Ultrasonic Humidifiers

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Federal Technology Alert

A publication series designed to speed the adoption of energy-efficient and renewable technologies in the Federal sector

Prepared by the New Technology Demonstration Program

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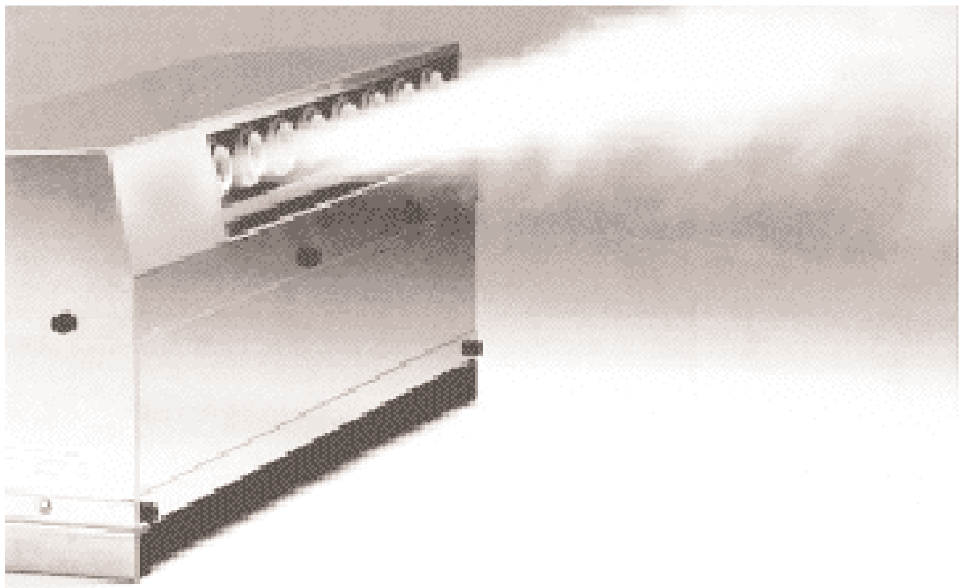
Ultrasonic Humidifiers

Technology for high-efficiency, low-maintenance air humidification



Humidifiers are used in buildings to maintain humidity levels to ensure quality and handling capabilities in manufacturing processes, to lower the transmission rate of disease-causing bacteria in hospitals, to reduce static electricity in manufacturing clean rooms and in computer rooms, and to provide higher levels of employee comfort. Ultrasonic humidifiers are proven to reduce humidifier energy use by 90 to 93%.

Energy-Saving Mechanism

Ultrasonic humidifiers rely on an adiabatic process that generates a water mist without raising its temperature. This process requires much less energy than alternative systems that boil water in a reservoir, use infrared light to reduce the surface tension of a pool of water, or use rotating disks to sling a spray of small droplets.

Application

The greatest energy and cost savings from ultrasonic humidifiers occur in applications requiring simultaneous cooling and humidifying. The types of facilities where this technology is best used are computer rooms for data processing centers, communication centers with large amounts of electronic switching equipment, clean rooms for electronic and pharmaceutical manufacturing, and hospital operating rooms. These applications represent approximately 10% of all humidifier installations.

Technology Performance

Users of ultrasonic humidifiers have been very pleased with the operation and cost savings of the equipment. One large installation documented in a national publication reported a reduction in annual energy use of 1.5 million kWh and a reduction in utility bills of $120,000 per year. This represented a 2.4-year payback for the project; a utility incentive program reduced the payback period to 1.2 years. The building manager for this facility expressed tremendous satisfaction with the conversion to ultrasonic humidifiers, particularly with regard to maintenance costs.

Two additional retrofit applications are reported in another national publication. These projects reported reductions in operating costs of over 90% resulting in annual savings of $110,000 and $230,000.

A fourth installation also reported reductions in energy costs of 90% as well as reduced maintenance requirements.

Case Study

A case study of an electrode canister and ultrasonic humidifiers illustrates the differences between these two technologies. The ultrasonic humidifier has higher equipment and non-energy operation and maintenance costs than the electrode canister humidifier. These increases, however, are offset by energy costs that are approximately 10% those of the electrode canister humidifier. In this example the ultrasonic humidifier has a savings-to-investment ratio of 2.2 and levelized energy cost of $0.04.

Technology in Perspective

Ultrasonic humidifiers are a proven technology that can dramatically reduce the energy use for building humidification. Equipment costs may come down in the future as more manufacturers enter the market, but it is unlikely that costs will drop by very much. System efficiencies are also likely to improve a little, but it is unlikely there will be further dramatic improvements.

The indirect cooling effects of ultrasonic humidifiers should be considered in applications that require simultaneous heating and humidification. In these applications the heating system energy use will increase by approximately 300 Wh/lb of H_2O provided by the humidifier. This indirect effect can negate much or all of the energy savings of an ultrasonic humidifier.

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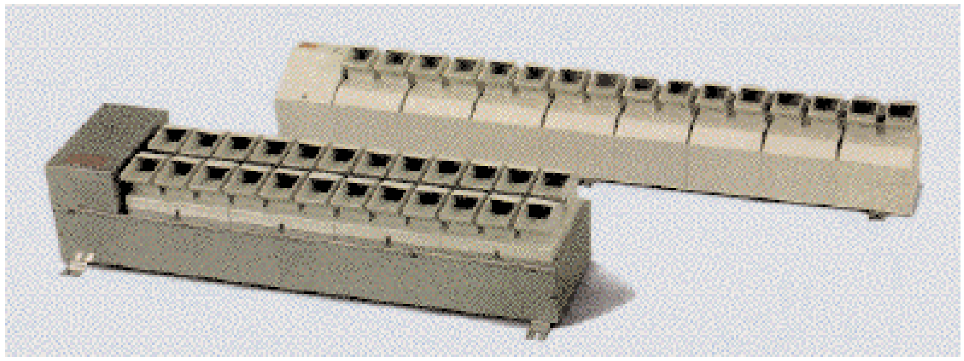

Abstract

Humidifiers are used in buildings to maintain humidity levels to ensure quality and handling capabilities in manufacturing processes, to lower the transmission rate of disease-causing bacteria in hospitals, to reduce static electricity in manufacturing clean rooms and in computer rooms, and to provide higher levels of employee comfort in offices.

Ultrasonic humidifiers generate a water mist without raising its temperature. An electronic oscillation is converted to a mechanical oscillation using a piezo disk immersed in a reservoir of mineral-free water. The mechanical oscillation is directed at the surface of the water, where at very high frequencies it creates a very fine mist of water droplets. This adiabatic process, which does not heat the supply water, reduces humidifier energy use by 90 to 93% compared with systems that do boil the water.

Ultrasonic humidifiers have been demonstrated to be more efficient and to require less maintenance than competing humidifier technologies such as electrode canisters, quartz lamps, and indirect steam-to-steam. They do not require anticorrosive additives that affect the indoor air quality of buildings using direct steam humidifiers.

There are two potential disadvantages of ultrasonic humidifiers. They must use mineral-free, deionized water or water treated with reverse osmosis. Treated water reduces maintenance costs because it eliminates calcium deposits, but increases other operating costs. Also, the cool mist from ultrasonic humidifiers absorbs energy from the supply air as it evaporates and provides a secondary cooling effect. This cooling is beneficial in applications where simultaneous humidification and air conditioning are required, but detrimental when heating and humidifying.

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Contents

About the Technology

Humidifiers are used in buildings to maintain humidity levels to ensure quality and handling capabilities in manufacturing processes, to lower the transmission rate of disease causing bacteria in hospitals, to reduce static electricity in manufacturing clean rooms and in computer rooms, and to provide higher levels of employee comfort in offices.

In the past, humidification was provided only where it was necessary for manufacturing and it relied on direct injection of steam from the boiler used to heat the building. This method was available, inexpensive, and better than no humidification at all. These systems were common in hospitals, print shops, and factories.

Direct steam systems evolved into steam-to-steam humidifiers that ensured that clean air is delivered in the supply ducts without contamination from anti-corrosive agents used in the boilers.

The advent of the electronics industry has led to the use of humidity control to reduce static electricity in manufacturing transistors and computer chips as well as in the controlled atmospheres of computer rooms.

Recently, humidity control is receiving more attention because of its potential benefits in terms of employee comfort, productivity, and health and other indoor air quality (IAQ) issues.

There are basically two categories of humidifiers: isothermal and adiabatic. Isothermal systems use electricity, steam, hot water, or natural gas as an external heat source to change water to steam. The steam is then added into the supply air for the conditioned space. This category includes electric immersion, electrode canister, and steam-to-steam humidifiers.

Adiabatic humidifiers use mechanical energy to generate a fog or mist of water particles that are injected into the supply air. They use less energy than isothermal humidifiers because they do not boil the water or lose hot water down the drain when flushing the reservoir.

With adiabatic humidifiers, heat from the air is absorbed by the water droplets causing them to evaporate. This process provides some free cooling as it raises the humidity of the supply air. Adiabatic humidifiers include misters and sprayers, atomizers, foggers, and piezo disk humidifiers. Ultrasonic humidifiers are piezo disk systems as shown in Figure 1.

Most humidifiers use potable tap water or softened water. These systems experience an increase in concentrations of dissolved minerals as pure water is evaporated and the minerals are left in the reservoir. Automated flushing systems are built into the units to reduce mineral concentrations, but they can increase water usage significantly.

Depending on local water quality, mineral content can become high enough in spite of the flushing cycles to cause solids to precipitate on the bottom and sides of the water reservoir and valves requiring periodic maintenance. It is essential that scaling be avoided with ultrasonic humidifiers. This is done by using deionized water. This can reduce water usage and maintenance requirements significantly. (Reverse-osmosis water treatment systems do use a flushing cycle to reduce mineral buildup and to prolong their useful lifetimes.)

The water treatment systems use one or more canisters to remove dissolved minerals through deionization (DI) or reverse osmosis (RO). A cut-away drawing of a DI bottle is shown in Figure 2. A combination of RO and DI is frequently the most cost-effective method of generating demineralized water for an ultrasonic humidifier. There are costs associated with replacing the canisters that

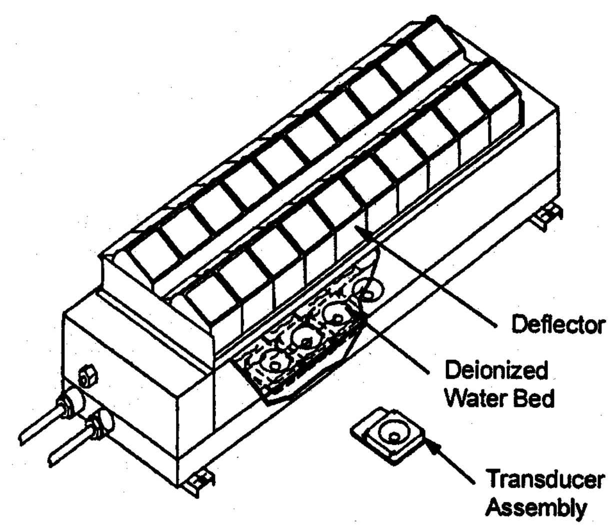

Figure 1. Ultrasonic Humidifier Components

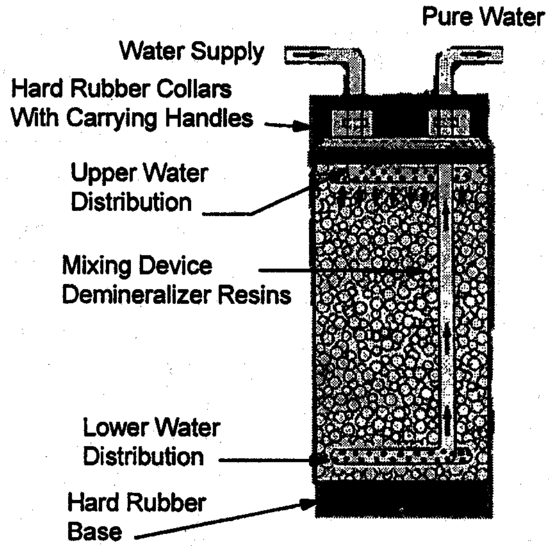

Figure 2. Water Pretreatment with Deionizing and Reverse Osmosis Canisters

offset some of the savings in water and maintenance costs associated with systems using potable tap water.

Application Domain

Ultrasonic humidification is a relatively recent technology development and there are relatively few installed units. There are no known Federal installations and less than 200 large-scale non-Federal installations. (This technology is also used in single-room humidifiers for residential use where many more units are in use.)

Ultrasonic humidifiers have the highest benefit when energy, maintenance costs, sensitive humidity control, and cleanliness are high priorities. The technology has a cost and large energy saving advantage over other humidification technologies when simultaneous cooling and humidification is required. It is not known how many Federal buildings use humidifiers or what fraction of those buildings would benefit from ultrasonic humidifiers. Approximately 10% of all humidifier applications require simultaneous cooling and humidification (e.g., data processing centers, communications centers, hospital operating rooms).

Other factors must be considered in the selection of humidifiers for a specific building. These include limitations of space, control precision, and water quality. Some technologies may need to be eliminated from consideration because of these factors in spite of cost or energy considerations.

Only five manufactures of ultrasonic humidifiers have been identified. Three of these are marketing their product aggressively while another is a very new company working to establish itself in this field. Information is easily obtainable from any of these four companies. One manufacturer maintains a computer program on the World Wide Web to assist potential customers in determining their humidification load, sizing equipment, and estimating operating costs.

Energy-Saving Mechanism

Ultrasonic humidifiers employ a low power electronic circuit that consists of an oscillator that generates high frequency electrical energy and an electro-acoustic power converter, or transducer (piezo disk), to convert the electric energy to mechanical energy. The oscillator is mounted on a circuit board in the humidifier control unit; the transducers are immersed in the reservoir of mineral-free water.

The transducers contain a metal disk that vibrates or oscillates in response to an electrical signal from the oscillator. At low frequencies, the water in the reservoir follows the oscillations of the transducer. As the frequency increases, the inertial effects of the water keep it from oscillating as fast as the transducer creating areas of momentary vacuum and compression.

The transducer is designed so that this compression is directed at the surface of the water where cavitation occurs, broken capillary waves are formed, and minute droplets break the surface tension of the water and quickly dissipate into the air forming a fog or mist. The droplets in the mist are typically 1 micron in diameter. The mist absorbs heat from the surrounding air, causing the water droplets to evaporate and raising the relative humidity of the air.

Other humidification technologies use either isothermal or adiabatic processes to add moisture to the air. Isothermal humidifiers operate at a constant air temperature by injecting steam from a boiler directly into the supply air or by using steam (indirectly), electricity, or a gas burner to boil water in a supply reservoir. This external source of energy causes the evaporation and consequently there is no indirect cooling effect.

Ultrasonic humidifiers are a specific type of adiabatic humidifier. These systems operate without changing the energy content of the supply water by adding heat to it. Quartz lamp humidifiers accomplish this by using infrared light to reduce the surface tension of the water in the reservoir allowing low-energy droplets to escape into the surrounding air. Other types of adiabatic humidifiers drop a stream of water onto a rotating disk that slings a spray of small droplets into the supply air. Ultrasonic humidifiers use a very high frequency mechanical oscillation to create a fog or mist of water droplets. All of these adiabatic humidifiers have an indirect cooling effect as the water droplets evaporate.

Other Benefits

Secondary benefits of ultrasonic humidifiers include:

- *Improved air quality*: unlike ultrasonic humidifiers, direct steam humidifiers inject steam from the building central boiler into the supply air system. These boilers require anti-corrosive additives that are subsequently evaporated and ejected into the building with the steam. These additives cause low levels of chemical amines in the supply air. These chemicals have been associated with health problems, physical discomfort (headaches, etc.), and deterioration of paintings and exhibits in museums.
- *Net cooling effect*: there is an evaporative cooling effect as each pound of water from an ultrasonic humidifier absorbs heat from the air as it evaporates.
- *Lower electrical wiring costs*: ultrasonic humidifiers require as little as 7% of the input power of alternative humidification technologies. Consequently there can be significant savings in the costs of wiring, electrical distribution boards, and standby power generation. The reduced electrical requirements can be particularly important when adding humidification to existing buildings.
- *Lower water use*: humidifiers using potable tap water or pretreatment with a water softener require skimming or periodic flushing to dilute the levels of dissolved salts in the water reservoir. This process can add significantly to the system water consumption, particularly for electrode type humidifiers. Flushing cycles of electric immersion and steam-to-steam humidifiers can be adjusted to reduce water wastage and minimize this impact.

Federal Sector Potential

The *Federal Technology Alert* series targets technologies that appear to have significant untapped Federal-sector potential and for which some installation experience exists.

Technology Screening Process

The new technologies presented in the *Federal Technology Alert* series are identified primarily through direct submittals from Federal agencies to the Program s Interlaboratory Council (ILC). The ILC also identifies new technologies through trade journals, product expositions, trade associations, other research programs, and other interested parties. Based on these responses, the technologies are evaluated by the ILC in terms of Federal-sector potential energy savings, procurement, installation and maintenance costs. They are also categorized as either just coming to market or as technologies for which field data and experience exist. Ultrasonic humidifiers were judged to have notable potential and to be life-cycle cost-effective in the proper applications. Several other technologies are slated for future *Federal Technology Alerts*.

Estimated Savings and Market Potential

There are no known estimates of the use of humidification in the Federal sector; therefore this report is unable to adequately quantify the energy-savings potential to the Federal sector through the application of this technology. There are certainly parallels between the types of applications in the private sector that benefit the most from ultrasonic humidifiers and similar applications in the Federal sector. These include controlled environments for laboratories, clean rooms, large computer installations, and large communications centers. Where it is properly applied, ultrasonic humidification can reduce energy use by up to 90 to 93% relative to other types of humidifiers. However, where simultaneous humidification and heating are required, the end results may be negative.

Laboratory Experience

Ultrasonic humidification has been demonstrated to be an effective and reliable method of providing building supply air within close tolerances to a specified relative humidity. Predicted energy savings for the humidification process are accurate (savings of up to 93% of the energy use for other humidifiers); however, the building operator must be aware that there is a secondary effect due to free cooling from an ultrasonic humidifier. This effect is beneficial when simultaneous humidification and cooling are required, and represents an additional energy savings. The free cooling is detrimental, however, in the many applications where simultaneous humidification and heating are required.

Application

Application Screening

Ultrasonic humidifiers are best applied in instances where both cooling and humidification occur simultaneously. They are particularly well suited to computer rooms for data processing centers, clean rooms for electronics and pharmaceutical manufacturing, and telecommunications centers.

Ultrasonic humidifiers lose much, if not all, of their efficiency advantage in applications where heating and humidification occur simultaneously. This is the case in most humidifier applications.

Although there may not be reduced energy use, ultrasonic humidifiers are also advantageous in applications where humidity must be carefully controlled. This technology does not require the heating of a large reservoir of water, and consequently it has an instantaneous response to the control system. This is important if the humidity must be maintained within a very narrow range.

Ultrasonic humidifiers may also be used when retrofitting existing buildings because of their low power requirements. Technologies with higher power requirements may require upgrading power service to the building in instances where ultrasonic humidifiers would not.

Where to Use Ultrasonic Humidifiers

Ultrasonic humidifiers are best applied where simultaneous cooling and humidification are required as in computer rooms and clean rooms for manufacturing electronic components. They are also recommended in applications where energy costs, maintenance, and cleanliness are high priorities.

Ultrasonic humidifiers are also well suited to applications requiring tight controls on humidity (–1%) due to their instantaneous response.

What to Avoid

Correct sizing and matching of the humidifier to the air-handling equipment is important. Excess misting or low air supply temperatures can result in incomplete evaporation and puddling in the duct work or floors. Ducted systems should avoid air velocities exceeding 1,000 ft/min and baffles or expansions should be used to ensure ideal air velocities of 400 to 600 ft/min.

Users should also avoid using anything except demineralized water in the humidifier. Water electrical resistance should exceed 1 mega-ohms.

The alternatives to ultrasonic humidifiers may be more appropriate for certain applications:

- direct- and steam-to-steam systems might be the best choice for humidification depending on piping and installation costs if direct steam injection is available
- electrode- and quartz-tube systems are favorable where first costs are important and electricity costs are low
- atomizing compressed-air systems can be the best alternative where there is a large humidification load with associated economies of scale.

Equipment Integration

All types of humidifiers (ultrasonic, heated steam, compressed air) must satisfy strict installation parameters to avoid a buildup of stagnant water in the air supply system. Air ducts should be sized so that the air velocity across the humidifiers is 450 to 750 feet per minute. Ultrasonic humidifiers in air supply ducts should be installed 10 to 12 feet upstream of any turns or obstructions in the duct work so that the mist has time to evaporate and does not condense on the duct walls or obstructions to air flow. Condensation can also be a problem if the supply air upstream of the humidifier is too cold. These requirements are less stringent for steam-type humidifiers that do not need to absorb heat from the supply air to evaporate a cool mist (e.g., 2 to 3 feet of unobstructed duct work).

Ultrasonic humidifiers are available with capacities of 2+ to 40 lb/hr; multiple units are installed to provide higher capacities. If several humidifiers are installed to provide the required capacity, they may be arranged in a step fashion with the humidifier closest to the entering air stream at the highest position. A stainless steel condensate drip pan should be installed such that it extends 2 feet downstream of the last humidifier as an added precaution.

Free-standing or wall-mounted humidifiers must be at least 18 inches from the ceiling and 8 feet from any seated personnel. Humidifiers also require laminar flow of the entering air. Installation recommendations for individual manufacturers should be checked and manufacturers contacted before making any installations that deviate from these guidelines.

Ultrasonic humidifiers also require a supply of mineral-free water. This subsystem is typically contained in a separate cabinet and contains one or more water treatment canisters.

Multiple canisters are used to provide redundancy and backup capacity. The humidifier control system typically contains two levels of alarms; the electrical conductivity of the water is used to signal when the canisters need to be changed or when to shut down the humidifier altogether.

Maintenance Impact

Ultrasonic humidifiers require very little maintenance. The expected lifetime of the transducers is 10,000 operating hours, so replacement is necessary only every 3 to 5 years. The water treatment system requires periodic maintenance, cleaning filters and switching out RO/DI canisters. The frequency of this operation depends on the local water quality and cannot be generalized. The maintenance of ultrasonic humidifiers is generally lower than that required by other types of humidifiers:

- electrode canisters require periodic replacement of the electrode and also routine disassembly to remove mineral deposits in the water reservoir and on the electrode
- direct steam and steam-to-steam humidifiers require routine disassembly to remove mineral deposits
- quartz infrared humidifiers require periodic replacement of the infrared lamps and routine maintenance to remove mineral deposits from the reservoir and flushing assembly.

Any of the humidifiers that use tap water and also have a flushing cycle to remove mineral-rich water from their reservoirs are also subject to malfunction of the drain mechanisms due to mineral deposits. This results in the reservoirs overflowing into the air duct system or onto the floor requiring cleanup and repair.

Costs

Equipment costs for ultrasonic humidifiers are typically higher than equipment costs for other types of humidifiers; installation costs are typically lower. A 100 lb/hr ultrasonic humidifier costs approximately $13,400 with an installation cost of $1,000; or approximately $145 per pound of capacity. A similar sized steam canister humidifier would cost $3,400 with a $2,000 installation cost. Two documented retrofit applications averaged $205 and $269 per pound of capacity, including installation (Longo 1994). In those two instances, however, the total retrofit costs were similar to the estimated costs using electric resistance humidifiers.

Utility Incentives and Support

Several utilities across the country have offered rebate programs covering ultrasonic humidifiers under their promotion programs for the use of energy efficient technologies. Examples of utilities that have offered rebates or actively promoted ultrasonic technology are:

- Northern States Power (MN)
- Virginia Power (VA)
- Potomac Electric Power (MD)
- North East Utilities (CT)
- Consumers Power (MI)
- Atlantic Electric (NJ)
- Wisconsin Electric Power (WI)
- Detroit Edison (MI)
- Massachusetts Electric (MA)
- Orange and Rockland Utilities (NY)
- Long Island Lighting (NY)
- Public Service Electric & Gas (NJ)
- Portland Electric (OR).

Technology Performance

Field Performance

Users of ultrasonic humidifiers have been very pleased with the operation and cost savings of the equipment. A brokerage information service in New Jersey replaced a large number of quartz infrared humidifiers in their computer rooms with a like number of ultrasonic humidifiers. The company reported a reduction in annual energy use of 1.5 million kWh and a reduction in utility bills of $120,000 per year (Randazzo 1997). This represented a 2.4 year payback for the project; a utility incentive program reduced the payback period to 1.2 years. The building manager for this facility expressed tremendous satisfaction with the conversion to ultrasonic humidifiers, particularly with regard to maintenance costs. He reported that the results in energy savings and reduced maintenance exceeded his own expectations and that he couldn t be more pleased with the change over.

Two additional retrofits were applications in communication centers for telephone switching equipment (Longo 1994). These projects reported reductions in operating costs of over 90% resulting in annual savings of $110,000 and $230,000.

An electronics manufacturing company in Pennsylvania installed ultrasonic humidifiers because of quality control problems. They had used direct steam humidifiers. Chemical amines used as anticorrosive agents in boiler water were entering the plant with the steam from the humidifiers. These chemicals were plating out on the gold connectors of the circuit boards manufactured in the plant resulting in customer complaints about bad electrical connections. Ultrasonic humidifiers were chosen to replace half of the direct-steam humidifiers to eliminate the problem with amines. Energy costs were reduced 90% with additional reductions in maintenance requirements.

A computer manufacturer in Massachusetts replaced a single steam generator humidifier in 1993 with an ultrasonic humidifier. This initial trial led to the replacement of 67 steam and infrared humidifiers with ultrasonic units. The resulting energy savings resulted in an estimated savings of $115,000 per year in electrical costs. This installation qualified under the Massachusetts Electric Company s Energy Initiative rebate program to defray the project costs.

Energy Savings

The retrofit of ultrasonic humidifiers at the New Jersey brokerage data center received a utility rebate for installing high-efficiency equipment. The utility required measured performance data to verify the projected energy savings. The brokerage firm contracted with an engineering service company to monitor the operation of the humidifiers (Randazzo 1997). Energy use for humidifiers was reduced by 96% from what it had been and electrical demand was reduced by 636 kW.

The building manager at another installation reported that his electrical consumption after changing to ultrasonic humidifiers is only 10% of what it had been with the previous humidifiers.

Maintenance

Both the data processing center in New Jersey and the electronics manufacturer in Pennsylvania reported lower maintenance costs as a result of their conversions to ultrasonic humidifiers. The New Jersey installation experienced some initial problems due to overmisting with puddling on the floors, but after adjustment the ultrasonic humidifiers are operating almost maintenance free. This is in contrast to the infrared humidifiers previously used which required frequent servicing to replace bulbs and clean water reservoirs.

There have also been only minor initial maintenance problems experienced at the Pennsylvania installation. In 2 years of operation, the only maintenance required has been the replacement of one solenoid valve controlling water level and a routine rinsing of the DI water treatment canisters every 2 months.

Awards and Recognition

The computer manufacturer in Massachusetts was a merit winner in the 1994 Facilities Management Excellence (FAME) Awards competition by the American Institute of Plant Engineers Foundation (AIPE) for their installation of ultrasonic humidifiers.

Case Study

Facility Description

The building manager needs information about the local utility rates, the humidifier load, and whether humidification occurs predominantly while the space is being heated or cooled.

Local gas and electricity rates can be obtained from the suppliers or from previous utility bills; electric rates may include demand charges.

Both the humidifier capacity and annual hours of operation are required to compute water and energy use. The rated capacity (lb H_2O/h) depends on a number of factors, including:

- design temperature and humidity of the conditioned space
- local outdoor design point temperature and humidity
- fraction of outdoor air in the ventilation system
- infiltration of outdoor air into the building through doors, windows, leaks, etc.
- sources of humidity in the conditioned space by human occupancy and activities, manufacturing or processing activities
- removal of moisture in the conditioned space by the air conditioning system, dehumidifiers, or hygroscopic materials used within the conditioned space.

Information on indoor design temperature and humidity for particular types of buildings can be found in the appropriate chapter of the ASHRAE HVAC Applications Handbook (1995).

Both the indoor temperature and humidity design conditions vary depending on the type of facility. The design temperature and humidity for office buildings are stated in the ASHRAE standards for indoor air quality.

The ASHRAE Fundamentals Handbook (1997) contains a table of design outdoor temperature and humidity for major cities throughout the United States and foreign countries organized by state and country. This table can be used to find an approximate local outdoor design condition for the humidifier.

Information about outdoor air used in the ventilation system and entering the conditioned space from doors, windows, and leaks is needed to determine natural sources of humidity. Data processing centers bring in as little as 5% outside air while manufacturing or processing facilities may use up to 100% outside air. Specific information should be available from the maintenance staff or equipment manufacturers.

Infiltration rates of outside air leakage into the building or humidified rooms are generally small for the applications that are best suited to ultrasonic humidifiers (e.g., data processing centers, manufacturing clean rooms, hospital operating rooms) and may be neglected.

Sources of humidity within the conditioned space depend on the number of people, occupancy rate, and manufacturing or process activities. Humidity from human sources averages 0.2 lb/h/person, although this value may be higher depending on the nature of activity. This rate is low for data processing centers with few human occupants in the room, but may be significant for other applications like hospital operating rooms.

Dehumidification can occur due to absorption of moisture from the air by hygroscopic materials as they absorb moisture, by condensation of moisture on cold surfaces, and by condensation due to air conditioning. The rate of heat removed by the air conditioner from condensing water is referred to as the latent load and may be stated as a percentage of the total system cooling capacity. The rate of moisture removal by the air conditioner can be computed by dividing the latent load (Btu/h) by 1,000 Btu/lb H_2O. The latent load is typically 20 to 30% of the total cooling load for conventional space conditioning. It should be much lower if humidification is occurring simultaneously with air conditioning. The latent load for a computer room is 0 to 10% of the total load.

Existing Technology Description

Consider the hypothetical application of humidifiers in a building housing electronics switching equipment for a communications company. The building is located near New York City and the winter design condition of 11¡F and 60% relative humidity (RH) (ASHRAE Fundamentals Handbook 1997, Chapter 26, p. 26.16).

The building is tightly sealed in order to control the indoor air quality (i.e., eliminate dust and control RH); 5% of the circulating air flow is filtered outdoor air to establish a positive pressure in the building. Cooling is provided by seven 20-ton air conditioners each with an air flow of 8,000 cfm. The air conditioners are set at the winter design condition so that there is no dehumidification of the incoming air; energy is wasted if it is first dehumidified by the air conditioner and then moisture added by the humidifier. The indoor design condition is 72¡F and 50% RH.

Humidity control has been provided by a 100 lb/h electrode canister humidifier with a nameplate power of 34 kW.

The number of annual operating hours for the humidifier will vary locally and is not well known. An estimate may be available from humidifier suppliers who have access to computer programs that perform an analysis of humidifier demand using hourly weather data. Alternatively, the building manager may need to perform a parametric analysis using several assumptions on humidifier operating hours. For this hypothetical analysis the operating hours are assumed to be 2,000 h/y.

New Technology Equipment Selection

A quick check can be made of the humidifier sizing. The humidity load for the building is expressed by:

$$H_{humidifier} = H_{load} - H_{sources} + H_{losses}$$

where the subscripts denote the load imposed by outdoor air entering the ventilation system, internal sources from people or building activities (e.g., cooking), and losses of moisture such as the air conditioner or condensation on cold surfaces. For this application the sources and losses are negligible.

The load due to outside air entering the ventilation system is calculated from:

$$H_{load} = \alpha \cdot Q_{airflow} \cdot \frac{i_{indoor} - i_{outdoor}}{100 \text{ cfm}}$$

where:

α is the fraction outside air brought into the ventilation system, Q is the total air flow rate (cfm), and i is the moisture content from Table 1 of the indoor and outdoor air at the design conditions.

For this example, $\alpha = 0.05$ and Q = 8,000 cfm for each of the seven air conditioners. Interpolation between the values in Table 1 gives $i_{indoor} = 3.70$ and $i_{outdoor} = 0.33$. The humidity load is thus:

$$H_{load} = 0.05 \cdot 8{,}000 \cdot \frac{3.70\text{-}0.37 \text{ lb/h}}{100 \text{ cfm}}$$

$$= 13.3 \text{ lb/h}$$

For this application, $H_{sources} = H_{losses} = 0$, so the humidifier load on each of the seven units is 13.3 lb/h and for the system $H_{humidifier}$ = 93 lb/h. Rounding up to 100 lb/h allows some excess capacity.

Once the load is known, equipment must be selected based on what capacities are commercially available. Each of the seven air conditioners can be equipped with an ultrasonic humidifier with a capacity of 15.8 lb/h and nameplate power of 375 W, for a total capacity of 110 lb/h.

Savings Potential

The installed cost of an electrode canister humidifier with 100 lb/h capacity is approximately $3,000.

Annual energy consumption is the number of hours of operation times the nameplate input power (kWh/year). Annual humidification load (lb H_2O/year) is computed by multiplying the nameplate rated capacity times the number of hours of operation.

For the baseline electrode canister humidifier the annual energy use is 68,000 kWh (2,000 h x 34 kW) and annual energy costs are $4,080 at $0.06 per kWh.

Routine servicing of the baseline system is required to remove mineral deposits from the reservoir, an annual cleaning of all moving parts, and periodic replacement of the electrodes. For purposes of this calculation it is assumed that the labor cost is $50/h and:

- the unit is serviced four times a year to remove mineral deposits, 1 hour of labor ($200/y)
- the electrode has an operating lifetime of 1,000 h and must be replaced twice a year, $175 parts and 1 hour labor ($450/y)
- there is an annual maintenance requiring disassembly of the drain valve for cleaning, 1 hours of labor ($100/y).

Annual non-energy operating and maintenance costs are $750.

Table 1. Moisture Content of Air (lb H_2O per hour/100 cfm)

Air Temp. (¡F)	Relative Humidity																	
	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	90%	100%
-20	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.06	0.07	0.08	0.08	0.09	0.09	0.10	0.12
-10	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.18	0.20
0	0.02	0.03	0.05	0.07	0.09	0.10	0.12	0.14	0.16	0.17	0.19	0.21	0.22	0.24	0.26	0.28	0.31	0.35
10	0.03	0.06	0.09	0.12	0.14	0.17	0.20	0.23	0.26	0.29	0.32	0.35	0.38	0.40	0.43	0.46	0.52	0.58
20	0.05	0.09	0.14	0.19	0.24	0.28	0.33	0.38	0.43	0.47	0.52	0.57	0.61	0.66	0.71	0.76	0.85	0.95
30	0.08	0.15	0.23	0.30	0.38	0.45	0.53	0.61	0.68	0.76	0.83	0.91	0.99	1.06	1.14	1.21	1.37	1.52
40	0.11	0.23	0.34	0.46	0.57	0.68	0.80	0.91	1.03	1.14	1.26	1.37	1.49	1.60	1.72	1.83	2.06	2.29
45	0.14	0.28	0.41	0.55	0.69	0.83	0.97	1.11	1.25	1.39	1.53	1.66	1.80	1.94	2.08	2.22	2.50	2.79
50	0.17	0.33	0.50	0.67	0.83	1.00	1.17	1.34	1.51	1.67	1.84	2.01	2.18	2.35	2.52	2.69	3.03	3.37
55	0.20	0.40	0.60	0.80	1.00	1.21	1.41	1.61	1.81	2.02	2.22	2.42	2.63	2.83	3.03	3.24	3.65	4.06
60	0.24	0.48	0.72	0.96	1.20	1.45	1.69	1.93	2.17	2.42	2.66	2.91	3.15	3.40	3.64	3.89	4.38	4.88
65	0.29	0.57	0.86	1.15	1.44	1.73	2.01	2.31	2.60	2.89	3.18	3.47	3.77	4.06	4.35	4.65	5.24	5.84
70	0.34	0.68	1.02	1.36	1.71	2.05	2.40	2.74	3.09	3.44	3.79	4.14	4.49	4.84	5.19	5.54	6.25	6.96
75	0.40	0.81	1.21	1.62	2.02	2.43	2.84	3.25	3.67	4.08	4.49	4.91	5.33	5.74	6.16	6.59	7.43	8.28
80	0.47	0.95	1.43	1.91	2.39	2.87	3.36	3.85	4.33	4.83	5.32	5.81	6.31	6.80	7.30	7.80	8.81	9.82
85	0.56	1.12	1.68	2.25	2.82	3.39	3.96	4.53	5.11	5.69	6.27	6.86	7.44	8.03	8.62	9.22	10.41	11.62
90	0.65	1.31	1.97	2.64	3.31	3.98	4.65	5.33	6.01	6.69	7.38	8.07	8.76	9.46	10.16	10.86	12.28	13.72
95	0.76	1.53	2.31	3.09	3.87	4.65	5.45	6.24	7.04	7.85	8.66	9.47	10.29	11.11	11.94	12.77	14.45	16.15

Ultrasonic humidifiers have an initial cost somewhat higher than other types of humidifiers. An equipment cost of $13,400 and installation cost of $1,000 are reasonable estimates for the application being discussed.

The configuration of seven ultrasonic humidifiers will operate fewer hours per year than the baseline electrode canister humidifier because this system has a total higher capacity (110 lb/h vs 100 lb/h). The annual humidification load of 200,000 lb H_2O will be provided in 1,820 hours of operation instead of 2,000. Annual power consumption is thus 4,800 kWh (seven times 0.375 kW times 1,820 h). Annual energy costs are $288 at $0.06 per kWh.

Ultrasonic humidifiers require maintenance of the water treatment equipment and periodic replacement of the electronic transducers. The cost of maintaining the water treatment system may be included in the cost of RO/DI water from a service company; if not estimates of labor and frequency of replacing the RO/DI canisters should be available from suppliers of deionized water.

This cost is significant in many instances and must be considered in all cost comparisons. It will vary with the level of dissolved solids in the local water supply, the annual water usage, etc.; values on the order of $0.07 per gallon or approximately $0.008 per lb H_2O are reasonable, although an estimate should be obtained from local suppliers of RO/DI water. Estimates range from $0.02 to $0.12 per gallon, $0.024 to $0.014 per pound. With a cost of $0.07 per gallon ($0.0084/lb), water treatment costs are $1,680/y.

Transducers for ultrasonic humidifiers have an expected lifetime of 10,000 operating hours; that is, 5.5 years at 1,820 h/y. Replacement transducers for 100 lb/h of capacity would cost approximately $1,200. About 6 hours of labor would be required to replace all the transducers. Total cost for transducer replacement is $1,500 for an average annual cost of $273 ($1,500 divided by 5.5 years). The combined average annual cost for RO/DI water and transducer replacement is thus $1,953.

A comparison of the two systems shows that the ultrasonic humidifier:

- saves 63,200 kWh per year or $3,792 at $0.06/kWh
- has non-energy O&M costs $1,203 higher than those of the electrode canister
- has replacement costs $11,400 higher than the electrode canister.

These costs and savings are summarized in Table 2.

There is an indirect cost or savings for an ultrasonic (or any adiabatic) humidifier due to the heat absorbed from the air from the mist leaving the humidifier. Approximately 1,000 Btu is absorbed from the air for every pound of water from the humidifier, or approximately 310 Wh/lb. The absorbed heat represents free cooling for an additional savings of about 100 W/lb H_2O (310 W/lb divided by the average COP of the air conditioner, 3). In heating, the absorbed heat must be replaced by the heating system and would represent an energy penalty on the order of 390 Wh/lb (assuming an 80% gas furnace). This indirect benefit results in an additional savings by reducing air conditioner energy use by approximately 20,000 kWh/y and energy costs by $1200/y at $0.06/kWh. These indirect savings are usually not included in life-cycle cost analyses prepared by the ultrasonic humidifier manufacturers.

Life-Cycle Costs

Table 3 shows the results of a life-cycle cost analysis comparing an ultrasonic humidifier with an electrode canister humidifier. Each humidifier has an annual load of 200,000 lb H_2O. Annual energy use is 67,200 kWh for the electrode canister humidifier and 4,800 kWh for the ultrasonic humidifier. Energy cost is assumed to be $0.06/kWh. Annual operating and maintenance costs are $750 for the electrode canister and $1,987 for the ultrasonic humidifier (assuming $0.07

Table 2. Comparison of Electrode Canister and Ultrasonic Humidifiers

	Electrode Canister Humidifier	Ultrasonic Humidifiers	Savings from Ultrasonic Humidifiers
Initial and Replacement Costs:			
a. Equipment	$1,000	$13,400	-$12,400
b. Installation	$2,000	$1,000	$1,000
c. Total	$3,000	$14,400	-$11,400
Energy Use and Cost			
a. Power Consumption	68,000	4,800	63,200 kWh
b. Energy Cost (@ $0.06/kWh)	$4,080	$288	$3,792/y
Non-energy O&M	$750	$1,953	$1,203

per gallon for RO/DI water). Replacement costs are $3,000 and $14,400 for the two systems, respectively.

The results in Table 3 are particularly sensitive to the cost of RO/DI water; sources have cited costs ranging from $0.02 to $0.07 per gallon. The results are also sensitive to the assumption for the number of operating hours for the humidifier.

Figure 3 shows the levelized energy costs from the preceding example across a range of water treatment costs and annual operating hours. Each line in the drawing shows the levelized energy costs at a fixed number of operating hours for RO/DI water treatment costs of $0.02 to $0.12 per gallon. As expected, the levelized energy costs decrease as the number of operating hours increase, with only small changes between 2,000 and 4,000 hours per year. The levelized energy cost is a linear function of the water treatment cost for a fixed number of annual operating hours.

Table 3. Life-Cycle Cost for Ultrasonic Humidifiers

Study Period: 20 years **Discount Rate: 4.1%**	**Electrode Canister Humidifier**	**Ultrasonic Humidifiers**	**Savings from Ultrasonic Humidifiers**
Initial Investment: Cash Requirements	$3,000	$14,400	-$11,400
Subtotal	$3,000	$14,400	-$11,400
Future Cost Items:			
Annual and Non-Annual Recurring Costs	$10,308	$26,030	-$15,722
Energy-Related Costs	$49,933	$5,869	$44,063
Total	$60,241	$31,899	$28,342
Total P.V. Life-Cycle Cost	$63,241	$46,299	$16,942
Net Savings:			
P.V. of non-investment savings			$28,342
- increased total investment			$11,400
Net Savings:			$16,942

Savings-to-Investment Ratio (SIR) for Ultrasonic Humidifiers Relative to Quartz Infrared

$$SIR = \frac{\text{P.V. of non-investment savings}}{\text{Increased total investment}} = 2.49$$

Adjusted Internal Rate of Return (AIRR): 8.95%

Simple Payback Occurs in Year 5

Discounted Payback Occurs in Year 6

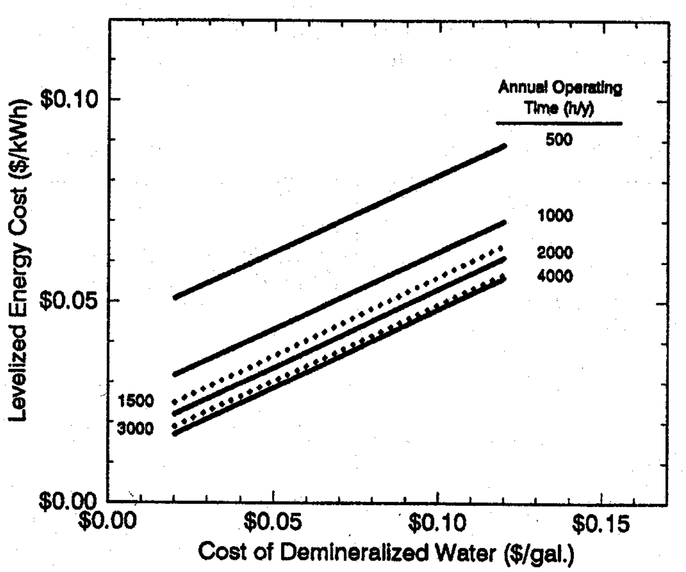

Figure 3. Parametric Analysis of Levelized Energy Cost for Set Operating Hours as Functions of Water Treatment Costs

The Technology in Perspective

The Technology s Development

Ultrasonic humidification is a relatively new technology and it should be considered carefully in buildings where RH levels must be maintained to reduce static electricity or for product quality. Although recent additions to the marketplace, these systems are proven to be effective. This technology should be compared with direct steam, steam-to-steam, wetted element, quartz lamp and electrode steam, and compressed air/water atomization systems. Ultrasonic humidifiers compare most favorably against the electric steam systems in regions with high energy costs and where simultaneous humidification and cooling are required.

Technology Outlook

Ultrasonic humidifiers will continue to be improved both in energy efficiency and in reduced costs as manufacturers compete for market share. It is unlikely, however, that there will be dramatic changes in cost or efficiency.

Manufacturers

The firms listed below were identified as suppliers of the technology at the time of this report s publication. This listing does not purport to be complete, to indicate the right to practice the technology, or to reflect future market conditions.

Ellis & Watts
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Fax: 513-752-4983

Energy-Wise, Inc.
P.O. Box 15443
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Phone: 202-547-3499
Fax: 202-547-3499

Humidifirst
120 South Street
Harrisburg, PA 17101
Phone: 717-231-7434
Fax: 717-231-7436
http://www.humidifirst.com

Liebert Corporation
1050 Dearborn Drive
P.O. Box 29186
Columbus, OH 43229
Phone: 800-877-9222
Fax: 614-841-6022
http://www.liebert.com

Stulz of North America
5350 Spectrum Drive, Suite I
Frederick, MD 21703
Phone: 301-663-8885
Fax: 301-663-9174
http://www.stulz.com

Who is Using the Technology

Federal Sites

There are no known Federal installations using ultrasonic humidifiers.

Non-Federal Sites

AT&T
White Plains, NY
Glen Calvano
(914) 397-5592

Sony, Inc.
Pitman, NJ
Fred Gilles
(609) 589-8000

Lucent Technologies
Breinigville, PA
Paul Grenewald
(610) 391-2640

TriQuint Semiconductors
Beaverton, OR
Terry Wilson
(503) 644-3535 x 1476

Stratus Computer
Marlboro, MA
Jack Bradley
(508) 460-2249

Steelcase, Inc.
Grand Rapids, MI
Dan O Malley
(616) 247-2710

For Further Information

ASHRAE 1995. HVAC Applications Handbook, Chapters 1-19.

ASHRAE 1996. HVAC Systems and Equipment, Chapter 20.

ASHRAE 1997. Fundamentals Handbook, pp. 26.1-26.53.

Longo, F. 1994. Ultrasonic Humidification for Telecommunications, Heating/Piping/Air Conditioning March, pp. 65-66.

Randazzo, M. 1997. Ultrasonic Humidifiers Save 1.5 Million Kwh/yr at N.J. Data Center, Energy User News, Reprint, January.

Shadid, B. 1994. The Cooling Effect of Ultrasonic Humidification, Heating/Piping/Air Conditioning, September, pp. 69-71.

Shadid, B. 1995. Maximizing Effectiveness in Humidification Retrofits, Engineered Systems, Reprint from March.

Shadid, B. 1993. The Wave of the Future: Ultrasonic Humidification, Engineered Systems, Vol. 10, No. 9, Reprint from November/December.

Appendix

Appendix A: Federal Life-Cycle Costing Procedures and the BLCC Software

Appendix A

Federal Life-Cycle Costing Procedures and the BLCC Software

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (10 CFR Part 436). A life-cycle cost evaluation computes the total long-run costs of a number of potential actions, and selects the action that minimizes the long-run costs. When considering retrofits, sticking with the existing equipment is one potential action, often called the *baseline* condition. The life-cycle cost (LCC) of a potential investment is the present value of all of the costs associated with the investment over time.

The first step in calculating the LCC is the identification of the costs. *Installed Cost* includes cost of materials purchased and the labor required to install them (for example, the price of an energy-efficient lighting fixture, plus cost of labor to install it). *Energy Cost* includes annual expenditures on energy to operate equipment. (For example, a lighting fixture that draws 100 watts and operates 2,000 hours annually requires 200,000 watt-hours (200 kWh) annually. At an electricity price of $0.10 per kWh, this fixture has an annual energy cost of $20.) *Nonfuel Operations and Maintenance* includes annual expenditures on parts and activities required to operate equipment (for example, replacing burned out light bulbs). *Replacement Costs* include expenditures to replace equipment upon failure (for example, replacing an oil furnace when it is no longer usable).

Because LCC includes the cost of money, periodic and aperiodic maintenance (O&M) and equipment replacement costs, energy escalation rates, and salvage value, it is usually expressed as a present value, which is evaluated by

$$LCC = PV(IC) + PV(EC) + PV(OM) + PV(REP)$$

where PV(x) denotes "present value of cost stream x,"
IC is the installed cost,
EC is the annual energy cost,
OM is the annual nonenergy O&M cost, and
REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost-reducing alternative and the LCC of the existing, or baseline, equipment. If the alternative's LCC is less than the baseline's LCC, the alternative is said to have a positive NPV, i.e., it is cost-effective. NPV is thus given by

$$NPV = PV(EC_0) - PV(EC_1)) + PV(OM_0) - PV(OM_1)) + PV(REP_0) - PV(REP_1)) - PV(IC)$$

or

$$NPV = PV(ECS) + PV(OMS) + PV(REPS) - PV(IC)$$

where subscript 0 denotes the existing or baseline condition,
subscript 1 denotes the energy cost saving measure,
IC is the installation cost of the alternative (note that the IC of the baseline is assumed zero),
ECS is the annual energy cost savings,
OMS is the annual nonenergy O&M savings, and
REPS is the future replacement savings.

Levelized energy cost (LEC) is the break-even energy price (blended) at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost-effective (NPV >= 0). Thus, a project's LEC is given by

$$PV(LEC*EUS) = PV(OMS) + PV(REPS) - PV(IC)$$

where EUS is the annual energy use savings (energy units/yr). Savings-to-investment ratio (SIR) is the total (PV) savings of a measure divided by its installation cost:

$$SIR = (PV(ECS) + PV(OMS) + PV(REPS))/PV(IC).$$

Some of the tedious effort of life-cycle cost calculations can be avoided by using the Building Life-Cycle Cost software, BLCC, developed by NIST. For copies of BLCC, call the FEMP Help Desk at (800) 363-3732.

About the Federal Technology Alerts

The Energy Policy Act of 1992, and subsequent Executive Orders, mandate that energy consumption in the Federal sector be reduced by 30% from 1985 levels by the year 2005. To achieve this goal, the U.S. Department of Energy's Federal Energy Management Program (FEMP) is sponsoring a series of programs to reduce energy consumption at Federal installations nationwide. One of these programs, the New Technology Demonstration Program (NTDP), is tasked to accelerate the introduction of energy-efficient and renewable technologies into the Federal sector and to improve the rate of technology transfer.

As part of this effort FEMP is sponsoring a series of Federal Technology Alerts (FTAs) that provide summary information on candidate energy-saving technologies developed and manufactured in the United States. The technologies featured in the FTAs have already entered the market and have some experience but are not in general use in the Federal sector. Based on their potential for energy, cost, and environmental benefits to the Federal sector, the technologies are considered to be leading candidates for immediate Federal application.

The goal of the FTAs is to improve the rate of technology transfer of new energy-saving technologies within the Federal sector and to provide the right people in the field with accurate, up-to-date information on the new technologies so that they can make educated judgments on whether the technologies are suitable for their Federal sites.

Because the FTAs are cost-effective and timely to produce (compared with awaiting the results of field demonstrations), they meet the short-term need of disseminating information to a target audience in a timeframe that allows the rapid deployment of the technologies—and ultimately the saving of energy in the Federal sector.

The information in the FTAs typically includes a description of the candidate technology; the results of its screening tests; a description of its performance, applications and field experience to date; a list of potential suppliers; and important contact information. Attached appendixes provide supplemental information and example worksheets on the technology.

FEMP sponsors publication of the FTAs to facilitate information-sharing between manufacturers and government staff. While the technology featured promises significant Federal-sector savings, the Technology Alerts do not constitute FEMP's endorsement of a particular product, as FEMP has not independently verified performance data provided by manufacturers. Nor do the FTAs attempt to chart market activity vis-a-vis the technology featured. Readers should note the publication date on the back cover, and consider the FTAs as an accurate picture of the technology and its performance at the time of publication. Product innovations and the entrance of new manufacturers or suppliers should be anticipated since the date of publication. FEMP encourages interested Federal energy and facility managers to contact the manufacturers and other Federal sites directly, and to use the worksheets in the FTAs to aid in their purchasing decisions.

Federal Energy Management Program

The Federal Government is the largest energy consumer in the nation. Annually, in its 500,000 buildings and 8,000 locations worldwide, it uses nearly two quadrillion Btu (quads) of energy, costing over $8 billion. This represents 2.5% of all primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to Federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the Federal infrastructure.

Over the years several Federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; and, most recently, Executive Order 12759 in 1991, the National Energy Policy Act of 1992 (EPACT), and Executive Order 12902 in 1994.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting New Technology Demonstrations, to hasten the penetration of energy-efficient technologies into the Federal marketplace.

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