

CHAPTER 4

PLACES OF ASSEMBLY

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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.)

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 the times of full seating, so that simultaneous loads may be considered to obtain optimum performance and operating economy. Dehumidification requirements should be considered before reducing equipment size. The intermittent or infrequent nature of the cooling loads may allow these buildings to benefit from thermal storage systems.

The 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 m² per person for the entire seating area, including exit aisles but not the stage, performance areas, or entrance lobbies.

Outdoor Air

Outdoor air ventilation rates as prescribed by ASHRAE *Standard 62* can be a major portion of the total load. The latent load (dehumidification and humidification) and energy used to maintain the relative humidity within prescribed limits is also a concern. 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. Lighting may be at the level of 1600 lux in convention halls where television cameras are expected to be used, or lighting may be virtually absent, 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.

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

Indoor Air Conditions

Indoor air temperature and humidity should follow ASHRAE comfort recommendations in Chapter 8 of the 2001 *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 while the winter indoor temperature may favor the cooler end of the scale.
- 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. Here 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 those 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. Ionization and chemically reactive filters should be considered 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 or natatorium, but it is important in a concert hall. Facilities that are used for varied functions 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 the selection of diffusers and grilles. When designing a performance theater or concert hall, an experienced acoustics engineer should be consulted. In these

projects, 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 outside 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. Care should be taken to avoid designs that permit noises to enter the space through air intakes or reliefs and carelessly designed duct systems.

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 the 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 the 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, due to 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 34](#). 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 a precooling concept. 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 the 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, people generally remain in one place throughout a performance, so they cannot avoid drafts. Therefore, good air distribution is essential.

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 in excess of 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 side-walls. For ceiling distribution, downward throw is not critical provided 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 the supply air is expected to travel 9 m or more from side-wall outlets to condition the center of the seating area. Due to the large size of most houses of worship, theaters, and halls, 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, the supply air blankets the seating area and is pulled down uniformly by the 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 careful engineering is applied in the selection of the diffusers. Because large air quantities are generally involved and because the building is large, fairly large capacity diffusers, which tend to be noisy, are frequently selected. 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.

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 prior to occupancy may be required due to the high thermal mass of the structure. The seating capacity of houses of worship 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 a high vaulted ceiling, which creates 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.

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

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

Motion picture theaters are the simplest of the auditorium structures mentioned here. They run continuously for periods of 4 to 8 h or more and, thus, are not a good choice for precooling techniques, except for the first matinee 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 sound systems make noise control less important than it is 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 m².

The 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 the major problem in motion picture 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 a period of 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 m².
- Because sound amplification is less used than that 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). The 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 the control board areas.

One phenomenon encountered in many theaters with overhead flies is the billowing of the stage curtain when it is down. This is primarily due to the stack effect created by the height of the main stage tower, the heat from the 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.

Loading docks adjacent to stages located in cold climates should be heated. The doors to these areas may be open for long periods, for example, 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 legitimate 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 by or followed by parties (and may include dancing) in the lobby area. Concert halls often have cocktail lounge areas that become very crowded, 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 theatres, noise control is important. The 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.

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 outside 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 the 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 does improve the sensible heat ratio. The large expanse of ice in hockey games represents a considerable reduction in 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.

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 required and the long air throws 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 the air through the rear of the service areas. More efficient ventilation systems may be selected if architectural considerations permit. Fogging of windows 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 the continuous operation of a fan 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, carbon filters and controllable recirculation rates should be considered. Concourse area air systems should be considered for their flexibility of returning or exhausting air. 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

Refer to Chapter 34 of the 2002 *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 of 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, the possibility of combining the air-conditioning system with the ice rink system may be analyzed. The designer should be aware that both systems operate at vastly different temperatures and may operate at different capacity levels at any given time. The radiant effects of the ice on the people and of the heat from the roof and lights on the ice must be considered in the design and operation of the system. Also, low air velocity at the floor is related to minimizing the refrigeration load. High air velocities will cause moisture to be drawn from the air by the ice sheet.

Fog is formed when moisture-laden air is allowed to cool 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 type of lighting used over ice rinks must be carefully considered when precooling is used before hockey games and between periods. Main lights should be capable of being 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 requirements.

Gymnasiums

Smaller gymnasiums, such as those in school buildings, are miniature versions of arenas and often have multipurpose features. For further information, see [Chapter 6, Educational Facilities](#).

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 located at the ceiling are also effective. Ventilation must be provided due to 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 does not usually require high quantities of outdoor air, but if used for other functions, system flexibility is required.

CONVENTION AND EXHIBITION CENTERS

Convention-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. These centers can be changed 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.

The 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/m² along with one person per 3.7 to 4.6 m². Loads of this magnitude are seldom considered because large power-consuming equipment is seldom in continuous operation at full load. An adequate design accommodates (in addition to lighting load) about 108 W/m² and one person per 3.7 to 4.6 m² as a maximum continuous load.

Alternative loads that are very different in character may be encountered. When the main hall is used as a meeting room, the load will be much more latent in character. Thus, multispeed fans or variable-volume systems may provide a better balance of load during these high-latent, low-sensible periods of use. The determination of 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 capable of operating on all outdoor air, because during set-up time, the hall may contain a number of 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 outside. 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.

NATATORIUMS

Environmental Control

A natatorium requires year-round humidity levels between 40 and 60% for comfort, energy consumption, and building protection. The designer must address the following concerns: humidity

control, ventilation requirements for air quality (outdoor and exhaust air), air distribution, duct design, pool water chemistry, and evaporation rates. A humidity control system will not provide satisfactory results if any of these items are overlooked.

Humidity Control

Humans are very sensitive to relative humidity. Fluctuations in relative humidity outside the 40 to 60% range can increase levels of bacteria, viruses, fungi and other factors that reduce air quality. For swimmers, 50 to 60% rh is most comfortable. High relative humidity levels are destructive to building components. Mold and mildew can attack wall, floor, and ceiling coverings, and condensation can degrade many building materials. In the worst case, the roof could collapse due to corrosion from water condensing on the structure.

Load Estimation

Loads for a natatorium include building heat gains and losses from outdoor air, lighting, walls, roof, and glass. Internal latent loads are generally from people and evaporation. Evaporation loads in pools and spas are significant relative to other load elements and may vary widely depending on pool features, the areas of water and wet deck, water temperature, and activity level in the pool.

Evaporation. The rate of evaporation can be estimated from empirical Equation (1). This equation is valid for pools at normal activity levels, allowing for splashing and a limited area of wetted deck. Other pool uses may have more or less evaporation (Smith et al. 1993).

$$w_p = \frac{A}{Y}(p_w - p_a)(0.089 + 0.0782V) \quad (1)$$

where

w_p = evaporation of water, kg/s

A = area of pool surface, m²

V = air velocity over water surface, m/s

Y = latent heat required to change water to vapor at surface water temperature, kJ/kg

p_a = saturation pressure at room air dew point, kPa

p_w = saturation vapor pressure taken at surface water temperature, kPa

The units for the constant 0.089 are W/(m²·Pa). The units for the constant 0.0782 are W·s/(m³·Pa).

Equation (1) may be modified by multiplying it by an activity factor F_a to alter the estimate of evaporation rate based on the level of activity supported. For Y values of about 2400 kJ/kg and V values ranging from 0.05 to 0.15 m/s, Equation (1) can be reduced to

$$w_p = 4 \times 10^{-5} A(p_w - p_a)F_a \quad (2)$$

The following activity factors should be applied to the areas of specific features, and not to the entire wetted area:

Type of Pool	Typical Activity Factor (F_a)
Residential pool	0.5
Condominium	0.65
Therapy	0.65
Hotel	0.8
Public, schools	1.0
Whirlpools, spas	1.0
Wavepools, water slides	1.5 (minimum)

The effectiveness of controlling the natatorium environment depends on the correct estimation of water evaporation rates. Applying the correct activity factors is extremely important in determining water evaporation rates. The difference in peak evaporation rates between private pools and active public pools of comparable size may be more than 100%.

Table 1 Typical Natatorium Design Conditions

Type of Pool	Air	Water	Relative Humidity, %
	Temperature, °C	Temperature, °C	
Recreational	24 to 29	24 to 29	50 to 60
Therapeutic	27 to 29	29 to 35	50 to 60
Competition	26 to 29	24 to 28	50 to 60
Diving	27 to 29	27 to 32	50 to 60
Elderly swimmers	29 to 32	29 to 32	50 to 60
Hotel	28 to 29	28 to 30	50 to 60
Whirlpool/spa	27 to 29	36 to 40	50 to 60

Actual operating temperatures and relative humidity conditions should be established before design. How the area will be used usually dictates design. The elderly prefer significantly warmer operating temperatures than those listed [Table 1](#).

Air temperatures in public and institutional pools should be maintained 1 to 2 K above the water temperature (but not above the comfort threshold of 30°C) to reduce the evaporation rate and avoid chill effects on swimmers.

Ventilation Requirements

Air Quality. Outdoor air ventilation rates prescribed by ASHRAE *Standard 62* are intended to provide acceptable air quality conditions for the average pool using chlorine for its primary disinfection process. The ventilation requirement may be excessive for private pools and installations with low use. They may also prove inadequate for high occupancy public installations.

Air quality problems in pools and spas are caused by water quality problems, so simply increasing ventilation rates may prove both expensive and ineffective. Water quality conditions are a direct function of pool use and the type and effectiveness of the water disinfection process used.

Because indoor pools usually have high ceilings, temperature stratification can have a detrimental effect on indoor air quality. Careful duct layout must ensure that the space receives proper air changes and homogeneous air quality throughout. Some air movement at the deck and pool water level is essential to ensure acceptable air quality. Complaints from swimmers indicate that the greatest chloramine (see the section on Pool Water Chemistry) concentrations occur at the water surface. Children are especially vulnerable to chloramine poisoning.

Exhaust air from pools is rich in moisture and may contain high levels of chloramine compounds. While most codes permit pool air to be used as makeup for showers, toilets, and locker rooms, these spaces should be provided with separate ventilation and maintained at a positive pressure with respect to the pool.

Pool and spa areas should be maintained at a negative pressure of 15 to 40 Pa relative to adjacent areas of the building to prevent moisture and chloramine odor migration. Active methods of pressure control may prove more effective than static balancing and may be necessary where outdoor air is used as a part of an active humidity control strategy. Openings from the pool to other areas should be minimized and controlled. Passageways should be equipped with doors with automatic closers to inhibit migration of moisture and air.

Exhaust air intake grilles should be located as close as possible to the warmest water in the facility. Installations with intakes directly above whirlpools have resulted in the best air quality.

Air Delivery Rates. Total airflow should be determined by a psychrometric analysis. Most codes require a minimum of six (6) air changes per hour, except where mechanical cooling is used. This rate may prove inadequate for some occupancy and use.

Where mechanical cooling is provided, air delivery rates should be established to maintain appropriate conditions of temperature and humidity. The following rates are typically desired:

Pools with no spectator areas	4 to 6 air changes per hour
Spectator areas	6 to 8 air changes per hour
Therapeutic pools	4 to 6 air changes per hour

Outdoor air delivery rates may be constant or variable, depending on the design. Minimum rates, however, must provide adequate dilution of contaminants generated by pool water and must maintain acceptable ventilation for occupancy.

Where a minimum outdoor air ventilation rate is established to protect against condensation in a building's structural elements, the rates are typically used for 100% outdoor air systems. These rates usually result in excessive humidity levels under most operating conditions and are generally not adequate to produce acceptable indoor air quality, especially in public facilities subject to heavy use.

Duct Design

As with any installation, proper duct design and installation is necessary for proper equipment performance. Poorly installed return duct connections, for example, can significantly reduce the performance of a dehumidifier. The following duct construction practices apply to natatoriums:

- Fiberglass duct liner should not be used. Where condensation may occur, the insulation must be applied to the exterior of the duct.
- Duct materials and hardware must be resistant to chemical corrosion from the pool atmosphere. The 400 series stainless steels are readily attacked by chlorides in moist environments. The 316 series stainless steel, painted galvanized, fabric (with appropriate grilles sewn in), or aluminum sheet metal may be used for exposed duct systems. Buried ductwork should be constructed from non-metallic fiberglass-reinforced or PVC materials due to the difficulty of replacing damaged materials.
- Grilles, registers, and diffusers should be constructed from aluminum. They should be selected for low static pressure loss and for appropriate throws for proper air distribution.
- Supply air should be directed against interior envelope surfaces prone to condensation (walls, glass, and doors). A portion of the supply air should be directed over the water surface to move contaminated air toward an exhaust point and control chloramines released at the water surface.
- Return air inlets should be located to recover the warm humid air and return it to the ventilation system for treatment, to prevent the supply air from short-circuiting, and minimize recirculation of chloramines.
- Exhaust air inlets should be located to maximize capture effectiveness and minimize the recirculation of chloramines. Exhausting from directly above whirlpools is also desirable. Exhaust air should be taken directly to the outside, through heat recovery devices where provided.
- Filtration should be selected to provide 45 to 65% efficiencies (as defined in ASHRAE *Standard* 52.1) and be installed in locations selected to prevent condensation in the filter bank. Filter media and support materials should be resistant to moisture degradation.
- Air systems may be designed for noise levels of NC 45-50; however, wall, floor, and ceiling surfaces should be evaluated for their attenuation effect.

Envelope Design

Glazing in exterior walls becomes susceptible to condensation when the outdoor temperature drops below the pool room dew point. The design goal is to maintain the surface temperature of the glass and the window frames a minimum of 3 K above the pool room dew point. Windows must allow unobstructed air movement on inside surfaces. Thermal break frames should be used. Recessed windows and protruding window frames should be avoided. Skylights are especially vulnerable and attention should be given to control condensation on them. Wall and roof vapor retarder designs

should be carefully reviewed, especially at wall-to-wall and wall-to-roof junctures and at window, door, and duct penetrations. The pool enclosure must be suitable for year-round operation at 50 to 60% relative humidity. A vapor barrier analysis (as in Figure 10 in Chapter 23 of the 2001 *ASHRAE Handbook—Fundamentals*) should be prepared. Failure to install an effective vapor retarder will result in condensation forming in the structure and potentially serious damage.

Pool Water Chemistry

Failure to maintain proper chemistry in the pool water causes serious air quality problems and deterioration of mechanical and building systems. Water treatment equipment should be installed in a separate, dedicated, well-ventilated space that is under negative pressure. Pool water treatment consists of primary disinfection, pH control, water filtration and purging, and water heating. For further information, refer to Kowalsky (1990).

Air quality problems are usually caused by the reaction of chlorine with biological wastes, and particularly with ammonia, which is a by-product of the breakdown of urine and perspiration. Chlorine reacts with these wastes, creating chloramines (monochloramine, dichloramine, and nitrogen trichloride) that are commonly measured as combined chlorine. The addition of chemicals to pool water increases total contaminant levels. In high-occupancy pools, water contaminant levels can double in a single day of operation.

The reduction of ammonia by chlorine is affected by several factors including water temperature, water pH, total chlorine concentration, and the level of dissolved solids in the water. Because of their higher operating temperature and higher ratio of occupancy per unit water volume, spas produce greater quantities of air contaminants than pools.

The following measures have demonstrated a potential to reduce chloramine concentrations in the air and water:

- **Ozonation.** In low concentrations, ozone has substantially reduced the concentration of combined chlorine in the water. In high concentrations, ozone can replace chlorine as the primary disinfection process; however, ozone is unable to maintain sufficient residual levels in the water to maintain a latent biocidal effect. This necessitates the maintenance of chlorine as a residual process at concentrations of 0.5 to 1.5 mg/kg.
- **Water Exchange Rates.** High concentrations of dissolved solids in water have been shown to directly contribute to high combined chlorine (chloramine) levels. Adequate water exchange rates are necessary to prevent the buildup of biological wastes and their oxidized components in pool and spa water. Conductivity measurement is an effective method to control the exchange rate of water in pools and spas to effectively maintain water quality and minimize water use. In high-occupancy pools, heat recovery may prove useful in reducing water heating energy requirements.

Energy Considerations

Natatoriums can be major energy burden on facilities, so they represent a significant opportunity for energy conservation. Several design solutions are possible using both dehumidification and ventilation strategies. When evaluating a system, the energy consumed by all elements should be considered, including primary heating and cooling systems, fan motors, water heaters, and pumps.

Natatoriums with fixed outdoor air ventilation rates without dehumidification generally have seasonally fluctuating space temperature and humidity levels. Systems designed to provide minimum ventilation rates without dehumidification are unable to maintain relative humidity conditions within prescribed limits. These systems may facilitate mold and mildew growth and may be unable to provide acceptable indoor air quality. Peak dehumidification loads vary with activity levels and during the cooling season when ventilation air becomes an additional dehumidification load to the space.

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 of the 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 or leased, 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, the length of time it will operate, the types of exhibitors, and the policies of the fair sponsors, it may be desirable to analyze the potential for 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 the 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 is 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 the plant 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, piping should be simply designed initially, preferably in a grid, loop, or modular layout, so that future additions can be made easily and economically.

Air Cleanliness

The efficiency of the 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, the filtering efficiencies do not have to exceed 30% (see ASHRAE *Standard* 52.1).

System Applicability

If a central air-conditioning plant is not built, the 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 the 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 the building characteristics, lighting load, and occupant load. If well or other water is available, it may produce a more economical installation than an air-source heat pump.

ATRIUMS

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; and (3) afford energy and lighting conservation. The temperature, humidity, and hours of usage of an atrium are directly related 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 in the design of an atrium.

Perimeter radiant heating (e.g., overhead radiant type, wall finned-tube or radiant type, floor radiant type, or combinations thereof) is commonly used for the expansive glass windows and skylights. Air-conditioning systems can heat, cool, and control smoke. The 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.

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