Active Humidification:

Seven Processes to Consider

An overview of active humidification and the advantages, disadvantages, and cost implications of seven approaches

By **DAVID A. SELLERS, PE**
Portland Energy Conservation Inc.
Portland, Ore.

Though not found in all HVAC systems, humidification processes are critical to the design intent of the systems they serve. For instance:[1]

• Research has established that a relative-humidity (RH) level between 30 and 60 percent is optimum for comfort and disease prevention.

• The influenza virus has its highest mortality rate at 50-percent RH. The mortality rate decreases both above and below this level.

• Maintaining higher RH levels can control disease-carrying bacteria.

• Computer rooms may require RH control to keep drives, printers, and other devices functioning smoothly.[2]

• Process industries often make RH a critical quality-control parameter to ensure proper product moisture content, ensure biological and chemical reaction rates, maintain product accuracy or uniformity, control corrosion, and minimize the potential for problems associated with static electricity.

• RH affects air's ability to absorb sound. The maximum reduction in sound strength will occur at 15- to 20-percent RH, with the effect more prominent for higher frequencies. A significant reduction in this phenomenon occurs around 40-percent RH; above 50 percent, the impact of RH is negligible.

The equipment and resource requirements associated with maintaining a specific humidity can vary greatly with location and the nature of the load served by the HVAC process. For example, in a hot and humid environment, serving a building with a year-round 50-percent RH requirement probably would require active dehumidification most of the time because of the moisture content of the ambient air, while in a more moderate climate, it might require active humidification during the winter and active dehumidification during the summer. So, an important question to ask early in the design process is whether active humidification really is needed to meet the load requirements, given the environment in which the project is located. The answer to that question can have significant first- and operating-cost implications (see the sidebar "To Humidify or Not to Humidify").

This article will focus on humidification processes you might consider if your answer to the active-humidification question is, "Yes, I need it."

HUMIDIFICATION PSYCHROMETRICS

When discussing humidification, it is important to have an understanding of some of the psychrometric properties associated with it. These include:[3]

• Dry-bulb temperature, which is the sensible temperature of the air in a sample. It is important

A member of HPAC Engineering*'s Editorial Advisory Board, David A. Sellers, PE, is a senior engineer specializing in commissioning and energy efficiency. Over the course of his career, he has worked in the design, mechanical- and controls-contracting, and facilities-engineering fields in the commercial-, institutional-, and industrial-buildings sectors. He can be contacted at* dsellers@peci.org.

To Humidify or Not to Humidify

Do we really need to be adding water to the air here during the winter? That was the question I asked myself as I shook the rain off my coat before walking into a design-review meeting in Seattle, where for most of the spring, fall, and winter, the forecast calls for rain and temperatures between 40 and 50 F. A building owner was requesting active humidification to maintain a minimum 30-percent relative humidity (RH) in his facility, which contained a lot of high-quality wood and finishes. After discussing the matter, the engineering team concluded that while on paper, the answer to the question was yes, in reality, it was no—if the owner could live with an occasional dip below 30-percent RH. Statistically, that was likely to occur for fewer than 100 hr per year, with about two-thirds of those hours occurring when the building would be unoccupied. Eliminating active humidification saved more than $100,000 in first cost, in addition to an estimated $6,000 per year in operating cost.

because controlling this temperature is a primary goal of most HVAC processes.

• Wet-bulb temperature, which is the temperature read by a thermometer with its bulb encased in a wetted wick. The cooling associated with evaporation lowers wet-bulb temperature relative to dry-bulb temperature, with dryer environments producing lower wet-bulb temperatures, all other things being equal. Wet-bulb temperature is important because, next to dry-bulb temperature, it is one of the easiest parameters to accurately and repeatedly measure in the field.

• Dew-point temperature, which is the temperature at which water will begin to condense out of a cooled air sample. It is important to know because any surface at or below this temperature will begin to condense moisture out of the air, even if the RH is well below saturation. This is highly undesirable because it can lead to water damage and indoor-air-quality (IAQ) problems. Thermal breaks and vapor barriers need to be provided to ensure that the surfaces in contact with the humidified environment always are above the dew point of the air. Providing pathways and a mechanism to safely dissipate condensation also can be important.

If the air in a sample is cooled to its dew-point temperature, then the dry-bulb temperature, wet-bulb temperature, and dew point are numerically equal.

• Relative humidity, which is a measure of the amount of moisture held in an air sample relative to the amount of

Direct steam injection	This approach injects steam from a boiler, usually a central plant, directly into an air stream. Because the boiler combustion process supplies the energy necessary to vaporize water, the humidification process in the air-handling unit is adiabatic.
Advantages	• This approach is one of the older, more-proven technologies. • Assuming a central plant that is large relative to the humidification load, the humidifier will respond fairly quickly to changes in humidification requirements.
Disadvantages	• The jacket heaters typically used to prevent the condensation of steam prior to its injection into the air stream add sensible heat to the air-handling system. This is unavoidable when the humidifier operates and represents a parasitic burden on the steam system. • If cooling is provided by mechanical means, the jacket heat gain also represents a parasitic load on the cooling plant. In 100-percent-outdoor-air systems, the parasitic load simply offsets some of the preheat requirements for most of the operating cycle. In economizer systems, it is offset by the free cooling provided by the economizer process and, thus, does not represent a significant additional cooling cost below a certain outdoor-air temperature. • Chemicals used to control boiler- and condensate-return-system water quality and chemistry end up being injected into the air stream. This can impact indoor-air quality in a variety of ways. Proper selection can avert any human-health problems, but there still can be issues with residues associated with treatment products.
Operating cost	• The energy costs associated with this approach are a direct function of the efficiency of the central boiler plant and its support systems. • The water costs are a function of the actual humidification load. Also, they are a direct function of the costs of placing makeup water in the central boilers because the water that is injected into the air stream does not return to the central plant as warm, treated condensate.
Installation cost	• Installation costs are high because of the control-interlock, steam-piping, and specialties requirements. • If a central boiler plant does not exist, providing steam-generating equipment for the sole purpose of serving the humidifiers can represent significant first- and operating-cost penalties.
Special considerations	• When the humidifier is shut down, the parasitic loads associated with the jacket heaters can be eliminated from both the steam system and the cooling system by providing an additional valve and control interlocks to shut down the supply of steam to the jacket heaters. • The interlock scheme described above generates an additional interlock requirement. Specifically, it requires an interlock system designed to ensure that the jackets are fully warmed up before the humidifier injects steam into the air stream. Without this, high condensate loads at start-up can flood the duct system, leading to indoor-air-quality problems and the potential for "rain" out of the duct. The "rain" issue can be particularly serious for trim humidifiers located near the point of use. All of these interlocks add cost and complexity, but are well worth it in terms of energy savings and the operational problems they avert.

TABLE 1. Considerations for direct steam injection.

Indirect steam injection	
	This approach uses steam, high-temperature hot water (above 250 F), gas, or electricity to boil water in a small secondary boiler at the air-handling-unit location. The steam from this process is used in the actual humidification cycle. The injection manifold system used for duct applications is nearly identical to that used by the direct-steam-injection approach.
Advantages	• The secondary boiler ensures that the steam injected into the HVAC process is free of any treatment chemicals used in the boiler plant. The quality of the makeup water controls the potential for contamination in the air-handling process. • The injection strategy is one of the older and more proven technologies.
Disadvantages	• The jacket heaters typically used to prevent the condensation of steam prior to its injection into the air stream add sensible heat to the air-handling system. This is unavoidable when the humidifier operates and represents a parasitic burden on the steam system. • If cooling is provided by mechanical means, the jacket heat gain also represents a parasitic load on the cooling plant. In 100-percent-outdoor-air systems, the parasitic load simply offsets some of the preheat requirements for most of the operating cycle. In economizer systems, it is offset by the free cooling provided by the economizer process and, thus, does not represent a significant additional cooling cost below a certain outdoor-air temperature. • There can be a significant lag between the time the control system calls for humidification and the time steam is injected into the HVAC process. This is a result of the thermal lag introduced into the process by the small local boiler, especially when the water in the boiler is cold, as it is upon start-up or when the demand for humidity is intermittent. This problem can be compounded by the stepped-capacity nature of some of the energy sources used: a) Steam and hot-water sources can achieve nearly infinite modulation when properly adjusted. Usually, the problem in an application driven by these supplies is a lack of stability that causes the steam or hot water to cycle off for a period of time, thus allowing the secondary-boiler water to cool, resulting in a lag between the time the control valve opens and the water in the boiler reaches steaming temperature. b) Gas-fired units typically have a minimum firing rate below which the burner will cycle. When this is the case, problems similar to those described above will occur. c) Electric units frequently are controlled incrementally. Thus, the available capacity will match demand only under very specific load conditions, introducing the potential for instability into the control response. Using a silicon controlled rectifier to control an electric heating element allows near-infinite modulation of capacity, providing performance similar to steam or hot-water-fired approaches. An optional control feature available from some manufacturers can help alleviate this problem by operating the heating element as necessary to maintain the boiler near the steaming temperature, in addition to operating it to generate steam. • The secondary boiler adds complexity, including the need for a makeup and blowdown system, to the process.
Operating cost	• Energy costs vary significantly, depending on the energy source. As a general rule, for most locations, energy costs for electrically fired systems are two to three times those for other approaches. Regardless of the rate structure, using fossil fuel to generate electricity and the electricity to create steam results in an emissions burden significantly greater than that with an approach using fossil fuel directly to create steam. • Because only the water injected into the air stream needs to be treated, this approach has the potential for lower water costs than an approach by which steam from a central plant is used directly, and, thus, all of the water entering the boilers at the central plant is required to be treated. However, the drain-down, flushing, and cleaning requirements associated with preventing unacceptable accumulations of scale and microbes in secondary boilers can eliminate this advantage because of distributed maintenance requirements and potentially higher water-use rates. In addition, many applications require treatment of makeup water at the humidifier location. In less-demanding applications with low consumption rates, replaceable deionized-water bottles can provide the necessary level of performance. In demanding applications such as cleanrooms, water from a central reverse-osmosis-deionized (RODI) water system may be required, which can have a very significant generation cost associated with it, often in the range of tens of cents per gallon. RODI water can be corrosive and may require special construction considerations for the makeup piping, related equipment, and secondary boiler.
Installation cost	• Jacket- and manifold-installation costs are similar to those of the direct-injection approach. • The complexity and hardware associated with the secondary boiler add significant cost. Much of this cost is related to the need to provide makeup, blowdown, and level-control systems and treat the makeup water. • Electrically fired systems can have somewhat hidden installation costs because of greater electrical-service requirements. If these costs are not recognized, they can generate a false economy.
Special considerations	• Considerations similar to those for direct steam injection (Table 1) apply. • The quality of the moisture injected into the HVAC process is highly dependent on the quality of the makeup water supplied to the secondary boiler and the cleanliness of that boiler. If either degrade, all of the advantages gained by isolating the HVAC process from the central-plant steam will be lost, and the resulting problems could be far worse than the chemical carryover from the central-plant boilers. Low-quality water can lead to scaling and other mineral deposits, which can make their way into the air-handling system. Lack of attention and failure to drain the secondary boiler when there is no humidification requirement can result in algae, bacteria, and other forms of microbiological growth in the stagnant, unheated water.

TABLE 2. Considerations for indirect steam injection.

moisture that could be held if the air sample were saturated. The RH of an air sample can be increased by lowering the sensible temperature and decreased by raising the sensible temperature, all without adding or removing moisture (i.e., you do not necessarily have to humidify or dehumidify to change RH).

• Humidity ratio[4] is the ratio of the mass of water vapor to the mass of dry air contained in an air sample. You have to add or remove moisture from an air sample to change its humidity ratio (i.e., you have to invoke a humidification or dehumidification process to change it).

Figure 1 illustrates a HVAC process for a 100-percent-outdoor-air system serving a hospital operating room with a setpoint of 70 F on a rainy fall day. The system includes two humidification processes.

Note that RH and wet-bulb temperature are changed with or without the addition of water, whereas dew point and humidity ratio are changed only with the addition of moisture via humidification. Note also that after the humidification processes, the dew point of the air supplied to the space is above the ambient outdoor-air temperature. Thus, if the air comes in contact with a surface that is at or near the outdoor ambient temperature, condensation will occur. In fact, there probably will be a vapor plume at the discharge of the fan system handling exhaust air from the space, created when warm, moist air from the process mixes with ambient air at the exhaust-discharge point. Let's look at the process in Figure 1 in more detail:

• The process starts with the preheating of saturated outdoor air (A to B). Notice how most of the parameters previously discussed increase. Humidity

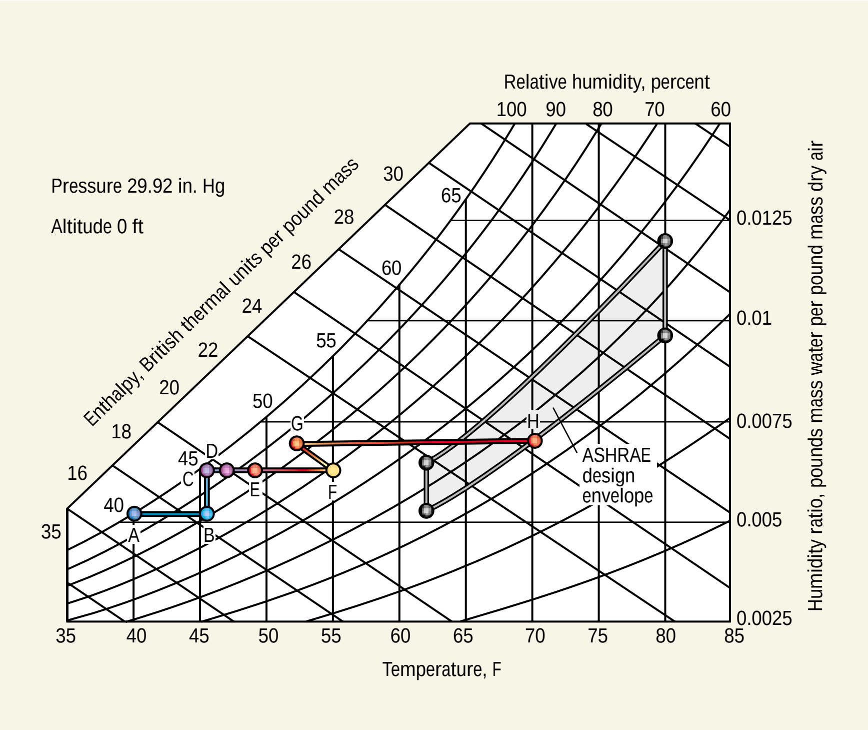

FIGURE 1. A HVAC process serving an operating room on a rainy fall day.

Evaporative pan	
	Most implementations of this approach involve the placement of a pan of water in the air stream or environment requiring humidification and the use of steam, high-temperature hot water, or electricity to evaporate the water as necessary to provide the required level of humidification.
Advantages	• Installation is somewhat less complex than it is with some of the direct- and indirect-injection approaches because there is no associated manifold system. This can be a limitation for duct-mounted applications with relatively high humidification requirements because of problems related to distributing vapor to the air stream. • Operation also is somewhat less complex, making this approach less prone to operating problems related to warm-up and injection.
Disadvantages	• Time-lag problems similar to those of the indirect-injection approach (Table 2) apply. • The lack of a distribution manifold makes distributing a large humidification load across a large duct cross-section difficult. Thus, this approach may be a poor selection for large systems with a heavy humidification burden.
Operating cost	• Considerations similar to those associated with indirect steam injection (Table 2) apply. • Because the level of complexity associated with this approach is somewhat lower than that of other injection technologies, there is potential for modest savings in maintenance man-hours related to troubleshooting and maintaining a less-complicated piece of equipment.
Installation cost	• The less-complex nature of this approach tends to make installation costs lower than those of other approaches. • In most cases, localized water-treatment technology will be required.
Special considerations	• Considerations similar to those in the second bulleted item for the indirect-injection approach (Table 2) apply.

TABLE 3. Considerations for the evaporative-pan approach.

ratio and dew point remain constant because no moisture is added.

• Next, the unit's primary humidifier adds moisture to raise the humidity ratio to a level that satisfies the upper limit of the coldest surgery design-temperature/

Self-contained electric electrode humidifiers	
This approach uses an electrode that passes current directly through ordinary tap water to generate the steam necessary to humidify an air stream or space. The steam is generated at atmospheric pressure and distributed via tubing to a duct system for duct applications.	
Advantages	• This is one of the least complex approaches available and has been aimed at minimizing the installation and operating requirements associated with providing humidification. • Typically, the container in which water is boiled is fabricated from plastic and designed to be disposable to allow the cleaning and maintenance issues associated with using tap water to be addressed with a minimum amount of labor.
Disadvantages	• The modular nature of this technology makes it unsuitable for applications with heavy humidification burdens or large air-handling systems. • Electricity is the only energy source available for this approach. • The quality of the moisture injected into the air stream tends to be lower than the moisture quality achieved with other approaches because scale is allowed to accumulate in the vaporization container until being disposed of. • The throwaway nature of the container that holds the heating elements used to vaporize water may make this approach less environmentally sound than others.
Operating cost	• Because this technology is electrically powered, the operating cost tends to be high on a per-pound-of-water-vaporized basis for the reasons listed in the first bulleted item for the indirect-steam-injection approach (Table 2). • Because the design uses ordinary tap water, water-treatment requirements associated with other processes are non-existent. • Most of the products available in this class incorporate a periodic drain-down cycle in an effort to control scale and other contaminants in the vaporization canister. However, this generally is less rigorous than what is used for other approaches, and, thus, the water consumption on a per-pound-of-humidification-produced basis may be lower.
Installation cost	• Because of the simple nature of the design, this approach has the potential to provide a low installed cost when viewed on a per-pound-of-humidification-produced basis. • Considerations regarding hidden electrical costs similar to those for indirect steam injection (Table 2) apply.
Special considerations	• The lack of complexity and low first cost associated with this approach lend it to applications with small, relatively minor humidification requirements. Unfortunately, this advantage can be a disadvantage in that the approach often is applied on small projects with a less sophisticated maintenance staff, meaning the maintenance and persistence of the process may be poor. As a result, the intent of the design may not be achieved in the long term, and indoor-air quality could be impacted adversely. This can be mitigated by ensuring that the end user is aware of the need to maintain the system.

TABLE 4. Considerations for self-contained electric electrode humidifiers.

RH requirement (in this case, 62 F/45 percent,[5] points B to C).[6] The humidifier is a steam-to-steam unit. As a result, the humidification process is adiabatic. However, there is a 1.5-F sensible-heat rise associated with the jacket heat on the humidifier manifolds (C to D).

• Fan heat[7] and distribution-system thermal gains add another 2 F of sensible-temperature rise, which establishes the supply-air condition at the terminal-equipment location (D to E). This condition becomes the starting point for the HVAC processes serving the multiple operating rooms associated with the air-handling system. These processes will vary primarily because of different zone-temperature setpoints and surgical-team preferences.

• A zone reheat coil adds sensible heat to make up for the cooling that is provided by the supply-temperature condition, but not required by the load condition (E to F).

• The zone trim humidifier adds moisture as necessary to bring the zone up to the minimum RH requirement (45 percent) at the current setpoint (70 F). But because an ultrasonic humidifier has been applied, a cooling effect associated with vaporizing the moisture droplets produced by the ultrasonic process occurs. This shows up as added cooling capacity, which is compensated for by the previous reheat process. The net effect shows up as the line from F to G.

• Finally, the sensible and latent loads in the space bring the supply condition up to the space condition (G to H).

HUMIDIFICATION APPROACHES

The preceding discussion presumes specific humidification approaches for the two humidification processes in the example, which are representative of the two fundamental techniques used to add moisture to an HVAC process:

• The use of an energy source external to the air stream to vaporize water, which then is injected into the air stream in a process that is adiabatic or isothermal.

• The use of energy from the air stream to evaporate water droplets, which are atomized by another process. Typically, the extraction of energy to vaporize water will result in a reduction in air-stream temperature.

The process selected depends on a variety of factors, including other requirements of the HVAC process, first cost, available energy sources, energy and water costs, and maintenance requirements. Tables 1-7 contrast some of the more common humidification approaches.

Regardless of the approach, the control and interlock systems are critical to successful operation (see the sidebar "Control and Interlock Systems"). Installation and configuration factors also are critical, with absorption distance being especially important. Injected water needs to be completely vaporized prior to encountering an obstacle such as a filter or coil, which can knock small, non-vaporized moisture droplets out of the air stream or cause condensation. The unabsorbed moisture then can cascade

Compressed-air-driven atomization This approach uses compressed air to create a mist of water via an atomization nozzle. The fine moisture droplets that are produced evaporate in the air stream or space served by the device.	
Advantages	• Because the energy required to evaporate the water is provided by the air stream, not the humidifier, the potential for significantly lower energy consumption and parasitic losses exists. • The contingency outlined above also minimizes the complexity of the installation. • For HVAC processes with simultaneous needs for humidification and cooling, the cooling effect associated with the air stream providing the energy to evaporate the moisture droplets can reduce demand on the refrigeration processes associated with the HVAC load. • Because the water's injection rate is not a function of a heating and evaporation process, this approach has the potential to be much more responsive to sudden variations in humidification demand than approaches such as indirect steam injection and evaporative pans.
Disadvantages	• The energy used by the air compressors represents a parasitic energy burden that may be hidden if not recognized at the outset. • The need to provide a compressed-air system can represent significant first and maintenance costs, in addition to energy costs. • If there is not demand for simultaneous cooling and humidification, the cooling effect of the water evaporating in the air stream will represent a demand on the HVAC system's heating process. • If the entering-air temperatures are low, and/or the humidification load is high, the air may not have sufficient energy content to evaporate the atomized water prior to becoming saturated. Thus, for some applications, the location of the injection system relative to heating elements and other devices that add heat to the air stream may be important.
Operating cost	• Because this approach does not require direct heating equipment, there is potential for a significant reduction in operating cost, *if the HVAC process can benefit from the cooling effect associated with evaporating the water in the air stream*. If there is not a need for cooling, then the process places a demand on the heating system that may match or exceed what the demand would be with an approach that uses heating energy to evaporate water and then inject it into an air stream adiabatically. Economizer-equipped systems may be able to compensate for this by simply recirculating more air, assuming their minimum outdoor-air fraction is not too high. Essentially, this allows energy recovered from the building to provide vaporization energy because the internal loads served by the system create the heat in the return air.[1] • The compressed-air burden associated with atomizing air runs in the range of 0.1 to 0.2 cfm of compressed air per pound of water to be atomized per hour. The electrical energy and related cost associated with this is a function of the compressor technology, the overall efficiency of the compressed-air system,[2] and electrical rates. • Water-treatment costs may be lower for this technology because there are no drain and fill cycles, and it is more tolerant of poor water quality in terms of what the humidification equipment requires to be able to operate and not degrade. However, the quality of the air stream fed by the process still may require that the water be treated to prevent problems with mineral dust and other contaminants. The standing water in the piping can create an indoor-air-quality concern during long off cycles.
Installation cost	• Assuming a central compressed-air system exists and is of adequate capacity, the first costs associated with this technology are lower than those of some of the other approaches. Duct-mounted applications still require a manifold system, but there are no condensate loads or large electrical loads to deal with, and the interlocks associated with a warm-up cycle and jacket heating are not necessary. Compressed-air piping is required, but the specialty requirements tend to be less than what is associated with steam, hot water, or gas, and there is no need for insulation in most instances. • If there is no compressed-air system or if additional compressed-air capacity must be added at the central plant, there can be a significant first-cost burden associated with the compressor installation. • Makeup-water piping requirements tend to be lower than with other approaches because the technology is not as sensitive to water quality, and drain and level-control systems usually are not necessary to the extent that they are with other systems. Some systems may employ a valve arrangement that flushes the supply-water system to prevent the long-term stagnation of flow during periods when humidification is not required. Air-side HVAC-process requirements still may dictate the need for water treatment and/or a reverse-osmosis-deionized water source, in which case the costs of the makeup piping escalate for reasons discussed previously.
Special considerations	• The quality of the compressed-air source can have a significant impact on the quality of the HVAC-process air stream. Compressed air that is dirty and/or contaminated with oil may cause significant indoor-air-quality problems, as well as problems with the humidification equipment itself.

Notes:
1) However, it is important to remember that this energy may not always be present, especially when the humidification demand peaks, which often is concurrent with the coldest outdoor-air conditions. Thus, it may be necessary to install the capacity necessary to handle the vaporization of the humidification water, even if it will not be required for much of the operating cycle.
2) Leakage can be a significant and difficult-to-predict-and-assess hidden cost, especially concerning large compressed-air systems. The author has observed plants in which a compressor ran 50-percent loaded with no useful load on the system (i.e., the processes it served were idle, and it was running to keep up with the leaks).

TABLE 5. Considerations for compressed-air-driven humidifiers.

into a multitude of problems.

All of the approaches that involve a tank or reservoir with standing water need to be designed and maintained in a manner that addresses the potential for biological and bacterial contamination. Typically, this involves making provisions for proper water treatment and drain-down cycles, as well as regular monitoring, inspection, and cleaning. Failure to do this can lead to serious IAQ problems.

Most of the approaches are available in a variety of configurations, including duct-mounted systems, free-standing systems, and specialized arrangements allowing direct interface with manufacturing and production processes.

FOOTNOTES

1) The statistics in the following bulleted items are from Chapter 20 of

Ultrasonic atomization	
	An emerging technology in the United States, this has seen application in Europe for a longer period of time. Humidification is achieved by using an ultrasonic transducer to generate high-frequency oscillations in the waves in the water reservoir. This results in the generation of fine mist, which humidifies the area served. The energy to evaporate water droplets comes from the air that is being humidified; thus, this approach also cools the air stream or area it serves.
Advantages	• All of the advantages listed for the compressed-air technology (Table 5) apply. • This technology requires very little energy to atomize water.
Disadvantages	• If there is not demand for simultaneous cooling and humidification, the cooling effect of the water evaporating in the air stream will represent a demand on the HVAC system's heating process. • If the entering-air temperatures are low, and/or the humidification load is high, the air may not have sufficient energy content to evaporate the atomized water prior to becoming saturated. Thus, for some applications, the location of the injection system relative to heating elements and other devices that add heat to the air stream may be important. • This technology requires high-quality reverse-osmosis deionized water to function properly.
Operating cost	• Because this approach does not require direct heating equipment, there is potential for a significant reduction in operating cost, *if the HVAC process can benefit from the cooling effect associated with evaporating the water in the air stream*. If there is not a need for cooling, then the process places a demand on the heating system that may match or exceed what the demand would be with an approach that uses heating energy to evaporate water and then inject it into an air stream adiabatically. Economizer-equipped systems may be able to compensate for this by simply recirculating more air, assuming their minimum outdoor-air fraction is not too high. Essentially, this allows energy recovered from the building to provide vaporization energy because the internal loads served by the system create the heat in the return air.[1] • The very low energy requirement associated with atomizing air via ultrasonic energy, coupled with relative simplicity and low maintenance requirements, gives this technology the potential to have one of the lowest overall operating costs of any of the approaches available. Energy-consumption reductions in the range of 90 to 93 percent are possible, assuming the HVAC process served can benefit or is not penalized by the cooling effect in the air stream.[2] • This technology requires a high-quality water supply; thus, the need to treat and maintain the water supply will offset some of the energy- and maintenance-savings potential of the approach. • This approach uses a water reservoir; thus, the cleaning, blowdown, and level-control issues discussed previously apply. It should be noted that not all manufacturers require a flush cycle, which minimizes the costs associated with supplying water.
Installation cost	• As with the compressed-air approach, the first costs associated with this technology are lower than those of some of the other approaches, but not as low as the self-contained electrode-type equipment. The Department of Energy Technology Alert referenced in the article provides some case-study information, including comparative first costs. Duct-mounted applications utilize a rack system, but there are no condensate loads or large electrical loads to deal with, and the interlocks associated with a warm-up cycle and jacket heating are not necessary. • Given that the system requires a high-quality water supply, the makeup, blowdown, drainage, and level-control installation costs are similar to those for indirect-steam-injection systems. It should be noted that not all manufacturers require a flush cycle, which minimizes the costs associated with that aspect of installation.
Special considerations	• The potential energy savings associated with this technology make it a viable candidate for a rebate as an energy-conservation measure in some service areas.

Notes:
1) However, it is important to remember that this energy may not always be present, especially when the humidification demand peaks, which often is concurrent with the coldes outdoor-air conditions. Thus, it may be necessary to install the capacity necessary to handle the vaporization of the humidification water, even if it will not be required for muc of the operating cycle.
2) Approximately 1,000 Btu per pound of water is required to supply the energy needed to convert the water droplets produced by the ultrasonic and compressed-air process to vapor.

TABLE 6. Considerations for ultrasonic humidifiers.

the 2000 ASHRAE Systems and Equipment Handbook and a 1998 U.S. Department of Energy (DOE) Federal Technology Alert on ultrasonic humidifiers. The DOE report can be viewed at *www.pnl.gov/fta/14_ultrahumid/14_ultrahumid.htm*.

2) Generally, this is becoming less important with newer technology. Manufacturer's data should be consulted before committing to humidification.

3) For more thorough, technical definitions of the following terms, see the chapter on psychrometrics in the ASHRAE Handbook of Fundamentals.

4) Some refer to this as mixing ratio. It is similar, but not identical, to specific humidity, which is the ratio of the mass of water vapor to the total mass of the moist-air sample.

5) Most hospital licensing codes require that a range of conditions—typically, 62 to 80 F and 45- to 55-percent RH—be maintained in operating rooms. For winter conditions, one tends to design for the coldest room at the lowest humidification requirement, which tends to minimize preheat and humidification energy. Trim humidifiers are used to bring the rooms set for warmer temperatures up to the minimum humidity requirement. For summer conditions, one tends to design for the coldest room at its upper humidity limit to minimize the dehumidification requirement in humid environments. In arid environments, one might be more inclined to design for the coldest room at the lower humidity limit to minimize humidification energy while ensuring that the coldest design-temperature requirement is met.

6) This point probably was established

Evaporative coolers and air washers	
By the nature of the processes they employ, evaporative coolers and air washers also humidify. The exposure of the air stream to a fine water spray and/or a wetted media results in the air stream approaching saturation as it leaves the process. Capacity control can be achieved by varying the water temperature that is sprayed into the air stream or bypassing air around the process or both.	
Advantages	• Although they seldom are employed for the sole purpose of humidification, in some applications, these technologies can provide the added benefit of humidification for little first cost beyond what is required to control the humidity parameter. • The control strategies employed, coupled with the psychrometrics of the process, make these technologies capable of fairly precise humidity control. If properly sized and implemented, control by bypassing air around the process also can provide a quick response to a sudden load change.
Disadvantages	• Both of these technologies are large and maintenance-intensive and can be highly customized. They usually are not practical unless they are being employed for evaporative cooling or air cleaning and the humidification capability is desirable.
Operating cost	• Energy costs for the humidification aspects of these processes usually are similar to or less than those associated with the compressed-air approach in that water is atomized, not evaporated, by the process, but there are pumps or other drivers to accomplish this atomization. • Because the evaporization energy for the water injected into the air comes from the HVAC air stream, the costs and benefits associated with the cooling effect this provides are as discussed previously. • Approaches that use a wetted media have a media-replacement cost associated with them that is significant and not present for other approaches. • Because these systems, by nature, use relatively large volumes of water, the water and water-treatment costs are higher than with many of the other approaches. The processes themselves are not as sensitive to water quality as some of the other approaches; however, HVAC-process-quality requirements may impact the requirements for makeup-water quality. In air-washing applications in which the process is used to dehumidify, spray water often is cooled via mechanical processes. Thus, the water evaporated by the process represents an energy and resource burden beyond that directly associated with the makeup stream it represents.
Installation cost	• Given the size of the equipment associated with these processes, first costs are among the highest—if not the highest—of those of any of the technologies discussed. • Water-supply, drain, blowdown, level-control, and treatment costs are driven by the cooling or air-washing functions, rather than the humidification function, and may be higher than what would be associated with some of the other approaches. • Control strategies that vary spray-water temperature or bypass air can have significant first costs associated with them because of the dampers, heat exchangers, and auxiliary control loops they may require. • When air is bypassed for control purposes, there can be a significant real-estate cost associated with the technology in terms of the space required for the bypass duct and its associated duct division and connection back to the main system.
Special considerations	• These processes usually make sense as a humidification strategy only when they are applied for other purposes and the humidification byproduct of the cooling or air-washing function also is desirable.

TABLE 7. Considerations for evaporative coolers and air washers.

based on the cooling-coil discharge condition necessary to dehumidify the coldest space; thus, it is at the top end of the humidity envelope. This minimizes cooling energy by minimizing the dehumidification performed. Humidification energy could be saved by humidifying only with the primary humidifier to the point necessary to satisfy the lower end of the humidity envelope for the coldest room. In fact, little, if any, additional humidity would be required to bring the outdoor air to this state point. However, this places an even larger load on the trim humidifiers, which already must be capable of handling a significant load and turndown range to accommodate the large design envelope associated with the operating-room requirements. Allowing the primary humidifier to pick up some of this load unloads the trim humidifiers a bit and narrows the range over which they must operate, which aids in their control. While this added moisture (i.e., energy) is in excess of what would be required to meet the minimum RH for a room at 62 F, the contingency goes away around a room setpoint of 68 F, where the humidity ratio created by the primary humidifiers results in a RH at the bottom end of the design envelope.

7) If you are unfamiliar with fan heat, see "Fan Heat: Its Source and Significance" by Gerald J. Williams, PE, in the January 1989 issue of *Heating/Piping/Air Conditioning*.

For HPAC Engineering *feature articles dating back to January 1992, visit* www.hpac.com.

Control and Interlock Systems

The dynamic requirements of loads relative to the response characteristics of humidification sources need to be considered for control systems. Not all approaches are capable of instantly responding to a load change, which can be a problem regarding variable air volume and applications demanding precise control over a wide range of operating conditions. Limit controls may be desirable, considering the significant water damage and subsequent indoor-air-quality problems that can occur if a humidifier runs out of control. Positive airflow interlocking always is a good idea. An airflow switch is much better than a starter auxiliary contact. Some technologies require warm-up interlocks to prevent problems at start-up and operational interlocks to shut down jacket heaters when humidification is not required.