INDOOR SWIMMING POOL INFORMATION FOR POOL MANAGERS AND OPERATORS

A warm body of water, such as a swimming pool, releases enormous amounts of water vapor (and dissolved chemicals) into the air above the water. In an outside swimming pool, the water vapor and contaminants are dispersed in the atmosphere. As long as the make-up water flow rate, chemical treatment flow rate and water heater capacity are appropriate, the pool water temperature and chemistry can be maintained at design levels.

Once a building encloses that body of water, things get complicated. The water vapor that escapes into the air must be removed. Adequate amounts of outside air for ventilation and contaminant control must be provided, and the building envelope must be protected from moisture migration.

The inside air temperature and relative humidity and the pool(s) water temperature are all interrelated in a complex cycle of heating or cooling and dehumidification by the HVAC system; heating and evaporation of the pool water; and infiltration or exfiltration and condensation within the building's walls and roof.

I. DEFINITIONS:

A. Dry Bulb Temperature:
The "dry bulb temperature" of air is a measure of the dry heat content of the air (also called "sensible" heat). This is what one normally thinks of as "air temperature" and is easily sensed by a human being.

B. Enthalpy:
Air at the same dry bulb temperature but different moisture content has a different total energy content. The "total energy content" is called enthalpy. The more water vapor the air has, the higher its enthalpy, even though its dry bulb temperature is the same.

Air that is fully saturated with water vapor (100% relative humidity) contains the maximum amount of energy possible for air at that dry bulb temperature.

C. Relative Humidity:
Relative humidity is a measure of the relative moisture content of air. Air with the same amount of moisture content has different relative humidities at different dry bulb temperatures. Given the same moisture content, air's relative humidity increases as its dry bulb temperature decreases.

D. Specific Humidity:
The total moisture content of air (regardless of its temperature) is measured by "specific humidity" (also called "**absolute humidity**"). Specific humidity may be measured in pounds of water vapor per pound of dry air.

E. Dewpoint Temperature:
Depending on its temperature, air at a constant specific humidity may have different relative humidities. But that air's "dewpoint temperature" is constant. The dew point temperature is therefore sometimes used to measure specific humidity. The dew point temperature is that dry bulb temperature at which air with a given specific humidity will become fully saturated.

In other words, air at its dewpoint temperature is also at 100% relative humidity.

Any surface in the pool enclosure building (or Natatorium), which is at a temperature less than or equal to the air's dewpoint temperature will become wet due to condensation of the water vapor in the air.

The dewpoint temperature defines absolute humidity as well as vapor pressure of the air.

F. Vapor Pressure:
Vapor pressure is the partial pressure of water vapor in the air. The higher the moisture content, the higher the vapor pressure. Like any pressure differential, vapor pressure differentials cause water vapor to flow from a location with high moisture (high vapor pressure) to low moisture (low vapor pressure).

It is the vapor pressure differentials between the warm, moist Natatorium and the relatively cool, dry outside air that drives damaging moisture into the thermal envelope.

G. Saturation Vapor Pressure:
A vapor pressure at (or above) the saturation vapor pressure will cause excess moisture to condense. A vapor pressure below the saturation vapor pressure will allow a material to "store" or "absorb" moisture without condensing. If the actual vapor pressure is always below the saturation vapor pressure at every point within an assembly, no condensation will occur. Water vapor will flow through the assembly without damaging it.

II. FACTORS AFFECTING THE RATE OF POOL EVAPORATION:

A. The ideal air condition in the Natatorium is a condition that strikes the best balance between bather (not spectator) comfort, indoor air quality, and rate of pool water evaporation.

1. In general, bathers are most comfortable at indoor air temperatures between 82º and 88º and relative humidities between 45% and 60% RH.
   a. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) recommends an air temperature 2ºF above the pool temperature (but not greater than 86º).
   b. See the extracted information for Natatoriums, from ASHRAE's 2003 Application Handbook (attached below).

2. A minimum amount of outside air is required to dilute the pollutants created by chemical reactions between bathers and swimming pool water.

   ASHRAE recommends a minimum outside air ventilation rate (in the breathing zone) of 0.5 cfm/sq. ft. of pool deck area. This is a starting place for ventilation system design and may be higher or lower depending on likely occupancy, use of water features, etc.

3. The rate of evaporation increases with:
   a. Higher pool water temperatures,
   b. Higher air velocity across the pool water's surface,
   c. Splashing or displacement of the water's surface by bathers or water features,
   d. Lower air dry bulb temperatures and

e. Lower air relative humidities.

B. Each gallon of water that is evaporated from the pool surface requires:
   1. A gallon of make-up water (and its associated chemical treatment),
   2. Approximately 8100 BTU's of heating energy (through the pool heating water system), and
   3. Additional energy to condition the air that accepts the evaporated water. Conditioning may include dehumidification and/or cooling as well as tempering of ventilation air.
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C. Neglecting ventilation, a space without a pool usually requires more heating than the same space with a pool. The evaporating pool water actually adds heat to the air.

Excessive evaporation rates increase operating costs and puts higher levels of chloramides into the air. Chloramides have been found to contribute to occupational asthma and pneumonia for lifeguards in poorly ventilated pool spaces.

III. NATATORIUM AIR AND WATER CONDITION GOALS:

A. Water and Air Conditions:
In general, follow the ASHRAE guidelines:

The pool water temperature should be set as low as comfortable for the majority of bathers. The largest surface area pool in a Natatorium should never be set at a pool water temperature above 86ºF. Generally, the largest pool in a Natatorium is used for lap swimming and competition and can appropriately be set between 78º and 80ºF in the winter. This allows use of a lower air temperature setpoint (+/-2º over the large pool setpoint).

B. Suggested Air Temperature Setpoints During The Winter:
In general, a lower air temperature and higher space relative humidity (at the same dewpoint) are desired as the best compromise between bather comfort, pool evaporation rates and protection of the building envelope.

Relative humidity setpoints should not be reduced below 45%RH. In very cold climates, proper space depressurization may cause the actual relative humidity to drop below setpoint. This is acceptable for short periods of time as the resultant lower dewpoints help protect the building's thermal envelope, even if they (temporarily) create less comfortable conditions for bathers.

To minimize evaporation, ASHRAE recommends an air dry-bulb temperature 2ºF higher than the pool water temperature (but no higher than 86ºF) and fairly high space relative humidity levels.

A higher relative humidity (at a lower temperature) is much more comfortable to a wet bather than a higher temperature (at a lower relative humidity). And, lower air temperatures decreases stack effect.

An 80ºF largest area pool water setpoint, an 82°F space air temperature setpoint and a 45%-55% relative humidity setpoint is usually appropriate for small Natatoriums in the front range of Colorado. An average space condition of 82°F and 50%RH equates to a dew point temperature of about 62ºF and will generally be comfortable to pool occupants.

These conditions are as measured at the deck level. A slightly higher temperature setpoint and slightly lower relative humidity setpoint is recommended for roof mounted pool HVAC units (that sense air conditions at the ceiling). Their return air openings are usually higher than the occupied space and the air is usually warmer and somewhat drier at the top of the Natatorium.

Actual air conditions at the pool deck may be significantly cooler and drier than at the air sensors because of the infiltration of cold, dry outside air at interior and exterior doors.

C. Outside Air for Ventilation:
ASHRAE minimum ventilation rates (of 0.5 cfm/sq. ft. of pool & pool deck area) should be maintained at all times. Higher values may be required for humidity control or to offset higher rates of evaporation from water features such as falls, slides, etc.

D. Space pressurization:
ASHRAE also recommends that the Natatorium be maintained at a "slightly negative pressure of 0.05 to 0.15 inches of water" (to offset stack effect). In reality, even 0.05"w.c. (measured at the roof) is a very negative building pressure and is difficult to achieve in most Natatoriums.

Only a slight negative pressure differential is required to offset moisture transport via air pressure (about 0.001"w.c. at the affected area). However, this pressure difference must be provided at the highest point in the enclosure. Since stack effect varies with building height, much higher negative space pressurization will be created at the pool deck. The design winter negative space pressurization setpoint should offset anticipated "wintertime average" stack effect (or use a "re-set" control strategy). One should also remember that wind conditions may also influence space pressurization.

A negative space pressure differential between -0.03 and -0.09"w.c (as measured near the pool deck) should be maintained in most Natatoriums. Negative space pressurization may be re-set based on outside air temperature to save energy and minimize bather discomfort.

In addition to cool drafts, the proper space pressure relationship to the outdoors may cause icing in the Natatorium where cold outside air encounters moisture. This is especially true at outside doors and windows. Windows, window frames and doors should be properly sealed to minimize this problem.

A Natatorium's water treatment and heating systems must work in concert with its HVAC system and the building's thermal envelope. Proper understanding and integration of these factors will maximize occupant health and comfort, minimize building maintenance and increase energy efficiency. Inattention to the influence these seemingly separate systems have on one another is an invitation for trouble.

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 65 and 68°F 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.

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).

$$w_p = \frac{A}{Y}(p_w - p_a)(95 + 0.425V) \qquad (1)$$

where

- w_p = evaporation of water, lb/h
- A = area of pool surface, ft²
- V = air velocity over water surface, fpm
- Y = latent heat required to change water to vapor at surface water temperature, Btu/lb
- p_a = saturation pressure at room air dew point, in. Hg
- p_w = saturation vapor pressure taken at surface water temperature, in. Hg

The units for the constant 95 are Btu/(h·ft²·in. Hg). The units for the constant 0.425 are Btu·min/(h·ft³·in. Hg).

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 1000 Btu/lb and V values ranging from 10 to 30 fpm, Equation (1) can be reduced to

$$w_p = 0.1A(p_w - p_a)F_a \qquad (2)$$

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 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

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 2 to 4°F above the water temperature (but not above the comfort threshold of 86°F) 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 0.05 to 0.15 in. of water 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 nonmetallic 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 5°F 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 *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 ppm.
- **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.

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