CHAPTER 3

COMMERCIAL AND PUBLIC BUILDINGS

THIS chapter summarizes load characteristics and both general and specific design criteria that apply to commercial buildings. Design criteria include such factors as comfort level; cost; and fire, smoke, and odor control. Specific information is included on dining and entertainment centers, office buildings, bowling centers, communication centers, transportation centers, and warehouses. Museums, libraries, and archives are covered in Chapter 21.

GENERAL CRITERIA

In theory, most systems, if properly applied, can be successful in any building. However, in practice, such factors as initial and operating costs, space allocation, architectural design, location, and the engineer's evaluation and experience limit the proper choices for a given building type.

Heating and air-conditioning systems that are simple in design and of the proper size for a given building generally have fairly low maintenance and operating costs. For optimum results, as much inherent thermal control as is economically possible should be built into the basic structure. The relationship between the shape, orientation, and air-conditioning capacity of a building should also be considered. Because the exterior load may vary from 30 to 60% of the total air-conditioning load when the fenestration area ranges from 25 to 75% of the exterior envelope surface area, it may be desirable to minimize the perimeter area. For example, a rectangular building with a four-to-one aspect ratio requires substantially more refrigeration than a square building with the same floor area.

Building size, shape, and component selection are normally determined by the building architect and/or owner. Changing any of these parameters to reach optimum results requires cooperation among these individuals or groups.

Proper design also considers controlling noise and minimizing pollution of the atmosphere and water systems around the building.

Retrofitting existing buildings is also an important part of the construction industry because of increased costs of construction and the necessity of reducing energy consumption. Table 1 lists factors to consider before selecting a system for any building. The selection is often made by the owner and may not be based on an engineering study. To a great degree, system selection is based on the engineer's ability to relate factors involving higher first cost or lower life-cycle cost and benefits that have no calculable monetary value.

Some buildings are constructed with only heating and ventilating systems. For these buildings, greater design emphasis should be placed on natural or forced ventilation systems to minimize occupant discomfort during hot weather. To provide for future cooling, humidification, or both, the design principles are the same as those for a fully air-conditioned building.

The preparation of this chapter is assigned to TC 9.8, Large Building Air-Conditioning Applications.

Load Characteristics

Load characteristics for the building must be understood to ensure that systems respond adequately at part load as well as at full load. Systems must be capable of responding to load fluctuations based on the combination of occupancy variations, process load shifts, solar load variations, and atmospheric weather conditions (e.g., temperature and humidity changes). Some building loads may be brief and infrequent, such as an annual meeting of a large group in a conference room, whereas others may be more constant and long-lasting, such as operation of data processing equipment.

Analysis of any building for heat recovery or total energy systems requires sufficient load profile and load duration information on all forms of building input to (1) properly evaluate the instantaneous effect of one on the other when no energy storage is contemplated and (2) evaluate short-term effects (up to 48 h) when energy storage is used.

Load profile curves consist of appropriate energy loads plotted against the time of day. Load duration curves indicate the accumulated number of hours at each load condition, from the highest to the lowest load for a day, a month, or a year. The area under load profile and load duration curves for corresponding periods is equivalent to the load multiplied by the time. These calculations must consider the type of air and water distribution systems in the building.

Load profiles for two or more energy forms during the same operating period may be compared to determine load-matching characteristics under diverse operating conditions. For example, when thermal energy is recovered from a diesel-electric generator at a rate equal to or less than the thermal energy demand, the energy can be used instantaneously, avoiding waste. It may be worthwhile to store thermal energy when it is generated at a greater rate than demanded. A load profile study helps determine the economics of thermal storage.

Similarly, with internal source heat recovery, load matching must be integrated over the operating season with the aid of load duration curves for overall feasibility studies. These curves are useful in energy consumption analysis calculations as a basis for hourly input values in computer programs (see Chapter 31 of the 2001 *ASHRAE Handbook—Fundamentals*).

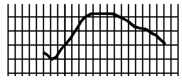
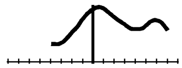
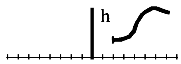
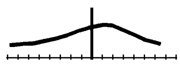
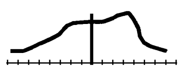
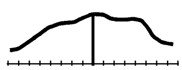
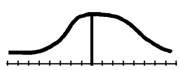
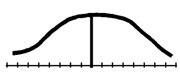
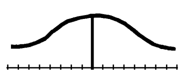
Aside from environmental considerations, the economic feasibility of district heating and cooling is influenced by load density and diversity factors for branch feeds to buildings along distribution mains. For example, the load density or energy per unit length of distribution main can be small enough in a complex of low-rise, lightly loaded buildings located at a considerable distance from one another, to make a central heating, cooling, or heating and cooling plant uneconomical.

Concentrations of internal loads peculiar to each application are covered later in this chapter and in Chapters 28, 29, and 30 of the 2001 *ASHRAE Handbook—Fundamentals*.

Table 1 General Design Criteria[a, b]

General Category	Specific Category	Inside Design Conditions: Winter	Inside Design Conditions: Summer	Air Movement	Circulation, air changes per hour
Dining and Entertainment Centers	Cafeterias and Luncheonettes	70 to 74°F 20 to 30% rh	78°F[d] 50% rh	50 fpm at 6 ft above floor	12 to 15
	Restaurants	70 to 74°F 20 to 30% rh	74 to 78°F 55 to 60% rh	25 to 30 fpm	8 to 12
	Bars	70 to 74°F 20 to 30% rh	74 to 78°F 50 to 60% rh	30 fpm at 6 ft above floor	15 to 20
	Nightclubs and Casinos	70 to 74°F 20 to 30% rh	74 to 78°F 50 to 60% rh	below 25 fpm at 5 ft above floor	20 to 30
	Kitchens	70 to 74°F	85 to 88°F	30 to 50 fpm	12 to 15[g]
Office Buildings		70 to 74°F 20 to 30% rh	74 to 78°F 50 to 60% rh	25 to 45 fpm 0.75 to 2 cfm/ft^2	4 to 10
Museums, Libraries, and Archives (Also see Chapter 21)	Average	68 to 72°F 40 to 55% rh		below 25 fpm	8 to 12
	Archival	See Chapter 21, Museums, Libraries, and Archives		below 25 fpm	8 to 12
Bowling Centers		70 to 74°F 20 to 30% rh	75 to 78°F 50 to 55% rh	50 fpm at 6 ft above floor	10 to 15
Communication Centers	Telephone Terminal Rooms	72 to 78°F 40 to 50% rh	72 to 78°F 40 to 50% rh	25 to 30 fpm	8 to 20
	Radio and Television Studios	74 to 78°F 30 to 40% rh	74 to 78°F 40 to 55% rh	below 25 fpm at 12 ft above floor	15 to 40
Transportation Centers (Also see Chapter 13, Enclosed Vehicular Facilities)	Airport Terminals	70 to 74°F 20 to 30% rh	74 to 78°F 50 to 60% rh	25 to 30 fpm at 6 ft above floor	8 to 12
	Ship Docks	70 to 74°F 20 to 30% rh	74 to 78°F 50 to 60% rh	25 to 30 fpm at 6 ft above floor	8 to 12
	Bus Terminals	70 to 74°F 20 to 30% rh	74 to 78°F 50 to 60% rh	25 to 30 fpm at 6 ft above floor	8 to 12
	Garages[j]	40 to 55°F	80 to 100°F	30 to 75 fpm	4 to 6
Warehouses		Inside design temperatures for warehouses often depend on the materials stored			1 to 4

Table 1 General Design Criteria[a, b] (*Concluded*)

Noise[c]	Filtering Efficiencies (ASHRAE *Standard* 52.1)	Load Profile	Comments
NC 40 to 50[e]	35% or better	Peak at 1 to 2 P.M. 	Prevent draft discomfort for patrons waiting in serving lines
NC 35 to 40	35% or better	Peak at 1 to 2 P.M. 	
NC 35 to 50	Use charcoal for odor control with manual purge control for 100% outside air to exhaust ±35% prefilters	Peak at 5 to 7 P.M. 	
NC 35 to 45[f]	Use charcoal for odor control with manual purge control for 100% outside air to exhaust ±35% prefilters	Nightclubs peak at 8 P.M. to 2 A.M. Casinos peak at 4 P.M. to 2 A.M. Equipment, 24 h/day	Provide good air movement but prevent cold draft discomfort for patrons
NC 40 to 50	10 to 15% or better		Negative air pressure required for odor control. (See also Chapter 31, Kitchen Ventilation.)
NC 30 to 45	35 to 60% or better	Peak at 4 P.M. 	
NC 35 to 40	35 to 60% or better	Peak at 3 P.M. 	
NC 35	35% prefilters plus charcoal filters 85 to 95% final[i]	Peak at 3 P.M. 	
NC 40 to 50	10 to 15%	Peak at 6 to 8 P.M. 	
to NC 60	85% or better	Varies with location and use	Constant temperature and humidity required
NC 15 to 25	35% or better	Varies widely due to changes in lighting and people	Constant temperature and humidity required
NC 35 to 50	35% or better and charcoal filters	Peak at 10 A.M. to 9 P.M. 	Positive air pressure required in terminal
NC 35 to 50	10 to 15%	Peak at 10 A.M. to 5 P.M. 	Positive air pressure required in waiting area
NC 35 to 50	35% with exfiltration	Peak at 10 A.M. to 5 P.M. 	Positive air pressure required in terminal
NC 35 to 50	10 to 15%	Peak at 10 A.M. to 5 P.M. 	Negative air pressure required to remove fumes; positive air in pressure adjacent occupied spaces
to NC 75	10 to 35%	Peak at 10 A.M. to 3 P.M. 	

Notes to Table 1, General Design Criteria

[a]This table shows design criteria differences between various commercial and public buildings. It should not be used as the sole source for design criteria. Each type of data contained here can be determined from the *ASHRAE Handbooks* and *Standards*.

[b]Consult governing codes to determine minimum allowable requirements. Outside air requirements may be reduced if high-efficiency adsorption equipment or other odor- or gas-removal equipment is used. See ASHRAE *Standard* 62 for calculation procedures. Also see Chapter 45 in this volume and Chapter 13 of the 2001 *ASHRAE Handbook—Fundamentals*.

[c]Refer to Chapter 47.

[d]Food in these areas is often eaten more quickly than in a restaurant; therefore, turnover of diners is much faster. Because diners seldom remain for long periods, they do not require the degree of comfort necessary in restaurants. Thus, it may be possible to lower design criteria standards and still provide reasonably comfortable conditions. Although space conditions of 80°F and 50% rh may be satisfactory for patrons when it is 95°F and 50% rh outside, inside conditions of 78°F and 40% rh are better.

[e]Cafeterias and luncheonettes usually have some or all food preparation equipment and trays in the same room with the diners. These establishments are generally noisier than restaurants, so noise transmission from air-conditioning equipment is not as critical.

[f]In some nightclubs, noise from the air-conditioning system must be kept low so patrons can hear the entertainment.

[g]Usually determined by kitchen hood requirements.

[h]Peak kitchen heat load does not generally occur at peak dining load, although in luncheonettes and some cafeterias where cooking is done in dining areas, peaks may be simultaneous.

[i]Methods for removal of chemical pollutants must also be considered.

[j]Also includes service stations.

Design Concepts

If a structure is characterized by several exposures and multipurpose use, especially with wide load swings and noncoincident energy use in certain areas, multiunit or unitary systems may be considered for such areas, but not necessarily for the entire building. The benefits of transferring heat absorbed by cooling from one area to other areas, processes, or services that require heat may enhance the selection of such systems. Systems such as incremental closed-loop heat pumps may be cost-effective.

When the cost of energy is included in the rent with no means for permanent or checkmetering, tenants tend to consume excess energy. This energy waste raises operating costs for the owner, decreases profitability, and has a detrimental effect on the environment. Although design features can minimize excess energy penalties, they seldom eliminate waste. For example, U.S. Department of Housing and Urban Development nationwide field records for total-electric housing show that rent-included dwellings use approximately 20% more energy than those directly metered by a public utility company.

Diversity factor benefits for central heating and cooling in rent-included buildings may result in lower building demand and connected loads. However, energy waste may easily result in load factors and annual energy consumption exceeding that of buildings where the individual has a direct economic incentive to reduce energy consumption. Heat flow (Btu) meters should be considered for charging for energy consumption.

Design Criteria

In many applications, design criteria are fairly evident, but in all cases, the engineer should understand the owner's and user's intent because any single factor may influence system selection. The engineer's experience and judgment in projecting future needs may be a better criterion for system design than any other single factor.

Comfort Level. Comfort, as measured by temperature, humidity, air motion, air quality, noise, and vibration, is not identical for all buildings, occupant activities, or uses of space. The control of static electricity may be a consideration in humidity control.

Costs. Owning and operating costs can affect system selection and seriously conflict with other criteria. Therefore, the engineer must help the owner resolve these conflicts by considering factors such as cost and availability of different fuels, ease of equipment access, and maintenance requirements.

Local Conditions. Local, state, and national codes, regulations, and environmental concerns must be considered in design. Chapters 26 and 27 of the 2001 *ASHRAE Handbook—Fundamentals* give information on calculating the effects of weather in specific areas.

Automatic Temperature Control. Proper automatic temperature control maintains occupant comfort during varying internal and external loads. Improper temperature control may mean a loss of customers in restaurants and other public buildings. An energy management control system can be combined with a building automation system to allow the owner to manage energy, lighting, security, fire protection, and other similar systems from one central control point. Chapters 35 and 46 include more details.

Fire, Smoke, and Odor Control. Fire and smoke can easily spread through elevator shafts, stairwells, ducts, and other routes. Although an air-conditioning system can spread fire and smoke by (1) fan operation, (2) penetrations required in walls or floors, or (3) the stack effect without fan circulation, a properly designed and installed system can be a positive means of fire and smoke control.

Chapter 52 has information on techniques for positive control after a fire starts. Effective attention to fire and smoke control also helps prevent odor migration into unventilated areas (see Chapter 45). The design of the ventilation system should consider applicable National Fire Protection Association standards, especially NFPA *Standards* 90A and 96.

DINING AND ENTERTAINMENT CENTERS

Load Characteristics

Air conditioning restaurants, cafeterias, bars, and nightclubs presents common load problems encountered in comfort conditioning, with additional factors pertinent to dining and entertainment applications. Such factors include

- Extremely variable loads with high peaks, in many cases, occurring twice daily
- High sensible and latent heat gains because of gas, steam, electric appliances, people, and food
- Sensible and latent loads that are not always coincident
- Large quantities of makeup air normally required
- Localized high sensible and latent heat gains in dancing areas
- Unbalanced conditions in restaurant areas adjacent to kitchens which, although not part of the conditioned space, still require special attention
- Heavy infiltration of outside air through doors during rush hours
- Smoking versus nonsmoking areas

Internal heat and moisture loads come from occupants, motors, lights, appliances, and infiltration. Separate calculations should be made for patrons and employees. The sensible and latent heat load must be proportioned in accordance with the design temperature selected for both sitting and working people, because the latent-to-sensible heat ratio for each category decreases as the room temperature decreases.

Hoods required to remove heat from appliances may also substantially reduce the space latent loads.

Infiltration is a considerable factor in many restaurant applications because of short occupancy and frequent door use. It is increased by the need for large quantities of makeup air, which should be provided mechanically to replace air exhausted through hoods and for smoke removal. Systems for hood exhaust makeup should concentrate on exhausting nonconditioned and minimally heated makeup air. Wherever possible, vestibules or revolving doors should be installed to reduce infiltration.

Design Concepts

The following factors influence system design and equipment selection:

- High concentrations of food, body, and tobacco-smoke odors require adequate ventilation with proper exhaust facilities.
- Step control of refrigeration plants gives satisfactory and economical operation under reduced loads.
- Exhausting air at the ceiling removes smoke and odor.
- Building design and space limitations often favor one equipment type over another. For example, in a restaurant having a vestibule with available space above it, air conditioning with condensers and evaporators remotely located above the vestibule may be satisfactory. Such an arrangement saves valuable space, even though self-contained units located within the conditioned space may be somewhat lower in initial and maintenance costs. In general, small cafeterias, bars, and the like, with loads up to 10 tons, can be most economically conditioned with packaged units; larger and more elaborate establishments require central plants.
- Smaller restaurants with isolated plants usually use direct-expansion systems.
- Mechanical humidification is typically not provided because of high internal latent loads.
- Some air-to-air heat recovery equipment can reduce the energy required for heating and cooling ventilation air. Chapter 44 of the 2000 *ASHRAE Handbook—HVAC Systems and Equipment* includes details. The potential for grease condensation on heat recovery surfaces must also be considered.
- A vapor compression or desiccant-based dehumidifier should be considered for makeup air handling and enhanced humidity control.

Because eating and entertainment centers generally have low sensible heat factors and require high ventilation rates, fan-coil and induction systems are usually not applicable. All-air systems are more suitable. Space must be established for ducts, except for small systems with no ductwork. Large establishments are often served by central chilled-water systems.

In cafeterias and luncheonettes, the air distribution system must keep food odors at the serving counters away from areas where patrons are eating. This usually means heavy exhaust air requirements at the serving counters, with air supplied into, and induced from, eating areas. Exhaust air must also remove the heat from hot trays, coffee urns, and ovens to minimize patron and employee discomfort and to reduce air-conditioning loads. These factors often create greater air-conditioning loads for cafeterias and luncheonettes than for restaurants.

Odor Removal. Transferring air from dining areas into the kitchen keeps odors and heat out of dining areas and cools the kitchen. Outside air intake and kitchen exhaust louvers should be located so that exhaust air is neither drawn back into the system nor allowed to cause discomfort to passersby.

Where odors can be drawn back into dining areas, activated charcoal filters, air washers, or ozonators are used to remove odors. Kitchen, locker room, toilet, or other malodorous air should not be recirculated unless air purifiers are used.

Kitchen Air Conditioning. If planned in the initial design phases, kitchens can often be air conditioned effectively without excessive cost. It is not necessary to meet the same design criteria as for dining areas, but kitchen temperatures can be reduced significantly. The relatively large number of people and food loads in dining and kitchen areas produce a high latent load. Additional cooling required to eliminate excess moisture increases refrigeration plant, cooling coil, and air-handling equipment size.

Advantageously located self-contained units, with air distribution designed so as not to produce drafts off hoods and other equipment, can be used to spot-cool intermittently. High-velocity air distribution may be effective. The costs are not excessive, and kitchen personnel efficiency can be improved greatly.

Even in climates with high wet-bulb temperatures, direct or indirect evaporative cooling may be a good compromise between the expense of air conditioning and lack of comfort in ventilated kitchens. For more information, see Chapter 31, Kitchen Ventilation.

Special Considerations

In establishing design conditions, the duration of individual patron occupancy should be considered. Patrons entering from outside are more comfortable in a room with a high temperature than those who remain long enough to become acclimated. Nightclubs and deluxe restaurants are usually operated at a lower effective temperature than cafeterias and luncheonettes.

Often, the ideal design condition must be rejected for an acceptable condition because of equipment cost or performance limitations. Restaurants are frequently affected in this way because ratios of latent to sensible heat may result in uneconomical or oversized equipment selection, unless an enhanced dehumidification system or a combination of lower design dry-bulb temperature and higher relative humidity (which gives an equal effective temperature) is selected.

In severe climates, entrances and exits in any dining establishment should be completely shielded from diners to prevent drafts. Vestibules provide a measure of protection. However, both vestibule doors are often open simultaneously. Revolving doors or local means for heating or cooling infiltration air may be provided to offset drafts.

Uniform employee comfort is difficult to maintain because of (1) temperature differences between the kitchen and dining room and (2) the constant motion of employees. Because customer satisfaction is essential to a dining establishment's success, patron comfort is the primary consideration. However, maintaining satisfactory temperature and atmospheric conditions for customers also helps alleviate employee discomfort.

One problem in dining establishments is the use of partitions to separate areas into modular units. Partitions create such varied load conditions that individual modular unit control is generally necessary.

Baseboard radiation or convectors, if required, should be located so as not to overheat patrons. This is difficult to achieve in some layouts because of movable chairs and tables. For these reasons, it is desirable to enclose all dining room and bar heating elements in insulated cabinets with top outlet grilles and baseboard inlets. With heating elements located under windows, this practice has the additional advantage of directing the heat stream to combat window downdraft and air infiltration. Separate smoking and nonsmoking areas may be required. The smoking area should be exhausted or served by separate air-handling equipment. Air diffusion device selection and placement should minimize smoke migration toward nonsmoking areas. Smoking areas must have a negative air pressure relationship with adjacent occupied areas.

Restaurants. In restaurants, people are seated and served at tables, and food is generally prepared in remote areas. This type of dining is usually enjoyed in a leisurely and quiet manner, so the ambient atmosphere should be such that the air conditioning is not noticed. Where specialized or open cooking is a feature, provisions should be made for control and handling of cooking odors and smoke.

Bars. Bars are often a part of a restaurant or nightclub. If they are establishments on their own, they often serve food as well as drinks, and they should be classified as restaurants with food preparation in remote areas. Alcoholic beverages produce pungent vapors, which must be drawn off. In addition, smoking at bars is generally considerably heavier than in restaurants. Therefore, outside air requirements are relatively high by comparison.

Nightclubs and Casinos. Both nightclubs and casinos may include a restaurant, bar, stage, and dancing area. The bar should be treated as a separately zoned area, with its own supply and exhaust system. People in the restaurant area who dine and dance may require twice the air changes and cooling required by patrons who dine and then watch a show. The length of stay generally exceeds that encountered in most eating places. In addition, eating in nightclubs and casinos is usually secondary to drinking and smoking. Patron density usually exceeds that of conventional eating establishments.

Kitchens. The kitchen has the greatest concentration of noise, heat load, smoke, and odors; ventilation is the chief means of removing these objectionable elements and preventing them from entering dining areas. To ensure odor control, kitchen air pressure should be kept negative relative to other areas. Maintenance of reasonably comfortable working conditions is important. For more information, see Chapter 31, Kitchen Ventilation.

OFFICE BUILDINGS

Load Characteristics

Office buildings usually include both peripheral and interior zone spaces. The peripheral zone extends from 10 to 12 ft inward from the outer wall toward the interior of the building and frequently has a large window area. These zones may be extensively subdivided. Peripheral zones have variable loads because of changing sun position and weather. These zone areas typically require heating in winter. During intermediate seasons, one side of the building may require cooling, while another side requires heating. However, the interior zone spaces usually require a fairly uniform cooling rate throughout the year because their thermal loads are derived almost entirely from lights, office equipment, and people. Interior space conditioning is often by systems that have variable air volume control for low- or no-load conditions.

Most office buildings are occupied from approximately 8:00 A.M. to 6:00 P.M.; many are occupied by some personnel from as early as 5:30 A.M. to as late as 7:00 P.M. Some tenants' operations may require night work schedules, usually not to extend beyond 10:00 P.M. Office buildings may contain printing plants, communications operations, broadcasting studios, and computing centers, which could operate 24 h per day. Therefore, for economical air-conditioning design, the intended uses of an office building must be well established before design development.

Occupancy varies considerably. In accounting or other sections where clerical work is done, the maximum density is approximately one person per 75 ft^2 of floor area. Where there are private offices, the density may be as little as one person per 200 ft^2. The most serious cases, however, are the occasional waiting rooms, conference rooms, or directors' rooms where occupancy may be as high as one person per 20 ft^2.

The lighting load in an office building constitutes a significant part of the total heat load. Lighting and normal equipment electrical loads average from 1 to 5 W/ft^2 but may be considerably higher, depending on the type of lighting and the amount of equipment. Buildings with computer systems and other electronic equipment can have electrical loads as high as 5 to 10 W/ft^2. An accurate appraisal should be made of the amount, size, and type of computer equipment anticipated for the life of the building to size the air-handling equipment properly and provide for future installation of air-conditioning apparatus.

About 30% of the total lighting heat output from recessed fixtures can be withdrawn by exhaust or return air and, therefore, will not enter into space-conditioning supply air requirements. By connecting a duct to each fixture, the most balanced air system can be provided. However, this method is expensive, so the suspended ceiling is often used as a return air plenum with the air drawn from the space to above the suspended ceiling.

Miscellaneous allowances (for fan heat, duct heat pickup, duct leakage, and safety factors) should not exceed 12% of the total load.

Building shape and orientation are often determined by the building site, but certain variations in these factors can increase refrigeration load by 10 to 15%. Shape and orientation should therefore be carefully analyzed in the early design stages.

Design Concepts

The variety of functions and range of design criteria applicable to office buildings have allowed the use of almost every available air-conditioning system. Multistory structures are discussed here, but the principles and criteria are similar for all sizes and shapes of office buildings.

Attention to detail is extremely important, especially in modular buildings. Each piece of equipment, duct and pipe connections, and the like may be duplicated hundreds of times. Thus, seemingly minor design variations may substantially affect construction and operating costs. In initial design, each component must be analyzed not only as an entity, but also as part of an integrated system. This systems design approach is essential for achieving optimum results.

There are several classes of office buildings, determined by the type of financing required and the tenants who will occupy the building. Design evaluation may vary considerably based on specific tenant requirements; it is not enough to consider typical floor patterns only. Included in many larger office buildings are stores, restaurants, recreational facilities, data centers, telecommunication centers, radio and television studios, and observation decks.

Built-in system flexibility is essential for office building design. Business office procedures are constantly being revised, and basic building services should be able to meet changing tenant needs.

The type of occupancy may have an important bearing on the selection of the air distribution system. For buildings with one owner or lessee, operations may be defined clearly enough that a system can be designed without the degree of flexibility needed for a less well-defined operation. However, owner-occupied buildings may require considerable design flexibility because the owner will pay for all alterations. The speculative builder can generally charge alterations to tenants. When different tenants occupy different floors, or even parts of the same floor, the degree of design and operation complexity increases to ensure proper environmental comfort conditions to any tenant, group of tenants, or all tenants at once. This problem is more acute if tenants have seasonal and variable overtime schedules.

Stores, banks, restaurants, and entertainment facilities may have hours of occupancy or design criteria that differ substantially from those of office buildings; therefore, they should have their own air distribution systems and, in some cases, their own heating and/or refrigeration equipment.

Main entrances and lobbies are sometimes served by a separate system because they buffer the outside atmosphere and the building interior. Some engineers prefer to have a lobby summer temperature 4 to 6°F above office temperature to reduce operating cost and thetemperature shock to people entering or leaving the building.

The unique temperature and humidity requirements of data processing installations and the fact that they often run 24 h per day for extended periods generally warrant separate refrigeration and air distribution systems. Separate backup systems may be required for data processing areas in case the main building HVAC system fails. Chapter 17 has further information.

The degree of air filtration required should be determined. The service cost and the effect of air resistance on energy costs should be analyzed for various types of filters. Initial filter cost and air pollution characteristics also need to be considered. Activated charcoal filters for odor control and reduction of outside air requirements are another option to consider.

Providing office buildings with continuous 100% outside air is seldom justified; therefore, most office buildings are designed to minimize outside air use, except during economizer operation. However, attention to inside air quality may dictate higher levels of ventilation air. In addition, the minimum volume of outside air should be maintained in variable-volume air-handling systems. Dry-bulb or enthalpy-controlled economizer cycles should be considered for reducing energy costs.

When an economizer cycle is used, systems should be zoned so that energy waste will not occur by heating outside air. This is often accomplished by a separate air distribution system for the interior and each major exterior zone.

High-rise office buildings have traditionally used perimeter dual-duct, induction, or fan-coil systems. Where fan-coil or induction systems have been installed at the perimeter, separate all-air systems have generally been used for the interior. More recently, variable air volume systems, including modulated air diffusers and self-contained perimeter unit systems, have also been used. If variable air volume systems serve the interior, perimeters are usually served by variable-volume or dual-duct systems supplemented with fan-powered terminals, terminals with reheat coils, or radiation (ceiling panels or baseboard). The perimeter systems can be hydronic or electric.

Many office buildings without an economizer cycle have a bypass multizone unit installed on each floor or several floors with a heating coil in each exterior zone duct. Variable air volume variations of the bypass multizone and other floor-by-floor, all-air systems are also being used. These systems are popular because of their low fan power and initial cost, and energy savings from independent operating schedules, which are possible between floors occupied by tenants with different operating hours.

Perimeter radiation or infrared systems with conventional, single-duct, low-velocity air conditioning that furnishes air from packaged air-conditioning units or multizone units may be more economical for small office buildings. The need for a perimeter system, which is a function of exterior glass percentage, external wall thermal value, and climate severity, should be carefully analyzed.

A perimeter heating system separate from the cooling system is preferable, because air distribution devices can then be selected for a specific duty rather than as a compromise between heating and cooling performance. The higher cost of additional air-handling or fan-coil units and ductwork may lead the designer to a less expensive option, such as fan-powered terminal units with heating coils serving perimeter zones in lieu of a separate heating system. Radiant ceiling panels for the perimeter zones are another option.

Interior space usage usually requires that interior air-conditioning systems allow modification to handle all load situations. Variable air volume systems are often used. When using these systems, low-load conditions should be carefully evaluated to determine whether adequate air movement and outside air can be provided at the proposed supply air temperature without overcooling. Increases in supply air temperature tend to nullify energy savings in fan power, which are characteristic of variable air volume systems. Low-temperature air distribution for additional savings in transport energy is seeing increased use, especially when coupled with an ice storage system.

In small to medium-sized office buildings, air-source heat pumps may be chosen. In larger buildings, internal source heat pump systems (water-to-water) are feasible with most types of air-conditioning systems. Heat removed from core areas is rejected to either a cooling tower or perimeter circuits. The internal source heat pump can be supplemented by a central heating system or electrical coils on extremely cold days or over extended periods of limited occupancy. Removed excess heat may also be stored in hot-water tanks.

Many heat recovery or internal-source heat pump systems exhaust air from conditioned spaces through lighting fixtures. Approximately 30% of lighting heat can be removed in this manner. One design advantage is a reduction in required air quantities. In addition, lamp life is extended by operation in a much cooler ambient environment.

Suspended ceiling return air plenums eliminate sheet metal return air ductwork to reduce floor-to-floor height requirements. However, suspended ceiling plenums may increase the difficulty of proper air balancing throughout the building. Problems often connected with suspended ceiling return plenums are as follows:

- Air leakage through cracks, with resulting smudges
- Tendency of return air openings nearest to a shaft opening or collector duct to pull too much air, thus creating uneven air motion and possible noise
- Noise transmission between office spaces

Air leakage can be minimized by proper workmanship. To overcome drawing too much air, return air ducts can be run in the suspended ceiling pathway from the shaft, often in a simple radial pattern. Ends of the ducts can be left open or dampered. Generous sizing of return air grilles and passages lowers the percentage of circuit resistance attributable to the return air path. This bolsters effectiveness of supply air balancing devices and reduces the significance of air leakage and drawing too much air. Structural blockage can be solved by locating openings in beams or partitions with fire dampers, where required.

Spatial Requirements

Total office building electromechanical space requirements vary tremendously based on types of systems planned; however, the average is approximately 8 to 10% of the gross area. Clear height required for fan rooms varies from approximately 10 to 18 ft, depending on the distribution system and equipment complexity. On office floors, perimeter fan-coil or induction units require approximately 1 to 3% of the floor area. Interior air shafts and pipe chases require approximately 3 to 5% of the floor area. Therefore, ducts, pipes, and equipment require approximately 4 to 8% of each floor's gross area.

Where large central units supply multiple floors, shaft space requirements depend on the number of fan rooms. In such cases, one mechanical equipment room usually furnishes air requirements for 8 to 20 floors (above and below for intermediate levels), with an average of 12 floors. The more floors served, the larger the duct shafts and equipment required. This results in higher fan room heights and greater equipment size and mass.

The fewer floors served by an equipment room, the greater the flexibility in serving changing floor or tenant requirements. Often, one mechanical equipment room per floor and complete elimination of vertical shafts requires no more total floor area than fewer larger mechanical equipment rooms, especially when there are many small rooms and they are the same height as typical floors. Equipment can also be smaller, although maintenance costs will be higher. Energy costs may be reduced with more equipment rooms serving fewer areas, because equipment can be shut off in unoccupied areas, and high-pressure ductwork will not be required. Equipment rooms on upper levels generally cost more to install because of rigging and transportation logistics.

In all cases, mechanical equipment rooms must be thermally and acoustically isolated from office areas.

Cooling Towers. Cooling towers are the largest single piece of equipment required for air-conditioning systems. Cooling towers require approximately 1 ft^2 of floor area per 400 ft^2 of total building area and are 13 to 40 ft high. When towers are located on the roof, the building structure must be capable of supporting the cooling tower and dunnage, full water load (approximately 120 to 150 lb/ft^2), and seismic and wind load stresses.

Where cooling tower noise may affect neighboring buildings, towers should be designed to include sound traps or other suitable noise baffles. This may affect tower space, mass of the units, and motor power. Slightly oversizing cooling towers can reduce noise and power consumption because of lower speeds, but this may increase initial cost.

Cooling towers are sometimes enclosed in a decorative screen for aesthetic reasons; therefore, calculations should ascertain that the screen has sufficient free area for the tower to obtain its required air quantity and to prevent recirculation.

If the tower is placed in a rooftop well or near a wall, or split into several towers at various locations, design becomes more complicated, and initial and operating costs increase substantially. Also, towers should not be split and placed on different levels because hydraulic problems increase. Finally, the cooling tower should be built high enough above the roof so that the bottom of the tower and the roof can be maintained properly.

Special Considerations

Office building areas with special ventilation and cooling requirements include elevator machine rooms, electrical and telephone closets, electrical switchgear, plumbing rooms, refrigeration rooms, and mechanical equipment rooms. The high heat loads in some of these rooms may require air-conditioning units for spot cooling.

In larger buildings with intermediate elevator, mechanical, and electrical machine rooms, it is desirable to have these rooms on the same level or possibly on two levels. This may simplify horizontal ductwork, piping, and conduit distribution systems and permit more effective ventilation and maintenance of these equipment rooms.

An air-conditioning system cannot prevent occupants at the perimeter from feeling direct sunlight. Venetian blinds and drapes are often provided but seldom used. External shading devices (screens, overhangs, etc.) or reflective glass are preferable.

Tall buildings in cold climates experience severe stack effect. The extra amount of heat provided by the air-conditioning system in attempts to overcome this problem can be substantial. The following features help combat infiltration from the stack effect:

- Revolving doors or vestibules at exterior entrances
- Pressurized lobbies or lower floors
- Tight gaskets on stairwell doors leading to the roof
- Automatic dampers on elevator shaft vents
- Tight construction of the exterior skin
- Tight closure and seals on all dampers opening to the exterior

BOWLING CENTERS

Bowling centers may also contain a bar, a restaurant, a children's play area, offices, locker rooms, and other types of facilities. Such auxiliary areas are not discussed in this section, except as they may affect design for the bowling area, which consists of alleys and a spectator area.

Load Characteristics

Bowling alleys usually have their greatest period of use in the evenings, but weekend daytime use may also be heavy. Thus, when designing for the peak air-conditioning load on the building, it is necessary to compare the day load and its high outside solar load and off-peak people load with the evening peak people load and zero solar load. Because bowling areas generally have little fenestration, solar load may not be important.

If the building contains auxiliary areas, these areas may be included in the refrigeration, heating, and air distribution systems for the bowling alleys, with suitable provisions for zoning the different areas as dictated by load analysis. Alternatively, separate systems may be established for each area having different load operation characteristics.

Heat buildup from lights, external transmission load, and pin-setting machinery in front of the foul line can be reduced by exhausting some air above the alleys or from the area containing the pin-setting machines; however, this gain should be compared against the cost of conditioning additional makeup air. In calculating the air-conditioning load, a portion of the unoccupied alley space load is included. Because this consists mainly of lights and some transmission load, about 15 to 30% of this heat load may have to be taken into account. The higher figure may apply when the roof is poorly insulated, no exhaust air is taken from this area, or no vertical baffle is used at the foul line. One estimate is 5 to 10 Btu/h per square foot of vertical surface at the foul line, depending mostly on the type and intensity of the lighting.

The heat load from bowlers and spectators may be found in Table 1 in Chapter 29 of the 2001 *ASHRAE Handbook—Fundamentals.* The proper heat gain should be applied for each person to avoid too large a design heat load.

Design Concepts

As with other building types having high occupancy loads, heavy smoke and odor concentration, and low sensible heat factors, all-air systems are generally the most suitable for bowling alley areas. Because most bowling alleys are almost windowless except for such areas as entrances, exterior restaurants, and bars, it is uneconomical to use terminal unit systems because of the small number required. Where required, radiation in the form of baseboard or radiant ceiling panels is generally placed at perimeter walls and entrances.

It is not necessary to maintain normal inside temperatures down the length of the alleys; temperatures may be graded down to the pin area. Unit heaters are often used at this location.

Air Pressurization. Spectator and bowling areas must be well shielded from entrances so that no cold drafts are created in these areas. To minimize infiltration of outside air into the alleys, the exhaust and return air system should handle only 85 to 90% of the total supply air, maintaining a positive pressure in the space when outside air pressurization is taken into consideration.

Air Distribution. Packaged units without ductwork produce uneven space temperatures, and unless they are carefully located and installed, the units may cause objectionable drafts. Central ductwork is recommended for all but the smallest buildings, even where packaged refrigeration units are used. Because only the areas behind the foul line are air conditioned, the ductwork should provide comfortable conditions within this area.

The return and exhaust air systems should have a large number of small registers uniformly located at high points, or pockets, to draw off the hot, smoky, and odorous air. In some parts of the country and for larger bowling alleys, it may be desirable to use all outside air to cool during intermediate seasons.

Special Considerations

People in sports and amusement centers engage in a high degree of physical activity, which makes them feel warmer and increases their rate of evaporation. In these places, odor and smoke control are important environmental considerations.

Bowling centers are characterized by the following:

- A large number of people concentrated in a relatively small area of a very large room. A major portion of the floor area is unoccupied.
- Heavy smoking, high physical activity, and high latent heat load.
- Greatest use from about 6:00 P.M. to midnight.

The first two items make furnishing large amounts of outside air mandatory to minimize odors and smoke in the atmosphere.

The area between the foul line and the bowling pins need not be air conditioned or ventilated. Transparent or opaque vertical partitions are sometimes installed to separate the upper portions of the occupied and unoccupied areas so that air distribution is better contained within the occupied area.

COMMUNICATION CENTERS

Communication centers include telephone terminal buildings, radio stations, television studios, and transmitter and receiver stations. Most telephone terminal rooms are air conditioned because constant temperature and relative humidity help prevent breakdowns and increase equipment life. In addition, air conditioning permits the use of a lower number of air changes, which, for a given filter efficiency, decreases the chances of damage to relay contacts and other delicate equipment.

Radio and television studios require critical analysis for the elimination of heat build-up and the control of noise. Television studios have the added problem of air movement, lighting, and occupancy load variations. This section deals with television studios because they present most of the problems also found in radio studios.

Load Characteristics

Human occupancy is limited in telephone terminal rooms, so the air-conditioning load is primarily equipment heat load.

Television studios have very high lighting capacities, and the lighting load may fluctuate considerably in intensity over short periods. Operating hours may vary every day. In addition, there may be from one to several dozen people onstage for short times. The air-conditioning system must be extremely flexible and capable of handling wide load variations quickly, accurately, and efficiently, similar to the conditions of a theater stage. The studio may also have an assembly area with a large number of spectator seats. Generally, studios are located so that they are completely shielded from external noise and thermal environments.

Design Concepts

The critical areas of a television studio are the performance studio and control rooms. The audience area may be treated much like a place of assembly. Each area should have its own air distribution system or at least its own zone control separate from the studio system. Heat generated in the studio area should not be allowed to permeate the audience atmosphere.

The air distribution system selected must have the capabilities of a dual-duct, single-duct system with cooling and heating booster coils, a variable air volume system, or a multizone system to satisfy design criteria. The air distribution system should be designed so that simultaneous heating and cooling cannot occur unless heating is achieved solely by heat recovery.

Studio loads seldom exceed 100 tons of refrigeration. Even if the studio is part of a large communications center or building, the studio should have its own refrigeration system in case of emergencies. The refrigeration equipment in this size range may be reciprocating units, which require a remote location so that machine noise is isolated from the studio.

Special Considerations

On-Camera Studio. This is the “stage” of the television studio and requires the same general considerations as a concert hall stage. Air movement must be uniform, and, because scenery, cameras, and equipment may be moved during the performance, ductwork must be planned carefully to avoid interference with proper studio operation.

Control Room. Each studio may have one or more control rooms serving different functions. The video control room, which is occupied by the program and technical directors, contains monitors and picture-effect controls. The room may require up to 30 air changes per hour to maintain proper conditions. The large number of necessary air changes and the low sound level that must be maintained require special analysis of the air distribution system.

If a separate control room is furnished for the announcer, the heat load and air distribution problems will not be as critical as those for control rooms for the program, technical, and audio directors.

Thermostatic control should be furnished in each control room, and provisions should be made to enable occupants to turn the air conditioning on and off.

Noise Control. Studio microphones are moved throughout the studio during a performance, and they may be moved past or set near air outlets or returns. These microphones are considerably more sensitive than the human ear; therefore, air outlets or returns should be located away from areas where microphones are likely to be used. Even a leaky pneumatic thermostat can be a problem.

Air Movement. It is essential that air movement in the stage area, which often contains scenery and people, be kept below 25 fpm within 12 ft of the floor. The scenery is often fragile and will move in air velocities above 25 fpm; also, actors’ hair and clothing may be disturbed.

Air Distribution. Ductwork must be fabricated and installed so that there are no rough edges, poor turns, or improperly installed dampers to cause turbulence and eddy currents in the ducts. Ductwork should contain no holes or openings that might create whistles. Air outlet locations and the distribution pattern must be carefully analyzed to eliminate turbulence and eddy currents in the studio that might cause noise that could be picked up by studio microphones.

At least some portions of supply, return, and exhaust ductwork will require acoustical material to maintain noise criterion (NC) levels from 20 to 25. Any duct serving more than one room should acoustically separate each room by means of a sound trap. All ductwork should be suspended by means of neoprene or rubber in shear-type vibration mountings. Where ductwork goes through wall or floor slabs, the openings should be sealed with acoustically deadening material. The supply fan discharge and the return and exhaust fan inlets should have sound traps; all ductwork connections to fans should be made with nonmetallic, flexible material. Air outlet locations should be coordinated with ceiling-mounted tracks and equipment. Air distribution for control rooms may require a perforated ceiling outlet or return air plenum system.

Piping Distribution. All piping in the studio, as well as in adjacent areas that might transmit noise to the studio, should be supported by suitable vibration isolation hangers. To prevent transmitting vibration, piping should be supported from rigid structural elements to maximize absorption.

Mechanical Equipment Room. This room should be located as far from the studio as possible. All equipment should be selected for very quiet operation and should be mounted on suitable vibration-eliminating supports. Structural separation of the room from the studio is generally required.

Offices and Dressing Rooms. The functions of these rooms are quite different from each other and from the studio areas. It is recommended that such rooms be treated as separate zones, with their own controls.

Air Return. Whenever practicable, the largest portion of studio air should be returned over the banks of lights. This is similar to theater stage practice. Sufficient air should also be removed from studio high points to prevent heat build-up.

TRANSPORTATION CENTERS

The major transportation facilities are airports, ship docks, bus terminals, and passenger car garages. Airplane hangars and freight and mail buildings are also among the types of buildings to be considered. Freight and mail buildings are usually handled as standard warehouses.

Load Characteristics

Airports, ship docks, and bus terminals operate on a 24 h basis, with a reduced schedule during late night and early morning hours.

Airports. Terminal buildings consist of large, open circulating areas, one or more floors high, often with high ceilings, ticketing counters, and various types of stores, concessions, and convenience facilities. Lighting and equipment loads are generally average, but occupancy varies substantially. Exterior loads are, of course, a function of architectural design. The largest single problem often is thermal drafts created by large entranceways, high ceilings, and long passageways, which have many openings to the outside.

Ship Docks. Freight and passenger docks consist of large, high-ceilinged structures with separate areas for administration, visitors, passengers, cargo storage, and work. The floor of the dock is usually exposed to the outside just above the water level. Portions of the side walls are often open while ships are in port. In addition, the large ceiling (roof) area presents a large heating and cooling load. Load characteristics of passenger dock terminals generally require the roof and floors to be well insulated. Occasional heavy occupancy loads in visitor and passenger areas must be considered.

Bus Terminals. This building type consists of two general areas: the terminal building, which contains passenger circulation, ticket booths, and stores or concessions, and the bus loading area. Waiting rooms and passenger concourse areas are subject to a highly variable people load. Occupancy density may reach 10 ft^2 per person and, at extreme periods, 3 to 5 ft^2 per person. Chapter 13, Enclosed Vehicular Facilities, has further information on bus terminals.

Design Concepts

Heating and cooling is generally centralized or provided for each building or group in a complex. In large, open-circulation areas of transportation centers, any all-air system with zone control can be used. Where ceilings are high, air distribution is often along the side wall to concentrate the air conditioning where desired and avoid disturbing stratified air. Perimeter areas may require heating by radiation, a fan-coil system, or hot air blown up from the sill or floor grilles, particularly in colder climates. Hydronic perimeter radiant ceiling panels may be especially suited to these high-load areas.

Airports. Airports generally consist of one or more central terminal buildings connected by long passageways or trains to rotundas containing departure lounges for airplane loading. Most terminals have portable telescoping-type loading bridges connecting departure lounges to the airplanes. These passageways eliminate the heating and cooling problems associated with traditional permanent structure passenger loading.

Because of difficulties in controlling the air balance because of the many outside openings, high ceilings, and long, low passageways (which often are not air conditioned), the terminal building (usually air conditioned) should be designed to maintain a substantial positive pressure. Zoning is generally required in passenger waiting areas, in departure lounges, and at ticket counters to take care of the widely variable occupancy loads.

Main entrances may have vestibules and windbreaker partitions to minimize undesirable air currents in the building.

Hangars must be heated in cold weather, and ventilation may be required to eliminate possible fumes (although fueling is seldom permitted in hangars). Gas-fired, electric, and low- and high-intensity radiant heaters are used extensively in hangars because they provide comfort for employees at relatively low operating costs.

Hangars may also be heated by large air blast heaters or floor-buried heated liquid coils. Local exhaust air systems may be used to evacuate fumes and odors that occur in smaller ducted systems. Under some conditions, exhaust systems may be portable and may include odor-absorbing devices.

Ship Docks. In severe climates, occupied floor areas may contain heated floor panels. The roof should be well insulated, and, in appropriate climates, evaporative spray cooling substantially reduces the summer load. Freight docks are usually heated and well ventilated but seldom cooled.

High ceilings and openings to the outside may present serious draft problems unless the systems are designed properly. Vestibule entrances or air curtains help minimize cross-drafts. Air door blast heaters at cargo opening areas may be quite effective.

Ventilation of the dock terminal should prevent noxious fumes and odors from reaching occupied areas. Therefore, occupied areas should be under positive pressure, and cargo and storage areas exhausted to maintain negative air pressure. Occupied areas should be enclosed to simplify any local air conditioning.

In many respects, these are among the most difficult buildings to heat and cool because of their large open areas. If each function is properly enclosed, any commonly used all-air or large fan-coil system is suitable. If areas are left largely open, the best approach is to concentrate on proper building design and heating and cooling of the openings. High-intensity infrared spot heating is often advantageous (see Chapter 15 of the 2000 *ASHRAE Handbook—Systems and Equipment*). Exhaust ventilation from tow truck and cargo areas should be exhausted through the roof of the dock terminal.

Bus Terminals. Conditions are similar to those for airport terminals, except that all-air systems are more practical because ceiling heights are often lower, and perimeters are usually flanked by stores or office areas. The same systems are applicable as for airport terminals, but ceiling air distribution is generally feasible.

Properly designed radiant hydronic or electric ceiling systems may be used if high-occupancy latent loads are fully considered. This may result in smaller duct sizes than are required for all-air systems and may be advantageous where bus loading areas are above the terminal and require structural beams. This heating and cooling system reduces the volume of the building that must be conditioned. In areas where latent load is a concern, heating-only panels may be used at the perimeter, with a cooling-only interior system.

The terminal area air supply system should be under high positive pressure to ensure that no fumes and odors infiltrate from bus areas. Positive exhaust from bus loading areas is essential for a properly operating total system (see Chapter 13).

Special Considerations

Airports. Filtering outside air with activated charcoal filters should be considered for areas subject to excessive noxious fumes from jet engine exhausts. However, locating outside air intakes as remotely as possible from airplanes is a less expensive and more positive approach.

Where ionization filtration enhancers are used, outside air quantities are sometimes reduced because of cleaner air. However, care must be taken to maintain sufficient amounts of outside air for space pressurization.

Ship Docks. Ventilation design must ensure that fumes and odors from forklifts and cargo in work areas do not penetrate occupied and administrative areas.

Bus Terminals. The primary concerns with enclosed bus loading areas are health and safety problems, which must be handled by proper ventilation (see Chapter 13). Although diesel engine fumes are generally not as noxious as gasoline fumes, bus terminals often have many buses loading and unloading at the same time, and the total amount of fumes and odors may be quite disturbing.

Enclosed Garages. In terms of health and safety, enclosed bus loading areas and automobile parking garages present the most serious problems in these buildings. Three major problems are encountered. The first and most serious is emission of carbon monoxide (CO) by cars and oxides of nitrogen by buses, which can cause serious illness and possibly death. The second problem is oil and gasoline fumes, which may cause nausea and headaches and can also create a fire hazard. The third is lack of air movement and the resulting stale atmosphere that develops because of increased carbon dioxide content in the air. This condition may cause headaches or grogginess. Most codes require a minimum ventilation rate to ensure that the CO concentration does not exceed safe limits. Chapter 13 covers ventilation requirements and calculation procedures for enclosed vehicular facilities in detail.

All underground garages should have facilities for testing the CO concentration or should have the garage checked periodically.

Clogged duct systems; improperly operating fans, motors, or dampers; clogged air intake or exhaust louvers, etc., may not allow proper air circulation. Proper maintenance is required to minimize any operational defects.

WAREHOUSES

Warehouses are used to store merchandise and may be open to the public at times. They are also used to store equipment and material inventory at industrial facilities. The buildings are generally not air conditioned, but often have sufficient heat and ventilation to provide a tolerable working environment. Associated facilities occupied by office workers, such as shipping, receiving, and inventory control offices, are generally air conditioned.

Load Characteristics

Internal loads from lighting, people, and miscellaneous sources are generally low. Most of the load is thermal transmission and infiltration. An air-conditioning load profile tends to flatten where materials stored are massive enough to cause the peak load to lag.

Design Concepts

Most warehouses are only heated and ventilated. Forced flow unit heaters may be located near heat entrances and work areas. Large central heating and ventilating units are widely used. Even though comfort for warehouse workers may not be considered, it may be necessary to keep the temperature above 40°F to protect sprinkler piping or stored materials from freezing.

A building designed for the addition of air conditioning at a later date will require less heating and be more comfortable. For maximum summer comfort without air conditioning, excellent ventilation with noticeable air movement in work areas is necessary. Even greater comfort can be achieved in appropriate climates by adding roof spray cooling. This can reduce the roof's surface temperature by 40 to 60°F, thereby reducing ceiling radiation inside. Low- and high-intensity radiant heaters can be used to maintain the minimum ambient temperature throughout a facility above freezing. Radiant heat may also be used for occupant comfort in areas permanently or frequently open to the outside.

If the stored product requires defined inside conditions, an air-conditioning system must be added. Using only ventilation may help in maintaining lower space temperature, but caution should be exercised not to damage the stored product with uncontrolled humidity. Direct or indirect evaporative cooling may also be an option.

Special Considerations

Forklifts and trucks powered by gasoline, propane, and other fuels are often used inside warehouses. Proper ventilation is necessary to alleviate the buildup of CO and other noxious fumes. Proper ventilation of battery-charging rooms for electrically powered forklifts and trucks is also required.

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