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 10 to 15°F 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 2016 *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 2016 *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 86°F 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.

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

Vapor Migration

A pool's indoor design dew point typically ranges from 62 to 69°F for ambient conditions of 82 to 84°F and 50 to 60% rh. In comparison, a typical space in winter might be 70°F at 40% rh with a 45°F dew point.

In summer, the 62 to 69°F 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

The balance between ventilation air and exhaust air must be controlled at all times. A pool room space must always be maintained with a negative pressure to prevent moisture and odors from migrating to other parts of the building. A positively pressurized indoor pool can accelerate building damage by pushing the high-moisture-content air into the building envelope. Note that a significant negative space pressure will not reduce or affect vapor migration to the outdoors in winter.

Ventilation Air

Ventilation air should be calculated as the minimum amount recommended in the current ASHRAE *Standard* 62.1. The effect of exceeding 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.

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.

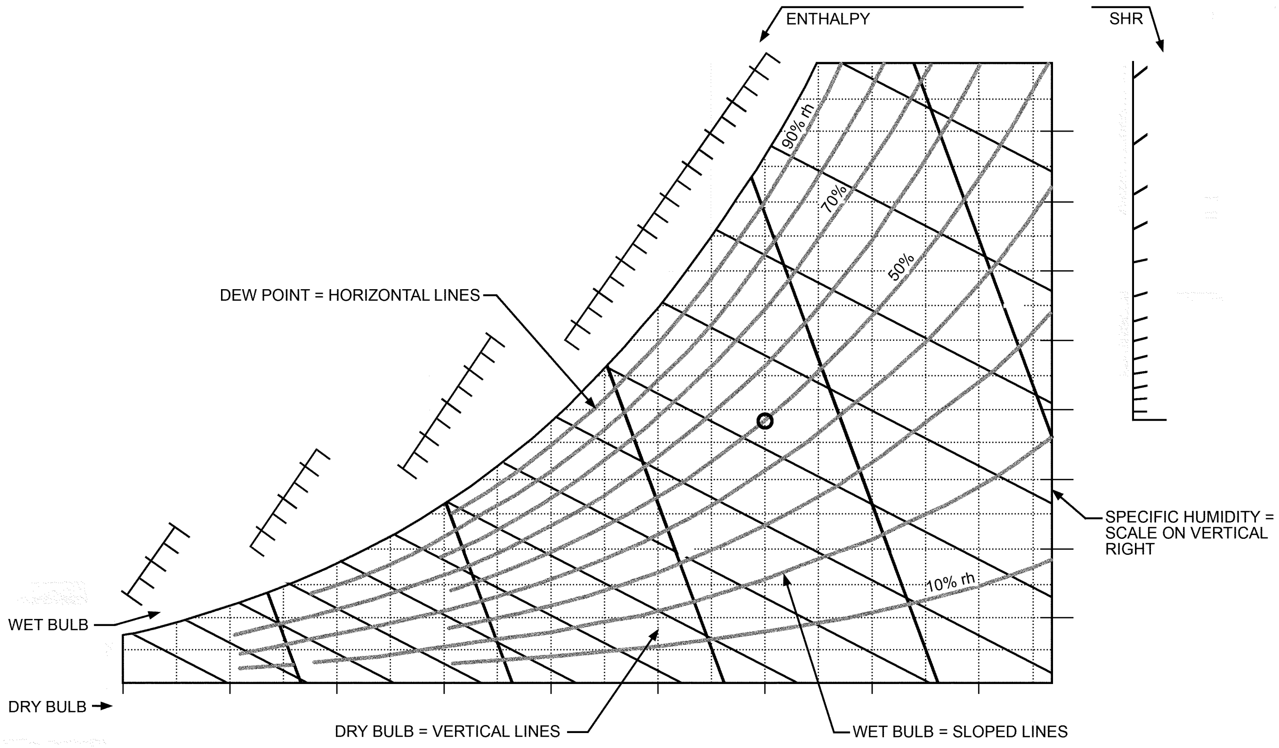

Fig. 1 Example Psychrometric Chart

- **Relative humidity (rh)** expresses the moisture content of air as a percentage of saturation.
- **Specific humidity** is the weight of the moisture in the air compared to the weight of air. The weight is measured in grains, and there are 7000 grains in a pound 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.

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.

In a typical indoor pool, indoor temperature ranges from 78 to 86°F 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 82°F db, 84°F db, and 86°F db and relative humidity values from 30 to 60%. An example is shown at 84°F db and 50% rh, showing that the dew point is 64°F.

This example shows that all surfaces inside the pool room must be kept above the dew-point temperature of 64°F to prevent visible condensation. Common design practice adds 5°F 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:

$$T_s = T_i - [K(1/R)(T_i - T_o)] \tag{1}$$

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

A B C

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

A B C

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

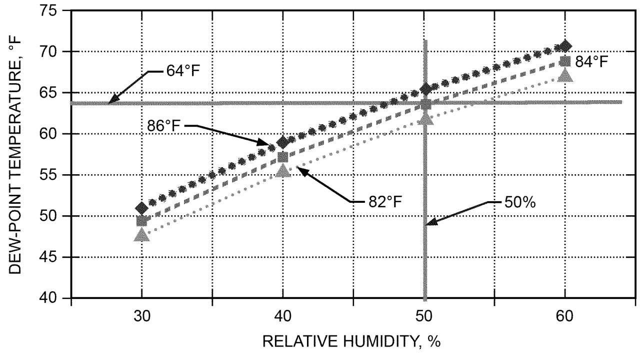

Fig. 4 Condensation Dew Point Chart

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

To apply Equation (1) to a window, the published window U-factor (see Chapter 15 of the 2017 *ASHRAE Handbook—Fundamentals*) must be converted to the required R-value; for example,

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

In this example, the indoor temperature is 84°F db and the outdoor temperature is 0°F db. This gives a 61.2°F surface temperature on the window. If the indoor space is at 50% rh, the dew point would be 64°F, which would lead to condensation on the glass surface unless the window glass is heated above the dew point (Figure 5).

Figure 6 plots three indoor conditions and several window U-values at different outdoor temperatures: 25°F, 0°F, and –25°F. 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.

Note that, as outdoor conditions get colder, the surface temperature of the glass drops dramatically and eventually attempts to eliminate condensation by reducing the space dew point are not realistic.

Outdoor Air

Outdoor air ventilation rates (as prescribed by ASHRAE *Standard* 62.1) can be a major portion of the total load. The latent load (dehumidification and humidification) and energy used to maintain relative humidity within prescribed limits are also concerns.

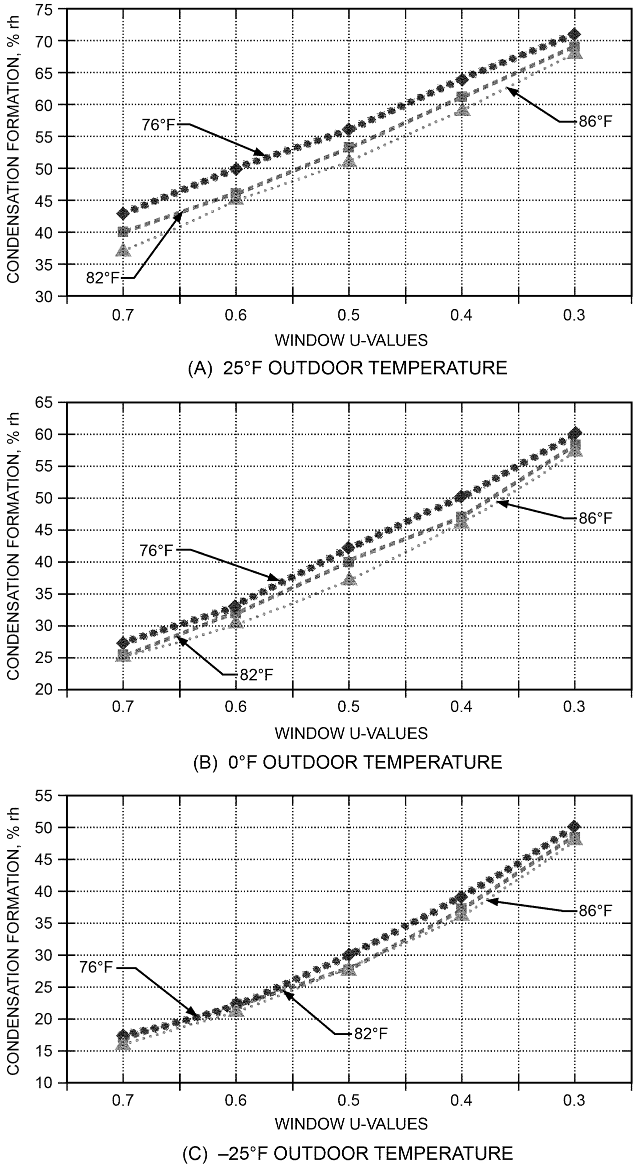

Fig. 6 Effects of U-Values and Indoor and Outdoor Temperatures on Dew Point

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 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).

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)

$$w_p = \frac{A}{Y}(p_w - p_a)(95 + 0.425V) \quad (2)$$

where

w_p = evaporation of water, lb/h
A = area of pool surface, ft^2
Y = latent heat required to change water to vapor at surface water temperature, Btu/lb
p_w = saturation vapor pressure taken at surface water temperature, in. Hg
p_a = saturation pressure at room air dew point, in. Hg
V = air velocity over water surface, fpm

Units for the constant 95 are Btu/(h·ft^2·in. Hg). Units for the constant 0.425 are Btu·min/(h·ft^3·in. Hg).

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 1000 Btu/lb and V values ranging from 10 to 30 fpm, Equation (2) can be reduced to

$$w_p = 0.1A(p_w - p_a)F_a \quad (3)$$

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 2 to 4°F above the water temperature (but not above the comfort threshold of 86°F) 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.

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.

Table 2 Typical Natatorium Design Conditions

Type of Pool	Air Temperature, °F	Water Temperature, °F	Relative Humidity, %
Recreational	75 to 85	75 to 85	50 to 60
Therapeutic	80 to 85	85 to 95	50 to 60
Competition	78 to 85	76 to 82	50 to 60
Diving	80 to 85	80 to 90	50 to 60
Elderly swimmers	84 to 90	85 to 90	50 to 60
Hotel	82 to 85	82 to 86	50 to 60
Whirlpool/spa	80 to 85	97 to 104	50 to 60

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 2017 *ASHRAE Handbook—Fundamentals* (full data are in the CD 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 2017 *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 0.05 to 0.15 in. of water 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.

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

Outdoor air delivery rates may be constant or variable, depending on design. Minimum rates, however, must adequately dilute 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. In colder/drier climates, greater amounts of outdoor air may decrease humidity levels below the recommended 40 to 60% range. This increases evaporation, adds to costs for makeup water and chemicals, and may make it difficult to maintain the proper water chemistry.

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 3 and 72 in. 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 30 fpm (as per the evaporation rate w_p in Equation [2]). If air movement over the water surface is increased from the standard 30 fpm to 125 fpm, 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 ventilation 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.
- 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 2017 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 62 and 70°F). The design goal is to keep the surface temperature of the glass and the window frames at least 3 to 5°F 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.

Exterior windows, exterior surfaces, and other condensation-prone areas should be blanketed with supply air (Figure 8). A good rule of thumb is 3 to 5 cfm per square foot of exterior glass. Select grilles, registers, and diffusers that deliver the required throw distance, and the specified volumetric flow rating.

Pool Water Chemistry

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:

- **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 ppm.
- **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 ppm.
- **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.

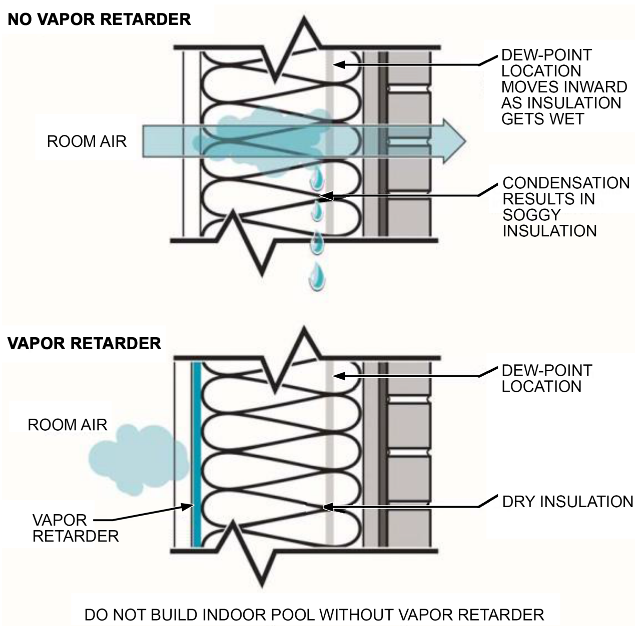

Fig. 7 Vapor Retarder Location for Indoor Pool
(Courtesy Seresco Technologies, Inc. 2013)

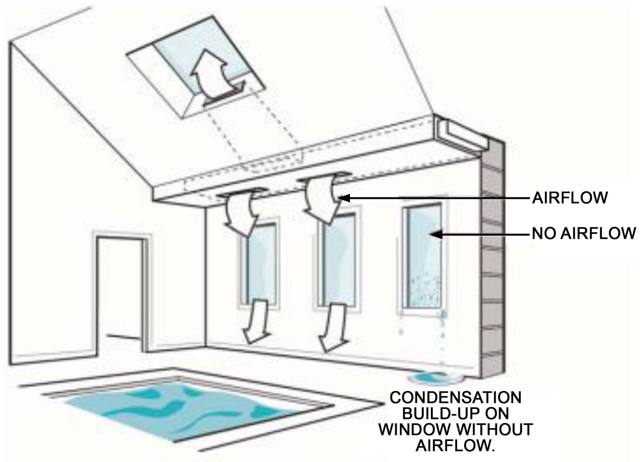

Fig. 8 Supply Air Blanketing of Condensation-Prone Areas
(Courtesy Seresco Technologies, Inc. 2013)

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.

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

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.

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.

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