiling plenum depth. The gauge of the duct may well be heavier than would be required for sheet metal rigidity as is defined in several sources. This is a major consideration for the first sections of ducts over occupied areas.

Chapter 6

Central Heating and Cooling Plants

Many, but not all, tall commercial office buildings will require a central plant to provide chilled water and hot water or steam to meet the cooling and heating needs of the building. If packaged direct expansion equipment is utilized on a floor-by-floor basis, as is discussed in detail in chapter 5, then a chilled water plant will not be required. Similarly, in cold climates, where heat is necessary in the colder weather, if electric resistance heat, either along the base of the outside wall or in an overhead fan-powered air-conditioning terminal supplying the periphery of a building, is used, then a central hot water or steam boiler is not required.

Moreover, there are geographical locations where chilled water and/or steam or hot water are available from a central utility. If these sources of cooling or heating are used for a project, then a refrigeration or boiler plant will not be necessary.

For most other installations, a central chilled water plant employing refrigeration machines and a central boiler plant will be required. The factors that should be considered to allow the most rational decision as to the type and location of the heating and cooling plant include:

- Weight, space requirements, and impact on the structural system.
- Effect on the construction schedule.
- Specific changes in mechanical room detailing and slab construction within which the equipment is located.
- Acoustical considerations.
- Ease and cost of operation and maintenance.
- Consideration of available energy sources.
- The annual operating costs and possibly the life-cycle costs of each alternative solution.
- Space and cost considerations of a long vertical flue from the fossil-fueled boiler.

The methods of calculating owning and operating costs are discussed in the *ASHRAE Handbook—Applications*. Alternative refrigeration machines are detailed in the *ASHRAE Handbook—Refrigeration* and boilers in the *ASHRAE Handbook—Systems and Equipment*. Useful reference information is also contained in the *ASME Boiler and Pressure Vessel Code* volumes.

6.1 PLANT ECONOMIC CONSIDERATIONS

A detailed analysis is needed to determine which refrigeration system to install in a project. The choices are usually limited to either centrifugal refrigeration machines or absorption machines. The centrifugal machines can be electric driven or steam driven and are almost always water-cooled. The absorption machines can be single-effect or double-effect machines, but to utilize the double-effect machines with the advantage that results from lower energy costs, high-pressure steam is required. The use of high-pressure steam is rare in a commercial project unless the steam is available from a central utility.

There are cases where air-cooled refrigeration machines have been installed in tall buildings, but this occurs infrequently for a number of reasons. The most important reasons are the limited sizes of commercially available air-cooled refrigeration equipment and the resultant space requirements for this type of equipment. The largest air-cooled refrigeration machine that can be purchased at this time is 400 tons (1,400 kW). Tall buildings, by their very nature, are large buildings, and the multiple number of air-cooled refrigeration machines that would be required to meet the needs of a large building and the relatively large space they would require will usually result in their not being a viable solution.

In addition, air-cooled equipment will probably have higher operating costs due to the higher condensing temperatures developed by the refrigeration equipment. This higher operating cost results from the fact that the refrigerant condensing temperature for air-cooled equipment is a function of the dry-bulb outside air temperature, while water-cooled equipment will have a refrigerant condensing temperature that is driven by the lower outside air wet-bulb temperature. This operating cost difference will exist even though there is no cooling tower fan or condenser water pump and the motor associated with the pumps that would be required for the water-cooled equipment.

The geographic locations where air-cooled equipment has found application in larger projects, including tall commercial buildings, would be in areas where water to meet the needs of the cooling tower make-up is either not available or is prohibitively expensive.

The heating plant for either low-rise or high-rise buildings, when electric resistance heat is not used, is selected from the same list of available plants that find application in other types of projects. This would include oil- or gas-fired boilers, boilers that use both oil or interruptible gas as a function of the availability of either fuel and their relative cost, or boilers that use electric energy. These boilers would be used to provide hydronic heat, low-pressure steam that is distributed to spaces in the building or as supplemental heat to heat pumps or heat recovery systems. The choice of the correct solution for a building is subject to an economic analysis that will consider the space requirements, first cost, and operating expense as a function of the cost of alternative available fuels and possible differences in maintenance costs.

6.2 CENTRAL PLANT LOCATIONS

Further complicating the decision is the location within the building of all equipment. The possible locations will affect structural costs, architectural design, construction time, and availability of the cooling or heating effect in relation to occupancy requirements. Not uncommonly, the latter requirement may have been a significant factor in a determination to place central heating and refrigeration plants below grade in certain projects even though this may result, in some cases, in design complications and possibly higher overall project costs. The placing of chiller plants and heating plants in floors above grade up to and including space directly below the roof is not only common but may be desirable in terms of the simplicity of construction and ease of providing the necessary ventilation air and other services to the equipment. Moreover, the two types of plants need not be installed at the same level in the building, as there is usually no direct interconnection of the two plants.

There is no location for a boiler plant or water-cooled refrigeration machines that cannot be utilized in a building. The location is determined through the consideration of several requirements for the equipment. Boiler plants and refrigeration plants can be located in the below-grade levels or in a rooftop mechanical equipment room or anywhere in between.

If a boiler is installed above grade, fuel (i.e., oil, gas, or electricity) must be brought to the boiler, and a flue, in the case of an oil- or gas-fired boiler, must be taken from the boiler to atmosphere. The location of a boiler plant should be determined by analysis vis-a-vis previously outlined parameters. Regardless of where it is installed, the detailing of the design must include appropriate acoustical design considerations and vibration isolation.

The considerations for the refrigeration plant location are more complex in that the chilled water and condenser water must be pumped to and from the location of the refrigeration plant to the air-conditioning supply equipment that requires chilled water. In addition, the cooling tower and the working pressure of the refrigeration machines, as well as the piping, fittings, and valves that are discussed in chapter 7, "Water Distribution Systems," must be reviewed. Moreover, electricity or steam must be brought to the machine to provide the energy to operate the equipment.

Again, key issues are the acoustical and vibration considerations. Owners have expressed concern about possible noise transmitted from the refrigeration equipment to occupied space on the floors above, below, or adjacent to the plant. This should not be a concern if the architectural, structural, and mechanical designs fully consider the vibration and acoustical requirements of the plant.

6.3 ACOUSTICAL CONSIDERATIONS OF CENTRAL PLANT LOCATIONS

The location of the refrigeration and the boiler plant, as well as the other equipment that will be utilized on the project, must be addressed by the HVAC designer and the acoustician retained for the project to allow the achievement of the desired acoustical levels in spaces above, below, or adjacent to the central plants. The proper solution will involve an understanding of the characteristics of the sound that will be generated by the equipment and the alternative paths that exist for transmission of the equipment noise and vibration to the occupied areas of the building. There are basically two paths that exist. The first is transmission of the noise itself through the floors, ceilings, and walls of the mechanical space. The second is vibration and the noise associated with vibration that is transmitted by the building structure to the occupied areas.

The starting point is the equipment and the noise and characteristics of the noise that the equipment will generate. If it is accepted that the refrigeration equipment used in large commercial buildings will either be centrifugal refrigeration machines or absorption machines, the acoustical characteristics of each should be considered. Centrifugal refrigeration machines generate significant noise due to the rotation of the compressor and the motor or steam turbine that drives the compressor, as well as the passing of refrigerant gas through the compressor and from the compressor to the condenser. In addition, the gears that may exist in the machine to increase the speed of the compressor beyond that of the electric motor that is driving the compressor can be a source of additional noise. Absorption chillers are relatively quiet in that there are no moving parts other than the solution circulation pumps, so the noise is usually limited to the higher frequency noises associated with the flow of steam through the control valves on the machine.

Regardless of the type of machine being installed on a project, it is prudent to specify a maximum sound level that will be generated by the machine at any operating point of capacity. It is not usual to require a maximum value in each octave band, since the levels by octave bands can vary, within limits, from manufacturer to manufacturer as a function of the specific design. It is possible to state, however, the maximum allowed sound as a single valued number using the A-weighted sound level that can be verified with any standard sound meter. The maximum permissible sound level that should be acceptable to all refrigeration machine manufacturers is 90 dBA for the machine and, separately, the same number for any gear train assembly between the motor drive and

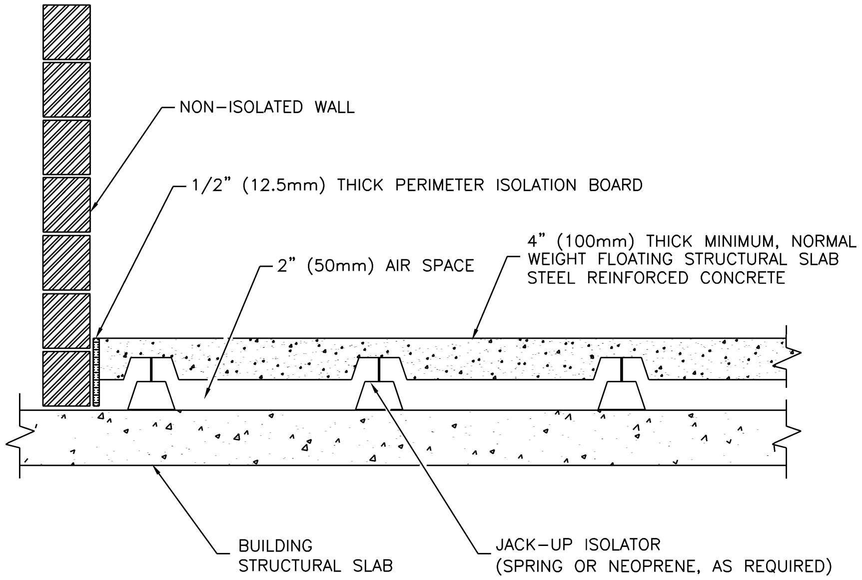

Figure 6-1. Concrete floating floor detail.

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the compressor that may be utilized by a manufacturer in the case of electric-drive centrifugal machines. This A-weighted sound level is also appropriate for an absorption machine.

6.3.1 Acoustical Considerations in the Refrigeration Plant MER

To limit the noise transmitted from the mechanical equipment room (MER) within which the refrigeration equipment is installed to contiguous adjacent occupied spaces, particular attention must be paid to the construction of the floor and ceiling slabs and any vertical wall that exists between these alternative spaces. The slab construction above and below the refrigeration plant should be 8 in. (200 mm) stone concrete with 100 psf (4.8 kPa) density. This is heavier weight concrete than was recommended for the mechanical equipment room limited to containing air-conditioning fan systems.

If occupied areas are located adjacent to the refrigeration plant mechanical equipment room, any separating wall should be made of standard 6 in. (150 mm) or 8 in. (200 mm) cinderblock or other material that will provide an installed STC (Sound Transmission Class) rating of at least 55. This construction will satisfy any acoustical concerns for either centrifugal or absorption refrigeration machines or boilers, as well as for the pumps and other equipment that will exist on a project, against an acoustical standard of NC-40. If centrifugal refrigeration equipment is in a location contiguous to spaces with a more stringent sound criteria requirement, as could be the case with equipment installed adjacent to or above or below a boardroom, other alternatives may be necessary. For example, if the equipment is installed over an extremely critical area, a concrete floating floor may be required. This is a very costly construction and one that should not be utilized unless necessary. The construction of a concrete floating floor is shown in Figure 6-1.

6.3.2 Vibration Isolation Requirements for Refrigeration Equipment

The second path for the transmission of noise from equipment that was noted above is that of structure-borne noise and vibration through the slab of the space. This is possible not only from the refrigeration equipment and the boilers but also from the pumps and piping that are installed in the mechanical equipment room to provide the chilled

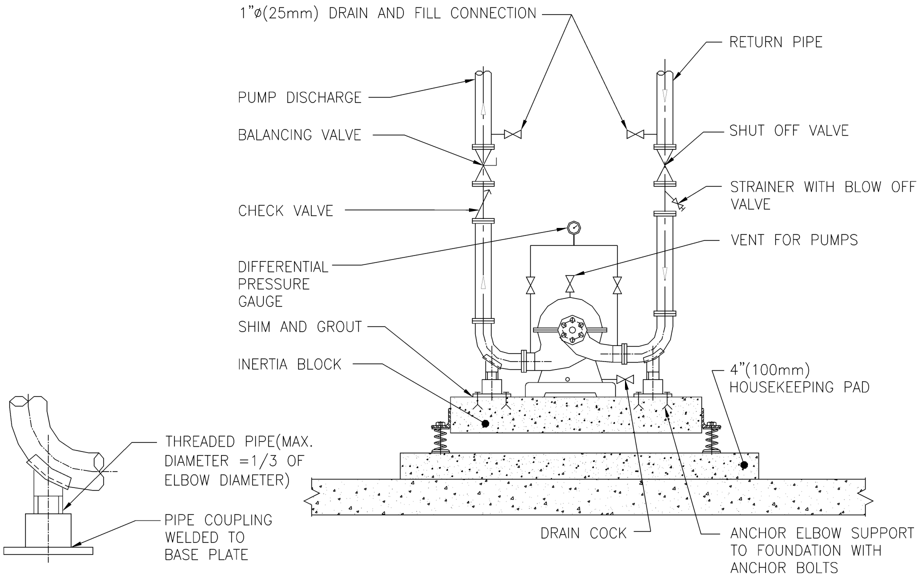

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Figure 6-2. Horizontal split-case pump detail.

and hot water distribution from the refrigeration equipment and the boilers. To isolate structure-borne noise, it is necessary to mount all rotating equipment in any mechanical equipment room on properly selected vibration isolation material. For upper story installations, the refrigeration machine, which will be provided by the manufacturer with an integral one-piece structural frame, should be mounted on bare, stable springs. The deflection of the springs that should be utilized is a function of the floor slab construction and depends not only on the weight but the natural frequency of the floor span and steel structure size. Notwithstanding this consideration, spring deflections around 2 in. (50 mm) are typical.

Large pumps associated with the chillers should be provided with spring-supported inertia block bases. The thickness of the base will vary with the motor horsepower. The concrete base should include, in the case of horizontally split pumps, supports and bare elbows for the suction and discharge connections. A typical detail for a horizontal split-case pump is shown in Figure 6-2. The bearing elbows, as shown in this figure, should be bolted and grouted to the concrete inertia block, which in turn will be mounted on spring isolators between it and a housekeeping pad.

When the refrigeration or boiler equipment is installed at a slab-on-grade, it is not always necessary to provide external springs. The springs can be deleted depending upon the proximity of occupied areas to the central plant equipment. If the equipment is directly below a utilized space or the building entrance lobby levels, spring isolation should remain as part of the standard specifications.

Piping in the central plant room should be provided with spring hangers or supports. As with all such isolation hangers, they must be supported from substantial elements of the building structure. This usually means there is a need for secondary steel between structural elements. The piping should not be hung from the slab itself. This piping should continue to be spring isolated beyond the plant to minimize structural transmission of noise and vibration energy. The distance beyond the mechanical equipment room that requires spring isolation piping cannot be developed on a generalized basis. It should be determined by a careful study of the installation by the project's acoustical engineer.

6.4 IMPACT OF CENTRAL PLANT LOCATION ON THE CONSTRUCTION SCHEDULE

A final consideration in the location of both the boiler plant and the chiller plant is the impact of the location on the construction schedule. This concern is especially critical in the case of the refrigeration plant, which is a complex installation that involves very high labor time due to the need to complete the chilled water, condenser water, and possible steam piping as well as provide for the electrical capacity requirements of the machines. The heaviest piping and the most difficult installation process for the piping in the building will occur at the refrigeration plant. As a result, if the refrigeration plant is on the uppermost level of the building, the installation of the machines and their associated piping can delay the overall schedule to complete the building. Accordingly, if the refrigeration equipment is not installed in the below-grade level (which may use space that has other priorities such as parking or storage and is not without its own complications), the refrigeration plant may well be best located above the lobby level and below the uppermost levels of the building. Additionally, the location of the refrigeration or boiler equipment on the upper level probably prohibits the possible early occupancy of the lower floors of the building until the uppermost floors of the building are completed.

Chapter 7

Water Distribution Systems

The design of the piping for water distribution systems for a commercial tall building differs from the design of these systems for a low-rise building primarily due to the hydrostatic pressure on the piping system as a result of the height of the building. This condition can affect the design of the chilled water, hot water, and the condenser water piping systems in the building, which are discussed in this chapter. The domestic water and sprinkler piping, due to their typical design details, are less concerned with the hydrostatic problem. The domestic water piping is briefly discussed in chapter 8, "Plumbing and Electric System Interfaces," and sprinkler piping in chapter 10, "Life Safety Systems."

The chilled and hot water systems are always closed systems, whereas the condenser water system is, usually, an open water system. A closed water system is one in which the pumped fluid is essentially not exposed to the atmosphere at any point. Examples of closed water systems in a building would be both the chilled water and hot water systems that deliver water to the various heat transfer equipment that functions to provide conditioned air and heat to the building. These systems always contain an expansion tank, which can be either an open expansion tank or a closed expansion tank. The open expansion tank is always at the highest point of the particular system and is open to atmosphere, but the area of the water in the tank is insignificant to the point that it does not alter the definition of a closed water system as one that is not exposed to atmosphere.

An open system is one in which the pumped fluid is exposed to atmospheric pressure at one or more points in the piping system. The piping distribution system for the condenser water, assuming the inclusion of a cooling tower in the design, is exposed to atmosphere by the clean break in the piping at the cooling tower. The exposure to atmosphere occurs at the point where the water is discharged into the cooling tower and remains open to atmosphere at the cooling tower basin or sump.

If an evaporative cooler or dry cooler—commonly referred to as an industrial fluid cooler—were to be used rather than a cooling tower for the condenser water that handles the heat of rejection from the refrigeration equipment, the piping system would be a closed system rather than an open system. The use of evaporative or dry coolers for an entire large commercial office building is extremely rare. However, they are used in portions of tall commercial buildings as a means of handling the heat of rejection from occupants' supplemental cooling systems, which may be installed in spaces needing additional cooling capacity or cooling capacity on an extended operational basis such as a data center.

As stated in the *ASHRAE Handbook—Systems and Equipment*, the "major difference in hydraulics between open and closed systems is that certain hydraulic characteristics of open systems cannot occur in closed systems. For example, in contrast to the hydraulics of an open system, in a closed system (1) flow cannot be motivated by static pressure differences, (2) pumps do not provide static lift, and (3) the entire piping system is always filled with water."

7.1 HYDROSTATIC CONSIDERATIONS

A major consideration in the design of a piping system in a tall building is the hydrostatic pressure that is created by the height of the building. This hydrostatic pressure affects not only the piping and its associated valves and fittings but also the equipment that is installed in the building. The equipment in the case of the chilled water system that would be involved includes the refrigeration machines, the casings for the chilled water pumps, the cooling coils installed in the air-conditioning systems, any heat exchangers provided, and, if included as the system of choice, fan coil units at the exterior wall of the building. A similar list of devices beyond the pipes, valves, and fittings themselves can be developed for other pumped systems in a project, such as the condenser water or any hot water system.

Beyond the static increment developed by the hydrostatic height of the building, there are dynamic pressures that are necessarily created by the pumps in any tall building that must be added to the static pressure increment to determine the working pressure on any element in the piping systems for the building. The dynamic pressure at the pump will be the total of the following elements:

- The friction loss through the piping and its associated valves and fittings.
- The residual pressure at the most remote piece of heat transfer equipment in the project that is necessary to allow that piece of equipment to function. This would include the pressure loss through the control valve at the equipment and the friction loss or pressure drop through the equipment.
- Any excess pressure caused by the pumps when they operate at low flow close to the shutoff head of the pump.

It is necessary to determine the working pressure of the piping and the equipment that is connected to the piping at various elevations in the building. This is done by adding the hydrostatic pressure head at the specific location to the dynamic head that can be developed by the pumps at that location. The considered dynamic head should be the head generated by the pump at or close to shutoff at full pump speed, even if variable speed pumps are used, since it is possible to operate the pumps at the shutoff point at full speed. Accordingly, the working pressure on piping and equipment will only be less as the static head at a specific location is reduced.

7.2 CHILLED WATER PIPING ARRANGEMENTS

The arrangement of the piping of the chilled water in any project is subject to alternative approaches as a function of the experience of the designing HVAC engineer, local practices that have developed in the area within which the project is located, and the needs of the project. There are basically two alternative approaches that find application in tall commercial buildings. Either of these two basic alternatives is subject to variation by the design engineer, but any specific solution will be a modification of either of the basic concepts.

The first arrangement is one in which the pumps that are associated with the refrigeration machines also distribute the chilled water to the cooling coils and other heat transfer equipment requiring chilled water that is installed in the project. A flow diagram of this arrangement is shown in Figure 7-1. This figure shows three chillers from three refrigeration machines. Each machine will handle one-third of the total load in the building. It is common on many projects that only two machines will be provided, each handling fifty percent of the total calculated load. It is also not unusual to include four

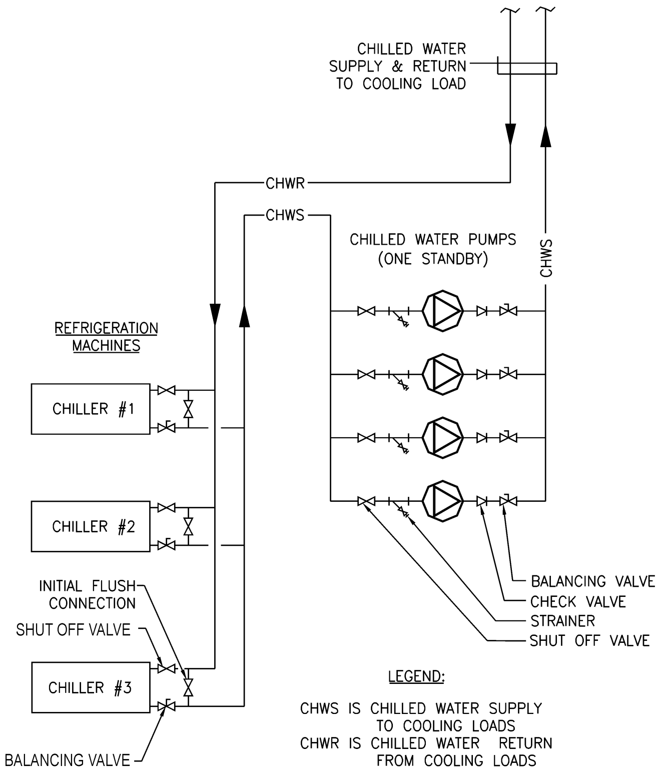


Figure 7-1. Direct chilled water pump distribution to cooling loads.

machines. Two could be rated at one-third of the total calculated load and two rated at one-sixth of the load. This will provide machines for operation at light loads such as for the overtime needs of a limited data center within a large building. The number of machines and their relative capacity as a function of the total load for a project is a judgment that must be made by the design engineer as a function of the needs of the building and its usage in overtime and on weekends where there may well be partial occupancy. It is not usual to provide spare refrigeration machines in most locations where service from the manufacturer or other service agencies and spare parts are readily available. In parts of the world with more limited access to service and parts, it is prudent practice to include a spare machine as well as an inventory at the job site of spare parts for the machines that would be provided by the refrigeration machine manufacturer as part of a response to the project specification.

In Figure 7-1, in addition to the three machines, there are four chilled water pumps. Each of the chilled water pumps is selected for the rated flow through each of the chillers. If the control of the flow of chilled water at the heat transfer equipment in the project is effected by two-way control valves, which is usually the case, the pumped amount of chilled water will vary with the cooling loads in the building. The pumps, therefore, will be variable-flow pumps and will require variable-frequency drives. In addition, the pumps are piped in parallel, as are the chillers, so any machine can operate with any of the pumps. This provides pump redundancy in the event of a pump failure for any reason. The inclusion of the spare pump is relatively common, as pumps will be down for service or repair in a random fashion that cannot be coordinated with the needs of the project or the service requirements of the chillers.

While not shown, the refrigerant condensers on the refrigeration machines would be piped in a similar fashion where four pumps are provided with three machines and any pump can be used with any of the three machines. These condenser water pumps,

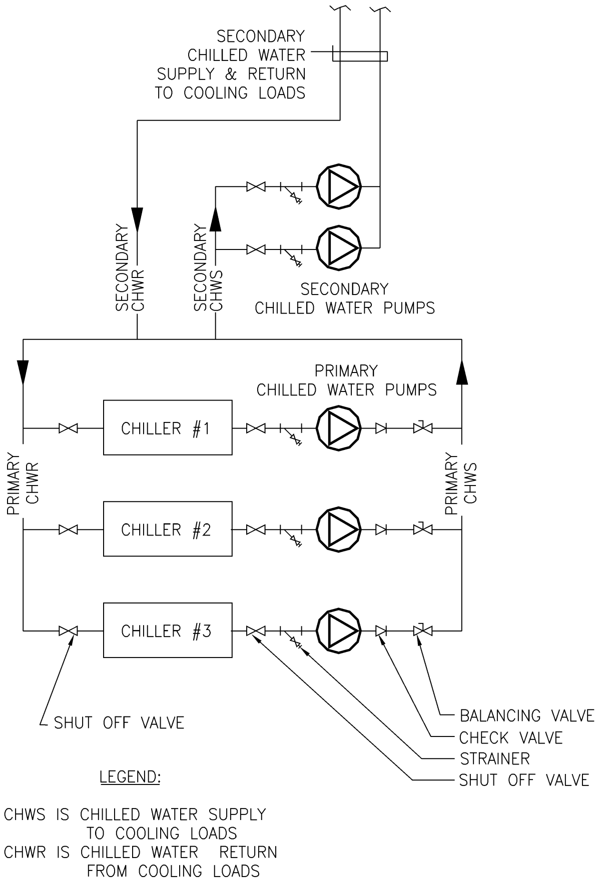


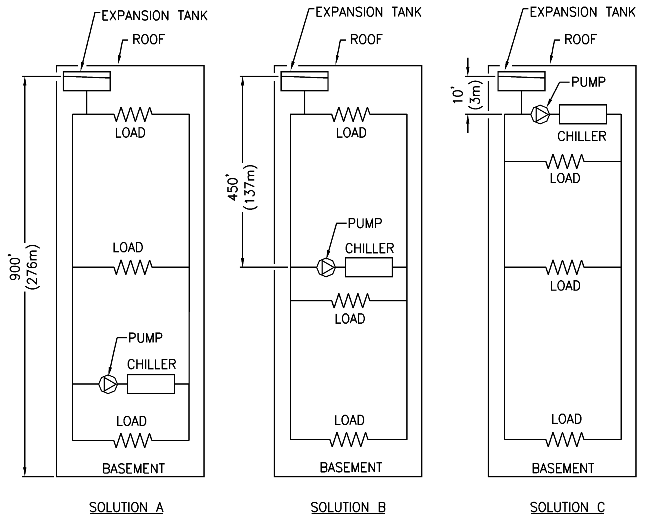
Figure 7-2. Secondary chilled water pump distribution to cooling loads.

however, will not have their flow change with load so they will not require variable-frequency drives.

The second common arrangement consists of primary and secondary pumps as shown in Figure 7-2. In this arrangement, contrary to the arrangement in Figure 7-1, each chiller is operated with a dedicated primary pump that will operate at constant speed and constant flow. It is possible to pipe both the chillers and the pumps in parallel, adding a spare as is the case in Figure 7-1.

The variable-speed secondary pumps shown in Figure 7-2 distribute the water to the chilled water coils installed in the air-conditioning equipment as well as the other heat transfer equipment that is required for the project. Proponents of this arrangement point to the fact that the flow through each chiller is constant and will not vary, as the control valves on the cooling coils and heat transfer equipment reduce the chilled water flow when the cooling load on the coil or on the equipment is reduced. Most chiller manufacturers will stipulate a maximum velocity through the cooler of the chiller, which is usually 10 fps (3m/s), but will also require that the flow not be reduced below a stated minimum velocity, which will be approximately 3 fps (1 m/s). The piping arrangement in Figure 7-2 will ensure that the flow is constant and eliminate any possible flow problem.

In the arrangement of Figure 7-1, a bypass bridge could be required at the pumps when cooling capacity control at each piece of heat transfer equipment is being achieved by two-way throttling valves. Any bypass bridge that would be required in the arrangement shown in Figure 7-2 would be at the secondary pumps. In either case,



STATIC PRESSURE =	900 FT.(276m)	450 FT.(138m)	10 FT.(3m)
PUMP SHUT OFF HEAD =	140 FT.(43m)	140 FT.(43m)	140 FT.(43m)
TOTAL HEAD (IN FT.) =	1040 FT.(319m)	590 FT.(181m)	150 FT.(46m)
TOTAL HEAD (IN PSI.) =	$\frac{1040}{2.31}$ =450 PSI (3100kPa)	$\frac{590}{2.31}$ =255 PSI (1758kPa)	$\frac{150FT.}{2.31}$ =65 PSI (448kPa)

Figure 7-3. Chiller working pressure for a 900 foot (276 m) tall, 70-story building.

the system under light load will pump more water than is needed at the heat transfer equipment, which will necessitate the inclusion of a bypass bridge to relieve the excess water being pumped. The designs being implemented today, however, usually include variable-speed pumps. With this design, the flow will tend to be proportionate with the load, eliminating the need for a bypass bridge. Accordingly, in both Figure 7-1 and Figure 7-2, the bypass bridge is not shown and will not be required if variable-speed pumps are employed.

7.3 IMPACT OF THE REFRIGERATION MACHINE LOCATION

The decision about the level on which the refrigeration machines and the supporting chilled water and condenser water pumps are located in a building is a decision that can have a cost impact on the refrigeration equipment, the pumps, the piping, and the fittings and valves associated with the piping. The economic impact will be due to the change in the design working pressure to which the equipment, piping, fittings, and valves will be subjected by the system.

As stated in chapter 6, the refrigeration plant can be located at virtually any level in a building from a basement mechanical equipment room to one located on the roof. To illustrate the impact of the refrigeration machine location at various levels in a building, Figure 7-3 shows three alternative chiller locations in a 70-story, 900 foot (276 m) tall building with cooling coils or heat transfer equipment at the basement level, in a mid-level mechanical equipment room, and in a mechanical equipment room on the roof. The expansion tank at the top of the building in all three alternatives is an open tank that is at the highest point in the system. If a closed expansion tank were used, the maximum pressure must be established and considered in the determination of the working pressure of the system.

The working pressure on any equipment or the piping, valves, and fittings at any location in a building is the sum of the hydrostatic height of the water in the piping above the point being considered plus the dynamic pressure created by the pump at the point being analyzed. The hydrostatic and dynamic pressures are determined in feet of water. Their sum, when added together, is the total pressure or working pressure in feet at the referenced point. To determine the working pressure in PSIG, this total pressure in feet must be divided by 2.31. This is the conversion factor to convert pressure in feet of water to pressure in PSIG.

For example, in Solution A shown in Figure 7-3, the vertical height of the column of water above the refrigeration machine is 900 ft (276 m.). The pump that is pumping water through the machines has a maximum head close to shutoff of 140 ft (43 m). The total pressure is, therefore, the sum of these two pressures, or 1,040 ft (319 m), which, when divided by 2.31, provides the working pressure on the machines of 450 PSIG (3,100 kPa).

The calculations for the alternative refrigeration plant locations at the midlevel in the building and at the top of the building are also shown in Figure 7-3. The working pressure on the refrigeration equipment at the midlevel of the building is 255 PSIG (1,760 kPa) and for equipment at the top of the building is 65 PSIG (448 kPa).

The standard working pressure for the coolers and condensers on large refrigeration machines from all of the major manufacturers in the United States is 150 PSIG (1,000 kPa). The machines can be manufactured for any working pressure above 150 PSIG (1,000 kPa) at an additional cost. The incremental increase in the cost of any given vessel becomes larger with each unit of increase in the working pressure. Accordingly, it is necessary for the HVAC design engineer to accurately determine and separately specify the working pressure on both the cooler and the condenser of the refrigeration machines.

It is possible to reduce the working pressure on the refrigeration machine by locating the chilled water pump on the discharge side rather than the suction side. If this is done, the residual pump pressure on the refrigeration machine's water boxes is a minimal value and the working pressure on the vessel is reduced to the sum of the hydrostatic pressure and this nominal value of dynamic pressure from the pumps. This can result in a reduction in the cost of the refrigeration machines, but it will not alter the pressure on the pump casing and flanges, which must still be the sum of the static and dynamic pressure.

7.4 CHILLED WATER PRESSURE REDUCTION

The cost of the refrigeration equipment as well as the pipe, fittings, and valves in the tall building will increase as the working pressure on the equipment and piping increase. A means of reducing the pressure on the refrigeration equipment by altering its location to an elevation above the basement has been discussed. This, however, will not alter the maximum pressure that will be experienced by the pipe, fittings, and valves at any location that is used, for example, to extend the piping to chilled water coils. It is possible, however, to reduce the chilled water working pressure on both the machines and piping through the use of plate-and-frame heat exchangers, which will segregate groups of floors into separate static pressure zones.

For example, we can reduce the static pressure on all of the piping, valves, fittings, and heat transfer equipment in a building through the use of flat plate heat exchangers. The availability of flat plate heat exchangers with the ability to provide secondary water that is within 2°F (1°C) or less of the primary water has made the use of secondary distribution systems a viable option that did not exist when commercially available technology was limited to shell-and-tube heat exchangers with an approach differential between the primary and secondary water of approximately 8°F (4.4°C).

In the 900 ft (276 m) tall building previously discussed, with the refrigeration machine in the basement of the building, it is possible to break the chilled water system into three separate zones as shown in Figure 7-4.

Each zone has static pressure of one-third of the total building height or 300 ft (92 m). All of the pumps are located on the discharge side of the refrigeration machines or the secondary zone heat exchangers. The result is that the maximum head of each zone

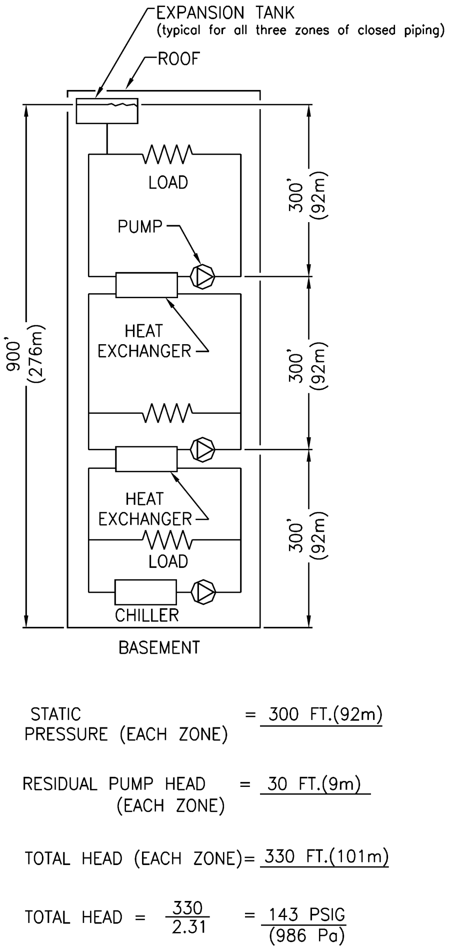


Figure 7-4. Zoned chilled water for a 900 ft (276 m) tall, 70-story building.

is 143 PSIG (986 kPa), which is below the threshold design pressure of 150 PSIG (1,000 kPa), or the point at which consideration must be given to an increase in the pressure rating of the chiller of the refrigeration machine as well as other heat transfer equipment.

The pumping head on the primary chilled water pump in the basement will not change substantively from that required where no secondary systems were included, since the primary chilled water pump must now overcome the loss through the flat plate heat exchanger. In addition, motor-driven pumps are added at each secondary water heat exchanger. Finally, with the addition of the two additional zones and the resultant chilled water temperature increase, there will be a requisite increase in the gallons of water flowing through the systems on the upper floors. Accordingly, while there are benefits in the reduction in pressure, there are partially offsetting considerations that must be analyzed to determine the overall cost-effectiveness of the use of the flat plate heat exchangers to reduce the operating pressure on the equipment, piping, valves and fittings at a given level.

The use of flat plate heat exchangers and their location in a chilled water piping system is subject to an economic analysis by the design HVAC engineer to determine the first cost of alternative arrangements as well as the operating cost differentials, if any, for any scheme. The use of two heat exchangers and three sets of pumps as shown in Figure 7-4 would rarely be cost effective and, therefore, is rarely used. It is not uncommon, however, to include a single heat exchanger, which will reduce the working pressure on the entire chilled water system to a level that will lower the cost of the piping, valves, and heat transfer equipment installed in the project.

The use of a flat plate heat exchanger to obtain a reduction in the working pressure on the condenser of the refrigeration machines, while feasible, is not often given consideration, as the condenser water piping is usually in a single shaft with minimal, if any, offsets and a resultant small number of fittings. Valves are also only installed at the machines and are few in number. This limit in the number of fittings and smaller number of valves may not be sufficient to offset the cost of the flat plate heat exchanger and its valving as well as the added pump on the secondary side of the heat exchanger. Beyond that, there will be an increase in the temperature of the condenser water, which will increase the cost of operating the refrigeration machines.

7.5 PIPING, VALVES, AND FITTINGS

The working pressure on the piping, valves, and fittings at various levels in a building must be determined to permit a proper specification of the piping material. In the United States, with steel pipe, Schedule 40 pipe is the standard wall thickness for pipes up to 10 in. (250 mm) diameter. For pipes 12 in. (300 mm) and larger, the pipe standard that is used has a wall thickness of 0.375 in. (9.5 mm). Either of these standards would accommodate the working pressures that would be experienced in any expected pipe diameter in any tall commercial building. The allowable pressures for various pipe diameters can be found in the ASME publications referenced at the end of this chapter and in the publications of various pipe manufacturers. The valves that are used should be reviewed in the valve manufacturers' literature to ensure their ability to meet the project's requirements.

For steam condensate piping or for condenser water piping, where corrosion is a possible concern, pipe with a heavier wall thickness should be given consideration, but this consideration would not be due to the working pressure on either system.

Piping materials other than steel are often used. For pipe sizes below about 4 in. (100 mm) in the cases of runouts or in open condenser water piping where corrosion is a concern, copper is the usual choice. The use of copper pipe is rare, but the use of copper tubing is common. The limiting factor in the use of copper tubing will usually be at the joints where the ability to handle higher working pressure is restricted.

7.6 PIPING DESIGN CONSIDERATIONS

The design of the piping must also take into consideration other factors, including expansion and contraction in the piping and the static and dynamic loads of the piping, as they will be reflected in the structural steel framing system of the building; the need for access to expansion joints and the anchors and guides for the piping, which should be subjected to periodic inspection after the building is constructed; the provision of firestopping between the pipe and the sleeve located at all penetrations of rated slabs, walls, and partitions; and, if required, seismic restraints on the piping systems and the pumps.

In addition to providing for the expansion and contraction of the piping due to changes in the temperature of the ambient condition or the temperature of the pumped fluid in the piping, a problem can present itself in concrete buildings. The problem will result from the frame shortening that will occur as the concrete shrinks as it cures over time. Concrete-framed structures, through shrinkage or creep, can be shortened over time in the range of 1/8 in. (3 mm) per floor. While this movement is relatively small, it amounts to about 9 in. (225 mm) for a 70-story building. This condition will require that attention be paid by the designer to provide sufficient flexibility in the pipe above, below, and between anchor points to allow for pipe movement with respect to the structure. To properly design for this condition, the HVAC designer should obtain from the structural engineer the exact amount of movement that the piping system can experience so the system can be designed to accommodate this frame-shortening condition.

7.6.1 Expansion and Contraction

The full range of movement of piping during various operating periods must be anticipated and accounted for by the HVAC design engineer. This analysis must also consider the movement of the piping during the construction phrase. It is of extreme importance that the determination of the movement of the piping be considered in the structural design of the building, as the loads from piping movement can be substantial. These loads can be even greater during construction in that, frequently and for long periods of time, the piping will be subjected to widely varying outside air temperatures, since the building will be neither heated nor cooled.

The HVAC design engineer must provide the expected dynamic loads and the static loads of the piping due to the weight of the fluid-filled pipe to the design structural engineer to allow the structural system to satisfy the loads developed by the piping system at the point where the piping is being supported by the building steel.

7.7 THE ECONOMICS OF TEMPERATURE DIFFERENTIALS

Traditionally, rules of thumb in the selection of refrigeration machines in the United States have utilized a 10°F (5.6°C) or 12°F (6.7°C) temperature differential between entering and leaving water in the chiller and a 10°F (5.6°C) differential or 3 gpm per ton (0.054 mL/J) of capacity for the condenser. These guidelines are appropriate for small buildings, as they have little impact on project cost, but can be viewed with an alternate perspective on large buildings, specifically including the tall commercial building. In projects of this type, the capital costs of the piping, valves, and fittings can be substantially reduced, with a possible penalty in refrigeration machine operating cost, by using larger temperature differentials with a lower flow of water and a consequent reduction in the diameter of the piping.

For a large project with a total cooling capacity requirement of 4,000 tons (14,000 kw), the chilled water flow at a 10°F (5.6°C) temperature differential or 2.4 gallons per ton (0.04 mL/J) would be 9,600 gpm (600 L/s). If a 16°F (8.9°C) temperature differential or 1.5 gpm per ton (0.027 mL/J) were used, the total flow from the refrigeration plant would be 6,000 gpm (380 L/s). The resultant pipe size at a 10°F (5.6°C) differential would be 20 in. (500 mm) diameter at a velocity just below 10 ft per sec (3.0 m/s); whereas with a 16°F (8.9°C) differential, the resultant pipe diameter would be 16 in. (400 mm) at a velocity just below 10 ft per sec (3.0 m/s). The savings in the piping at the greater temperature differential would be significant. Moreover, while the kW per ton for the refrigeration machines under both conditions would need to be studied, with the same discharge temperature, the operating energy consumption would probably be unchanged.

For the condenser water piping on the 4,000 ton (14,000 kw) refrigeration plant with a 10°F (5.6°C) temperature differential, the condenser water flow would be 12,000 gpm (760 L/s). If this temperature differential were increased to 15°F (8.3°C), there would be a reduction in the condenser water to 8,000 gpm (500 L/s). The pipe diameter for 12,000 gpm (760 L/s) would be 24 in. (600 mm) and, at 8,000 gpm (500 L/s), the diameter would be 20 in. (500 mm). Again this change would result in a significant first cost savings, which would vary as a function of the distance between the refrigeration machines and the cooling towers.

The energy consumption for the refrigeration machines might increase to a marginal degree, as the condensing temperature of the refrigerant and the resultant energy usage is in large part, but not solely, a function of the leaving condenser water temperature.

The consideration of higher temperature differentials in both the chiller and condenser of the refrigeration plant is a matter worthy of evaluation on any tall commercial building, as there can be significant savings in the cost of the piping, fittings, and valves that are part of the overall refrigeration plant for the project.

Chapter 8

Plumbing and Electrical System Interfaces

Tall commercial buildings contain plumbing and electrical systems that interface with the work being detailed by the HVAC engineer. It is the purpose of this chapter to briefly discuss these systems and the points at which they interface with the HVAC designs.

8.1 PLUMBING SYSTEMS

The plumbing systems that are designed for any building fall into several discrete categories including the domestic water system, which will provide both hot and cold water to various fixtures and water-consuming equipment installed throughout the building; the sanitary system, which will be connected to water closets, lavatories, drains, etc., in the building and will drain the waste from these fixtures to a sewer system external to the building; and a stormwater system, which will collect rainwater or melted snow and pipe it to an appropriate disposal point, usually a public sewer.

All of these systems are part of the mechanical designs for a project, but none, other than the domestic water system, has any involvement with the HVAC design. The involvement with the domestic water system is limited to providing makeup water to the chilled, hot water, and condenser water systems and the possible heating of the domestic hot water system by the hot water boiler that is included as a part of the HVAC system. The makeup water is required due to the small amount of leakage that can occur at several locations in the HVAC piping systems, including the pumps, and, more important, the loss due to evaporation. The major element of evaporation occurs in the condenser water system at the cooling tower. The possible heating of the domestic water is discussed in a later section of this chapter.

The tall commercial building presents essentially two problems in the design of the domestic water system. Both problems are concerned with maintaining the pressure on domestic water fixtures within specific pressure limitations. The first is to provide a means to develop and maintain adequate pressure at the plumbing fixtures in the highest portion of the building. The second is to provide a means not to exceed the pressure requirements on fixtures and equipment in the lower reaches of a building.

Water is supplied to the fixtures either through gravity house tanks or pressure-boosting systems. In order to limit pressure to acceptable levels, the building is divided into multiple vertical zones. This is accomplished by tanks or pressure-reducing stations that limit the zones to 15 or 20 floors while maintaining the pressure at the lowest floor of the zone to an allowable value that will permit any connected water fixtures to operate properly. This pressure is usually between 80 and 85 psi (550 and 586 kPa).

The domestic water system is used to initially fill the chilled water, condenser water, and hot water systems. This is usually done through the expansion tank provided with the chilled and hot water systems or through the cooling tower at the top of the building for the condenser water system. In addition, domestic water is provided to the condenser water system on an ongoing basis to replace the water that evaporates in the cooling tower as it adiabatically cools the condenser water. The HVAC engineer must provide to the plumbing designer the amount of water that will be required on a peak cooling day for cooling tower makeup. This will become a key component of the plumbing engineer's estimate of the project's total water requirements that will be provided to the municipal water authority in a request for service availability. The remainder of the estimate of the daily water consumption will be based on the water consumed per capita per day for various purposes in the building. These estimates will be made by the plumbing engineer.

The means of providing the limited amount of hot water to restrooms and janitorial connections can vary as a function of the building usage and type of tenancy, but, as noted above, the piping system must accommodate the pressure problems in a tall building as well as the minimum and maximum pressures that are necessary to operate the fixtures at the lavatories in the toilet room. In central domestic water heating, the plumbing engineer will furnish the HVAC engineer the hourly energy load for the domestic hot water and the expected peak hot water demand load. The energy load is used to size the boiler that will be provided in the HVAC design documents as the heat source for the hot water heater. The demand load, representative of the peak domestic flow rate, will be utilized to size the steam or boiler water piping to the domestic hot water heater. The piping to the hot water heater will be on the HVAC drawings, but the domestic hot water heater will be included in the plumbing documentation.

As an alternative, it has become quite common to install a separate electric hot water heater on every floor or every third or fourth floor of a commercial building. This permits the project's needs to be met at lower first cost than would be the case with a central domestic heating solution. In the event of the inclusion of a separate electric hot water heater in the design, there will be no interface required between the HVAC and plumbing drawings to provide domestic hot water to the project.

8.2 ELECTRICAL SYSTEMS

The electrical systems that will be provided for the tall commercial building will include electrical power for the lighting, small power for office equipment such as computers, printers, copiers, etc., and power in support of other building system needs. These other needs will encompass the elevators and mechanical equipment (i.e., motors for the pumps and fans and potentially the motors for an electric drive refrigeration machine). In addition, electric power will be required for the communications systems in the building, as well as the fire alarm and other miscellaneous systems such as the building management and security systems.

The capacity provided by the electric utility will be in response to a load letter they receive outlining the project's electrical needs by load type category. The letter is prepared by the electrical design engineer, but much of the information in the load letter will be based on the electrical needs of the mechanical equipment provided by the HVAC and plumbing design engineers to the electric design parties. The information contained in the load letter is a summary of the electrical design or connected load, which by code must be used as the basis of the design of the electrical equipment and feeder distribution system throughout the building. The capacity provided by the electric utility will be based on their review of the load letter and their estimate of the maximum kilowatt demand that the building will actually experience based on their knowledge of historical operating data from other buildings.

The electrical design engineer will be concerned with the analysis and selection of the most beneficial voltage offered by the electric utility. This analysis will include the evaluation of the electrical needs of the project's mechanical equipment and its physical location within the building relative to the point of service entry from the electric utility.

The selection of the building's voltage from the utility will also be influenced by the impact of the service voltage alternative on the mechanical equipment from both a cost and availability standpoint. For example, the use of a high-voltage distribution scheme will require the HVAC designer to determine the premium in cost for the starters and motors that will be needed to operate the mechanical equipment at that higher voltage. This will include the refrigeration machines if electric drive centrifugal machines have been selected for the project. The saving in the high-voltage distribution cable will be offset, in part, by the premium paid for the refrigeration equipment as well as the fans and pumps that will operate at that voltage. The high-voltage distribution scheme will often result in the need for above-grade transformer vaults. The transformers require ventilation air to remove the heat given off by the transformers. If these transformers are not located to allow the heat to be adequately dissipated naturally, the HVAC designer will be required to address the effect of this additional heat gain by providing the necessary outside air intakes, fans, ductwork, and spill air louvers. If the transformers are provided by the electric utility, the ventilation of the vault will be subject to their specific requirements.

8.2.1 HVAC Interface with the Emergency/Standby Generator

The intent of the model building codes with regard to the life safety system is that the installed system should have a high degree of reliability and available capabilities even in the event of the loss of power to the building and the life safety system from the normal source of electricity. To achieve this ability for the system to be continuously available and to operate continuously during a power failure, every new tall commercial building will have installed within the building an oil-fired emergency generator plant. This plant will provide electricity to components of the life safety system in the event that the normal source of electric power to these components is interrupted for any reason.

The alternative types of emergency generator equipment that find application in commercial buildings, the components of the life safety system, and the arrangement of the specific devices with the building emergency generator plant are all discussed in chapter 10. The details in this chapter address the interface between the HVAC and electrical design disciplines, which is necessary to develop complete design documentation for the project.

The same emergency generator plant installed to provide electric power to the life safety system may also provide backup power to other equipment and systems in a building to allow their continuous operation in the event of a power failure. These alternative points of connection would usually be limited to equipment that supports critical functions in a building, such as the building's telecommunications systems or data processing areas. The provision of backup power to these areas is voluntary and is not mandated by any code. Therefore, the provision of a secondary electrical source of power to these areas will be a commercial judgment made by the building's developer or occupants.

The HVAC and electrical interdisciplinary coordination requires that the HVAC design engineer provide to the electrical designer the power requirements of the equipment for the life safety system components that are on the HVAC drawings. The HVAC designer must also provide the electrical needs of the equipment provided for the commercially critical areas that are on the HVAC drawings. Similar load information will be provided to the electrical design engineer by the fire protection engineer and the vertical transportation designer on their backup power requirements for the equipment that is involved with the life safety system in their documentation.

The information from all of the other design disciplines, along with the electrical design engineer's knowledge of the equipment and systems that require emergency power, will allow the electrical engineer to determine the needed capacity of the generator plant. When this information on the generator plant is provided to the HVAC engineer, the necessary information to be shown on the HVAC drawings can be developed.

The information contained on the HVAC design documents would detail the work that will be installed by the HVAC contractor in conjunction with the oil supply for the backup source of electric power for the project and the ventilation air and exhaust air from the generator room that will be necessary to allow the generator to operate. The oil supply details on the HVAC drawings will include the location and the capacity of the main oil storage tanks (usually at the lowest below-grade basement level), any day tank that is necessary at the generator room level, the oil piping from the oil tanks to the standby generator equipment, and the routing of the fuel oil fill and vent piping. The quantity of oil that must be stored will be defined in the applicable building code. The model codes require a minimum storage to allow the generators to operate at full capacity for two hours. Some local codes will require a larger quantity of oil to be stored. For example, New York City requires six hours of fuel oil storage. Prudent design on large projects may frequently result in large storage quantities of 24 hours or more to ensure the continuous viability of the life safety system as well as other nonmandatory equipment that could be operating off the emergency generator system.

In addition to providing the oil for the prime mover in the generator set, the HVAC discipline is responsible for delivering the required ventilation air to the generator room to provide for combustion and to dissipate heat radiated from the engine block and from the coolant piped to the generator radiator. The HVAC documents must also provide a properly sized exhaust flue to handle the exhaust requirements of the products of combustion that are developed by the operating generator. The sizing of the flue is critical. There may well be the need for the flue to be generously sized due to a complex routing of the flue, the length of the exhaust pipe with the need for multiple bends to get the exhaust gas to atmosphere, and limitations on the back-pressure capabilities of the emergency generator.

A final concern of the HVAC designer is to provide adequate acoustical treatment of the generator plant and air distribution systems to minimize the transmitted noise within the building or to areas external to the building from the generator plant. This is particularly important when it is understood that the generator plant will be test run at regular intervals without a loss of building power to ensure that the generator plant capacity will be available in the event of an actual power failure.

Chapter 9

Vertical Transportation

As is noted in the introductory portions of this design guide, the construction of tall buildings only became possible with the development of the elevator safety braking system and the elevator itself, with the resulting ability to move people expeditiously through the multiple levels of a tall building. The HVAC designer does not have a significant involvement with the elevators installed in a building other than to provide cooling in the elevator machine room to ensure that the controlling electronics of the elevator system are maintained at an appropriate temperature to allow their reliable operation and, as discussed subsequently in this chapter, if required by code, to vent the elevator shafts and the elevator machine room to atmosphere.

9.1 THE BASIS OF THE SYSTEM CONFIGURATION

Every tall building will require a vertical transportation system. The vertical transportation system will always include elevators and may include escalators. The escalators, when included, will meet the limited and special needs that may develop in a building, to allow the efficient transferring of people from an entrance level to a main lobby that exists on the floor above the entrance level. Escalators are also frequently included to move large volumes of people to cafeteria levels if they are located below the entrance lobby level. In addition, escalators will be required if a sky lobby with double-deck elevators, discussed later in this chapter, is part of the design for a building. In most tall buildings escalators will not be required.

The selection of the elevators, including their arrangement within the core, is of critical importance to the architect. While there are rules of thumb, discussed below, that will indicate for concept design purposes the number of elevators required based on the area or diversified population in a building, the application of these rules of thumb is not appropriate in the actual design of a tall commercial building due to the multiple arrangements and types of elevators available and the inherent complexity of the possible solutions that can be utilized in the actual design. The need for an independent, experienced elevator consultant is a matter that must be understood by the developer who is putting together the design team. Once a building is finished with a given arrangement of elevators, it is not possible to significantly alter or improve the performance of the system that has been installed. It is there and, except for minor tweaking, cannot be changed insofar as the arrangement, the number of cabs, and the floors that are served by each cab are concerned.

The configuration of an elevator system, which will include a determination of the number of elevators and the arrangement of the cabs in banks, their individual capacity with regard to the number of people that can occupy a cab at one time, and the speed of the elevators for a specific project will be determined by several considerations. These will include the number of floors in the building, the populations on different floors, the location of special-use facilities such as a cafeteria, and the type of occupancy for which the building will be constructed. A corporate or single-occupancy building could have an alternative elevator system specified when compared to a multitenanted developer building.

The populations for various building types (e.g., general office usage, with diversified occupancy or executive spaces) have been developed by vertical transportation consultants and companies that manufacture elevators based on the usable space in a building and an analysis of the actual populations in multiple buildings. These studies indicate there will be approximately one person for each 150 to 160 ft^2 (14 to 15 m^2) of usable floor area. Special areas such as a trading floor will be more densely occupied and can run as high as 70 ft^2 (6.5 m^2) of usable area per person. Moreover, designs in Europe and Asia will usually allow for greater population than in the United States because staff are typically allocated less working area per person.

The population density for elevator calculations as determined by these densities is different from those used in the HVAC load calculations. HVAC loads use the peak number of people that will be experienced in a limited space, not a diversified population over a space of multiple floors. This is a significant difference, since the HVAC load calculations for general office space will usually be one person per 100 ft^2 (9.3 m^2).

The rules of thumb alluded to above, which can only be used by the architect to determine a preliminary potential number of elevators required when addressing the conceptual design of the core for a project, would be to allow one elevator for each 40,000-50,000 gross ft^2 (3,700-4,600 gross m^2) of the building or one elevator for every 225-250 building occupants. As stated above, these rules of thumb should be used with the understanding that a more accurate determination of the number of elevators by an elevator consultant in a traffic analysis may well alter the quantity of elevators for the project.

Once the population of a building is determined, the elevator consultant who is configuring the system can determine the number of elevators and the floors they will serve, the speed of the elevator, and the platform size of each cab and their resulting capacity in pounds, which will be converted into people in the cab. The determination will be based on generally accepted standards in two separate categories. The categories for a bank of elevators are

- handling capacity expressed as a percentage of the total population that is served by the bank of elevators that will be moved in five minutes and
- interval in seconds, which is the average time that an elevator will be dispatched from the main lobby or terminal floor during the heaviest time of peak elevator usage.

The handling capacity for an office building will usually be allowed by the elevator consultant to vary from a low of 12.5 percent to a high of 15 percent, with the lower number being acceptable in a developer building and the higher percentage being the standard used in an owner-occupied building.

The interval that will be acceptable in an owner-occupied building will generally be 25 seconds or less and in a multiuse developer building 30 seconds or less.

The determination of both the handling capacity and interval involves a series of assumptions based on experience. These will start with the population served in an elevator bank, the population that will be using the elevator at the peak time of usage during the day (usually in the morning up-peak period when occupants are arriving at work and little traffic is going down), the number of people on each trip in each car during this peak usage time, the number of cars in the bank, the number of stops the elevator makes at this peak time, and an assumed speed of the elevator. The calculations or traf-

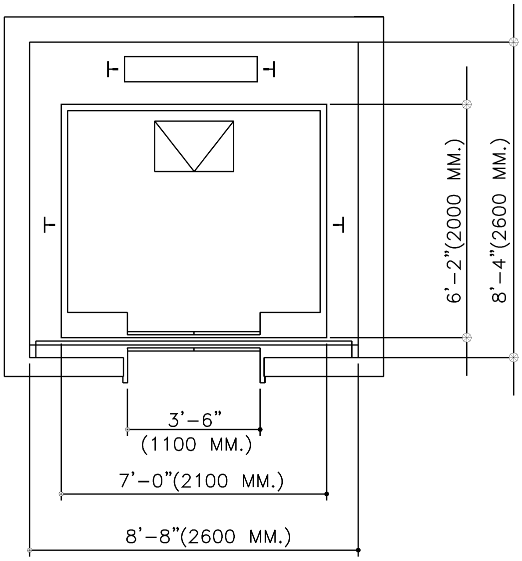


Figure 9-1. Typical size of commercial passenger elevator. Capacity: 3500 lb (1600 kg).

fic analyses using these assumptions are made in a series of iterations with changes in the floors served by the bank, the number of cars in the bank, the capacity of each elevator, and alternate speeds at which the elevator can travel.

9.2 ALTERNATIVE ELEVATOR CONFIGURATIONS

In tall commercial buildings, as defined in this design guide (i.e., greater than 20 to 24 floors), multiple banks of elevators will be required to meet the handling capacity and interval criteria that have been established for office buildings. There are also other accepted standards that will affect the elevator configuration. These are:

- In the United States, for office buildings, the platform size for first-class office buildings should have a capacity between 3,500 lb (1,600 kg) and 4,000 lb (1,800 kg). In most cases, the platform dimension should have greater width than depth to facilitate the entering and leaving of passengers. Figure 9-1 provides the typical dimensions for a 3,500 lb (1,600 kg) elevator.
- The handling capacity and interval of each bank in a project should be relatively equal, but neither criteria should ever differ in a bank-to-bank comparison by more than 10 percent.
- The maximum number of elevators in any one bank is generally limited to eight and they should be arranged as four opposite four to make the necessary movement from the call button to any responding elevator as direct as possible.
- If four or six elevators are determined as acceptable, they should also be arranged in facing sets of two or three.

The arrangement of eight, six, and four elevators in a bank is shown in Figure 9-2.

The above standard requiring relative parity in the handling capacity and interval from bank to bank in a given property will usually result in an unequal number of floors served by each bank. This results from the longer travel distance for the banks serving upper floors and the inherently longer travel time to complete a round trip. Accordingly, the banks serving the upper floors frequently serve fewer floors to reduce the round-trip travel time and maintain approximate parity in the interval.

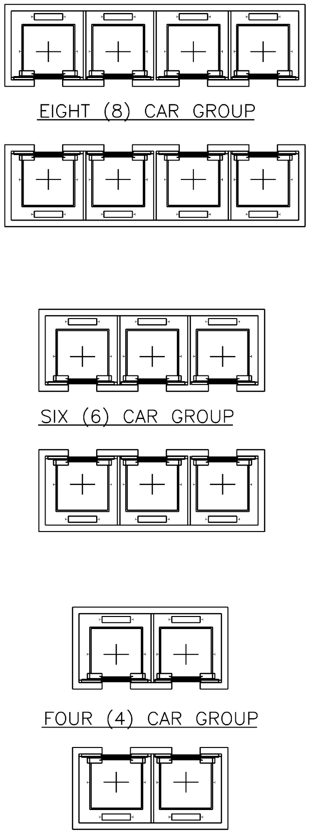


Figure 9-2. Typical alternative passenger car configurations.

With these guidelines in hand, it is possible for the elevator consultant to select and configure the elevators for a building. This may involve a process of give-and-take with the architect who is incorporating the elevator selections into the core design, but through the process of alternative selections of elevator systems with different platform sizes, speed, and the number of floors served, a mutually acceptable solution will be determined.

9.2.1 Configurations for Super Tall Buildings

Over the past several decades, innovations in the available elevator types have become available to meet the special needs of the super tall building. The definition of a super tall building is somewhat arbitrary but could well fit the design of a building with a minimum of 60 stories. There are two conceptual configurations available from the major elevator manufacturers. These are a system utilizing a sky lobby approach and a system using double-deck elevators.

9.2.1.1 Sky Lobby Concept

In the sky lobby concept, high-speed, high-capacity shuttle cars transport passengers from the entrance level to a sky lobby located at the point where the passengers transfer to a second bank of elevators that serve the local floors above the sky lobby. Figure 9-3 shows in cross section an arrangement of elevators for a building with a single sky lobby. The lower half of the building is served by local elevators configured with low-rise, mid-rise, and high-rise groupings. An express shuttle is available to take building occupants to a single-level sky lobby where they will have a second arrange-

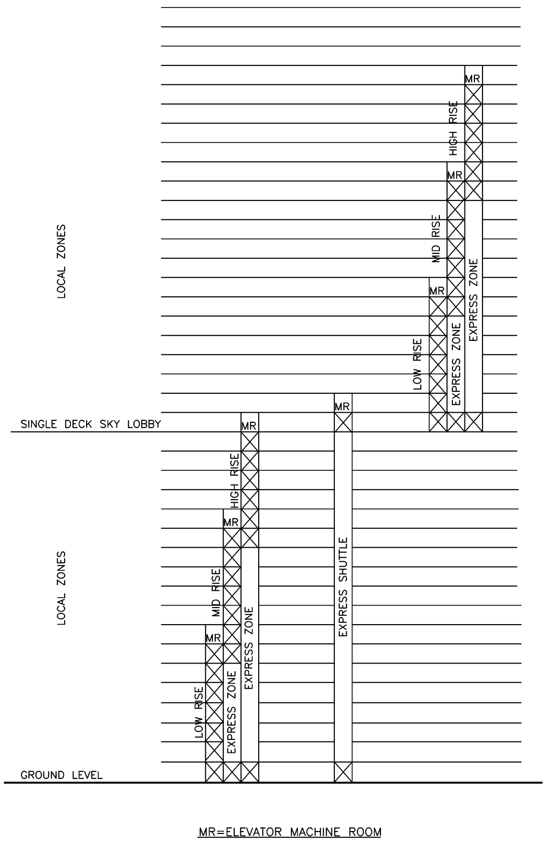


Figure 9-3.
Configuration for super tall building.

ment of low-rise, mid-rise, and high-rise elevators. This configuration effectively has two standard buildings one on top of the other.

This process in a super tall building of 80 or 90 stories or more could be repeated with passengers being express-carried to a second sky lobby from the entrance level where they transfer to the bank of elevators that serve the floors to which they are going. In this latter case, the result would be a building that, in effect, would resemble three standard buildings being stacked one on top of the other, each of the buildings having its own independent local elevator system served from the entrance level by the express shuttle elevators.

9.2.1.2 Double-Deck Elevators

An alternative to the sky lobby that has found application in tall buildings is a double-deck elevator. In this alternative, a dramatic reduction in the area required by the elevator shafts in the building core is possible. Each elevator is two cabs high and each cab serves every other floor. One serves all of the even number floors, the other every odd number floor. The two floors at the entrance level are connected by escalators to allow a passenger to get to the cab serving the floor he is attempting to reach. What results is a system where the two elevator cabs use a single hoistway, which, in turn, results in a more efficient core design for the project inasmuch as the number of elevator shafts is reduced. This benefit is obtained through a substantial premium in the cost of the elevators. Figure 9-4 shows in cross section the double-deck arrangement in a building with local floor stops.

This arrangement of double-deck elevators serving local floors has had limited application and has usually been installed in a single-tenant building with a high density

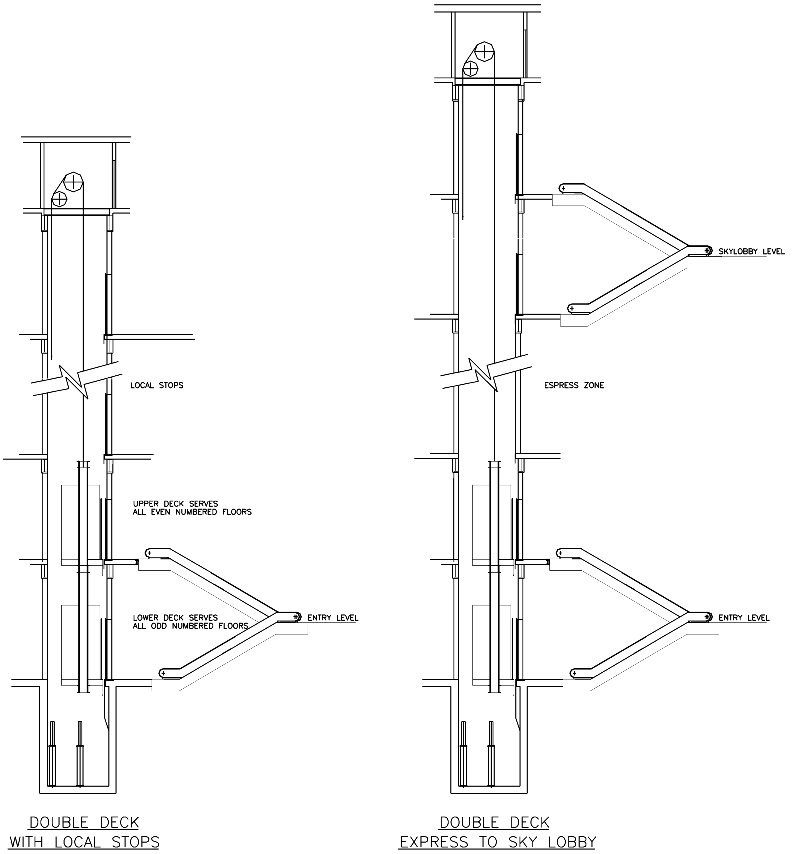


Figure 9-4. Double deck configuration for a tall building.

of population or a building where the saving in shaft space is considered of prime import. The most common application of double-deck elevators has been in super tall buildings in combination with the sky lobby concept. In this case, the shuttle elevators to the sky lobby will be double-deck elevators. When the vertical transportation system is provided in this configuration, escalators are required at the entrance level to allow people entering the building to efficiently proceed to the correct level of elevator. Escalators will also be required at each sky lobby to simplify the movement up or down to the proper bank of local elevators to take a passenger to his or her local floor destination. A typical configuration of the double-deck elevator with a sky lobby is shown in cross section in Figure 9-4.

9.3 SERVICE ELEVATOR

For all large commercial office buildings of an area in excess of 250,000 ft^2 (23,000 m^2), the inclusion in the design of a dedicated service elevator with its own service lobby should be given strong consideration. All buildings greater than 300,000 to 350,000 ft^2 (28,000 to 32,500 m^2) should include a dedicated service elevator. The sizing of the platform for a service elevator should, due to the nature of its particular usage, differ from the platform size of a passenger elevator. The platform should be greater in depth than width and should have an entrance door that will accept the largest broken-down piece of equipment that will be in the building. Figure 9-5 shows the typical dimensions for a 6,000 lb (2,800 kg) service elevator.

The platform dimension for the service elevator, however, may well need to be modified from an ideal size to one that will conform to the structure framing, which can

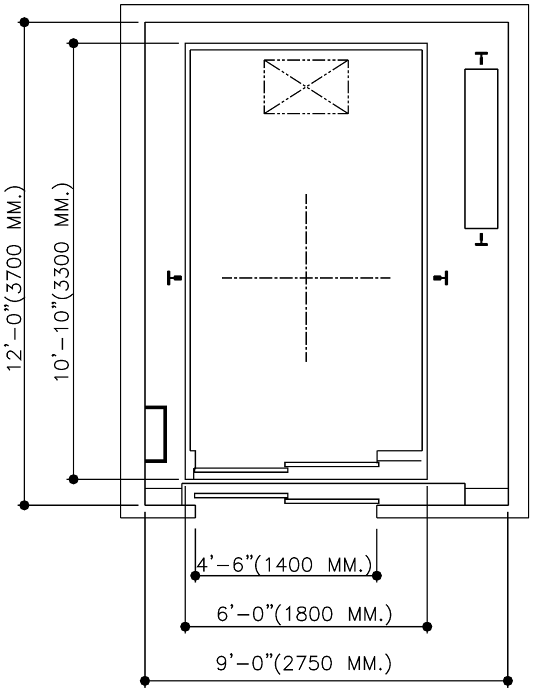


Figure 9-5. Typical size of commercial service elevator. Capacity: 6000 lb (2800 kg).

be driven, in large part, by the passenger elevators. When a dedicated service elevator is provided, it must have a dedicated service lobby on each floor to allow its use in delivering materials to meet the needs of a specific floor. The final requirement for the service car is that it should serve all floors in the building, including mechanical equipment room floors.

The use of a passenger elevator as a swing car that can be converted on an as-needed basis to a service car is usually not appropriate in a tall commercial building. This is due to the inherently large total area of that type of building and the adverse impact on the handling capacity and interval that will occur when a passenger elevator in a given bank is used as a service car. Moreover, if a passenger elevator is used as a swing service car, the fact that there are multiple banks of elevators serving the several floors will mean that the service car will not be available on all floors of the building and will usually not stop at the mechanical floors. While these are not requirements, they are significant issues that should be given consideration in arriving at the configuration of the service elevator system.

9.4 HVAC INVOLVEMENT WITH THE VERTICAL TRANSPORTATION SYSTEM

The HVAC designer has limited involvement with the vertical transportation system. The involvement will be to provide adequate cooling to the elevator machine room and to vent the elevator shaft so that it will conform to the codes that are in effect regarding the elevator system. The need for the elevator machine room at the top of each shaft for each cab may well result, as discussed in chapter 5, in the use of the floor on which the elevator machine room is located as a mechanical equipment room for air conditioning and plumbing equipment, including fans, coils, heat exchangers, refrigeration machines, and boilers. In this case, the providing of cooling and any required venting of the shaft to atmosphere is simplified when compared to the case where the area around the elevator machine room were to be used for general office occupancy.

9.4.1 Elevator Machine Room Cooling

The elevator machine room in a building has cooling loads that consist not only of the electric motor that drives the hoisting mechanism for the elevators, but also of extensive heat-generating electronic controls for the elevators. The electronic components that are part of the system will require that the elevator machine room be cooled in hot weather to a maximum temperature of 80°F (27°C) and be heated in cold weather so the space temperature will not drop below 60°F (16°C). One means of maintaining the temperature between these allowable levels is to provide a package DX condenser water unit in the elevator machine room, but, due to possible significant operational availability restrictions on the use of a water-cooled unit, the HVAC designer is cautioned to review that alternative with the building developer. The use of a package DX condenser water unit may well be necessary for a low-rise or mid-rise elevator bank for which the elevator machine room is in the middle of the building, unless the elevator machine room location results in the use of the remainder of the floor as a mechanical equipment room. For the elevator machine room for the elevator bank that serves the top of the building, it is possible to use air-cooled DX equipment, which will not require the operation of the condenser water system on a 24/7 basis.

The ultimate size of the water-cooled or air-cooled DX unit will be determined by the information provided by the elevator manufacturer who is selected as the provider of the elevators for the project. For the initial design stages, the necessary general information to allow the project to be designed and bid can be provided by the elevator consultant. The amount of cooling as the electronic devices and motor drives for the hoist have evolved can be significant. With current elevator designs, the DX unit may require 10 to 15 tons (35 to 52 kW) or more of capacity in a single elevator machine room.

9.4.2 Elevator Hoistway and Machine Room Venting

All elevators that are installed in the United States must conform to ASME A17.1, *Safety Code for Elevators and Escalators*, as it is modified by the local applicable building code. These modifications can vary by jurisdiction, with many areas modifying the code by stated amendments of the A17.1 code.

One of the requirements of many codes is the inclusion of a vent opening at the top of each elevator shaft that is 3.5 percent of the plan area of the hoistway or 3 ft^2 (0.27 m^2) per elevator, whichever is greater. The rationale for the opening is not entirely clear, but it was probably originally intended to allow the venting of smoke during a building fire. Regardless of the reason for its inclusion, the HVAC project design, where the vent is required, subject to the exclusions detailed below, must provide a duct that connects the vent to atmosphere. This is simple at the top of the building, but for a low-rise or mid-rise elevator in which the elevator machine room for the elevator bank is not in a mechanical equipment room, the extension of the connecting duct to atmosphere may be troublesome.

When designing super tall buildings, where elevator speeds are greater than 1,400 fpm (7 mps), vents at the bottom of the shafts may be required by code to facilitate the rapid escape of air when the high-speed car is traveling in the down direction.

Under many codes, including the model *International Building Code* (IBC), for a commercial office building that is fully sprinklered, the need for the vent and its extension to atmosphere may be waived for passenger elevators. The vent is still required for a dedicated service car, but this is normally easily handled, since the service car will be serving all floors in the building and the extension of the vent opening is a simple task where the elevator terminates at the top floor of the building.

In addition, under the *International Building Code*, the vent may be closed under normal building operating conditions by including an automatic damper in the atmospheric vent. This automatic damper must open upon the detection of smoke by any of the elevator lobby smoke detectors that are provided in the project. The elevator smoke detectors are disccussed in chapter 10, “Life Safety Systems.”

Chapter 10

Life Safety Systems

Every tall commercial building that is constructed in the United States will include design details and operating systems that, in total, will constitute a life safety system. The requirements for both the design details and operating systems that will be included will be defined in the building code that applies in the jurisdiction within which the building will be located. The building code will address construction details of the building, will outline minimum criteria for the means of egress from the building in the event of a fire or other emergency, and will specify protective features and systems that must be included to achieve the level of protection that can reasonably be provided to allow adequate egress time and protection for building occupants who may be exposed to a fire or the smoke generated by a fire.

10.1 THE UNIQUE FIRE SAFETY PROBLEM OF THE TALL COMMERCIAL OFFICE BUILDING

Before getting at the specifics of the life safety system, it is appropriate to repeat the General Services Administration's working definition of a tall building as it was noted in chapter 1. That definition stated:

> A high-rise building is one in which emergency evacuation is not practical and in which fires must be fought internally because of height (GSA 1971).

From the perspective of life safety systems, this definition recognizes that the usual characteristics of such buildings are: (1) they are beyond the reach of fire department aerial equipment; (2) they pose a potential for significant stack effect; and (3) they require unreasonable evacuation time.

The HVAC engineer will primarily be concerned with the design of the smoke management system, but the HVAC engineer must understand how the entire life safety system functions and the concerns that the other design professionals must address to result in an integrated total system. Accordingly, other facets of the system beyond smoke management are outlined in this chapter.

10.2 CODES AND STANDARDS

The design of the life safety systems for any building is a multidisciplinary effort involving the architect and structural engineer as well as the HVAC, electrical, and fire protection engineers. The architect will be concerned with the location and details of the fire stairs and areas of refuge as well as the fire rating of the shafts and internal separation of spaces in the building. The structural engineer will specify the fire-retardant material that will protect the structural system. The remaining elements of the life safety systems, which constitute the fire management systems, will be designed by the HVAC, electrical, and fire protection engineers.

Each of these areas of design will be governed by the local building code that applies in the jurisdiction within which the building is being constructed and, frequently, by reference to national fire protection standards that have been developed in the United States by the National Fire Protection Association (NFPA). These standards are applicable to many facets of a building design, specifically including those areas of concern to the mechanical and electrical design trades, which would be the fire alarm systems, the fire standpipe and sprinkler systems, and the smoke detection and smoke management systems. The critical NFPA standards are included in the "References" section.

The details of the rationale for these standards and many of the details of current fire suppression technology and practices are provided in the *Fire Protection Handbook* that is published by NFPA. This book is periodically updated to be consistent with the continually evolving practices that are being developed in fire technology. The book is also an excellent source for material on matters beyond the issue of fire suppression. While not all jurisdictions completely adhere to the recommendations in this book, it is the single most valuable resource on state-of-the-art fire technologies.

Several complications may present themselves when applying these NFPA standards and the codes that references them. First, while many local codes will adopt specific standards by reference, others may include modifications to portions of the standards that apply in the applicable location. Second, the authority having jurisdiction, as designated by the governing authority in the area within which the building is being constructed, will have the responsibility of interpreting both the standard and the applicable building code. Their interpretation can well differ and may be more restrictive than would be the case through a literal reading of the standard or the code by the design team. It is therefore imperative that the design professionals involved in any tall commercial project review the interpretation of both the applicable NFPA standards and the building code with both the building department and the fire department that are the responsible agencies in the area within which the building will be constructed. It will be their readings of any applicable standard and code that the design professionals will be faced with applying in a project design.

Finally, in the United States, there are major insurance carriers that have design criteria that can be more restrictive than either the NFPA standards or the building code and, if the building is being constructed by an entity that desires to comply with the requirements of one of these insurance carriers, it will be necessary that the design be completed to meet the stated requirements of these agencies.

Modifications are always being considered to building codes. For example, discussions currently are taking place in New York City to increase the width of stairwells to 68 inches (1,727 mm) to allow simultaneous two-way travel with the occupants proceeding down to exit the building and the fire department personnel going up to fight the fire. This change has not been incorporated into the codes of the City of New York but is included in this design guide to indicate that changes are always possible and under discussion by various governmental agencies. It is therefore prudent for the design professionals on any project to be cognizant of impending changes that will allow the inclusion of the appropriate design details on any project.

10.3 COMPONENTS OF A FIRE MANAGEMENT SYSTEM

The HVAC designer will work with the electrical and fire protection engineers to specify an integrated fire management system. Among the several features and systems that must be designed by this group of design professionals to provide for the fire management portion of the total life safety system for a properly engineered high-rise building would be: (1) a detection system that will include manual fire alarm pull boxes, a system of smoke detectors, and flow switches and supervisory switches in the fire standpipe and the sprinkler piping systems; (2) fire standpipe and automatic sprinkler systems; (3) a smoke management system; (4) an emergency electric power system; (5) an automatic elevator recall system; (6) communication and alarm notification systems; and (7) a central fire command center.

10.3.1 Detection System

A key element in the detection system is a system of smoke detectors. They are not required in all areas of a commercial office building but rather will be installed in locations that will provide specific functions for the building. These functions can include the altered control and/or shutdown of specific fans and the recall of elevators. Both of these control functions are discussed later in this chapter. The activation of a smoke detector can also result in the activation of stair pressurization fans. The smoke detectors, through their sensing of a smoke condition, are therefore an important means of providing notification of a fire condition in a building.

Smoke detectors are a joint responsibility of the electrical and HVAC trades in that the smoke detection system and the wiring of the entire system will be completed by the electrical contractor, but the installation of any smoke detectors that are required at system fans or in ductwork will be completed by the sheet metal contractor. This joint involvement of two trades requires close coordination in the design documentation to ensure each trade is clear on what they must provide and what they must do and there are no conflicts in the definition and detailing of the efforts of each contractor.

Smoke detectors should be installed where required according to *NFPA 90A, Standard for the Installation of Air Conditioning and Ventilating Systems*, and as detailed in the building code. The NFPA standard will mandate detectors in the return air connection on each floor for buildings using either a central air-conditioning supply system or a local floor-by-floor air-conditioning system. Smoke detectors are also required downstream of the filters in each supply system to shut down these fans in the event of a filter fire or smoke being brought into the building from the outside. Building codes will typically require smoke detectors on the ceiling of each elevator lobby and in mechanical equipment rooms, transformer and telephone equipment rooms, and similar spaces unless the room is protected by an automatic suppression system such as sprinklers.

The second component of the detection system involves the sprinkler system. All new high-rise office buildings erected in the United States under the model building codes will be required to be fully sprinklered. Some local codes, such as the Chicago Building Code, will allow compartmentation to be used as an alternative to the use of sprinklers, but even in that city, most builders will install sprinklers throughout the building, forgoing the alternative that is permitted.

For the purpose of monitoring sprinkler system performance, water flow devices will be required to be installed in the horizontal sprinkler piping on every floor level to locate water flow from any activated system. Water flow devices will also be installed in the vertical fire standpipe distribution system for additional system monitoring. All control valves in the fire protection system have to be equipped with supervisory switches that will indicate to building operating personnel an immediate signal of any unauthorized operation. The supervisory switches on the control valves are included to allow the building staff to be aware of an unauthorized valve closure, to ensure that the system is always functional, and, accordingly, are not a part of the early detection system. They are, however, an important part of the fire standpipe and sprinkler system.

An alarm from any water flow switch will be transmitted to an approved, proprietary alarm receiving facility, a remote station, a central station, or the fire department, or to various combinations of all of these possible receptors. In the installed system, all flow and tamper switch alarms will be recorded on a fire alarm control panel located in the central fire command center, which will be manned at all times. Alarms are also installed at the fire pumps to indicate operation, power failure, and abnormal pressure in the pump discharge.

The final component of the early detection system is the manual fire alarm pull boxes. Manual fire alarm pull boxes should be provided as required by code, which as a minimum will be at the point where occupants of a building will normally exit a floor and enter the fire stairs. This will allow the occupant who has observed a fire and is exiting the floor to initiate a fire alarm signal at the central fire command center. The fire command center will provide visual indication of the location of the manual pull box to allow building personnel to go to the point of the alarm initiation to determine the basis for the alarm before reporting the alarm to the local fire department. The control of fans, elevators, and other building components will usually not be automatically instigated with the actuating of a manual pull station, as they are subject to activation by a prankster.

The activation of the smoke detector in the elevator lobby will lower the elevator to its appropriate floor, as determined by the location of the fire, as is discussed later in this chapter. An alarm condition from any water flow switch control valve will activate the various components of the communication system, place in the operational mode required by the local fire department all equipment necessary to prevent the spread of smoke, and activate the elevator control system. The activation of the other components in the early detection system, such as the manual fire alarm pull box, sprinkler supervisory switch, or smoke detector other than the detector in the elevator lobby, will require investigation by the building before the instigation of a full-scale fire response.

10.3.2 Fire Standpipe and Sprinkler Systems

There are separate purposes behind the installation of fire standpipe systems and sprinkler systems. The standpipe system is provided to allow the fire department to fight a fire by bringing a flow of water through a hose connection provided at each floor in the standpipe in an effort to extinguish the fire. It requires a constant flow of water for as long as the fire fighter has a need for the flow. On the other hand, a sprinkler system provides the best means of protection from small fires, as this system automatically functions by putting water on a fire and, as a minimum, holding the fire in check until the trained fire fighter arrives and uses the fire standpipe system to extinguish the fire.

Standpipe systems are required in all tall commercial buildings as defined in this design guide. In general, in the United States, most applicable codes require a standpipe as a function of the area of the floors in a building and/or the height of the building. The height and depth of the floor relate to the maximum practical distance from which a fire can be fought externally from extension ladders and exterior equipment. When a fire occurs, the time that should be used to fight the fire and extinguish it is critical. Extinguishing a fire in its incipient stage is easier than extinguishing one that has progressed to the point of full floor involvement. Accordingly, for buildings with greater height than 75 feet (23 m), if that is the code-mandated maximum, it is necessary to extend a pipe riser up the stairwell and maintain a supply of water in that pipe at all times so that the fire fighters need only connect a hose to a valve provided on the fire standpipe at every floor.

Generally, in an actual fire condition, the hose is connected by the fire fighter one floor below or at an intermediate landing in the stair beneath the fire. This connection is made with a hose that may be brought to the location of the fire or may be permanently installed in the building in a cabinet adjacent to the fire standpipe. The permanent connection of the fire hose to the fire standpipe riser is determined by the operative building code that governs the building. The use of the hose immediately adjacent to the stair and door also provides a line for the firefighter to follow as an escape guide route in the event of dense smoke. By following the hose, the firefighter will be brought to the floor below the fire, which should be clear of smoke.

The amount of water supplied to the standpipe system is defined in the applicable code. It should be related to the number of fire hoses used simultaneously, but the amount of water that must be available and the arrangement of the pumps and piping can vary from jurisdiction to jurisdiction. The city fire department will usually require that they have an unlimited source of water available from the standpipe system to fight a fire. Major urban areas do not usually have a problem meeting this requirement, but a building in a rural community may not be prepared to provide adequate water to a tall building within its bounds. Under these conditions, it may be necessary to meet the needs for a given quantity of water by providing adequate storage capacity for an acceptable quantity of water within the building.

The means of distribution and the capacity of any storage tanks in a building will also be different with alternative codes, so caution is suggested on the part of the designer to ensure that the design for a given project will not only comply with NFPA but also be in conformance with the local code and the authority having jurisdiction in interpretation of the code.

While the fire standpipe system permits the fire department personnel to extinguish a fire that has developed in a building, the best way to provide means of early protection from fires is a sprinkler system. The sprinkler system in any space, including all areas of a commercial office building, should be designed, unless modified, for example by an owner or insurer, in accordance with *NFPA 13, Standard for the Installation of Sprinkler Systems*. This standard establishes alternative occupancy classifications that are applicable only with regard to the sprinkler design. The alternative classifications in NFPA 13 should not be confused with occupancy classifications, which are established in building codes and govern matters other than the sprinkler design, such as exiting requirements, fire ratings of partitions, walls, and slabs, etc.

The alternative NFPA occupancy classifications for a given space are determined by the type, amount, and arrangement of combustibles and the potential severity of a fire based on the burning characteristics of these combustibles in the space. In an office building, NFPA considers the quantity and combustibility of material of all office space—including data processing areas, any restaurant or food service seating areas or conference rooms, large presentation spaces or auditoriums—to be low and any fire to have relatively low rates of heat release. Accordingly, NFPA places all of these spaces in its lowest classification for sprinkler design, which is Light Hazard.

If an office building contained a full service restaurant cooking kitchen, that space would be considered Ordinary Hazard (Group I) space and would be subjected to different design standards than the office space with the Light Harzard classification.

The design classification, whether Light Hazard or Ordinary Hazard (Group I), will govern the schedule of pipe sizes, the spacing of the sprinklers, the sprinkler discharge densities, and the water supply requirements for the space, with more stringent requirements being applied in the Ordinary Hazard (Group I) spaces.

For all office building spaces, NFPA also will permit the combination of the fire standpipe and sprinkler piping. This is not true of many codes in Europe, which will require separate pipe risers for the fire standpipe and sprinkler systems.

10.3.3 Smoke Management Systems

The control of mechanical ventilation systems in a tall commercial building is needed to remove smoke from the area within which a fire has developed and to maintain smoke-free areas that will allow the occupants to exit the building without being subjected to the smoke generated by the fire. The means to achieve these goals is a function of the architectural design of the building and the specific systems that are provided for the project. The HVAC design engineer is responsible for the design of the smoke control systems using fans that are installed as part of the air-conditioning system in the building or fans that are installed solely for smoke control.

For the most exhaustive treatment of practical information and methods of analysis for smoke management, the reader is referred to the 2002 publication *Principles of Smoke Management* by John H. Klote and James A. Wilke, which is jointly published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., and the Society of Fire Protection Engineers. In addition, the *ASHRAE Handbook—Applications* has a chapter on "Fire and Smoke Management" and the *ASHRAE*

Transactions references several papers that address this issue. Additional information is contained in *NFPA 92A, Recommended Practice for Smoke Control Systems,* and *NFPA 92B, Guide for Smoke Management Systems in Malls, Atria and Large Areas*.

When there is a fire in a tall building, there is a tendency for smoke generated by the fire to migrate from the area of the fire to other areas of the building. The basis of this migration is the natural buoyancy and volumetric expansion of smoke; the stack effect that is directly related to the outdoor air temperature and the height of the building; the wind currents around the building, which will alter the air movement that takes place at the outdoor air and spill dampers and ultimately can affect the movement of both air and smoke within the building; and the operating mode and the performance of the fans in the building.

To obtain the necessary control over the tendency of smoke to migrate to occupied spaces, the fans in the building must be operated without recirculation of the return air that is transported from the area of a fire to a mechanical equipment room. If that air were recirculated by the air-conditioning supply systems, it could carry the entrained smoke back to occupied sections of the building. This must not be allowed to happen. A key concern, therefore, is to operate building fans in a manner that will overcome any stack effect while ensuring that smoke-ladened air is not distributed from the fire area to occupied building sections not in the actual fire zone.

The exact method of control and fan operation must be reviewed with the local authority having jurisdiction since their desires can well vary from city to city. Many fire departments in various jurisdictions will require the building fans to automatically shut down with their subsequent start-up and control being effected by the fire fighters at the job site in response to the specific situation that is observed in the building. Moreover, any operation of the building fans will be contingent upon the specific design details of the project, but the operation of the project fans to minimize smoke migration from the fire floor can be stated in a general manner prior to consideration of the specific system alternatives.

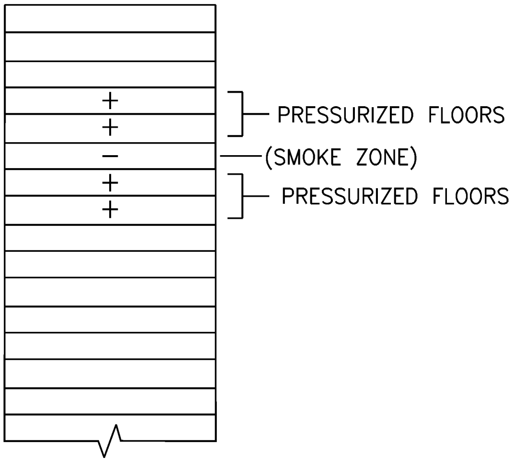
All the dampers that are used in a building for the purpose of smoke control should be constructed and classified for leakage in accordance with Underwriters Laboratories Standard for smoke dampers, UL555S. This standard includes the construction requirements and tests for a rated damper including its maximum leakage rate. The dampers should be Class II or III if used for smoke control purposes.

In the tall commercial building, each floor is usually considered a smoke zone. In the event of a fire, the fan systems should be operated to keep the floor on which the fire occurs in a negative pressure relationship to the floors above and below it, so as to extract any smoke rather than having it exfiltrate into the adjacent floor. This process of containment can be enhanced by maintaining one or two floors above and below the smoke zone floor in a positive relationship to the smoke zone floor through an altered operation of the fans that supply these floors. The pressure relationships are shown in Figure 10-1.

The method of obtaining the negative pressure on the smoke zone floor and a positive pressure condition on the floors above and below the smoke zone floor will differ as a function of the type of system used in the project, the alternatives being central air-conditioning systems or floor-by-floor air-conditioning systems. These alternatives were discussed in detail in chapter 5. The smoke control operation of these two alternative approaches must be discussed separately, as the solutions differ for either approach.

10.3.3.1 Smoke Management with Central Air-Conditioning Systems

In this approach to meeting the air-conditioning needs of a tall commercial building, the conditioned air is delivered to occupied areas by large built-up air-conditioning



NOTES:
1. THE FIRE IS LIMITED TO SPACE ON THE FLOOR MARKED SMOKE ZONE.

2. ONE OR TWO FLOORS ABOVE AND BELOW THE SMOKE ZONE ARE PRESSURIZED.

Figure 10-1. Tall building smoke zone arrangement.

systems that meet the needs of multiple floors and are installed in a central mechanical equipment room.

As noted in chapter 5, it is recommended that two-position dampers (i.e., open or closed) be installed in both the supply and return air duct connections that are provided at each floor. This would be in the supply air duct that brings air to the floor and in the return air duct connection at the point where return air is extracted from the ceiling plenum on the floor. These dampers have the capability of being opened or closed remotely through the building management system so as to cause supply air to be supplied or not supplied to a given floor and to cause return air to be exhausted or not exhausted from a particular floor.

With these specific capabilities in mind, a method of fan control that has been employed is to have the supply fan go to 100 percent outside air (i.e., using no return air), have the return fan go to 100 percent spill (i.e., exhausting all return air out of the building), and modify the floor dampers to pressurize adjacent floors to contain the fire within its known location while removing the smoke being generated from the fire floor. This would mean closing the damper in the supply duct to the fire area and opening the damper in the return (exhaust) duct from the same area. In areas adjacent to the fire region (i.e., the floor or floors immediately above and below the fire floor), the supply fan would inject 100 percent fresh air, and the return air (exhaust) ducts would be closed. The result of these actions would be to effectively pressurize areas above and below the fire floor as well as the stairwells and elevator shafts and remove as many products of combustion from the building as possible without contamination of areas adjacent to the fire.

The variable-frequency drive on the supply and return fans would operate to control the supply and return fans to ensure the proper degree of air movement by the respective fan. The return air fan must extract at least 6 to 8 air changes per hour from each floor where there is a fire to allow the removal of smoke from the floor. As noted, the above

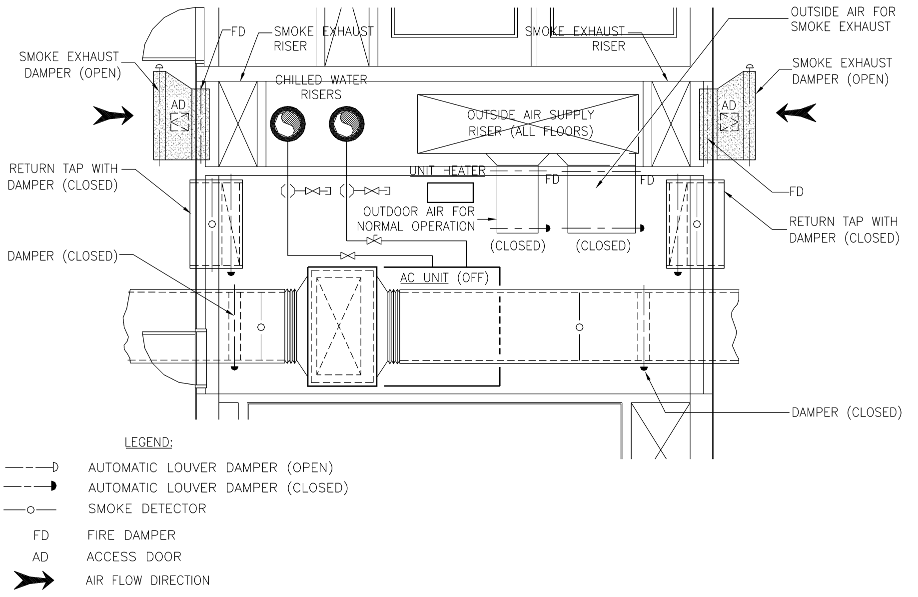


Figure 10-2. Floor-by-floor air-conditioning unit layout (smoke operation—smoke floor).

is but one possible operating scenario of the fan systems, and the experience of the HVAC designer and the requirements of different fire departments may result in alternative modes of fan operation.

10.3.3.2 Smoke Management with Floor-by-Floor Air-Conditioning Systems

The fan arrangement with the air-conditioning systems installed on a floor-by-floor basis is different from the central air-conditioning supply system just discussed. Here, in order to properly eliminate smoke on a fire floor, it is necessary to provide a smoke exhaust shaft to each local fan room that terminates in the same central fan room that contains the supply fan that supplies outside air to the local fan room. The smoke exhaust shaft to which this smoke exhaust fan is connected should be sized, as should the fan itself, for between 6 and 8 air changes per hour of the largest floor in the vertical stack of floors to which the duct is connected. Each duct tap to the smoke exhaust shaft must contain a two-position (open or closed) damper. The effect is that a control similar to that of the central fan room alternative can now be effected.

In the event of a fire on a particular floor, the duct tap to the smoke exhaust riser on that floor opens, and the duct tap to the smoke exhaust riser on all other floors remains closed. The smoke exhaust fan is started, with return air from the fire floor only being exhausted to atmosphere. Supply air to the floor or floors above and below the fire zone can be operated with 100 percent outside air to again pressurize the floor, effectively keeping the smoke-laden air within the fire floor while it is exhausted to atmosphere in a period of time.

An example of how the unit on the fire floor could operate is shown in Figure 10-2. It is the same physical arrangement that was shown in Figure 5-2, but the operation of the fan and the position of various dampers is quite different. Again, the use of the unit can only be controlled in accordance with the desires of the local fire authorities. What is key is that the several automatic louver dampers (ALDs) shown must be capable through the building management system of assuming a position that the fire department considers appropriate for the existing emergency condition in the building.

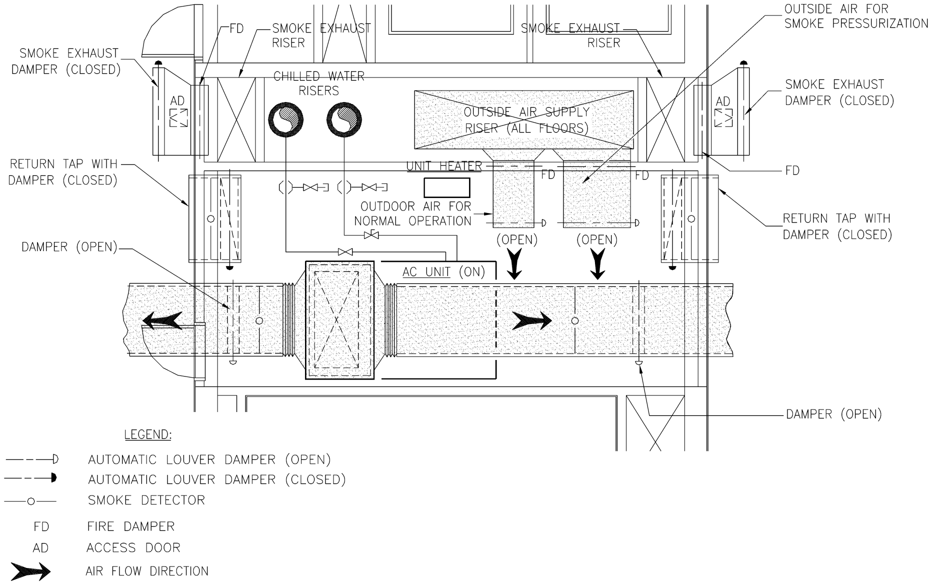


Figure 10-3. Floor-by-floor air-conditioning unit layout (smoke operation—floor above and below smoke floor).

The units on the one or two floors above and below the fire floor will operate as shown in Figure 10-3. For these units: (1) the outside air for smoke pressurization and the outside air for normal operation of the unit will both open, (2) the return air damper and the smoke exhaust riser damper will both close, and (3) the supply unit will operate with 100 percent outside air. To ensure sufficient outside air, all of the other floor-by-floor units using the outside air riser must be shut and the outside air riser must be sized to provide sufficient air to the number of floors on which the supply units will operate with 100 percent outside air.

10.3.3.3 Smoke Management in Atriums

An architectural feature of many buildings is the inclusion of an atrium to enhance the aesthetics of the building. The inclusion of an atrium presents special conditions of smoke removal that are usually covered within the operative code for the jurisdiction within which the building is located. Until recently, codes in the United States have mandated that a required rate of smoke removal be provided for an atrium in terms of air changes per hour over the total volume of the atrium and any open connected areas. The latest research has determined that this approach of air changes over a period of time is not an appropriate solution for a proper smoke management design for an atrium. Accordingly, both the *International Building Code* and NFPA 5000 utilize a performance-based design approach as detailed in *NFPA 92B, Guide for Smoke Management Systems in Malls, Atria and Large Areas* and as discussed in *Principles of Smoke Management* by Klote and Milke.

Tall commercial buildings that contain an atrium must be provided with a smoke management system that will obtain smoke movement control and removal. Generally, this is accomplished through the use of mechanical fans. Natural venting of these spaces is not normally a viable alternative. Under the *International Building Code* and NFPA 5000, the fans that are installed in an atrium must function so as to contain the height of the accumulated smoke layer in the upper portions of the atrium at a minimum of 10 ft (3.048 m) above the highest walking surfaces of the egress means from the smoke zone. The exhaust fans will remove air from the upper levels of the atrium. They will exhaust a sufficient quantity of air to keep the smoke above the desired level from the largest calculated plume mass flow rate for alternative configurations that are possible. The means of determining the plume configuration will be based on the design fire as defined in the building code. This, in turn, will permit the calculation of the fan capacity that will obtain the goal of a 10 ft (3.048 m) smoke-clear area above the highest egress level. The means of analyzing the plume configuration and exhaust fan capacity are detailed in the NFPA 92B publication and in the Klote and Milke text.

The system must also be configured to provide a natural or mechanical supply of outside air or air from spaces adjacent to the smoke zone to replace the air that is being exhausted.

The action of the designed system for the atrium has the multiple goals of maintaining an environment that will provide a means of egress for the occupants of the building while providing ongoing conditions that will enable fire fighting personnel to enter the space and both locate and control the fire.

10.3.3.4 Stairwell Pressurization

Most building codes will require that the fire stairwells in a tall commercial building be pressurized to keep them smoke-free in the event of a fire in the building. The smoke-free atmosphere is required for three reasons: (1) the stairs will be an area of refuge to be used by the building occupants who are directed to leave a fire floor or floor in proximity to the fire floor; (2) the stairs are an essential element in the escape route for the controlled evacuation of people from the building; and (3) the stairs will be used by the fire fighters as they attempt to control and extinguish the fire.

The stair pressurization system must be capable of maintaining a pressure differential between the stair and any floor that is sufficient to prohibit smoke-laden air from entering the stairwell. The pressure differential will have a minimum and maximum value that, in the case of the lower value, will be sufficient to keep the smoke from entering the stairwell and, in the case of the maximum value, will still allow the door to be opened by occupants trying to enter the stair. The minimum value stated in the NFPA 101 *Life Safety Code* is 0.05 in. of water (12.4 Pa) in a sprinklered building. For a door 7 ft (2.1 m) tall by 3 ft (0.9 m) wide, this would yield a pressure of 5.5 lb (24N) against the total surface of the door. NFPA 101 limits the force that will be required to set the door in motion in a new building to 30 lb (133N), which, for the same 7 ft (2.1 m) by 3 ft (0.9 m) door, would equate to a pressure of 0.27 in. of water (67.2 Pa). This maximum allowable value need not be the basis of the design, and frequently the maximum pressure will be between 0.05 in. of water (12.4 Pa) and 0.15 in. of water (37.3 Pa), but the minimum and the maximum pressure will be established in the design specifications, and this range of pressure differentials will need to be maintained in the stair pressurization system.

Establishing this range of pressure is important, as it is necessary to design any stairway pressurization system to stay within this range with all doors closed or with a stipulated number of doors open. Alternative means of achieving these goals have resulted in a multiplicity of configurations for stairwell pressurization systems, not all of which would be successful for the tall commercial building.

For the tall commercial building it is necessary to inject outside air into the stair at multiple levels of the stair. There is not full agreement on the number of floors between the points of injection, but three floors or less is probably a prudent recommendation.

The fans that bring the outside air into the stair will usually be located in mechanical equipment rooms at more than one level in the building to limit the size of the vertical duct attached to any fan installed to pressurize the stairs. Moreover, the air must be brought from a location that will eliminate any possible contamination with smoke-laden air being expelled from the building. Alternative means have been used to maintain the pressure in the stair between the allowable minimum and maximum values. One successful means of maintaining the pressure differential involves the installation of a series of barometric dampers, one on each floor, to open when the maximum pressure is reached. The barometric dampers and the associated jumper duct will relieve excess air from the pressurized stair to the ceiling plenum adjacent to the stair. The jumper duct will require fire dampers that are necessary to retain the fire rating of the exit stairs. The quantity of air being delivered by the fan under this arrangement would be constant and would be determined by consideration of the number of floors served by the fan, the tightness of the stair, and the maximum number of doors that can be opened at any point of time.

10.3.4 The Emergency/Standby Generator System and the Life Safety System

The interface details between the HVAC and electrical designers in the design of the generator plant for a building were discussed in chapter 8. This chapter is concerned with the technical means of providing power to the life safety system as required by the model building codes and NFPA. The NFPA requirements are provided in the National Electric Code, which is detailed in NFPA 70.

The distinction between an "emergency" and a "standby" generator is not a function of the equipment used to provide secondary electrical capacity but rather is determined by the loads that are being operated by the generator; specifically, the National Electric Code recognizes three classifications of load that will need to be or can be connected to a secondary power system:

- *"Emergency loads," which are addressed in the National Electric Code in Article 700*. These are the loads that are considered essential to the life safety of people and are required to permit safe evacuation of the building. Included are load items such as the fire command station (including its lighting), the fire alarm system, communication systems, egress lighting (including the main lobby in the building), exit signs, fire pumps, elevators, and elevator cab lighting, and other equipment that, if not in receipt of backup power, could result in a hazard to building evacuees.
- *"Legally required standby loads," which are addressed in the National Electric Code in Article 701*. These are loads that are required to assist fire fighting and rescue operations. Included are load items such as smoke exhaust or pressurization fans, sump pumps, sewage ejector pumps, and other mechanical equipment that could be used by fire fighters or rescuers as well as loads that, if not in receipt of backup power, could result in a hazard to rescuers.
- *"Optional standby loads," which are addressed in the National Electric Code in Article 702*. These are loads that the building operation may choose to provide with backup power for business continuity purposes. As noted in chapter 8, this could involve telecommunications or data processing equipment and the HVAC systems that allow this equipment to operate by maintaining the critical environment for the spaces within which the equipment is installed.

The National Electric Code requires that the generator plant supplying the emergency and legally required standby loads be automatically started with full power in a specified period of time. The emergency loads must receive backup power 10 seconds after a loss of power. The legally required standby system must be capable of accepting electrical loads within 60 seconds of the failure of the normal electric service. The source of power may be separate for each category, but usually a single generator plant will supply both the emergency and legally required standby loads so the 10-second delivery of power for the emergency loads will govern if the secondary source is the generator plant.

The secondary source need not be a generator plant. For example, the fire alarm system must be installed so any data collected by it will not be lost when a failure of the primary electric source occurs. The data collected by the system can only be protected by the inclusion of a battery system to protect the volatile memory of the fire alarm system during the short period of time for the transition of the system electric power to the generator plant. While it is possible to use a battery backup as the sole secondary source, this becomes complicated by the time frame for which the batteries must provide the power. As a result, the generator plant will be used and the batteries will only be employed for the secondary source of power until the generator is on line.

It is also possible to use battery pack units as the secondary source of power to egress lighting fixtures and exit signs, but the available power from the generator is usually the source of power for these fixtures in a new building. In recent projects, some owners, in a reaction to possible external threats, have also placed the egress lighting on both emergency power and battery packs as well.

The approved secondary source of power beyond battery systems is oil-fired diesel generator sets or oil-fired gas turbines. The use of oil-fired gas turbines is not common. In part this is a result of the 20 to 40 seconds that are required by a gas turbine to provide beneficial power after being started. This exceeds the time limit for power to the emergency loads, which would require battery packs at all lighting fixtures and exit signs and UPS power to the other emergency loads if a gas turbine were to be used. In addition to this limitation, an oil-fired gas turbine generator set is more expensive than a diesel generator set of equal size and gas turbines are only available in a limited number of units whose capacity could be utilized to meet the secondary power requirements of tall commercial buildings. Oil-fired gas turbine generators have found application in existing buildings where the generator is to be installed on an upper floor when the structure has limited ability to handle additional structural loads. In these cases, the lighter weight of the gas turbine as compared to a diesel engine may well lead to the use of the gas turbine as a more cost-effective solution.

Spark plug-energized diesel engines or gas turbines using natural gas as a fuel rather than oil are not permitted under the model building codes, as the code requirement is to have the fuel source for the generator captive to the building. This requirement is in the building codes so that in the event of a disaster that interrupted both the electric and natural gas service to the building, the performance of the life safety system would not be compromised.

The model codes and NFPA also state that the capacity of the emergency/standby power system must be sufficient to be capable of supplying power to all of the equipment that must be operational by the life safety system at a given point of time. Where a backup power supply system is required to serve emergency loads, it is permitted to also serve legally required standby loads, as well as optional standby loads, as long as there is a load-shedding capability to ensure that life safety loads are given priority.

With the inclusion of permitted load shedding, this does not mean that all connected equipment must be simultaneously operational. For example, not all elevators in a building would be required to operate at the same time. The elevator needs would be met by conforming to the building code, which, in the event of a power outage, would usually permit the operation of any one elevator at a time in each bank, with the other elevators in the bank being operated sequentially after the first elevator is brought to its agreed terminal floor. The elevator design would then permit a second and then the additional elevators to be operated in the bank until all elevators and their passengers are at the terminal level in the building, but the emergency/standby generator would only be sized to handle the largest electric motor in a given bank of elevators.

What is therefore required to determine the capacity of the emergency/standby power system is to determine what equipment will need to operate at any given point of time and select the generator to provide that required capacity. As was noted in chapter 8, this necessitates that the electrical design engineer obtain from the HVAC, fire protection, and elevator designers their secondary electrical needs and review these requirements along with the needs of the equipment on the electrical drawings. This will allow the electrical designer to determine the size of the generator plant that must be provided for the project.

It is possible on very large projects with high optional standby loads beyond the life safety system to install a separate generator to meet the needs of the life safety system and a separate plant of one or more generators for the special optional loads. This could maintain a higher degree of protection and isolation for the life safety generator while avoiding the complication of the interface with the conventional building loads.

10.3.5 Elevator Recall System

Any detailed analysis of life safety for the occupants of a high-rise building indicates that the proper control of the elevator system in the event of a prospective fire catastrophe is to return the cabs to the lowest floor that they serve in the case of mid-rise or high-rise elevator banks or to the lobby level in the case of the low-rise bank. There are several reasons for this strategy. First, it removes the elevators from the building egress system, forcing the prospective users to go to the area of refuge designated for them. This will help control and direct flow of people through the building. Second, it has been determined that some fire-caused deaths in high-rise buildings have resulted from people being trapped in the elevators and ultimately asphyxiated by smoke inhalation. Third, and most important, it places the entire elevator system under the control of the fire department, who can use the elevators for controlled evacuation and ultimately for the overriding benefit of the largest number of people in the building.

The means for causing the elevators to return to their terminal floor would be the activation of specific alarm device(s) included in the total system (i.e., smoke detector located in the elevator lobby or sprinkler flow alarm).

If a fire and power failure occur simultaneously, the emergency generator must be capable of operating at least one elevator serving every floor in the building at all times with a means to transfer the emergency power to all of the elevators in any bank. This will allow the elevators that are operating at the time of the power failure to be brought down to a terminal floor and effect a controlled evacuation of the elevator passengers.

The use of the elevators in the above-specified fashion requires the active cooperation of the elevator manufacturer and the fire control people but gives great benefit to the building's occupants. It recognizes that the elevator usage in the building must be controlled by the people who know what is happening, and where, in the event of a building fire situation. It permits the elevators to be used, not only for building evacuation, but also for the quickest possible movement of the fire fighting personnel to the area within the building where they can do the most good in controlling the fire.

10.3.6 Communication Systems

The life safety system for the high-rise office building will be required by code to be provided with a voice alarm/public address communication system to allow the occupants of the building to be informed of any emergency that may develop as well as the action they must take to exit to an area of refuge. The voice alarm/public address system will operate from the central fire command center. The voice alarm system will generate an audible trouble signal when activated by the operation of any smoke detector or sprinkler water flow device. The system will also be configured to permit the fire department to communicate from the fire command center with both the occupants and the fire fighters who will be in various locations in the building. The system will provide the ability to selectively make announcements on office floors but also in elevators, elevator lobbies, and exit stairways.

In addition to the voice alarm/public address communication system, a two-way fire department communication system must be provided in tall buildings for the exclusive use of the fire department. It will allow fire fighters to establish two-way communication throughout the building, which will permit fire fighters in the building to provide the status of the emergency to the central fire control center personnel. These two-way communication devices are installed in every elevator, elevator lobby, and fire stair.

10.3.7 Central Fire Command Center

A central fire command center will be required in every tall building. It will be provided in a location that will be approved by the fire department. A ground floor location in close proximity to the elevator control panel will usually be required. The purpose of the central fire command center is to provide a location where the fire fighting personnel can operate during a fire or other emergency. The central fire command center will provide visual confirmation and status of all of the building alarm systems and status and operational control of all of the smoke management systems. The fire command center will also provide the ability to selectively communicate within the building to any area and to fire department locations external to the building. Accordingly, the central fire command center will contain the following:

- Voice fire alarm system panels and controls
- Fire department communication systems controls
- Fire detection and alarm system annunication panels
- Elevator status and cab locations
- Sprinkler valve and water flow status indication
- Controls for unlocking all doors in fire stairs
- Emergency generator status indication
- Fire pump status indication
- Status and operational control of all building fans, dampers, and systems
- Status and operational control of all floor dampers
- A telephone for fire department use for external communications

The obvious purpose of the central fire command center is to permit a single point within the building to be the rendezvous and control point for the fire department and building personnel. It is the brain and the heart of the ultimate fire response achieved by the building. Its organization, both internally and in terms of the functions that are possible, should be carefully reviewed and analyzed by the designer of the overall system with the local fire department.

10.4 FIRE SAFETY RESPONSE PLAN

Having established the fire management approach that is utilized in the high-rise building, the difficulty of evacuating a building under a fire emergency must be recognized and addressed. During the normal workday, when people desire to leave the building, they will use the vertical transportation system, which will consist of elevators and possibly escalators to get them to the street level. During a fire, as was discussed, the elevators will usually not be available, since they will have been returned automatically to their terminal floor and will be under control of the fire department. Further, even if available, the elevator system is not capable of handling the mass of people who would be attempting an exodus under these circumstances. Elevators are not installed in any building with the capacity to permit rapid evacuation of substantial portions of the population of the building under condition of emergency.

If the occupants of the building cannot be evacuated vertically, they must be trained to move to areas of refuge that have been established within the building. Typically, these would be stairwells or other designated fire-safe areas, which will be three or more floors beneath the fire floor. From these areas, people can be removed from the building on a controlled basis by the fire department. Accordingly, every high-rise office building will be required by NFPA 101 and by the building code to have in place a fire safety organization and fire response plan. The plan would involve detailing for the building fire marshals all emergency procedures that will be followed in the event of a fire and posting of all areas of refuge that should be used by occupants in an emergency and will require regularly called fire drills to ensure proper understanding of what is to be done in the unfortunate event of an actual fire condition in the building. Only through proper and regular rehearsal of procedures under non-fire conditions by the building fire marshals with all building occupants will the occupants be fully capable of proper response to an actual fire. The people who live in the building must know that their safety is contingent upon their following the fire safety plan, which will involve their going to their designated area of refuge when a fire alarm is sounded. This reaction can only be achieved through the dissemination of the fire response plan and periodic drills that follow the plan.

An additional point not to be overlooked is the inherent conflict between the use of stairwells as areas of refuge and the security system in the building. Quite frequently, as part of a building security system, the stairwell doors, to the limit allowed by code, will be locked from the inside to prevent exit from the stairs on any floor other than the main lobby floor. For example, in New York City, under a non-fire condition, an unlocked reentry door must be provided on every fourth floor, and it is not possible to enter an office floor from a stair on any of the three floors between the reentry floors. These are not proper restrictions under fire conditions for either the occupants or fire fighters who must be afforded reentry paths from stairwells to any floor in the building. Accordingly, means must be provided to automatically open the secured doors, where installed, if any of the building fire detection devices are actuated.

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