Related Commercial Resources

CHAPTER 6. INDOOR SWIMMING POOLS

INDOOR pools are challenging facilities to get right. When designing a structure to enclose a swimming pool, it is necessary to completely understand what is happening inside the structure to properly control the indoor atmosphere for occupancy comfort, occupancy health, and structure preservation. A holistic, integrated approach to design is needed to ensure a successful outcome.

This chapter addresses the needs of both the architectural design team and the mechanical HVAC design team. Architectural aspects are included because the building envelope must be designed to be suitable for this high-dew-point application. Some aspects of the envelope design must be approached in a certain way because the mechanical system cannot solve the problems they cause.

Many owners, designers, and facility operators are under the misconception that a properly designed HVAC system can clean the air when chloramine odors become an issue and can make condensation issues go away. This is not the case. If chemicals are offgassing, the source of the problem (water chemistry) must be addressed. If the building envelope is not designed correctly and appropriately for this application, there will be condensation and building degradation issues. The HVAC system can influence these issues either positively or negatively, but will not resolve the issues.

The HVAC system and the water treatment system are critical to the success of the facility. These systems must all work together to provide the best indoor air and water quality in the facility. If one of these systems is compromised in any way, the other system will be affected and cannot correct the issue caused by the shortcomings of the other system.

The owner and design team must put occupant health and safety first, and this requires budgeting for a suitable building HVAC system and water treatment system. Compromises directly affect aspects of the facility. Bad air quality, condensation, and building degradation negatively affect the facility's economic viability by increasing operating and maintenance costs while possibly reducing patron memberships. Although most mechanical systems can be applied in any geographic location, some systems or combination of technology may work better than others.

For both engineers and architects, the key to understanding indoor pools is understanding that this is a high-dew-point application. The elevated dew point affects every aspect of this facility. This chapter reviews the implications of this higher dew point, how to calculate loads, and best practices for best possible occupant comfort and satisfaction.

1. DESIGN COMPONENTS

Environmental Control

Like most indoor spaces, a natatorium requires year-round humidity levels between 40 and 60% for comfort, reasonable energy consumption, and building envelope protection. However, space temperatures are generally 5 to 8 K warmer in a natatorium than in a traditional space, and this drives up the dew point. To minimize operating costs, it is recommended the humidity levels be allowed to go to the high end in summer, only trying to keep humidity levels lower in winter. The designer must address humidity control, room pressure control, ventilation requirements for air quality (outdoor and exhaust air), air distribution, duct design, pool water chemistry, and evaporation rates. A humidity control system alone will not provide satisfactory results if any of these items are overlooked. (See Chapter 25 of the 2020 *ASHRAE Handbook—HVAC Systems and Equipment* for dehumidifier application and design information.)

Air Quality Control

Many critical items affect a natatorium's indoor air quality (IAQ). The design team must work with all trades associated with the pool to ensure a complete system design is in place for the best possible air quality. Chloramine reduction and control are critical aspects; source capture exhaust, secondary disinfection, UV, and other technology to reduce or remove chloramines are at least as important as the HVAC aspects of the design. The HVAC system must effectively get air where it is needed. A stratified room or areas that do not get air turnover will suffer.

Humidity Control

When wet, people become more sensitive to relative humidity and experience an evaporative cooling effect on the skin surface. Fluctuations in relative humidity outside the 50 to 60% range are not recommended. Sustained levels above 60% can promote factors that reduce indoor air quality. Relative humidity levels below 50% significantly increase the facility's energy consumption. For swimmers, 50 to 60% rh limits evaporation and corresponding heat loss from the body and is comfortable without being extreme. Higher relative humidity levels can be 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 structure could fail because of corrosion from water condensing on the structure

There are three approaches to humidity control for indoor pools: compressorized, chilled-water coil and ventilation. All are viable options, but must be fully evaluated to understand what they will provide for year-round control. Geography and patron expectations will factor significantly in on whether or not a ventilation only approach might be considered. Ventilation supplemented with a compressor or chilled water coil are also sometimes considered. See Chapter 25 of the 2020 *ASHRAE Handbook—HVAC Systems and Equipment* for details on the compressorized dehumidifiers available.

Temperature Control

The relation between temperature and humidity determines evaporation from the pool water surface and the space's condensation dew point. To minimize evaporation and operating costs, the air temperature should be kept as warm as is practical, ideally at or above the water temperature, with a maximum of 30°C db, which is generally understood to the maximum for human comfort. All surfaces in the space must be maintained above the space dew point to prevent condensation from developing that could damage the building and allow growth of mold and fungi.

Vapor Migration

A pool's indoor design dew point typically ranges from 16 to 20°C for ambient conditions of 28 to 29°C and 50 to 60% rh. In comparison, a typical space in winter might be 21°C at 40% rh with a 7°C dew point.

In summer, the 16 to 20°C space dew point is not a condensation concern. The vapor pressure outdoors might be a little higher than it is indoors, but if the vapor migrates through the building envelope, it is too warm for condensation to occur.

The serious concern is in winter, when the indoor vapor pressure is significantly higher than it is outdoors and there is a push from indoors to outdoors to try to equalize pressure. If the vapor is allowed to migrate through the wall, it will encounter a temperature at or below dew point. Condensation or freezing will result, and the structure's integrity will be negatively affected.

Building Pressurization

A natatorium must always be maintained with a negative pressure at all elevations to prevent moist air from migrating through the exterior walls and to prevent moisture and odors from migrating through adjacent walls to other parts of the building. (Note that a significant negative space pressure will not reduce or affect vapor migration to the outdoors in winter.) A positively pressurized indoor pool can accelerate building damage by pushing the high-moisture-content air into the building envelope, where it can condense.

One way to maintain negative pressure is balancing ventilation air and exhaust air. Another approach is to maintain the differential pressures between the natatorium and the outdoors, and the natatorium and an adjacent space, at set values.

Regardless of the control method chosen, accurate calculation of the amount of infiltration to the natatorium is essential. If the infiltration rate is underestimated, the space may not be able to achieve a negative pressure without an excessive amount of exhaust. To keep operational costs for ventilation reasonable, the infiltration rate and performance of the air barrier are very important. If the air barrier is not continuous, the amount of exhaust air increases. Experience has shown that the offset between supply and exhaust air can sometimes reach 20 to 25% in poorly constructed natatoriums. Treating all air that will eventually be exhausted is a continuous energy penalty, so efforts to minimize this will reduce operating costs.

To properly design the air barrier, there must be coordination and discussion with the architect, who needs to detail and specify the correct sealants and joints for a continuous air barrier. Ideally, the architect should clearly identify the location of the natatorium air barrier on the construction documents.

The entire perimeter of the designated air barrier should be reviewed to ensure that ductwork that crosses the air barrier does not contribute to the infiltration rate. Since most spaces adjacent to the natatorium are on a nighttime control cycle, with the outdoor air damper closed and the HVAC unit off, ducts that cross the air barrier can cause excessive infiltration during the night cycle. Infiltration of adjacent space air into the natatorium is often overlooked during design and construction and can lead to excessive energy costs and freezing conditions in the adjacent spaces.

The architect should also include a whole-room air leakage test to ensure that the natatorium leaks at a prescribed rate. (A whole-room leakage test is the same as a whole-building leakage test but for just the natatorium.) The leakage rate and the test procedure should be discussed between the architect and the HVAC engineer. ASTM *Standard* E779 is an example of a whole-building leakage test that has been successfully used. Once the leakage rate has been established, the engineer will know precisely how much offset will be needed to achieve the negative space. All modes of operation that vary the amounts of outdoor and/or exhaust air should be evaluated as part of the space pressure test to determine the correct amount of exhaust air to maintain a negative space pressure. If the building HVAC equipment other than the natatorium includes economizer operation, this should be in operation and its effect on natatorium pressure evaluated. Any mode of operation that varies the amount of ventilation and/or exhaust air (e.g., event mode, night setback) must be tested and evaluated so a negative pressure is present at all times in the natatorium.

This negative space needs to take stack effect into consideration. During cold outdoor temperatures, the bottom half of the natatorium is automatically in a negative pressure due to the stack effect. The challenge is to also have the top of the natatorium negative to the outdoors when it is cold outside. The colder it is and the taller the natatorium ceiling, the greater the negative pressure will be at the deck. Door opening forces could exceed ICB 1010.1.3 (Door opening force) and a vestibule could be required. Establishing door opening force should be coordinated with the architect. In some cases, the locker room can be designed as the vestibule. Vestibules effectively cut the door opening force in half. For specifics on stack effect, see Chapter 4.

Ventilation Air

Ventilation air should be calculated as the minimum amount recommended in the current ASHRAE *Standard* 62.1. The effect of these amounts must be reviewed to compensate for any additional moisture being introduced to the space and any effects on increased evaporation, human comfort, and space operating costs. How the ventilation air is introduced to the space must be evaluated to ensure the temperature is above the space dew point to prevent fogging and condensation.

Exhaust Air

Exhaust air must always be in amounts greater than the ventilation air to maintain negative pressure, but the amount by which exhaust must exceed ventilation depends on building tightness. Strategic exhaust has a positive influence on IAQ. Low exhaust air at or near the surface of the pool water surface should also be evaluated to assist in evacuating any chloramines from the space. This exhaust air is rich in energy, and heat recovery is highly recommended to help reduce operating costs.

Location of Mechanical Equipment

The location of mechanical and electrical equipment rooms affects the degree of sound attenuation treatment required.

2. DESIGN ISSUES

Condensation (water vapor changing from gaseous to liquid state) is the major issue for indoor swimming pools. Both visible and concealed condensation must be prevented. To understand how this happens, a basic familiarity with psychometrics is necessary. The following five terms are commonly encountered when dealing with a psychometric chart (Figure 1):

- **Dry bulb (db) temperature** is the sensible temperature of the air (i.e., what can be read from a common thermometer).
- **Wet-bulb (wb) temperature** is taken by surrounding the sensor with a wet wick and measuring the temperature as the water evaporates from the wick. As the water evaporates from the wick, it draws heat required for evaporation from the thermometer bulb, cooling the thermometer in proportion to the amount of evaporation.
- **Dew-point (dp) temperature** is the temperature at which moisture condenses and forms visible water. The colder the air, the less moisture it can hold.
- **Relative humidity (rh)** expresses the moisture content of air as a percentage of saturation.
- **Specific humidity** is the mass of the moisture in the air compared to the mass of air.

A complete understanding of dew point is important. Figure 2 shows three stages of moisture condensation from the air:

- In Figure 2A, the surface of the glass is clear. This means the glass temperature is above the dew-point temperature.
- In Figure 2B, water is starting to form on the surface of the glass, so the glass temperature is at the dew point.
- In Figure 2C, the glass surface is below the dew point and condensate has formed on the surface.

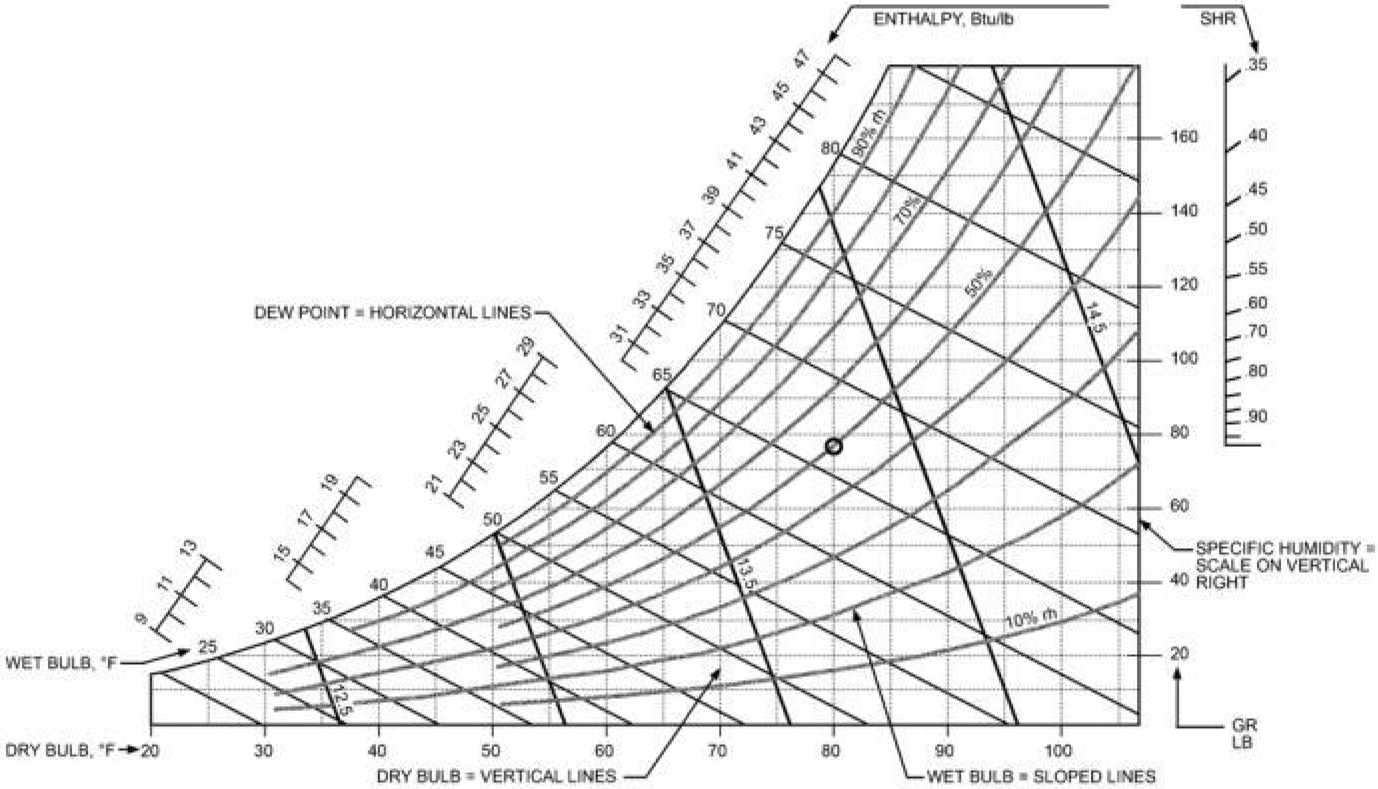

Figure 1. Example Psychrometric Chart

Without proper understanding and control of dew point and condensation, moisture can form on the indoor and outdoor surfaces of the structure. Figure 3 shows examples of moisture formation and the results.

A B C

Figure 2. Stages of Moisture Condensation on Glass (Courtesy Desert-Aire Corp)

In a typical indoor pool, indoor temperature ranges from 25.6 to 30°C db. Figure 4 shows three plotted curves with values derived from the psychometric chart. This graph allows plotting the dew-point temperature at indoor temperatures of 28°C db, 29°C db, and 30°C db and relative humidity values from 30 to 60%. An example is shown at 29°C db and 50% rh, showing that the dew point is 18°C.

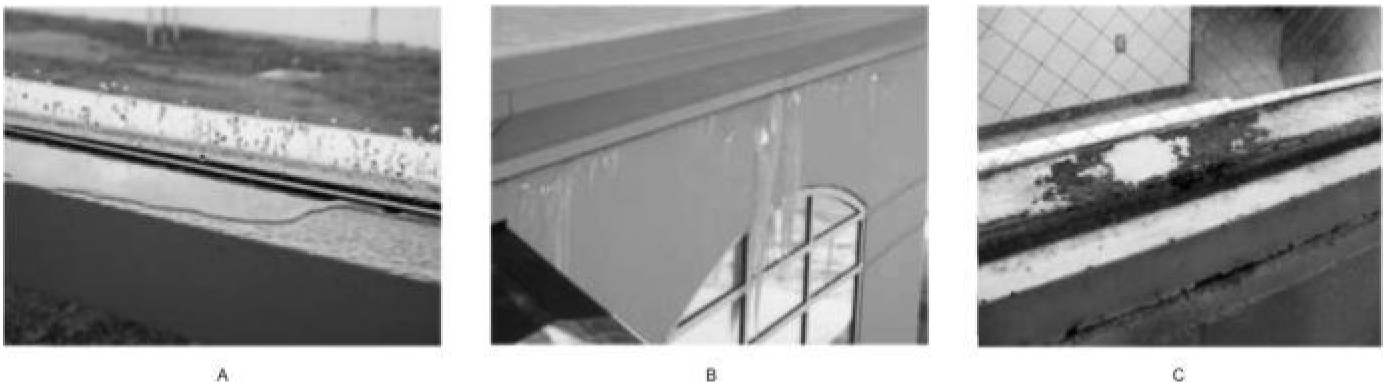

Figure 3. Structural Damage Caused by Condensation (Courtesy Desert-Aire Corp)

This example shows that all surfaces inside the pool room must be kept above the dew-point temperature of 18°C to prevent visible condensation. Common design practice adds 3 K to this temperature as a safety factor.

The architect's responsibility is to design wall and ceiling components with this surface temperature in mind, to assist the HVAC design engineer in preventing moisture from forming inside the structure.

Equation (1) calculates the surface temperature of a structural component:

$$T_s = T_i - [K(1/R)(T_i - T_o)] \quad (1)$$

where

T_s = surface temperature

T_i = indoor space temperature

K = indoor air film coefficient; 0.68 for vertical surface, 0.95 for horizontal roof or skylight, 0.76 for 45° roof or skylight

R = total R-value of structural component

T_o = outdoor temperature

To apply Equation (1) to a window, the published window U-factor (see Chapter 15 of the 2021 *ASHRAE Handbook—Fundamentals*) must be converted to the required R-value; for example,

$$R = 1/U = 1/0.4 = 2.5$$

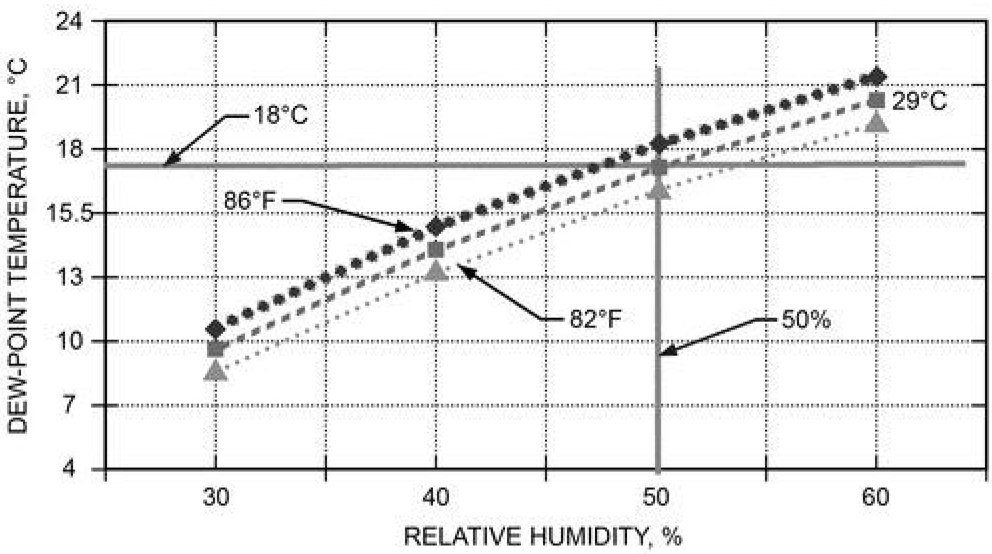

Figure 4. Condensation Dew Point Chart

In this example, the indoor temperature is 29°C db and the outdoor temperature is –18°C db. This gives a 16.2°C surface temperature on the window. If the indoor space is at 50% rh, the dew point would be 17.8°C, which would lead to condensation on the glass surface unless the window glass is heated above the dew point (Figure 5).

Figure 5. Condensation on Windows: Glass Surface Is below Space Dew Point

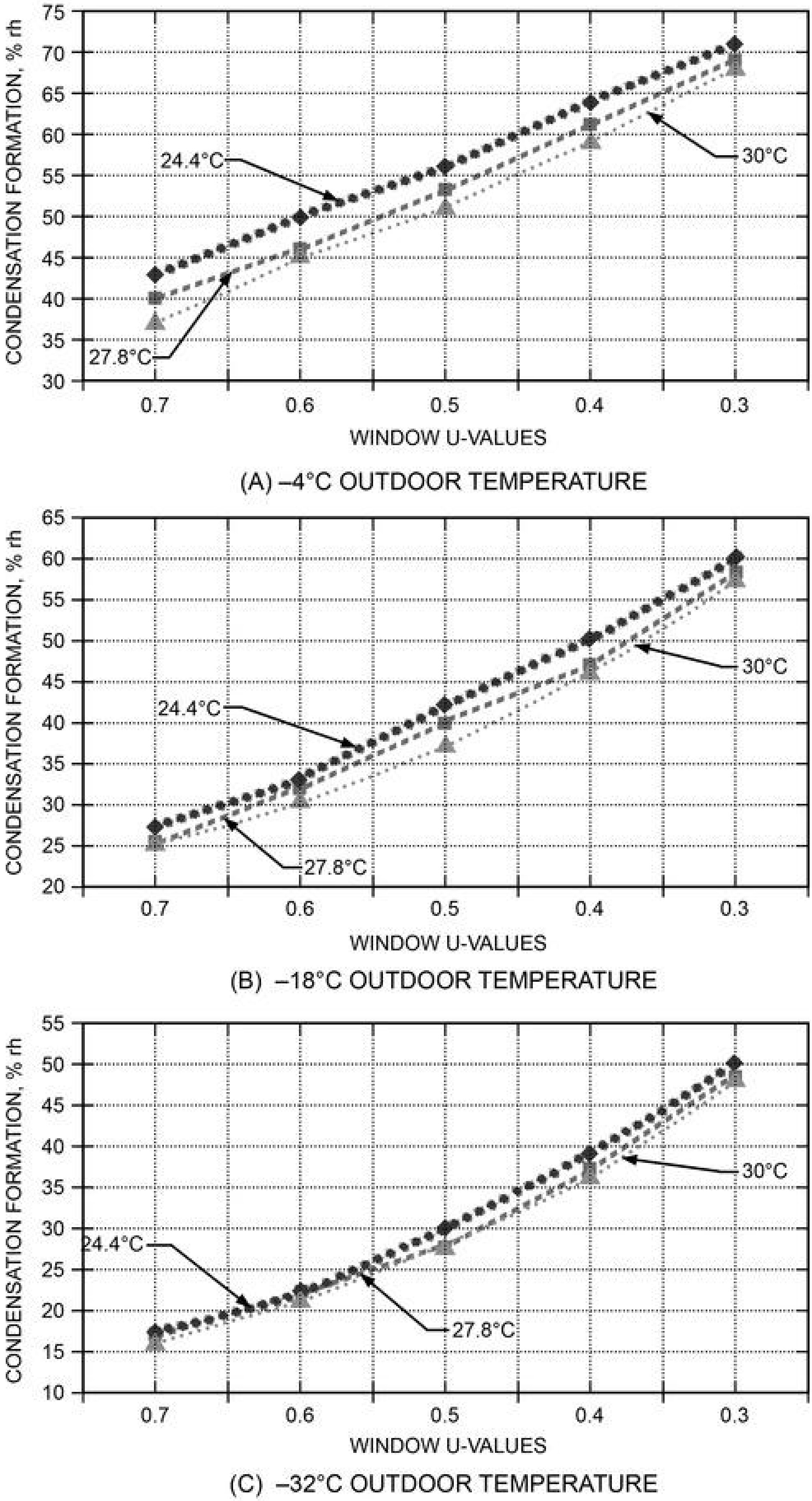

Figure 6. Effects of U-Values and Indoor and Outdoor Temperatures on Dew Point

Figure 6 plots three indoor conditions and several window U-values at different outdoor temperatures: –4°C, –18°C, and –32°C. The left vertical axis shows the relative humidity at which condensation will occur: whenever the indoor relative humidity exceeds these values at the given outdoor condition, condensation will form on the window surface unless the window surface is warmed above the indoor dew point.

Outdoor Air

Outdoor air ventilation rates (as prescribed by ASHRAE *Standard* 62.1) can be a major portion of the total load, depending on the geographic location. 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.

Load Estimation

Loads for a natatorium include 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/water features, 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 (2). 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).

$$w_p = \frac{A}{Y}(p_w - p_a)(0.089 + 0.0782V) \quad (2)$$

where

w_p = evaporation of water, kg/s

A = area of pool surface, m^2

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

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

p_a = saturation pressure at room air dew point, kPa

V = air velocity over water surface, m/s

Table 1 Typical Activity Factors for Various Pool Feature Types

Type of Pool	Typical Activity Factor (F_a)
Baseline (pool unoccupied)	0.5
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)
Water-park-type features (dumping buckets, sprays, etc.)	N/A

Units for the constant 0.089 are W/(m^2 · Pa). Units for the constant 0.0782 are (W · s)/(m^3 · Pa).

Equation (2) 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 (2) can be reduced to

$$w_p = 4 \times 10^{-5} A(p_w - p_a)F_a \quad (3)$$

Table 1 lists activity factors that should be applied to the areas of specific features, and not to the entire wetted area.

The effectiveness of controlling the natatorium environment depends on 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%.

Actual operating temperatures and relative humidity conditions should be established before design. How the area will be used usually dictates design (Table 2).

Air temperatures in public and institutional pools are recommended to be maintained 1 to 2 K above the water temperature (but not above the comfort threshold of 30°C) for energy conservation through reduced evaporation and to avoid chill effects on swimmers.

Competition pools that host swim meets have two distinct operating profiles: (1) swim meets and (2) normal occupancy. It is recommended that both be fully modeled to evaluate the facility's needs. Although swim meets tend to be infrequent, the loads during meets are often considerably higher than during normal operations. To model the swim meet load accurately, it is recommended that the designer know the number of spectators, number of swimmers on the deck, and operating conditions required during the meets. The operator may request a peak relative humidity of 55%, which has a significant effect on total loads. A system designed for swim meet loads should also be designed to operate for considerable portions of the year at part loads. Depending on the layout of the space and location of the spectator gallery, it might be beneficial to provide a separate microclimate to that area, with a separate dedicated unit.

Table 2 Typical Natatorium Design Conditions

Type of Pool	AirTemperature, °C	WaterTemperature, °C	Relative Humidity, %
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

Water parks and water feature (slides, spray cannons, arches, etc.) loads are not fully covered by this chapter. Use caution when evaluating the evaporation from water features/toys installed in natatoriums. Applying higher activity factors when evaluating the evaporation rates at water parks and water features/toys is only one component of accounting for this evaporation. Currently the design professional must rely on experience and professional judgment when calculating the evaporation in water parks and from the water features/toys because manufacturers of these items do not publish evaporation rates. Since these loads are not guaranteed to be accurate, the designer is encouraged to manage space condition expectations by disclosing that the loads are estimates and the space conditions may fluctuate from the design.

It is recommended that the dehumidification load generated by each water feature be calculated individually. The water toys' manufacturers should be contacted to provide specifications related to the pattern and size of the sheet of water that is generated by each water feature/toy to allow for proper load determination. The wet area created by the water toy/feature must be included as wet deck when calculating the ventilation air required for the space as well as the wetted surface for the evaporation load. Because of the concentrated nature of the loads in these facilities, it is recommended that more supply air and outdoor air be used in these facilities compared to what is recommended for traditional pools.

Ventilation Requirements

Air Quality. Outdoor air ventilation rates prescribed by ASHRAE *Standard* 62.1 are intended to provide acceptable air quality conditions for the average pool (where chlorine is used for primary disinfection). The ventilation requirement may be excessive for private pools and installations with low use, and may also prove inadequate for high-occupancy public or water park installations.

Air quality problems in pools and spas are often 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 water disinfection used.

It is recommended that the ASHRAE climate data included with Chapter 14 of the 2021 *ASHRAE Handbook—Fundamentals* (full data are provided with the PDF download and Handbook Online versions of the chapter) be used when calculating the effects of ventilation air on the natatorium's latent load, as mentioned in ASHRAE *Standard* 62.1.

Because indoor pools usually have high ceilings, temperature stratification and stack effect (see Chapter 16 of the 2021 *ASHRAE Handbook—Fundamentals*) can have a detrimental effect on indoor air quality. Careful duct layout is necessary to 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 the ill effects of chloramine inhalation.

Pool and spa areas should be maintained at a negative pressure of 15 to 40 Pa relative to the outdoors and 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 and sweeps to inhibit migration of moisture and air.

Exhaust air from pools is rich in moisture and may contain high levels of corrosive chloramine compounds. Exhaust air intake grilles should be located as close as possible to the warmest body of water in the facility. Warmer and more agitated waters offgas chemicals at higher rates compared to traditional pools. This also allows body oils to become airborne. Ideally, these pollutants should be removed from close to the source before they have a chance to diffuse and negatively affect air quality. Installations with intakes directly above whirlpools have resulted in the best air quality.

Air Delivery Rates. Most codes require a minimum of six air changes per hour, except where mechanical cooling is used. This rate may prove inadequate for some occupancy and use. *Note*: the term “air changes” here refers to the number of air exchanges in the space, not the amount of air being exchanged with new outdoor ventilation air.

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

Pools 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

Ventilation air is the amount of air required by local codes to be introduced during occupied hours to maintain a healthy environment for the occupants. ASHRAE *Standard* 62.1 is used by most local code departments to determine this minimum amount of outdoor air.

Climate control outdoor air is used to control the humidity and temperature in the space. This type of design is usually referred to as **100% outdoor air systems** (i.e., the maximum amount of outdoor air that the fan can supply from the mechanical piece of equipment to the space is 100%). A detailed evaluation of the annual bin weather conditions of the outdoor air must be developed for the natatorium’s specific geographical location. The annual bin profile analysis will help determine if climate control outdoor air is viable for space condition control and how much heating and cooling might be required to maintain space conditions within acceptable ranges. A well-designed system will operate between the code-required minimum outdoor air levels and 100% outdoor air while always trying to use the least amount of outdoor air to try to minimize operating costs. Heat recovery is strongly recommended to help keep the operating costs to a minimum.

The indoor pool’s moisture load needs to be calculated first to establish an accurate system load to maintain the desired space humidity from all moisture-generating items (e.g., water surfaces, spectators, swimmers, water toys). Once the moisture load is established, the amount of outdoor air required to remove this moisture can be calculated based on the ASHRAE weather data for the project location (see the climate data tables download accompanying Chapter 14 of the 2021 *ASHRAE Handbook—Fundamentals*). The amount of sensible heat and cooling can also be calculated to provide room-neutral air to the space. Varying the amount of climate control outdoor air (while never dropping below the code-required ventilation outdoor air requirements) during seasonal changes can help reduce overdrying the air. Overdrying can increase evaporation loads and greater chemical requirements, adding to the facility’s operating costs.

Air Distribution Effectiveness and Duct Design

Proper duct design and installation in a natatorium is critical. Failure to effectively deliver air where needed will result in air quality problems, condensation, stratification, and poor equipment performance. Ductwork that fails to deliver airflow into the breathing zone at the pool deck level and water surface, for example, will lead to air quality problems in those areas. The following duct construction practices apply to indoor pools:

- Deliver air into the breathing zone at the deck. ASHRAE *Standard* 62.1 defines the breathing zone as the area between 75 and 1800 mm from the floor level. The best quality air in the facility is what is delivered from the supply duct. That air must get to where the patrons are to ensure they are breathing the best possible quality air.
- Supply air should be directed against envelope surfaces prone to condensation (glass and doors). Air movement over the pool water surface must not exceed 15 m/s (as per the evaporation rate w_p in Equation [2]). If air movement over the water surface is increased from the standard 0.15 m/s to 0.6 m/s, the evaporation will increase by approximately 30%. Air that moves across the water surface is best handled by a source-capture-type exhaust system. Evaporation from the water surface should be evaluated using Equation (2).
- Return air inlets should be located to recover warm, humid air and return it to the air handler system for treatment, to prevent supply air from short-circuiting and to minimize recirculation of chloramines. It is recommended that return air inlets be located both high and low. This helps prevent air stratification and ensure that incoming ventilation air reaches the breathing zone, as recommended in ASHRAE *Standard* 62.1.
- Exhaust air inlets should be located to maximize capture effectiveness and minimize recirculation of chloramines. Exhausting from directly above whirlpools is also desirable. Exhaust air should be taken directly to the outdoors, through heat recovery devices when provided.
- **Source capture exhaust** (i.e., exhaust air taken as close as possible to the water surface and exhausted to the outdoors) could be part of the climate control equipment or an independent piece of equipment. If the latter, it must be coordinated with the climate control equipment operation.
- Duct materials and hardware must be resistant to chemical corrosion from the pool atmosphere. Stainless steels, even the 316 series, are readily attacked by chlorides and are prone to pitting. They require treatment to adequately perform in a natatorium environment. Galvanized steel and aluminum sheet metal may be used for exposed duct systems. If galvanized duct is used, steps should be taken to adequately protect the metal from

corrosion. It is recommended that, at a minimum, the galvanized ducts be properly prepared and painted with epoxy-based or other durable paint suitable to protect metal surfaces in a pool environment. Note that galvannealed ductwork is easier to weld and paint than hot-dip galvanized, but galvannealed is more susceptible to corrosion if left bare. Certain types of fabric duct (airtight) with appropriate grilles sewn in are also a good choice. Buried ductwork should be constructed from nonmetallic fiberglass-reinforced or PVC materials because of the more demanding environment. Proper means of water drainage in the duct must be considered when ductwork is buried.

- 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.
- 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.
- Fiberglass duct liner should not be used. Where condensation may occur, the insulation must be applied to the duct exterior.
- Air systems should be designed for noise levels listed in Table 1 of Chapter 48 (NC 45 to 50); however, the room wall, floor, and ceiling surfaces should be evaluated for their reverberation times and speech intelligibility.

Envelope Design

An indoor pool is a special-application structure and requires care to ensure the entire structure is suitable for a high-dew-point application. There must be

- Enough insulation that no exterior wall or roof surface ever falls below the space dew-point temperature in cold weather.
- Effective vapor migration protections to ensure moisture from the space is prevented from migrating into any build sections (walls, roofs, joints where they meet). A vapor retarder analysis (as in Figure 10 in Chapter 27 of the 2021 ASHRAE *Handbook—Fundamentals*) should be prepared. Failure to install an effective vapor retarder results in condensation forming in the structure, and potentially serious envelope damage.
- Complete elimination of thermal bridging. Window and door frames must be thermally broken.

Figure 7 shows where the vapor retarder should be located in a wall for an indoor pool application. The vapor retarder must be on the warm side of the dew point. The entire pool enclosure (walls and ceilings) must have a vapor retarder in the correct location. Where walls join the roof or floor meet, it is especially vital to ensure there is no breach in the vapor barrier.

A properly located and installed vapor retarder is the only way to protect a structure from vapor migration and the ensuing moisture damage.

Condensation forms on exterior windows when the outdoor temperature drops below the pool room's dew point (typically between 16 and 22°C). The design goal is to keep the surface temperature of the glass and the window frames at least 2 to 3 K above the pool room's dew point. Windows must allow unobstructed air movement on indoor surfaces, and thermal break frames should be used to raise the window's indoor temperature. Avoid recessed windows and protruding window frames. Skylights are especially vulnerable and require attention to control condensation. Wall and roof vapor retarder designs should be carefully reviewed, especially at wall-to-wall and wall-to-roof junctures and at window, door, skylight, and duct penetrations.

Condensation Control

Exterior windows and doors are primary condensation concerns, so it is extremely important that supply air is focused there. Warm air from the dehumidifier keeps the window surface temperature above the dew-point temperature, which ensures that windows and exterior doors remain condensation free.

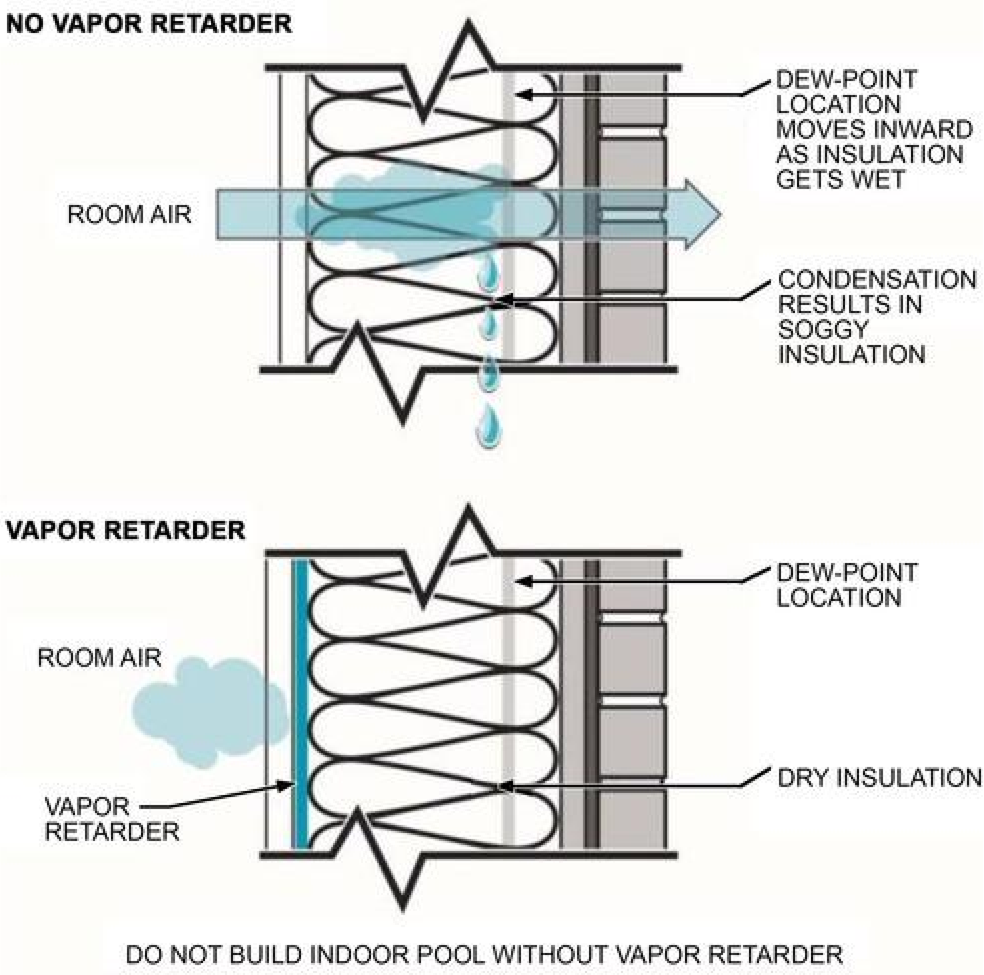

Figure 7. Vapor Retarder Location for Indoor Pool (Courtesy Seresco Technologies, Inc. 2013)

Exterior windows, exterior surfaces, and other condensation-prone areas should be blanketed with supply air (Figure 8). A good rule of thumb is 15 to 28 L/s per square metre of exterior glass. Select grilles, registers, and diffusers that deliver the required throw distance, and the specified volumetric flow rating.

Pool Water Chemistry and Air Quality

Failure to maintain proper chemistry in the pool water causes serious air quality problems and deterioration of mechanical systems and building components. Water treatment equipment and chemicals should be located 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, see 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. Adding chemicals to pool water increases total contaminant levels. In high-occupancy pools, water contaminant levels can double in a single day of operation.

Chlorine's efficiency at reducing ammonia is affected by several factors, including water temperature, water pH, total chlorine concentration, and 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; before implementing any of these steps, however, be sure to confirm with local codes that the measures are acceptable.

- **Ozonation.** In low concentrations, ozone can substantially reduce the concentration of combined chlorine in the water. In high concentrations, ozone can replace chlorine as the primary disinfection process; however, ozone cannot remain at sufficient residual levels in the water to maintain a latent biocidal effect, so chlorine must be kept as a residual process at concentrations of 0.5 to 1.5 mg/kg.
- **Water exchange rates.** High concentrations of dissolved solids in water directly contribute to high combined chlorine (chloramine) levels. Adequate water exchange rates are necessary to prevent build-up 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.

- **Medium-pressure UV.** Using medium-pressure UV lamps for water treatment can reduce the amount of chloramines, and should be evaluated during design. Medium-pressure UV can replace chlorine as the primary disinfection process; however, it does not remain at sufficient residual levels in the water to maintain a latent biocidal effect. Consequently, chlorine is required as a residual process at concentrations of 0.5 to 1.5 mg/kg.
- **Secondary disinfectants.** These can reduce trichloramine levels.
- **Swimmer showers.** Requiring each swimmer to shower before entering the water helps reduce the amount of body oils released into the water, thereby reducing the amount of chloramines generated.
- **Bathroom breaks.** Facilities that require all swimmers to exit the pool every hour and visit the restrooms dramatically reduce the amount of urine introduced into the pool.

Energy Considerations

Natatoriums can be a major energy burden on facilities, so they represent a significant opportunity for energy conservation and recovery. ASHRAE *Standard* 90.1 offers some recommendations. Several design solutions are possible using both dehumidification and ventilation strategies. When evaluating a system, the seasonal space conditions and energy consumed by all elements should be considered, including primary heating and cooling systems, fan motors, water heaters, and pumps.

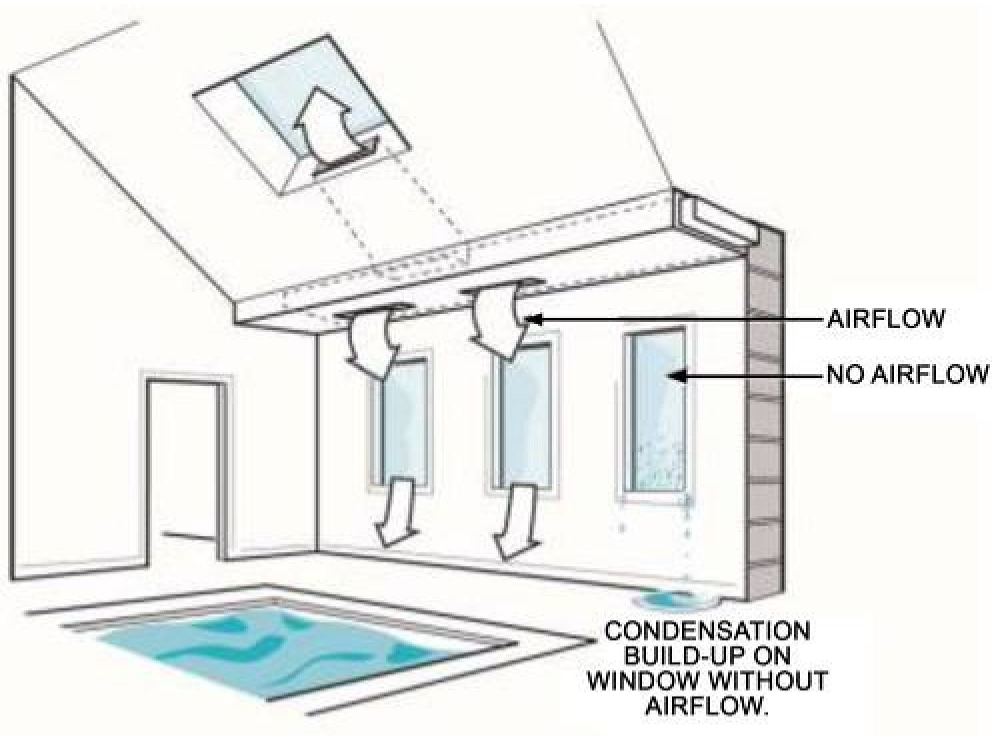

Figure 8. Supply Air Blanketing of Condensation-Prone Areas (Courtesy Seresco Technologies, Inc. 2013)

Operating conditions factor significantly in the total energy requirements of a natatorium. Although occupant comfort is a primary concern, the effects of low space temperatures and relative humidity levels below 50% (especially in winter) should be discussed with the owner/operator:

- Lower room air temperature or lower relative humidity increases evaporation from the pools, thus increasing dehumidification requirements and increasing pool water heating costs
- Warmer water temperatures increase evaporation from the pools, thus increasing the dehumidification requirements and increasing pool water heating costs
- Matching equipment staging capabilities to occupied/unoccupied, consistent, or seasonal activity level changes can also reduce energy operating costs

It is recommended to model the space on both a summer and winter design day to establish whether higher summertime indoor relative humidity level is beneficial to reducing equipment size and operating costs.

Because these facilities require considerable air movement and the supply fans operate 24/7/365, fans and equipment that uses less fan energy lead to considerable energy savings over the equipment life.

These facilities require outdoor and exhaust air. This gives the opportunity for energy recovery from the exhaust air to preheat outdoor air. The economics of a heat recovery decision should be always reviewed, regardless of the facility location: these facilities have warm indoor conditions and show good paybacks for energy recovery, even in warmer climates. A detailed evaluation of the heat exchange process must be done to ensure no condensation develops in the energy recovery device so, in cold climates, ice does not develop and damage equipment or develop an imbalance of airflow.

Compressorized systems can optionally heat pool water with compressor waste heat. The economics of this option should always be reviewed: the heating contributions can be significant and have a dramatic return on investment (ROI).

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, and may facilitate mold and mildew growth and be unable to provide acceptable IAQ. Peak dehumidification loads vary with activity levels and during the cooling season, when ventilation air becomes an additional dehumidification load to the space.

Automated controls should be used to reduce large fluctuations in temperature and humidity. Examples include

- Staging of heating, cooling, and dehumidification equipment to match the varying occupant or seasonal loads
- Staging of exhaust and ventilation air to match
  - Occupied and unoccupied hours
  - CO_2 or volatile organic compounds (VOC) staging of exhaust and ventilation air
- Building negative pressure control
- Energy recovery from
  - Exhaust air
  - Condenser heat recovery
- Chlorine usage based on water and air readings

Design Checklist

The following items should be addressed when evaluating and designing a system for an indoor pool climate control system. This list is a minimum, and additional items can be added by the design team.

- With design team and owner/operators, identify (1) indoor space temperature, (2) water temperature, and (3) design relative humidity levels for both summer and winter.
- Obtain minimum R and U values from architect to determine minimum surface temperature for condensation.
- Include a proper vapor retarder and install it correctly with no breaks.
- Determine correct amount of ventilation air required for proper IAQ and to meet local code requirements.
- Determine correct amount of exhaust air to provide negative building pressure.
- Evaluate whether a source capture exhaust system is needed.
- Evaluate outdoor air/exhaust air energy recovery systems.
- Use correct dehumidification weather data to determine moisture load from the ventilation air.
- Total all moisture/latent loads from (1) people, (2) ventilation air, and (3) water surface.
- Total all sensible loads from (1) building envelope, (2) people, (3) ventilation air, (4) lighting, and (5) other sources.
- Select equipment to meet both sensible and latent peak loads.
- Design air distribution system to deliver air into the breathing zone and prevent air stratification and visible condensation.

- Properly commission equipment and building.
- Include a quarterly equipment maintenance contract as part of operating expense.

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.

ASHRAE. 1992 (withdrawn). Gravimetric and dust-spot procedures for testing air-cleaning devices used in general ventilation for removing particulate matter. ASHRAE *Standard* 52.1-1992.

ASHRAE. 2022. Energy standard for buildings except low-rise residential buildings. ANSI/ASHRAE *Standard* 90.1-2022.

ASTM. 2019. Standard test method for determining air leakage rate by fan pressurization. *Standard* E779. ASTM International, West Conshohocken, PA.

Kowalsky, L., ed. 1990. *Pool/spa operators handbook*. National Swimming Pool Foundation, Merrick, NY.

Seresco. 2013. *Natatorium design guide*. Seresco, Ottawa, ON.serescodehumidifiers.com/designguide/.

Smith, C.C., R.W. Jones, and G.O.G. Löf. 1993. Energy requirements and potential savings for heated indoor swimming pools. *ASHRAE Transactions* 99(2):864-874.

BIBLIOGRAPHY

ACCA. 2017. HVAC design for swimming pools and spas. ANSI/ACCA 10 Manual SPS-2010 (RA 2017). Air Conditioning Contractors of America, Arlington, VA.

ASHRAE. 2022. Safety standard for refrigeration systems. ANSI/ASHRAE *Standard* 15-2022.

ASHRAE. 2022. Designation and safety classification of refrigerants. ANSI/ASHRAE *Standard* 34-2022.

CDC. 2018. *Model aquatic health code (MAHC): An all-inclusive model public swimming pool and spa code.* Centers for Disease Control and Prevention, Atlanta. www.cdc.gov/mahc/editions/current.html.

Harriman, L., G. Brundrett, and R. Kittler. 2001. *Humidity control design guide for commercial and institutional buildings*, Ch. 27: Swimming pools. ASHRAE.

Kittler, R. 1989. Indoor natatorium design and energy recycling. *ASHRAE Transactions* 95(1):521-526. Paper CH-89-02-3.

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