

## HUMIDIFICATION SYSTEMS: A COST AND EFFICIENCY COMPARISON

The requirements of modern industrial processes, as well as more stringent indoor air quality (IAQ) standards, have resulted in an increased demand for effective humidification control of both industrial and commercial indoor spaces. ASHRAE Standard 62-1989, for instance, states, "Relative humidity in habitable spaces preferably should be maintained between 30% and 60%... to minimize growth of allergenic and pathogenic organisms." (Section 5.11)

A number of humidification solutions, both old and new, are available to fill this demand. Each is discussed below, followed by a detailed comparison in terms of humidification effectiveness, IAQ, installation costs, and operating costs.

### **BOILER STEAM HUMIDIFIERS:**

Many buildings were originally equipped with steam humidifiers as a byproduct of the traditional boiler room. Fueled by either gas or electricity, water is boiled to provide hot water, heat, and humidity for an entire building. To add humidity, boiler steam is released directly into the air stream.

Steam humidifiers offer distinct advantages. They introduce water in the vapor phase directly into the air stream, and therefore can often be applied in tight spaces without causing wetting of the ducts. However, since steam humidification results in a substantial increase in the dew point of the air stream, care must be taken to avoid downstream condensation on duct surfaces. If the walls of the duct are allowed to fall below this increased dew point temperature, condensation will form on the inside surfaces of the duct. Additionally, if an operational boiler room already exists, a humidification retrofit has relatively low first costs.

Boiler steam humidification, however, has fallen out of favor. As well as raising supply air temperature and placing a greater load on cooling systems, boiler steam contains chemicals that are dangerous to both people and materials. Amines, which are added to the water to prevent boiler corrosion, are carcinogenic and also attack paints, canvasses, wood, and pottery finishes. Therefore, boiler steam humidification is now considered unacceptable from an indoor air quality (IAQ) standpoint.

### **CLEAN STEAM HUMIDIFIERS:**

In response to the health hazard posed by boiler steam humidification, a variety of steam alternatives have evolved. The clean steam humidifier, for example, consists of a dedicated steam generator used only for humidification. The steam generator can be either an electric boiler or a gas-fired boiler. Since make-up water must not be chemically treated, demineralized water is normally used to reduce the buildup of minerals inside the boiler as well as inside the treated spaces. To prevent rust, stainless steel boiler vessels are employed.

Although clean steam provides good humidification effectiveness and acceptable IAQ, it has relatively high operating costs.

### **STEAM HEAT EXCHANGER HUMIDIFIERS:**

Another solution to the unsafe nature of boiler steam is the steam-to-steam heat exchanger humidifier (HX). These systems achieve clean steam humidification by separating building steam from humidification steam via a heat exchanger. Boiler steam is used to evaporate chemical-free, demineralized water in a tank, converting it to clean steam.

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space requirement of a dedicated boiler. By using partially demineralized make-up water, mineral residue is reduced, keeping maintenance costs down. The latest steam HX models have a wide range of applications, from small space (10 lbs/hr.) to factory-scale humidifiers (capacities up to 1,500 lbs/hr.)

The main drawbacks of this form of steam humidification, as with boiler steam humidification, are high initial investment and running costs. Generally speaking, compared to other methods of humidification, steam systems cost more to install and a lot more to run.

### **CANISTER STEAM HUMIDIFIERS:**

This type of clean steam humidification system has lower first costs as compared to boiler-type humidifiers. Canister humidifiers are generally wall-mounted, packaged steam generators. The energy source was traditionally electric but some manufacturers now offer natural gas-fired units as well. Canister-type units are easy to install and particularly suited to smaller areas, though some models are designed for up to 1,140 lbs. per hour. Overall, canister humidifiers provide good humidification effectiveness and IAQ.

However, operating costs for electric canister humidifiers tend to be quite high, due to higher unit cost of electric power as compared to natural gas. For larger electric canister systems, which require a lot of power, it may be necessary to increase electrical panel capacity, adding to first cost. Additionally, maintenance can be expensive when replaceable water canisters are utilized as a solution to mineral buildup on heating electrodes. Maintenance costs, however, can be lowered somewhat if the water supply is softened.

### **COLD-WATER HUMIDIFICATION SYSTEMS:**

Cold-water humidification systems utilize the

sensible heat of the air stream to affect the evaporation of water, a process which results in conversion of sensible heat to latent heat. Therefore, cold-water humidification systems cool the air as they humidify it. This means that cold-water humidifiers can utilize excess building heat as part of the energy source for humidification and are, therefore, considerably more energy efficient.

Care must be taken, however, to install such systems in a location – in the air ducts or air handling units – where enough heat is present in the air stream to effect evaporation of the water. Typically, this means that cold-water humidification systems must be installed after supply air and return air have been mixed. If the air doesn't have sufficient heat, the moisture-holding capacity of the air will not be high enough and it will not be possible to maintain sufficient humidity in the treated space.

Several types of cold-water humidification systems are in common use in commercial and industrial applications. All these systems use a relatively small amount of energy to atomize water into small droplets, then heat from the treated space is used to do the actual evaporation. If there is excess heat (i.e., waste heat) available in the space, the operating cost of the humidification is greatly reduced, as compared to steam humidification systems. Atomization is important because it increases the surface area of the water, and thereby speeds up the process of evaporation. Some of the more common cold-water humidification systems are discussed below.

### **WATER TREATMENT CONSIDERATIONS:**

With cold-water humidification systems it is important to use only demineralized water – water from which most of the mineral content

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has been removed – or water with naturally low mineral content. Steam-type systems vaporize the humidification water in a tank, so that any minerals present in the supply water are left behind in the tank. But cold-water humidification systems evaporate small droplets of the supply water in the air stream itself. Any mineral content present in the atomized water droplets is left in the air stream in the form of a dust particle.

As an example, if a cold-water humidification system that generates 1,000 lbs/hr. of moisture is used with supply water that has 100 parts per million, by weight of mineral content, it will generate one pound of mineral dust every ten hours. Over time, this can cause quite a housekeeping problem even in a large space. Furthermore, since naturally occurring waters generally contain high levels of calcium, magnesium, and sodium, it is important to study the effect of these minerals on any manufacturing process. Mineral dust would, for instance, cause significant problems in a computer clean room application.

Another point to consider is the potential for bacterial fouling of the supply water. Water supplied from municipal treatment plants is normally treated with chlorine. But the chlorine must be removed when water is demineralized with reverse osmosis technology, otherwise it would damage the osmotic membranes. Reverse osmosis systems are the most common and least expensive type of system used to remove mineral content for humidification applications. The demineralized, and now dechlorinated water is often stored in a tank where it could easily be contaminated by bacteria. Usually, the water is kept free of bacteria by injecting a small amount of ozone into the storage tank. Ozone can be generated with an inexpensive device that irradiates

atmospheric air with ultraviolet light. The ozone is then pumped into the tank, usually for about four hours per day. Water treated with ozone has a limited residual kill capacity; (i.e., once the ozonated water is pumped into the distribution lines, it dissipates and can no longer kill bacteria.) Therefore, it is important to ensure that water is not left to stagnate for extended periods of time in any part of the humidification system.

### CENTRIFUGAL HUMIDIFIERS:

In centrifugal humidification, water is sprayed at low-pressure against a spinning disc, harnessing centrifugal force to atomize the water. This kind of system has several advantages, such as low operating cost and low first cost. Overall, it is an energy efficient method that is most suited to humidification of small industrial spaces (such as a small woodworking or printing shop) or agricultural applications. Due to the size of the units, centrifugal humidifiers are not generally applied in ducted air systems, with the exception of smaller systems for home use.

### ULTRASONIC HUMIDIFIERS:

Ultrasonic humidifiers operate by means of a transducer that sits in a shallow water bath. The transducer converts high frequency electricity into mechanical oscillation, causing small droplets to break away from the surface of the water bath and become airborne. Demineralized water is normally used, both to prevent mineral buildup on the transducers and to eliminate mineral dusting of the treated spaces.

Ultrasonic humidifiers are more energy efficient than steam or centrifugal humidifiers, though IAQ is a concern in some models due to open water baths, which can promote bacterial growth. New generation ultrasonic humidifiers are addressing this IAQ situation, utilizing a

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variety of methods to minimize bacterial dangers.

### COMPRESSED AIR ATOMIZERS:

Compressed air atomizing nozzles discharge a high velocity air stream around a water orifice. The high velocity air stream creates a vacuum at the orifice tip, which shears the water into particles. Droplet sizes range from sub-micron to 30-microns in diameter, depending on the velocity of the atomizing air.

Compressed air atomizers should also be used with demineralized water to meet IAQ standards and to avoid dusting from mineral salts found in normal tap water. They have been successfully applied in some industrial applications where the nozzles are located in the plant itself, with waters having as much as 250 parts per million (ppm) of dissolved mineral content.

As with any humidification system that functions without making steam, operating costs are relatively low. When compressed air atomizers are installed in air ducts or air handling units, the latest models have been able to achieve evaporation distances close to that of steam by decreasing the air to water ratio, but this does increase energy consumption.

Typical compressed atomizing systems have an air control assembly that contains an air regulator, solenoid valve, and may contain a modulating water valve, too. A drain-down solenoid is usually incorporated to relieve nozzle pressure at shutdown and prevent dripping. Some systems have self-cleaning features and can close off the water flow on shutdown, thus eliminating any need for open reservoirs where bacteria can potentially grow.

The primary drawback of compressed air atomizers, however, is operating costs. Though they are low compared to steam-type systems,

compressed air atomizers can sometimes be cost prohibitive in larger facilities.

### HIGH-PRESSURE COLD-WATER FOGGING:

High-pressure cold-water fogging operates in a fashion similar to other cold-water humidification systems, in that they all generate small water droplets and use heat from the space to effect evaporation. But fog achieves small particle sizes through the utilization of pressurized water – inherently a more energy-efficient method.

The typical high-pressure fogging system consists of a high-pressure pump, which delivers demineralized water at 1,000 to 2,000 psi to a series of fog nozzles. A typical fog nozzle has an orifice diameter of five to seven thousandths of an inch. Water jets out of the orifice and hits the impaction-pin, which breaks the water stream up into billions of micron-sized droplets. Some fog nozzles create as many as five billion super-fine fog droplets per second, with droplets averaging about five microns in diameter.

High-pressure fog systems can be controlled by using solenoid valves to turn on stages of fog nozzles or by controlling the speed of the high-pressure pump with a variable frequency drive. The latter method offers the most precise control of humidity but is generally more expensive.

The space requirement for the high-pressure pump systems is minimal and the first cost is often less than that of both steam and compressed air systems. Maintenance costs, also, are relatively low, mainly involving replacement of water filters and service to the high-pressure pumps. The biggest advantage of high-pressure cold-water fogging, though, is running costs. (See Figure 1: Energy Cost Comparison Chart.) A typical fog system uses

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### ENERGY COST COMPARISON CHART (ANNUAL)

MeeFog™ System	\$750	.4%
Centrifugal Humidifiers	\$980	6%
Ultrasonic Atomizers	\$1,270	8%
Compressed Air Atomizers	\$2,500	15%
Electric Steam Humidifiers	\$16,800	100%

*Assumptions:* \$.05 per kW hour, 1000 hours operation, 1000 lbs. per hour moisture output.

Figure 1

Cold-water fogging, however, is generally only cost-effective for installations requiring more than 200 lbs. per hour of water. Below this level, installation costs are high as the cost of the high-pressure pump needed for a small application does not drop proportionally. Additionally, high-pressure fog has a longer evaporative distance than steam and usually requires the use of a fog droplet filter to remove droplets that don't evaporate quickly enough. The fog droplet filter is positioned downstream of the nozzle manifold to prevent wetting of the ducts.

### CASE STUDY: COST COMPARISON

A U.S. postal site in Washington, DC, originally had building steam humidification which was discontinued for IAQ reasons. The facility requested quotes from various vendors. Clean steam humidification was out of the question due to space limitations. Centrifugal humidification was also rejected due to IAQ, while ultrasonic humidifiers were deemed unfit for such a large site due to the amount of space that would be taken up by system equipment. That left steam HX (heat exchanger), electric canister steam, compressed air, and

high-pressure cold-water fogging. Each of these candidates were evaluated against four criteria: humidification effectiveness, first cost, IAQ acceptability, and annual operating costs.

For the purposes of price calculation, loads were estimated at approximately 4,120 lbs. per hour for each air handling unit (AHU); based on outside air (OA) temperature minimum of 10°F, winter supply air temperature of 60°F, winter room temperature of 70°F, night setback temperature of 55°F, and a minimum relative humidity of 40%. Each AHU had a capacity of 265,000 CFM, with a total of three units existing at the facility.

### HUMIDIFICATION EFFECTIVENESS:

Humidification effectiveness was defined as a measure of a system's ability to add moisture to the air to the point of saturation, as well as to achieve precise control of humidity levels. While all of the four systems tested produced acceptable levels of humidity for this application, on a scale of one to ten, where ten is the best, steam HX scored highest on humidification effectiveness, due to the minute size of droplet it creates. Electric canister steam placed second, with fog and compressed air tying for third. (See Figure 2.)

### HUMIDIFICATION EFFECTIVENESS CHART

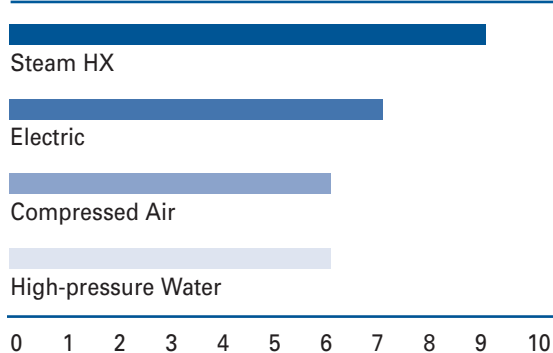


Figure 2

This chart compares the humidification effectiveness features of each system, based on a scale of 1-10, with 10 being the best.

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### FIRST COST:

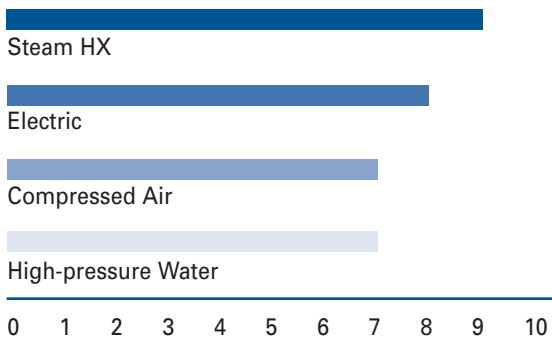
The estimates on the right were obtained from a respected East Coast manufacturer's representative.

In this example, high-pressure fog worked out to be the cheapest to install, coming in at 67% less expensive than steam HX, due to the low cost of installation equipment. Note that electric canister humidifier equipment costs are close to those of high-pressure fogging, though if upgrade of electric service is required, first costs grow accordingly.

### INDOOR AIR QUALITY:

IAQ standards make it essential that no potentially harmful chemicals be introduced into the air, and that no environment that supports bacterial growth be used in building humidification. Each of the systems considered provide IAQ which falls well within OSHA regulations. HX scored best again, followed by electric, with cold water fog and compressed air tied once more. (See Figure 3.)

### IAQ COMPARISON CHART



*Figure 3*

This chart compares the indoor air quality features of each humidification system, based on a scale of 1-10, with 10 being the best.

### HUMIDIFICATION SYSTEM FIRST COST COMPARISON CHART

	Steam HX	Electric Canister	Compressed Air	Fog
Equipment	\$196,000	\$129,600	\$136,000	\$122,000
Distribution Piping	3,000	3,000	3,000	2,000
Steam Piping	9,000			
Water Piping			1,000	1,000
Pneumatic Piping			5,000	
Electric Service		30,000	3,000	1,500
Auto Temp Control	4,000	2,000	25,000	inc. in equip.
<b>Total for 1 AHU</b>	<b>\$212,000</b>	<b>\$164,600</b>	<b>\$173,000</b>	<b>\$126,500</b>
<b>Total for 3 AHU</b>	<b>\$530,000</b>	<b>\$411,500</b>	<b>\$432,500</b>	<b>\$316,250</b>

### ANNUAL OPERATING COSTS:

It is in the area of operating costs that the most dramatic differences are noted. Outside air was estimated at 135,000 of lbs. dry air per hour. Detailed calculations were conducted as to the amount of moisture that would need to be added per year, based on a system of five degree temperature bins taken from Chapter 30 of the ASHRAE Handbook of Fundamentals, as follows:

### ANNUAL OPERATING COSTS

OA Temp	Hours per year Each Temp.	Grains Moisture Added Per Lb. Dry Air	Lbs. Water Added Per Hour	Lbs. Water Added
10	20	31	660	13,200
15	99	31	600	60,000
20	212	28	540	114,480
25	377	24	466	176,148
30	648	20	386	250,128
35	858	14	272	233,376
40	765	7	135	104,176
			<b>Total</b>	<b>951,628</b>

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Thus, one typical AHU requires 951,628 lbs. of moisture for humidification each year. When considering three units, however, consumption is only 2.5 times that amount, due to increased system efficiency. Energy costs per 100 lbs. of water added, work out as follows:

**A. Steam HX Humidifier:**

One pound of humidification steam requires 1,000 BTUs of fuel

Cost = \$0.08 per 1,000 BTUs

Fuel efficiency = 80% = \$0.10 per 1,000 BTUs

Pipe system efficiency = 80% = \$0.12 per 1,000 BTUs

The addition of a skimmer (to remove floating impurities from the water) to a steam generator increases fuel consumption by 50 percent.

Net cost = \$0.12 x 1.5 = \$0.18 per 1,000 BTUs

Cost of operation for HX Humidifiers is \$1.80 per 100 lbs. of humidification.

**B. Electric Canister Humidifier:**

A 10 kW electric canister humidifier uses 1 kWh to produce 2.94 lbs/hr. of steam

Energy cost = \$0.08 kWh

Efficiency = 100%

Cost of operation for electric canister humidifiers is \$2.72 per 100 lbs. of humidification.

**C. Compressed Air Humidifier:**

It takes about 1 kW of electrical power to produce 4.5 cfm of compressed air and 4.5 cfm of compressed air will produce about 25 lbs/hr. of atomized water.

Energy cost = \$0.08/kWh

Cost of operation for compressed air humidifiers is \$0.32 per 100 lbs. humidification.

**D. High-pressure Fog System:**

High-pressure fog pump requires 5 kW for 2,000 lbs/hr. of fog. This figure takes into account losses on fog droplet filters for a typical fog system installation.

Energy cost = \$0.08 kWh

Cost of operation for high-pressure fog is \$0.02 per 100 lbs. humidification.

**OPERATING COST COMPARISON CHART**

System Type	Cost/100 Lbs.	Annual Cost/1 AHU	Annual Cost/ 3 AHUS
Steam HX	\$1.80	\$17,129	\$42,823
Electric Canister	2.72	25,884	64,710
Compressed Air	0.32	3,045	7,613
High-pressure Fog	0.02	190	476

In summary, while steam HX scores slightly higher on IAQ and humidification effectiveness, high first costs prohibit its use in many applications. Electric canister humidification, while having considerably lower installation costs than HX, compares poorly when viewed in terms of energy consumption. And compressed air, despite being far superior to steam HX and electric canister in terms of energy consumption, consumes 15 times more power than high-pressure fog.

Fog delivers acceptable IAQ and humidification effectiveness while keeping both installation and operating costs down. Of course, these estimates may vary from site to site, but in many facilities requiring more than 250 lbs/hr. of water, high-pressure fogging works out to be an option worth serious consideration.



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