Related Commercial Resources

CHAPTER 5. PLACES OF ASSEMBLY

ASSEMBLY rooms are generally large, have relatively high ceilings, and are few in number for any given facility. They usually have a periodically high density of occupancy per unit floor area, as compared to other buildings, and thus have a relatively low design sensible heat ratio.

This chapter summarizes some of the design concerns for enclosed assembly buildings. (Chapter 3, which covers general criteria for commercial and public buildings, also includes information that applies to public assembly buildings.)

Other relevant ASHRAE resources include the following.

- **ASHRAE's Epidemic Task Force (ETF)** (www.ashrae.org/technical-resources/resources). Established in March 2020, the ETF has developed an array of guidance documents on engineering improvements to reduce the risk of infection in the built environment. One-page overviews of guidance for industrial settings, safe vaccine transportation, reducing exposure to airborne aerosols, and various applications can be found at www.ashrae.org/technical-resources/covid-19-one-page-guidance-documents.
- **ASHRAE Task Force for Building Decarbonization (TFBD)**. The ASHRAE position statement on reducing carbon in buildings is available at www.ashrae.org/about/position-documents. Research is ongoing to develop additional guidance, which is anticipated to begin release in 2023.
- **Operational excellence.** To help ensure that building HVAC systems are designed and installed in ways that achieve excellent operation throughout the building's life, an ASHRAE Presidential Elect Advisory Committee led by ASHRAE President Darryl Boyce developed and released *Designing for Operational Excellence—Intentional Design for Effective Operation and Maintenance* (ASHRAE 2022).

1. GENERAL CRITERIA

Energy conservation codes and standards must be considered because they have a major impact on design and performance.

Assembly buildings may have relatively few hours of use per week and may not be in full use when maximum outdoor temperatures or solar loading occur. Often they are fully occupied for as little as 1 to 2 h, and the load may be materially reduced by precooling. The designer needs to obtain as much information as possible about the anticipated hours of use, particularly times of full seating, so that simultaneous loads may be considered to optimize performance and operating economy. Dehumidification requirements (full and part load) should be considered before determining equipment size. The intermittent or infrequent nature of the cooling loads may allow these buildings to benefit from thermal storage systems.

Occupants usually generate the major room cooling and ventilation load. The number of occupants is best determined from the seat count, but when this is not available, it can be estimated at 0.7 to 0.9 m^2 per person for the entire seating area, including exit aisles but not the stage, performance areas, or entrance lobbies.

Safety and Security

Assembly buildings may need new safety and security considerations regarding extraordinary incidents. Designers should follow the recommendations outlined in Chapter 61.

Outdoor Air

Outdoor air ventilation rates as prescribed by ASHRAE *Standard* 62.1 can be a major portion of the total load. The latent load (dehumidification and humidification) and energy used to maintain relative humidity within prescribed limits are also concerns. Humidity must be maintained at proper levels to prevent mold and mildew growth and for acceptable indoor air quality and comfort.

Lighting Loads

Lighting loads are one of the few major loads that vary from one type of assembly building to another. Levels can vary from 1600 lux in convention halls where television cameras are expected to be used, to virtually nothing, as in a movie theater. In many assembly buildings, lights are controlled by dimmers or other means to present a suitably low level of light during performances, with much higher lighting levels during cleanup, when the house is nearly empty. The designer should ascertain the light levels associated with maximum occupancies, not only for economy but also to determine the proper room sensible heat ratio.

Indoor Air Conditions

Indoor air temperature and humidity should follow ASHRAE comfort recommendations in Chapter 9 of the 2021 *ASHRAE Handbook—Fundamentals* and ASHRAE *Standard* 55. In addition, the following should be considered:

- In arenas, stadiums, gymnasiums, and movie theaters, people generally dress informally. Summer indoor conditions may favor the warmer end of the thermal comfort scale, and the winter indoor temperature may favor the cooler end.
- In churches, concert halls, and theaters, most men wear jackets and ties and women often wear suits. The temperature should favor the middle range of design, and there should be little summer-to-winter variation.
- In convention and exhibition centers, the public is continually walking. The indoor temperature should favor the lower range of comfort conditions both in summer and in winter.
- In spaces with a high population density or with a sensible heat factor of 0.75 or less, reheat should be considered.
- Energy conservation codes must be considered in both the design and during operation.

Assembly areas generally require some reheat to maintain the relative humidity at a suitably low level during periods of maximum occupancy. Refrigerant hot gas or condenser water is well suited for this purpose. Face-and-bypass control of low-temperature cooling coils is also effective. In colder climates, it may also be desirable to provide humidification. High rates of internal gain may make evaporative humidification attractive during economizer cooling.

Filtration

Most places of assembly are minimally filtered with filters rated at 30 to 35% efficiency, as tested in accordance with ASHRAE *Standard* 52.1. Where smoking is permitted, however, filters with a minimum rating of 80% are required to remove tobacco smoke effectively. Filters with 80% or higher efficiency are also recommended for facilities having particularly expensive interior decor. Because of the few operating hours of these facilities, the added expense of higher-efficiency filters can be justified by their longer life. Low-efficiency prefilters are generally used with high-efficiency filters to extend their useful life. Consider using ionization and chemically reactive filters where high concentrations of smoke or odors are present.

Noise and Vibration Control

The desired noise criteria (NC) vary with the type and quality of the facility. The need for noise control may be minimal in a gymnasium, but it is important in a concert hall. Multipurpose facilities require noise control evaluation over the entire spectrum of use.

In most cases, sound and vibration control is required for both equipment and duct systems, as well as in diffuser and grille selection. When designing a performance theater or concert hall, consult an experienced acoustics engineer because the quantity and quality or characteristic of the noise is very important.

Transmission of vibration and noise can be decreased by mounting pipes, ducts, and equipment on a separate structure independent of the music hall. If the mechanical equipment space is close to the music hall, the entire mechanical equipment room may need to be floated on isolators, including the floor slab, structural floor members, and other structural elements such as supporting pipes or similar materials that can carry vibrations. Properly designed inertia pads are often used under each piece of equipment. The equipment is then mounted on vibration isolators.

Manufacturers of vibration isolating equipment have devised methods to float large rooms and entire buildings on isolators. Where subway and street noise may be carried into the structure of a music hall, it is necessary to float the entire music hall on isolators. If the music hall is isolated from outdoor noise and vibration, it also must be isolated from mechanical equipment and other internal noise and vibrations.

External noise from mechanical equipment such as cooling towers should not enter the building. Avoid designs that allow noises to enter the space through air intakes or reliefs and carelessly designed duct systems.

For more details on noise and vibration control, see Chapter 49 of this volume and Chapter 8 in the 2021 *ASHRAE Handbook—Fundamentals*.

Ancillary Facilities

Ancillary facilities are generally a part of any assembly building; almost all have some office space. Convention centers and many auditoriums, arenas, and stadiums have restaurants and cocktail lounges. Churches may have apartments for clergy or a school. Many facilities have parking structures. These varied ancillary facilities are discussed in other chapters of this volume. However, for reasonable operating economy, these facilities should be served by separate systems when their hours of use differ from those of the main assembly areas.

Air Conditioning

Because of their characteristic large size and need for considerable ventilation air, assembly buildings are frequently served by single-zone or variable-volume systems providing 100% outdoor air. Separate air-handling units usually serve each zone, although multizone, dual-duct, or reheat types can also be applied with lower operating efficiency. In larger facilities, separate zones are generally provided for entrance lobbies and arterial corridors that surround the seating space. Low-intensity radiant heating is often an efficient alternative. In some assembly rooms, folding or rolling partitions divide the space for different functions, so a separate zone of control for each resultant space is best. In extremely large facilities, several air-handling systems may serve a single space, because of the limits of equipment size and also for energy and demand considerations.

Peak Load Reduction

There are several techniques currently in use to help address peak loads. **Thermal storage** is discussed in Chapter 50 of the 2020 *ASHRAE Handbook—HVAC Systems and Equipment*. Another popular technique, **precooling**, can be managed by the building operator. Precooling the building mass several degrees below the desired indoor temperature several hours before it is occupied allows it to absorb a part of the peak heat load. This cooling reduces the equipment size needed to meet short-term loads. The effect can be used if cooling time of at least 1 h is available prior to occupancy, and then only when the period of peak load is relatively short (2 h or less).

The designer must advise the owner that the space temperature will be cold to most people as occupancy begins, but will warm up as the performance progresses; this should be understood by all concerned before proceeding with precooling. Precooling works best when the space is used only occasionally during the hotter part of the day and when provision of full capacity for an occasional purpose is not economically justifiable.

Stratification

Because most assembly buildings have relatively high ceilings, some heat may be allowed to stratify above the occupied zone, thereby reducing load on the equipment. Heat from lights can be stratified, except for the radiant portion (about 50% for fluorescent and 65% for incandescent or mercury-vapor fixtures). Similarly, only the radiant effect of the upper wall and roof load (about 33%) reaches the occupied space. Stratification only occurs when air is admitted and returned at a sufficiently low elevation so that it does not mix with the upper air. Conversely, stratification may increase heating loads during periods of minimal occupancy in winter. In these cases, ceiling fans, air-handling systems, or high/low air distribution may be desirable to reduce stratification. Balconies may also be affected by stratification and should be well ventilated.

Air Distribution

In assembly buildings with seating, people generally remain in one place throughout a performance, so they cannot move away from drafts. Therefore, good air distribution is essential. Airflow modeling software could prove helpful in predicting potential problem areas.

Heating is seldom a major problem, except at entrances or during warm-up before occupancy. Generally, the seating area is isolated from the exterior by lobbies, corridors, and other ancillary spaces. For cooling, air can be supplied from the overhead space, where it mixes with heat from the lights and occupants. Return air openings can also aid air distribution. Air returns located below seating or at a low level around the seating can effectively distribute air with minimum drafts; however, register velocities over 1.4 m/s may cause objectionable drafts and noise.

Because of the configuration of these spaces, supply jet nozzles with long throws of 15 to 45 m may need to be installed on sidewalls. For ceiling distribution, downward throw is not critical if returns are low. This approach has been successful in applications that are not particularly noise-sensitive, but the designer needs to select air distribution nozzles carefully.

The air-conditioning systems must be quiet. This is difficult to achieve if supply air is expected to travel 9 m or more from sidewall outlets to condition the center of the seating area. Because most houses of worship, theaters, and halls are large, high air discharge velocities from the wall outlets are required. These high velocities can produce objectionable noise levels for people sitting near the outlets. This can be avoided if the return air system does some of the work. The supply air must be discharged from the air outlet (preferably at the ceiling) at the highest velocity consistent with an acceptable noise level. Although this velocity does not allow the conditioned air to reach all seats, the return air registers, which are located near seats not reached by the conditioned air, pull the air to cool or heat the audience, as required. In this way, supply air blankets the seating area and is pulled down uniformly by return air registers under or beside the seats.

A certain amount of exhaust air should be taken from the ceiling of the seating area, preferably over the balcony (if there is one) to prevent pockets of hot air, which can produce a radiant effect and cause discomfort, as well as increase the cost of air conditioning. Where the ceiling is close to the audience (e.g., below balconies and mezzanines), specially designed plaques or air-distributing ceilings should be provided to absorb noise.

Regular ceiling diffusers placed more than 9 m apart normally give acceptable results if the diffusers are carefully selected. Because large air quantities are generally involved and because the building is large, fairly large capacity diffusers are frequently selected, but these tend to be noisy. Linear diffusers are more acceptable architecturally and perform well if selected properly. Integral dampers in diffusers should not be used as the only means of balancing because they generate intolerable amounts of noise, particularly in larger diffusers.

Mechanical Equipment Rooms

The location of mechanical and electrical equipment rooms affects the degree of sound attenuation treatment required. Those located near the seating area are more critical because of the normal attenuation of sound through space. Those near the stage area are critical because the stage is designed to project sound to the audience. If possible, mechanical equipment rooms should be in an area separated from the main seating or stage area by buffers such as lobbies or service areas. The economies of the structure, attenuation, equipment logistics, and site must be considered in selecting locations for mechanical equipment rooms.

At least one mechanical equipment room is placed near the roof to house the toilet exhaust, general exhaust, cooling tower, kitchen, and emergency stage exhaust fans, if any. Individual roof-mounted exhaust fans may be used, thus eliminating the need for a mechanical equipment room. However, to reduce sound problems, mechanical equipment should not be located on the roof over the music hall or stage but rather over offices, storerooms, or auxiliary areas.

2. HOUSES OF WORSHIP

Houses of worship seldom have full or near-full occupancy more than once a week, but they have considerable use for smaller functions (meetings, weddings, funerals, christenings, or daycare) throughout the rest of the week. It is important to determine how and when the building will be used. When thermal storage is used, longer operation of equipment before occupancy may be required because of the structure’s high thermal mass. Seating capacity is usually well defined. Some houses of worship have a movable partition to form a single large auditorium for special holiday services. It is important to know how often this maximum use is expected.

Houses of worship test a designer’s ingenuity in locating equipment and air diffusion devices in architecturally acceptable places. Because occupants are often seated, drafts and cold floors should be avoided. Many houses of worship have high, vaulted ceilings, which create thermal stratification. Where stained glass is used, a shade coefficient equal to solar glass (SC = 0.70) is assumed.

Houses of worship may also have auxiliary rooms that should be air conditioned. To ensure privacy, sound transmission between adjacent areas should be considered in the air distribution scheme. Diversity in the total air-conditioning load requirements should be evaluated to take full advantage of the characteristics of each area.

It is desirable to provide some degree of individual control for the platform, sacristy, and bema or choir area.

3. AUDITORIUMS

The types of auditoriums considered are movie theaters, playhouses, and concert halls. Auditoriums in schools and the large auditoriums in some convention centers may follow the same principles, with varying degrees of complexity.

Movie Theaters

Movie theaters are the simplest of the auditorium structures discussed here. They run continuously for periods of 8 h or more and, thus, are not a good choice for precooling techniques, except for the first matinée peak. They operate frequently at low occupancy levels, and low-load performance must be considered. Additionally, they tend to have lower sensible heat factors; special care must be taken to ensure proper relative humidity levels can be maintained without overcooling the space.

Motion picture studios often require that movie theaters meet specific noise criteria. Consequently, sound systems and noise control are as critical in these applications as they are in other kinds of theaters. The lobby and exit passageways in a motion picture theater are seldom densely occupied, although some light to moderate congestion can be expected for short times in the lobby area. A reasonable design for the lobby space is one person per 1.8 to 2.8 m^2.

Lights are usually dimmed when the house is occupied; full lighting intensity is used only during cleaning. A reasonable value for lamps above the seating area during a performance is 5 to 10% of the installed wattage. Designated smoking areas should be handled with separate exhaust or air-handling systems to avoid contamination of the entire facility.

Projection Booths. The projection booth represents a larger challenge in movie theater design. For large theaters using high-intensity lamps, projection room design must follow applicable building codes. If no building code applies, the projection equipment manufacturer usually has specific requirements. The projection room may be air conditioned, but it is normally exhausted or operated at negative pressure. Exhaust is normally taken through the housing of the projectors. Additional exhaust is required for the projectionist’s sanitary facilities. Other heat sources include sound and dimming equipment, which require a continuously controlled environment and necessitate a separate system.

Smaller theaters have fewer requirements for projection booths. It is a good idea to condition the projection room with filtered supply air to avoid soiling lenses. In addition to the projector light, heat sources in the projection room include the sound equipment, as well as the dimming equipment.

Performance Theaters

Performance theaters differ from motion picture theaters in the following ways:

- Performances are seldom continuous. Where more than one performance occurs in a day, performances are usually separated by 2 to 4 h. Accordingly, precooling techniques are applicable, particularly for afternoon performances.
- Performance theaters generally play to a full or near-full house.
- Performance theaters usually have intermissions, and the lobby areas are used for drinking and socializing. The intermissions are usually relatively short, seldom exceeding 15 to 20 min; however, the load may be as dense as

one person per 0.5 m^2.

- Because sound amplification is less used than in motion picture theaters, background noise control is more important.
- Stage lighting contributes considerably to the total cooling load in performance theaters. Lighting loads can vary from performance to performance.

Stages. The stage presents the most complex problem. It consists of the following loads:

- A heavy, mobile lighting load
- Intricate or delicate stage scenery, which varies from scene to scene and presents difficult air distribution requirements
- Actors, who may perform tasks that require exertion

Approximately 40 to 60% of the lighting load can be eliminated by exhausting air around the lights. This procedure works for lights around the proscenium. However, it is more difficult to place exhaust air ducts directly above lights over the stage because of the scenery and light drops. Careful coordination is required to achieve an effective and flexible layout.

Conditioned air should be introduced from the low side and back stages and returned or exhausted around the lights. Some exhaust air must be taken from the top of the tower directly over the stage containing lights and equipment (i.e., the fly). Air distribution design is further complicated because pieces of scenery may consist of light materials that flutter in the slightest air current. Even the vertical stack effect created by the heat from lights may cause this motion. Therefore, low air velocities are essential and air must be distributed over a wide area with numerous supply and return registers.

With multiple scenery changes, low supply or return registers from the floor of the stage are almost impossible to provide. However, some return air at the footlights and for the prompter should be considered. Air conditioning should also be provided for the stage manager and control board areas.

In many theaters with overhead flies, the stage curtain billows when it is down. This is primarily caused by the stack effect created by the height of the main stage tower, heat from lights, and the temperature difference between the stage and seating areas. Proper air distribution and balancing can minimize this phenomenon. Bypass damper arrangements with suitable fire protection devices may be feasible.

In cold climates, loading docks adjacent to stages should be heated. Doors to these areas may be open for long periods (e.g., while scenery is being loaded or unloaded for a performance).

On the stage, local code requirements must be followed for emergency exhaust ductwork or skylight (or blow-out hatch) requirements. These openings are often sizable and should be incorporated in the early design concepts.

Concert Halls

Concert halls and music halls are similar to performance theaters. They normally have a full stage, complete with fly gallery, and dressing areas for performers. Generally, the only differences between the two are in size and decor, with the concert hall usually being larger and more elaborately decorated.

Air-conditioning design must consider that the concert hall is used frequently for special charity and civic events, which may be preceded or followed by parties (and may include dancing) in the lobby area. Concert halls often have cocktail lounge areas that become very crowded, possibly with heavy smoking during intermissions. These areas should be equipped with flexible exhaust-recirculation systems. Concert halls may also have full restaurant facilities.

As in theaters, noise control is important. Design must avoid characterized or narrow-band noises in the level of audibility. Much of this noise is structure-borne, resulting from inadequate equipment and piping vibration isolation. An experienced acoustical engineer is essential for help in the design of these applications.

4. ARENAS AND STADIUMS

Functions at arenas and stadiums may be quite varied, so the air-conditioning loads will vary. Arenas and stadiums are not only used for sporting events such as basketball, ice hockey, boxing, and track meets but may also house circuses; rodeos; convocations; social affairs; meetings; rock concerts; car, cycle, and truck events; and special exhibitions such as home, industrial, animal, or sports shows. For multipurpose operations, the designer must provide highly flexible systems. High-volume ventilation may be satisfactory in many instances, depending on load characteristics and outdoor air conditions.

Load Characteristics

Depending on the range of use, the load may vary from a very low sensible heat ratio for events such as boxing to a relatively high sensible heat ratio for industrial exhibitions. Multispeed fans often improve performance at these two extremes and can aid in sound control for special events such as concerts or convocations. When using multispeed fans, the designer should consider the performance of the air distribution devices and cooling coils when the fan is operating at lower speeds.

Because total comfort cannot be ensured in an all-purpose facility, the designer must determine the level of discomfort that can be tolerated, or at least the type of performances for which the facility is primarily intended.

As with other assembly buildings, seating and lighting combinations are the most important load considerations. Boxing events, for example, may have the most seating, because the boxing ring area is very small. For the same reason, however, the area that needs to be intensely illuminated is also small. Thus, boxing matches may represent the largest latent load situation. Other events that present large latent loads are rock concerts and large-scale dinner dances, although the audience at a rock concert is generally less concerned with thermal comfort. Ventilation is also essential in removing smoke or fumes at car, cycle, and truck events. Circuses, basketball, and hockey have a much larger arena area and less seating. The sensible load from lighting the arena area improves the sensible heat ratio. The large expanse of ice in hockey games considerably reduces both latent and sensible loads. High latent loads caused by occupancy or ventilation can create severe problems in ice arenas such as condensation on interior surfaces and fog. Special attention should be paid to the ventilation system, air distribution, humidity control, and construction materials. See Chapter 44 of the 2022 *ASHRAE Handbook—Refrigeration* for more details on ice rinks.

Enclosed Stadiums

An enclosed stadium may have either a retractable or a fixed roof. When the roof is closed, ventilation is needed, so ductwork must be run in the permanent sections of the stadium. The large air volumes and long air throws required make proper air distribution difficult to achieve; thus, the distribution system must be very flexible and adjustable.

Some open stadiums have radiant heating coils in the floor slabs of the seating areas. Gas-fired or electric high- or low-intensity radiant heating located above the occupants is also used.

Open racetrack stadiums may present a ventilation problem if the grandstand is enclosed. The grandstand area may have multiple levels and be in the range of 400 m long and 60 m deep. The interior (ancillary) areas must be ventilated to control odors from toilet facilities, concessions, and the high population density. General practice provides about four air changes per hour for the stand seating area and exhausts air through the rear of the service areas. More efficient ventilation systems may be selected if architectural considerations allow. Window fogging is a winter concern with glass-enclosed grandstands. This can be minimized by double glazing, humidity control, moving dry air across the glass, or a radiant heating system for perimeter glass areas.

Air-supported structures require continuous fan operation to maintain a properly inflated condition. The possibility of condensation on the underside of the air bubble should be considered. The U-factor of the roof should be sufficient to prevent condensation at the lowest expected ambient temperature. Heating and air-conditioning functions can be either incorporated into the inflating system or furnished separately. Solar and radiation control is also possible through the structure's skin. Applications, though increasing rapidly, still require working closely with the enclosure manufacturer to achieve proper and integrated results.

Ancillary Spaces

The concourse areas of arenas and stadiums are heavily populated during entrance, exit, and intermission periods. Considerable odor is generated in these areas by food, drink, and smoke, requiring considerable ventilation. If energy conservation is an important factor, consider using carbon filters and controllable recirculation rates. Concourse area air systems should be evaluated for their flexibility in returning or exhausting air, and the economics of this type of flexibility should be evaluated with regard to the associated problem of air balance and freeze-up in cold climates.

Ticket offices, restaurants, and similar facilities are often expected to be open during hours that the main arena is closed; therefore, separate systems should be considered for these areas.

Locker rooms require little treatment other than excellent ventilation, usually not less than 10 to 15 L/s per square metre. To reduce the outdoor air load, excess air from the main arena or stadium may be transferred into the locker rooms. However, reheat or recooling by water or primary air should be considered to maintain the locker room temperature. To maintain proper air balance under all conditions, locker rooms should have separate supply and exhaust systems.

Ice Rinks

See Chapter 44 of the 2022 *ASHRAE Handbook—Refrigeration* for ice sheet design information. When an **ice rink** is designed into the facility, the concerns of groundwater conditions, site drainage, structural foundations, insulation, and waterproofing become even more important, with the potential of freezing soil or fill under the floor and subsequent expansion. The rink floor may have to be strong enough to support heavy trucks. The floor insulation also must be strong enough to take this load. Ice-melting pits of sufficient size with steam pipes may have to be furnished. If the arena is to be air conditioned, consider combining the air-conditioning system with the ice rink system, although the designer should be aware that both systems operate at vastly different temperatures and have considerably different operation profiles. The radiant effects of the ice on the people and of heat from the roof and lights on the ice must be considered in the system's design and operation. Low air velocities at the ice sheet level help minimize the refrigeration load. Conversely, high air velocities cause the ice to melt or sublimate.

Fog forms when moisture-laden air cools below its dew point. This is most likely to occur close to the ice surface within the boarded area (playing area). Fog can be controlled by reducing the indoor dew point with a dehumidification system or high-latent-capacity air-conditioning system and by delivering appropriate air velocities to bring the air in contact with the ice. Air-conditioning systems have had limited success in reducing the dew-point temperature sufficiently to prevent fog. The section on Ice Rink Dehumidifiers in Chapter 25 of the 2020 *ASHRAE Handbook—HVAC Systems and Equipment* has more information on fog control.

The type of lighting used over ice rinks must be carefully considered when using precooling before hockey games and between periods. Main lights should be able to be turned off, if feasible. Incandescent lights require no warm-up time and are more applicable than types requiring warm-up. Low-emissivity ceilings with reflective characteristics successfully reduce condensation on roof structures; they also reduce lighting and, consequently, the cooling requirements.

Gymnasiums

Smaller gymnasiums, such as those in schools, are miniature versions of arenas and often have multipurpose features. For further information, see Chapter 8.

Many school gymnasiums are not air conditioned. Low-intensity perimeter radiant heaters with central ventilation supplying four to six air changes per hour are effective and energy efficient. Unit heaters on the ceiling are also effective. Ventilation must be provided because of high activity levels and resulting odors.

Most gymnasiums are located in schools. However, public and private organizations and health centers may also have gymnasiums. During the day, gymnasiums are usually used for physical activities, but in the evening and on weekends, they may be used for sports events, social affairs, or meetings. Thus, their activities fall within the scope of those of a civic center. More gymnasiums are being considered for air conditioning to make them more suitable for civic center activities. Design criteria are similar to arenas and civic centers when used for such activities. However, for schooltime use, space temperatures are often kept between 18 and 20°C during the heating season. Occupancy and the degree of activity during daytime use do not usually require high quantities of outdoor air, but if used for other functions, system flexibility is required.

5. CONVENTION AND EXHIBITION CENTERS

Convention and exhibition centers schedule diverse functions similar to those at arenas and stadiums and present a unique challenge to the designer. The center generally is a high-bay, long-span space, and can change weekly, for example, from an enormous computer room into a gigantic kitchen, large machine shop, department store, automobile showroom, or miniature zoo. They can also be the site of gala banquets or used as major convention meeting rooms.

Income earned by these facilities is directly affected by the time it takes to change from one activity to the next, so highly flexible utility distribution and air-conditioning equipment are needed.

Ancillary facilities include restaurants, bars, concession stands, parking garages, offices, television broadcasting rooms, and multiple meeting rooms varying in capacity from small (10 to 20 people) to large (hundreds or thousands of people). Often, an appropriately sized full-scale auditorium or arena is also incorporated.

By their nature, these facilities are much too large and diverse in their use to be served by a single air-handling system. Multiple air handlers with several chillers can be economical.

Load Characteristics

The main exhibition room is subject to a variety of loads, depending on the type of activity in progress. Industrial shows provide the highest sensible loads, which may have a connected capacity of 215 W/m^2 along with one person per 3.7 to 4.6 m^2. Loads of this magnitude are seldom considered because large power-consuming equipment is rarely in continuous operation at full load. An adequate design accommodates (in addition to lighting load) about 108 W/m^2 and one person per 3.7 to 4.6 m^2 as a maximum continuous load.

Alternative loads of very different character may be encountered. When the main hall is used as a meeting room, the load will be much more latent. Thus, multispeed fans or variable-volume systems may provide a better balance of load during these high-latent, low-sensible periods of use. Accurate occupancy and usage information is critical in any plan to design and operate such a facility efficiently and effectively.

System Applicability

The main exhibition hall is normally handled by one or more all-air systems. This equipment should be able to operate on all outdoor air, because during set-up, the hall may contain highway-size trucks bringing in or removing exhibit materials. There are also occasions when the space is used for equipment that produces an unusual amount of fumes or odors, such as restaurant or printing industry displays. It is helpful to build some flues into the structure to duct fumes directly to the outdoors. Perimeter radiant ceiling heaters have been successfully applied to exhibition halls with large expanses of glass.

Smaller meeting rooms are best conditioned either with individual room air handlers, or with variable-volume central systems, because these rooms have high individual peak loads but are not used frequently. Constant-volume systems of the dual- or single-duct reheat type waste considerable energy when serving empty rooms, unless special design features are incorporated.

Offices and restaurants often operate for many more hours than the meeting areas or exhibition areas and should be served separately. Storage areas can generally be conditioned by exhausting excess air from the main exhibit hall through these spaces.

6. FAIRS AND OTHER TEMPORARY EXHIBITS

Occasionally, large-scale exhibits are constructed to stimulate business, present new ideas, and provide cultural exchanges. Fairs of this type take years to construct, are open from several months to several years, and are sometimes designed considering future use of some buildings. Fairs, carnivals, or exhibits, which may consist of prefabricated shelters and tents that are moved from place to place and remain in a given location for only a few days or weeks, are not covered here because they seldom require the involvement of architects and engineers.

Design Concepts

One consultant or agency should be responsible for setting uniform utility service regulations and practices to ensure proper organization and operation of all exhibits. Exhibits that are open only during spring or fall months require a much smaller heating or cooling plant than those open during peak summer or winter months. This information is required in the earliest planning stages so that system and space requirements can be properly analyzed.

Occupancy

Fair buildings have heavy occupancy during visiting hours, but patrons seldom stay in any one building for a long period. The length of time that patrons stay in a building determines the air-conditioning design. The shorter the anticipated stay, the greater the leeway in designing for less-than-optimum comfort, equipment, and duct layout. Also, whether patrons wear coats and jackets while in the building influences operating design conditions.

Equipment and Maintenance

Heating and cooling equipment used solely for maintaining comfort and not for exhibit purposes may be secondhand, if available and of the proper capacity. Another possibility is to rent the air-conditioning equipment to reduce the capital investment and eliminate disposal problems when the fair is over.

Depending on the size of the fair, length of operation time, types of exhibitors, and fair sponsors' policies, it may be desirable to compare using a centralized heating and cooling plant versus individual plants for each exhibit. The proportionate cost of a central plant to each exhibitor, including utility and maintenance costs, may be considerably less than having to furnish space and plant utility and maintenance costs. The larger the fair, the more savings may result. It may be practical to make the plant a showcase, suitable for exhibit and possibly added revenue. A central plant may also form the nucleus for commercial or industrial development of the area after the fair is over.

If exhibitors furnish their own air-conditioning plants, it is advisable to analyze shortcuts that may be taken to reduce equipment space and maintenance aids. For a 6-month to 2-year maximum operating period, for example, tube pull or equipment removal space is not needed or may be drastically reduced. Higher fan and pump motor power and smaller equipment are permissible to save on initial costs. Ductwork and piping costs should be kept as low as possible because these are usually the most difficult items to salvage; cheaper materials may be substituted wherever possible. The job must be thoroughly analyzed to eliminate all unnecessary items and reduce all others to bare essentials.

The central plant may be designed for short-term use as well. However, if it is to be used after the fair closes, the central plant should be designed in accordance with the best practice for long-life plants. It is difficult to determine how much of the piping distribution system can be used effectively for permanent installations. For that reason, initial piping design should be simple, preferably in a grid, loop, or modular layout, so that future additions can be made easily and economically.

Air Cleanliness

The efficiency of filters needed for each exhibit is determined by the nature of the area served. Because the life of an exhibit is very short, it is desirable to furnish the least expensive filtering system. If possible, one set of filters should be selected to last for the life of the exhibit. In general, filtering efficiencies do not have to exceed 30% (see ASHRAE *Standard* 52.1).

System Applicability

If a central air-conditioning plant is not built, equipment installed in each building should be the least costly to install and operate for the life of the exhibit. These units and systems should be designed and installed to occupy the minimum usable space.

Whenever feasible, heating and cooling should be performed by one medium, preferably air, to avoid running a separate piping and radiation system for heating and a duct system for cooling. Air curtains used on an extensive scale may, on analysis, simplify building structure and lower total costs.

Another possibility when both heating and cooling are required is a heat pump system, which may be less costly than separate heating and cooling plants. Economical operation may be possible, depending on building characteristics, lighting load, and occupant load. If well or other water is available, it may allow a more economical installation than an air-source heat pump.

7. ATRIUMS

Atriums provide shelter and daylit spaces within a building, and usually have glazed roofs. They became popular during the Victorian era when steel and glass building structures became possible. A famous example was the Crystal

Palace, the Great Britain pavilion at the Works of Industry of All Nations exhibit in 1851. The original was actually only used as a temporary structure, but was rebuilt in south London after the exhibition (though it was later destroyed by fire). A detailed, full-scale replica was constructed in Dallas, Texas, and is used as a business building.

Before air conditioning was common, covered atrium spaces assisted with passive, natural ventilation and shading their host buildings. They helped reduce external solar gains so that buildings were both comfortable and healthy. These impressive architectural spaces also expanded architectural design options and provided individuality to a building. They became regularly used across Europe and North America. The introduction of electricity and development of mechanical cooling and air conditioning opened up different design solutions, however, so atriums fell out of favor with architects throughout much of the first half of the 20th century. It was not until 1967 that architect and developer John Portman opened the Hyatt hotel in Atlanta and showed how a central atrium could provide an attractive and low-cost space within an air-conditioned high-rise building and atriums became fashionable again.

Many atriums are air conditioned and require extensive engineering systems, whereas others are naturally ventilated and are often included as an energy saving strategy. In both cases, engineering design is an essential key to success.

Good atrium design covers all aspects, from HVAC and passive solar design to daylight, fire and smoke control, innovative glazing systems and shading, environmental needs for people and plants or even complex landscapes, and often for low energy consumption and potential energy savings for the whole building. Good atrium design acts as an energy reduction measure; poor atrium design uses large amounts of energy.

Atrium types range from commercial offices to retail, leisure, hotels, and mixed use. There is potential for hybrid designs using passive solar linked to mechanical HVAC.

Atriums have diverse functions and occupancies. An atrium may (1) connect buildings; (2) serve as an architectural feature, leisure space, greenhouse, and/or smoke reservoir (see Chapter 54 for details on atrium smoke control); and (3) afford energy and lighting conservation. The temperature, humidity, and hours of use of an atrium directly relate to those of the adjacent buildings. Glass window walls and skylights are common. Atriums are generally large in volume with relatively small floor areas. The temperature and humidity conditions, air distribution, impact from adjacent buildings, and fenestration loads to the space must be considered during design.

Perimeter radiant heating (e.g., overhead, wall finned-tube, floor, or combinations thereof) is commonly used for expansive glass windows and skylights. Air-conditioning systems can heat, cool, and control smoke. Distribution of air across windows and skylights can also control heat transfer and condensation. Low supply and high return air distribution can control heat stratification, as well as wind and stack effects. Some atrium designs include a combination of high/low supply and high/low return air distribution to control heat transfer, condensation, stratification, and wind/stack effects.

The energy use of an atrium can be reduced by installing double- and triple-panel glass and mullions with thermal breaks, as well as shading devices such as external, internal, and interior screens, shades, and louvers.

Extensive landscaping is common in atriums. Humidity levels are generally maintained between 10 and 35%. Hot and cold air should not be distributed directly onto plants and trees.

REFERENCES

ASHRAE members can access *ASHRAE Journal* articles and ASHRAE research project final reports at technologyportal.ashrae .org. Articles and reports are also available for purchase by nonmembers in the online ASHRAE Bookstore at www.ashrae.org/bookstore.

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