Modern Evaporative Coolers

Not all evaporative coolers are created equal. Modern machines operate more efficiently and with much less fuss than the old swamp coolers did.

ADOBE

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Here is an inside view *(left)* and an outside view *(right)* of a modern evaporative cooler by Adobe.

by Larry Kinney

Dave Emmitt owns Direct Drive Service, a company in Colorado that specializes in efficient low-mass boilers—and high-efficiency evaporative coolers. We're not talking swamp coolers on the roof of a mobile home; Emmitt's staff install coolers in the attics of large, site-built homes. The coolers pull in air from large gable vents, cool it by 30°F or so, and distribute it via several large ducts, typically to a hallway below. Cool air is directed by the patterns of window openings or by backdraft dampers, also known as up ducts, in the ceilings of rooms on the top story. The process is controlled by a multifunction thermostat that has the smarts to throttle back the fan speed when the setpoint temperature is about to be met, rinses out the reservoir to keep water and air clean, and partially automates much of the end-of-season maintenance.

"We install modern evaporative cooler systems in new homes that cost $2 million," reports Emmitt. "These people can afford conventional compressor-based cooling and the higher bills that go with it, but they prefer the better comfort and fresh, clean air our systems give them. The $300 we save them on their utility bill each summer just pays for a barbeque with 50 of their closest friends."

Emmitt's retrofit business is also doing quite well. Colorado homeowners who have never had cooling systems generally tend to install conventional A/C systems—as do those who are disenchanted with their old swamp coolers. But if Emmitt gets to them first, they are more likely to upgrade to one of the high-quality evaporative coolers he installs, which deliver two or three ACH and wash the pollen out of that air before it gets inside. Emmitt is enjoying a growing customer base, fueled largely by word of mouth from happy customers.

Evaporative Cooling Innovations

Emmitt wouldn't be getting the same good word of mouth if he were selling old-fashioned swamp coolers, but modern evaporative coolers are several technological leaps ahead of those old machines. All evaporative coolers—old and new—rely on the same design principle: Water can be used to cool air. Air blowing through a wet medium—a tee shirt, aspen fibers (excelsior) or treated cellulose, fiberglass, or plastic—evaporates some of the water and its dry bulb temperature is lowered (see "Wet's the Difference: Dry Bulb and Wet Bulb Temperatures"). The cooling effect of an evaporative cooler depends on two factors. The first is the local difference between the air's dry bulb and wet bulb temperatures; the second is the cooler's efficiency (see Table 1, p. 27). Exactly how an evaporative cooler takes advantage of water's chilling effect—the pathway and the velocity of the air as it passes over the media combined with the condition of the media—determines how efficient it is as a cooling device.

Today's evaporative coolers come in one of three general designs: direct, indirect, and indirect/direct. Modern direct evaporative coolers couple high-performance media—generally plastic-coated cellulose—with low-velocity air flow. This combination maximizes moisture transfer from the wet media to the hot, dry air. The effectiveness with which an appliance makes this transfer—known in the trade as its direct saturation effectiveness—is a key measurement of the appliance's cooling efficiency.

Direct evaporative coolers humidify the incoming air, making them inappropriate for use in humid climates. Indirect evaporative coolers take advantage of evaporative cooling effects, but use an air-to-air heat exchanger to cool without raising the humidity of the cooled airstream. Indirect/direct coolers cool in two stages. In the first stage, the air passes through an indirect cooler, which lowers the temperature without adding humidity. The air that enters the second, direct cooling stage is already substantially cooler than the outside air, and it can be cooled a good deal more because it's still largely dry. Combining these two techniques enables efficient indirect/direct units to deliver air that is cooler than the outside wet bulb temperature.

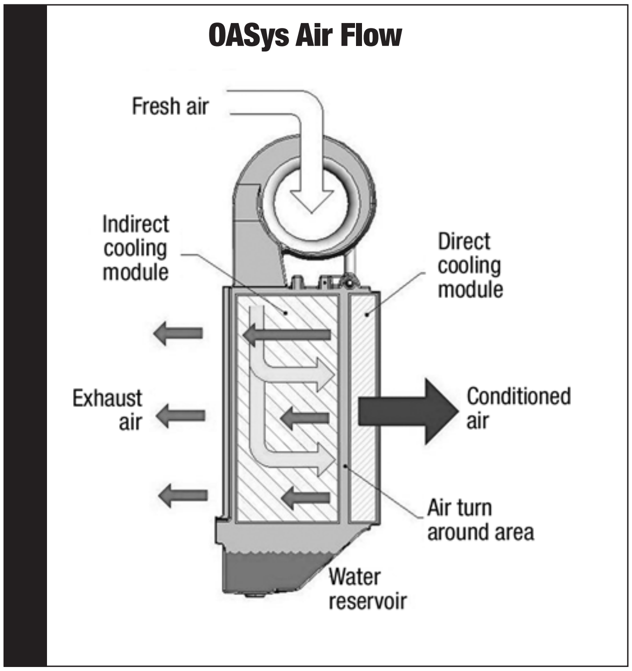


Figure 1. The OASys system employs a single cabinet that houses all its parts. This simplifies the overall design, helps maintain tolerances, shortens assembly time, and ensures a long lifetime.

After losing a good deal of market share to conventional cooling, there's optimism in the evaporative cooling industry that higher-quality units will lead the way to recovery (see "Copious Refinements," p. 28). One particularly promising new design is being manufactured by Speakman CRS—short for Clean, Renewable, Sustainable—a branch of the Speakman Company, a firm that has been producing showerheads and other water-related products for more than 130 years. The company manufactures an indirect/direct evaporative cooler, called the OASys, that was developed by the Davis Energy Group in Davis, California (see Figure 1).

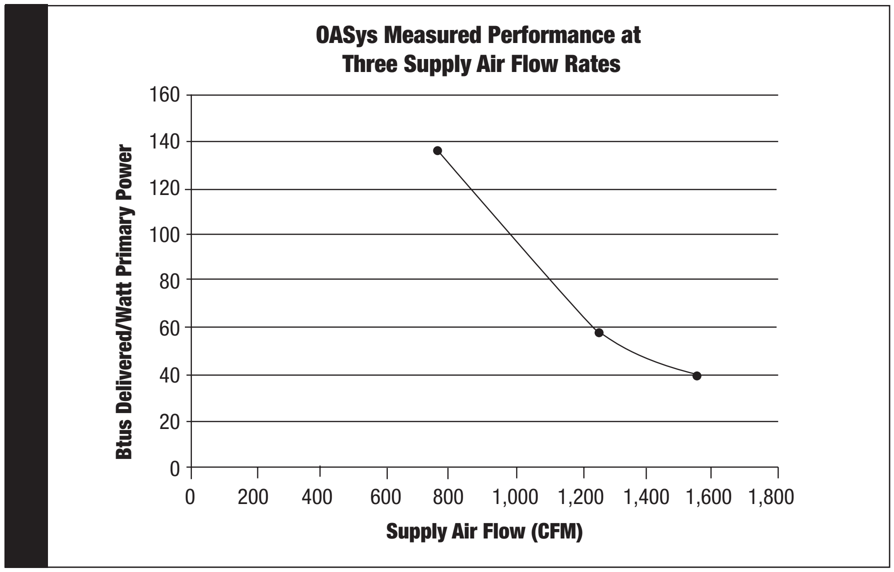
The OASys system uses a single blower that pulls in outside air and directs most of it—about 70%—through the dry side of a heat exchanger that uses 14-inch-thick media to efficiently and indirectly cool the airstream without adding moisture. This partially cooled air then passes through a direct-cooling module before being directed into the home. About 30% of the outside airstream is used in the other, wet side of the counterflow heat exchanger, where it is cooled, gathers moisture, and is then discharged to the outdoors. Water from both the indirect- and the direct-cooling processes gathers in a single reservoir, which is purged with a frequency that is tied to the amount of scale-causing minerals in local tap water and the rate of water use by the system. The rate of water use in turn depends on the blower speed, which is controlled by a multifunction thermostat.

This machine incorporates a number of improvements over earlier indirect/direct evaporative coolers designed for residential use. It employs a single polyethylene cabinet that houses all parts of the system. This substantially simplifies the overall design, helps maintain tolerances, shortens assembly time, and ensures a long lifetime. The OASys also uses an electronically commutated motor (ECM) controlled by a smart thermostat, so blower speed can be changed while maintaining high motor efficiency. This is important, because overall system efficiency of the OASys is best at low fan speeds and low air flow rates (see Figure 2).

Engineers at the Davis Energy Group took these plots of efficiency at different flow rates and other test results—such as temperatures delivered under different conditions of wet and dry bulb temperatures—and performed simulations of a very efficient 1,600 ft^2 home in eight of

California's climate zones. The results for Fresno are most pertinent for the Southwest, as Fresno has a hot, arid climate not unlike many locations in the Southwest (1% dry bulb 101°F, mean coincident wet bulb 70°F). The base case home with a conventional DX air conditioning system rated at 12-SEER uses 1,890 kWh per year with a peak of 3 kW, while the OASys uses 135 kWh per year with a peak of 0.52 kW. This amounts to an annual energy savings of 93% and a peak demand savings of 83%.

In another evaporative cooling development, AdobeAir has recently introduced its own series of efficient evaporative coolers that fit in a sidewall (see Figure 3). These units are easy to install either in new dwellings or as retrofits and have clear aesthetic and mechanical advantages over rooftop or concrete-pad-mounted coolers.



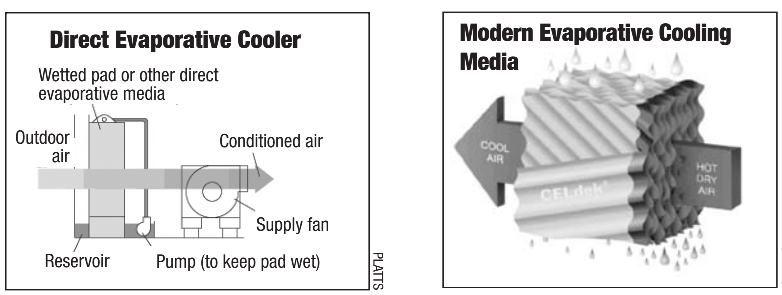
LARRY KINNEY

Figure 2. The data gathered was at entering dry bulb temperatures of 104ºF, with the unit supplying dry bulb temperatures of 68ºF. Power plotted is the sum of fan and pump power. The vertical axis shows overall efficiency in that it expresses the ratio of cooling Btu's out versus the combined power use of the pump motor (20 watts or so) and that of the power consumed by the fan motor. The point of the graph is that spectacular efficiencies are achieved at lower flows, both because of the overall design of the device and the fact that its motor is quite efficient at low speeds—unlike most motors used in the evaporative cooling industry. (Source: Davis Energy Group.)

Water and Energy Use

There's no getting away from the fact that an evaporative cooler relies on, and so consumes, a significant amount of water, but the newer units use up much less than the old-fashioned coolers do. Evaporating 1 lb of water yields about 1,060 Btu of cooling. Accordingly, if an evaporative cooler were 100% effective, 1 gallon of water would yield roughly 8,800 Btu of evaporative cooling. If the flow of water and the flow of air are well matched in a carefully designed evaporative cooler, the air is cooled efficiently and most of the water in the media is evaporated. However, some extra water is needed to flush out the residue of air pollutants and scale in the water. In inefficient units, water that is not evaporated by the cooler is continuously diluted by makeup water in the reservoir or sump, with the residue going down an overflow drain. This bleed system contin-

Wet's the Difference: Dry Bulb and Wet Bulb Temperatures



PLATTS

MUNTERS

Figure A. Direct evaporative coolers use a fan to pull outside air through pads that are wet (left), filtering and cooling the air (right).

The temperature of air measured with a thermometer whose sensing element is dry is known as dry bulb temperature. If a thermometer's sensing element is surrounded by a wick wetted with pure water over which air is blown, the sensor is evaporatively cooled to its wet bulb temperature. When the relative humidity is at 100%, there is no difference between the dry bulb temperature and wet bulb temperature. But as the relative humidity of the air drops, so does wet bulb temperature with respect to dry bulb temperature. In climates such as those in the Southwest, where humidity is routinely quite low, the differences are substantial. For example, at 10% relative humidity and a dry bulb temperature of 90ºF, the wet bulb temperature is 58ºF—a difference of 32ºF. This difference is often called the depression of wet bulb below dry bulb.

Direct evaporative coolers use a fan to pull outside air through media (pads) that are kept thoroughly wet by water that is sprayed or dripped on them (see Figure

Table 1. Delivery Temperatures for Selected Cities in the Southwest

City	Dry Bulb Ambient Temp (°F)	Wet Bulb Ambient Temp (°F)	Depression (°F)	Temp Delivered @ 85% Effectiveness (°F)	Temp Delivered @ 105% Effectiveness (°F)
Albuquerque	93	60	33	65	58
Cheyenne	85	57	28	61	56
Denver	90	59	31	64	57
Las Vegas	106	66	40	72	64
Phoenix	108	70	38	76	68
Salt Lake City	94	62	32	67	60
Tucson	102	65	37	71	63

Note: Table shows delivery temperatures under severe conditions. During 99% of the typical cooling season, ambient temperatures and delivery temperatures are lower than those shown in the table.

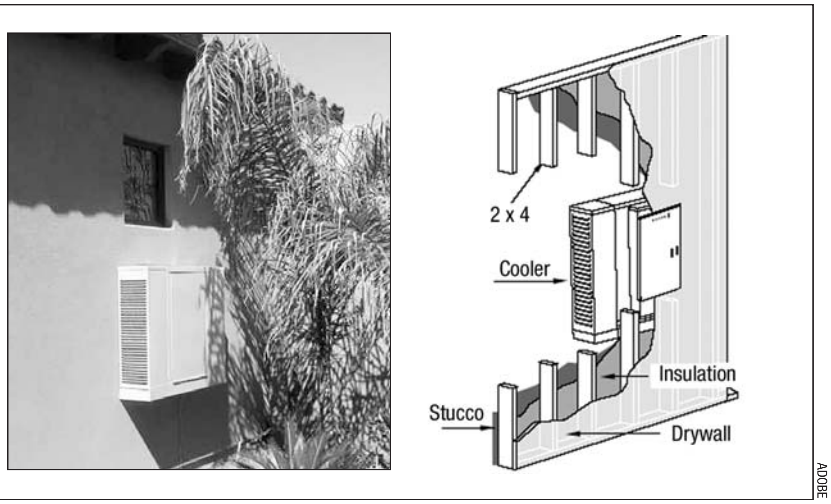


Figure 3. A new evaporative cooler by Adobe installs in the wall at the side of a home (photo and schematic).

uously dilutes the water and reduces the concentration of scale and impurities, but this method of cleaning wastes water.

Higher-quality units use a more effective and less wasteful batch process to deal with impurities. The sump is typically sloped so that heavier pollutants and scale tend to collect at the bottom. There is no continuous dilution; instead, after the cooler has run for several hours, the reservoir is drained and flushed automatically. Well-designed machines key the need for dumping to the elapsed run time of the pump so as to keep the sump full, but not overflowing. The residue of several gallons from this sump dump may be piped to a nearby garden. With this system of periodic purging, almost all of the water—over 95% in most places—is used to provide cooling. And the amount of water that is discharged is well matched to the needs of a garden; more water is delivered on hot days when the evaporative cooler works the most and plants are especially thirsty.

The trade-off for this water use at a home is that evaporative coolers reduce a power plant's use of water to generate electricity, because they use substantially less energy for cooling than conventional direct expansion (DX) air conditioning systems would. Generating 1 kWh of electricity with a thermoelectric plant in

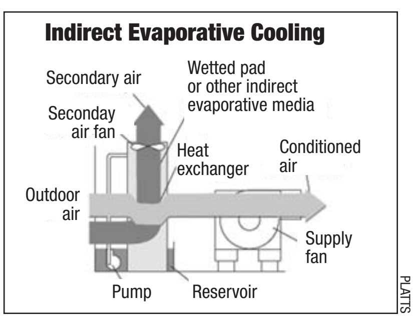


Figure B. Indirect evaporative cooling adds a second stage of evaporative cooling before the conditioned air enters the home.

A). This both filters the air and cools it. Lower fan speeds give the air more exposure time to the wetted media, which achieves greater cooling. Media for evaporative coolers have to be efficient, which means that they must allow for as much cooling as temperature conditions allow, while minimizing pressure drop, which saves fan power. Well-designed media filter the airstream, but are also self-cleaning, in that water dripping across them to the sump below performs a cleaning function. The water is typically delivered via tubes from a small pump that draws from a reservoir below. The reservoir is replenished with tap water whose level is controlled by a float valve. The resulting fresh, cool, humidified air is blown into buildings.

Direct evaporative cooler performance is measured relative to the wet bulb depression. Well-designed and properly operating systems with media at least 10 inches thick can achieve 93% effectiveness; that is, the dry bulb temperature can drop by 93% of the difference between the dry bulb and wet bulb temperatures. Older-style systems that typically use 2 inches of excelsior may achieve effectiveness ratings of 50% to at most 80%. I do not recommend the use of these less efficient units, although they are less expensive, because they also tend to waste water.

Indirect coolers commonly make use of an air-to-air heat exchanger (see Figure B). The main fan supplies outside air that is cooled by passing through a heat exchanger into the dwelling, while a secondary fan draws exhaust air from the dwelling, or fresh air, or some combination of the two through wetted passages that are in thermal contact with the dry passages of the heat exchanger.

Copious Refinements

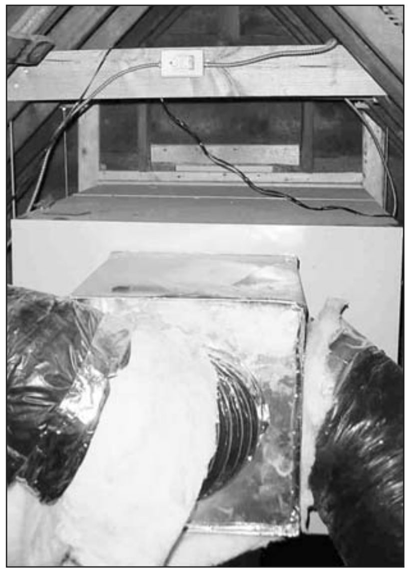
The word on innovations in evaporative cooling technology is anything but widespread, and this lack of awareness translates to meager sales—and the installation of conventional central compressor-based cooling systems. To help overcome barriers to embracing high-quality evaporative cooling systems, we present a summary of salient points.

Media. Instead of aspen fibers, or excelsior, which tend to shrink down with use, causing inefficiency and shortening the life of the unit, modern evaporative cooling media are made of special plastic-coated cellulose or similar material. This material is formed into a rigid rectilinear shape, typically between 4 and 24 inches thick. Air passageways are fluted to maximize cooling effectiveness while minimizing pressure drop (and fan power). The thicker the media, the greater the temperature drop of the air from entry to exit. Efficient units have media at least 8 inches thick; 12 inches or more is even better. The media resist scale and algae, are easy to clean, and last for many years, especially in regions where the water is largely free of impurities.

Appearance. Instead of having air flow in on all four sides, efficient machines that use thick media are designed to have unconditioned air flow in on one side, while conditioned air flows out the opposite side or out the bottom. This allows units to be placed in attics, on sidewalls, or on small pads outside the home, instead of on the roof.

Air quality. Conventional A/C systems are most effective when the home is tightly sealed and fresh-air makeup is at the minimum. Typical fresh-air rates for these systems are only 0.33 ACH, sometimes much less. Modern evaporative coolers literally wash and filter incoming air, leaving it substantially free of pollen, dust, and most pollutants. Typically, they provide fresh air at rates of 2–3 ACH.

Water. Evaporative coolers use water, but well-designed modern coolers use a batch flushing process to clean the sump, rather than a continuous bleeding process. The result is better cleaning and substantially lower water use. Modern coolers in efficient homes in the Southwest use about 3.3% of average annual residential water use. This amount of water costs \$5–\$20 per cooling season.



DIRECT DRIVE SERVICE

The photo shows an attic installation of a Phoenix evaporative cooler by Direct Drive Service. The cooler is installed close to the fresh-air intake and moves air into 24-inch-diameter supply ducts. The ducts are well insulated (improving energy performance and reducing noise) and relatively short, as they typically feed conditioned air into an upstairs hallway. Intake air ducts range from 28 x 42 inches down to 24 x 36 inches; the smaller size will accommodate a 3,000 CFM evaporative cooler. The cooler is suspended from trusses and uses vibration isolators at top and bottom. In the interests of safety, an electric cutoff is installed close to the unit, so that it can be maintained without risk of shock.

Security. Systems that rely on backdraft dampers (up ducts and related devices) to control the flow of evaporatively cooled air allow the windows in a home to be closed and locked.

Controls. Systems that make use of dampers that open when the home is pressurized by an evaporative cooler blower are typically equipped with digital thermostatic controls. These controls turn the system on and off; vary the blower speed to maximize energy efficiency in line with local weather conditions, indoor temperature, and the thermostat's setpoint; and control sump-flushing functions both during normal operations and at the end of the cooling season. This reduces end-of-season maintenance to a simple chore that can be done in only a few minutes.

Comfort. The increased efficiency of modern evaporative coolers—especially indirect/direct models; their digital controls; and their better distribution of cooled air make it possible to achieve comfortable temperatures in most Southwest climate zones throughout the cooling season. Many people thrive on the more humid air that evaporative cooling delivers—but, in truth, others aren't as enchanted. Short-term discomfort in very hot regions that occasionally experience periods of high humidity—such as the monsoon season in the low desert regions of Arizona—cannot be fully avoided. The solution of backup conventional A/C is undesirable from a policy perspective, since these periods typically correspond to peaks on the electric grid. Our grandparents dealt with it philosophically, with the help, no doubt, of plenty of cold beverages. Our periods of discomfort are much shorter and less intense than theirs were, and the quality of beer has been enhanced immeasurably!

Energy. An 1,800 ft^2 home in the Southwest that is about 48% more energy efficient than a home built to just meet the year 2000 International Energy Conservation Code for residential structures will save 3,600 kWh per year by using an efficient evaporative cooler rather than a 13-SEER central air conditioning system. Those who live in less efficient or larger homes save much more.

Table 2. Water and Energy Use in the Southwest

City	Cooling Energy DX (kWh/yr)	Cooling Energy Evaporative (kWh/yr)	Energy Saved (kWh/yr)	DX Source Water Use (Gal)	Evaporative Source Water Use (Gal)	Water Saved at Source (Gal)	Evaporative Site Water Use (Gal)	Net Evaporative Water Use (Gal)	Annual Increase HH Water Use Due to Evap Cool (%)
Albuquerque	2,487	334	2,153	1,244	167	1,077	3,470	2,394	2.6
Cheyenne	1,773	287	1.485	886	144	743	2,435	1,692	1.4
Denver	1,935	279	1,656	968	140	828	2,685	1,857	1.7
Las Vegas	4,722	497	4,225	2,361	249	2,112	6,696	4,583	2.6
Phoenix	6,043	574	5,469	3,022	287	2,735	8,619	5,884	5.1
Salt Lake City	2,839	357	2,483	1,420	178	1,241	3,981	2,739	2.1
SW average	4,063	438	3,625	2,032	219	1,813	5,754	3,941	3.3

DIRECT DRIVE SERVICE

This attic has an evaporative cooler (shown on p. 28) installed less than 1 ft from this fresh-air intake vent. Vents are closed during the heating season. An option under consideration is the addition of outside insulating shutters.

the Southwest uses about 0.5 gallons of water.

I ran simulations to estimate the energy and water used for cooling in six cities in the Southwest (see Table 2). The homes modeled are efficient 1,800 ft^2 structures whose overall energy use is 48% lower than that of homes that just meet the requirements of the year 2000 International Energy Conservation Code for the weather conditions associated with each city. I assumed that the DX systems have an energy efficiency rating (EER) of 11.1—roughly corresponding to a seasonal energy efficiency rating (SEER) of 12.9—and a thermostat setpoint of 76°F.

According to this analysis, modern residential evaporative coolers in the Southwest use an average of 5,800 gallons of water per year at the site, ranging from 2,400 gallons in Cheyenne to 8,600 gallons in Phoenix. For single-family households, this figure represents an average of only 3.3% of annual water use. However, from the overall environmental point of view, which takes into account water used at the power station, net water use for evaporative cooling averages 3,900 gallons of water per year, ranging from 1,700 gallons in Cheyenne to 5,900 gallons in Phoenix.

Most important by far is the savings in electricity use—and cost to the consumer—achieved by using evaporative instead of DX-based cooling (see Table 3). I compared the annual cost to the end user of using either a DX-based or an evaporative system to cool an 1,800 ft^2 new home that slightly exceeds Energy Star standards in five Southwestern cities. When local water rates are higher with increased consumption, the computations shown assume the higher marginal cost per gallon of water used. Water and electricity rates applicable to single-family residences in each city in 2003 were used to estimate costs.

First costs of cooling equipment tend to be a function of their efficiency, whether the systems are conventional or evaporative coolers. In the case of conventional A/C units, split systems have more than 3 times the market share of packaged systems. Average costs weighted for market share are $1,771 for A/C equipment and $3,265 for installed costs.

Single-stage evaporative cooling systems that have a saturation effectiveness of greater than 80% under all operating conditions, variable-speed (or at least two-speed) motors, and a sump dump feature for effective cleaning with minimal water use, cost from $600 to $1,120, depending on saturation effectiveness and blower horsepower. Blower horsepower is the principal factor that determines air flow rates. Equipment for indirect/direct evaporative coolers whose saturation effectiveness is in the 105%–110% range cost from $1,700 to slightly less than $3,000. Installation costs are lower than they are for central A/C systems, largely because ductwork is substantially simplified. Installations on a concrete pad next to a home cost from $600 to $1,000, while attic installations run from $800 to

$1,400, depending on the number of upducts that must be installed, and on such factors as access to plumbing and electricity.

Considering these cost ranges, the total installed cost for an efficient single-stage evaporative cooling system is typically between $1,600 and $2,200. The total installed cost for an efficient indirect/direct evaporative cooler is on the order of $2,500 to $3,500. In general, installed costs for efficient evaporative equipment are lower than installed costs for comparable compressor-based central cooling systems. Lifetime (20-year) costs—including first costs, maintenance costs, and energy costs over 20 years—are on the order of $5,500 in the Southwest. For a comparable compressor-based cooling system, lifetime costs would be roughly double, depending on the local climate.

Table 3. Cooling Cost Comparisons

City	Cooling Energy DX Cost ($/Yr)	Cooling Energy Evap Cost ($/Yr)	Cooling Energy Saved with Evap ($/Yr)	Evap Water Cost ($/Yr)	Total Evap Cooling Cost ($/Yr)	Net Savings Evap vs DX ($/Yr)
Albuquerque	214	29	185	5	33	181
Cheyenne	151	24	126	6	30	121
Denver	141	20	121	5	25	116
Las Vegas	444	47	397	13	60	384
Phoenix	502	48	454	20	68	434
Salt Lake City	185	23	161	5	28	157
SW average	335	36	299	12	48	287

Utility Incentive Programs

Meeting demand for electric power during peak periods in the summer is a major—and burgeoning—problem for most utilities in the fast-growing Southwest. Indeed, peak demand is rising faster than total electricity sales throughout the region. Most new homes in the Southwest include air conditioners whose demands are at least 3 kW—sometimes much more—and existing housing is increasingly being retrofitted with conventional air conditioning. Given these considerations, a number of utility companies have initiated demand-side management (DSM) programs that provide incentives to owners of both existing and new homes to install energy-efficient evaporative cooling equipment.

In California, both the Pacific Gas and Electric Company (PG&E) and Southern California Edison (SCE) have programs that provide incentive payments of $300 to $500 for the purchase of energy-efficient evaporative coolers. To qualify, units must have a saturation efficiency of 85% or better; must have sump water removal systems (no water-wasting continuous bleeding systems); and must be configured to automatically exhaust air through pressure relief dampers (up ducts) into the attic, and then through attic vents to the outdoors. SCE requires a variable-speed fan and a dedicated thermostat remote from the cooler. Both utilities offer an additional rebate of $100 for the installation of up ducts in the attic.

In Colorado, Utah Power and Xcel Energy are expanding their programs that support evaporative cooling installations. Both utilities are experimenting with ways to steer consumers toward buying highly efficient units while still providing some incentives for lower-end evaporative coolers. Other utilities in the Southwest either have small-scale programs in operation or are in the planning stages.

I am hopeful that these types of program, as well as partnerships between programs like DOE's Building America and those conducted by local utility companies, will persuade production builders to construct model homes that illustrate the advantages of excellent evaporative cooling. These examples could help to establish the credibility of modern evaporative cooler systems that are appropriately integrated into well-designed homes.

To bring the technology to full fruition, designers and builders need to think of evaporative cooler systems as systems thoroughly integrated into energy-efficient structures. Techniques for sealing them carefully and simply during shoulder and winter seasons, and to eliminate the risk of freezing, need to be developed. Up ducts need to be redesigned to be thoroughly insulated and positively sealed during times when cooling is not needed, and optimized to ensure good distribution of cooling air. Further, controls need to be developed that not only vary fan speeds and control water-cleaning cycles, but also monitor efficiency performance to signal the need for maintenance. Finally, there is room for improvement in the heat exchanger technology used in indirect cooling systems. Several companies are working to develop more efficient systems that require less pressure drop across indirect media while achieving more effective cooling.

Larry Kinney is a senior researcher at the Southwest Energy Efficiency Project (SWEEP).

For more information:

"New Evaporative Cooling Systems: An Emerging Solution for Homes in Hot Dry Climates with Modest Cooling Loads" and "Evaporative Cooling Policy and Program Options: Promising Peak Shaving in a Growing Southwest" can be downloaded at www.swenergy.org.

Torcellini, P., N. Long, and R. Judkoff. *Consumptive Water Use for Power Production.* NREL/CP-550-35190. Golden, Colorado: National Renewable Energy Laboratory. November 2003.

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