Evaporative Cooling for a Growing Southwest: Technology, Markets, and Economics

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ABSTRACT

The Southwest is growing rapidly—a 37% increase in population is projected from 2000 to 2020 versus 16% for the total US. This is placing great pressures on an electric grid that must meet this new demand, much of which is caused by compressor-based air conditioning, a technology increasingly becoming the norm in both the residential and commercial sectors. Yet the region's climate is ideally suited for evaporative cooling, both because of its low humidity and large diurnal temperature swings. Lower front end costs and substantially lower energy and demand costs continue to characterize evaporative cooling systems as new sensors and controls coupled with longer-life, more-efficient, and easier-to-maintain equipment for the residential and commercial sectors have become available in the marketplace.

Both compressor-based cooling and evaporative cooling systems are becoming more efficient, but on a Btu-of-cooling-per-kWh-of-electricity basis, modern evaporative cooling systems are at least four times more efficient and demand is less by a factor of four or more.

This paper examines:

- The range of new technologies and trends in upgrading existing technologies in evaporative cooling;
- The cost-effectiveness of evaporative cooling versus compressor-based cooling;
- The market status of evaporative cooling in the Southwest and barriers to penetration; and
- Recommendations for promoting evaporative cooling systems in all sectors, including ongoing programs in the Southwest.

The stakes are high. Assuming a penetration of high-efficiency evaporative coolers in efficient new homes built in the Southwest between 2000 and 2020 reaches 40% by the end of 2020, we estimate that savings (versus SEER 13 air conditioning units) in the year 2020 will be 4,228 GWh of electric energy and 2,874 MW of peak demand savings. This will avoid the need for building four 700 MW power plants. Since incremental costs versus conventional air conditioning are negative, paybacks are instantaneous. However, water use must also be taken into account. High-efficiency residential evaporative coolers use an average of 5,100 gallons of water per year in the Southwest, about 3% of average annual residential water use. This amount of water costs $5 to $20 per cooling season. However, since evaporative coolers save on the order of 3,200 kWh per year, about 1,600 gallons of water are saved at the power station, for a net water use of 3,500 gallons. Net dollar savings for new homeowners are $254 per year.

Introduction

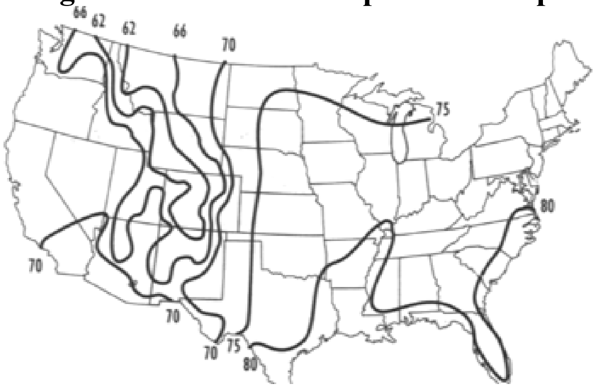
There's a world of difference between old-style swamp coolers and modern evaporative cooling systems. The former are cheap, require regular maintenance, consume more electricity, and waste water. The latter can provide years of trouble-free service and cool, clean, comfortable, fresh air at a lower energy cost than convention air conditioners—and initial costs are competitive as well. In addition, the latest evaporative cooler designs are a lot easier on the grid than are compressor-based cooling systems. Instead of peak demands of three to five kilowatts (kW) or more, typical demands for mid-size evaporative coolers are well less than one kW. In addition to improved performance, modern evaporative coolers include options for thermostatic control and automated flushing of reservoir water to reduce buildup of impurities. Accordingly, wide-spread use of evaporative coolers can help delay adding expensive new power plants to the electric grid and the controversial transmission lines that often accompany them. This is the main reason that a number of utility companies in areas with hot, dry summers and substantial population growth have programs to promote efficient evaporative coolers.

How Evaporative Cooling Works

When air blows through a wet medium—a tee shirt, aspen fibers (excelsior), or treated cellulose, fiberglass, or plastic—some of the water is transferred to the air and its dry bulb temperature is lowered. The cooling effect depends on the temperature difference between dry and wet bulb temperatures, the pathway and velocity of the air, and the quality and condition of the medium.

Dry bulb and wet bulb temperature. 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 wet wick 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 dry and wet bulb temperatures, but as the relative humidity of the air drops, so does the 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 percent relative humidity and a dry bulb temperature of 90ºF, the wet bulb temperature is 58ºF, a 32 degree difference. This is often called the "depression" of wet bulb below dry bulb. Climates with such large depressions favor evaporative cooling techniques, as shown in Figure 1.

Figure 1. Wet Bulb Temperature Map



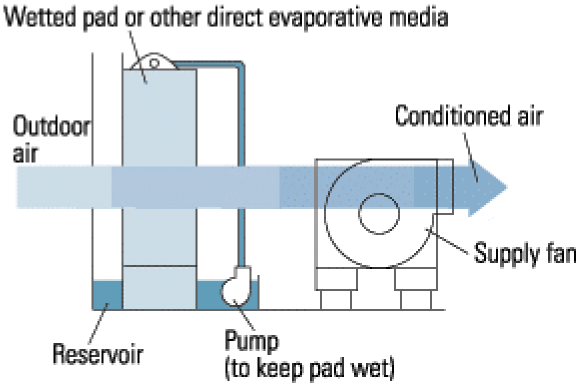
Source: Roy Otterbein, Otterbein Engineering; Home Energy, May/June 1996

The map shows lines of equal wet bulb temperatures that are not exceeded for more than 1% of the time during the cooling season. Weather regions with 1% wet bulb temperatures of 70ºF or below can be comfortably cooled with direct evaporative coolers, and those with 1% wet bulb temperatures of up to 75ºF can be made comfortable for many people.

Types of Evaporative Coolers

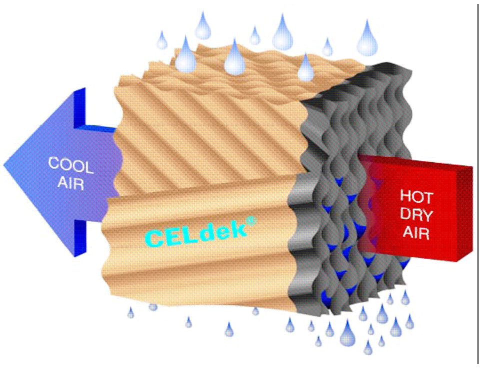
"Direct" evaporative coolers use a fan to pull outside air through media (pads) that are kept thoroughly wet by water that is sprayed or dripped on them (Figures 2 and 3). This both filters the air and cools it. Lower speeds give more exposure time to the wetted media, thereby achieving more cooling. Media for evaporative coolers has to be efficient, which means that it must allow for as much cooling as temperature conditions allow while minimizing pressure drop, thereby saving fan power. Well-designed media filters the air stream, but is also self-cleaning, in that water dripping across it 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 where the pattern of flow (and cool air delivered) is determined by the location and extent of openings in the conditioned envelope such as windows or special dedicated ducts, including "up-ducts" in the attic floor. These are effectively back-draft dampers which open when the home is pressurized by the evaporative cooler blower, thereby controlling the distribution of cooling air without the need for opening windows. Air is exhausted from attic vents.

Figure 2. Direct Evaporative Cooler



Source: Platts

Figure 3. Modern Evaporative Cooling Media

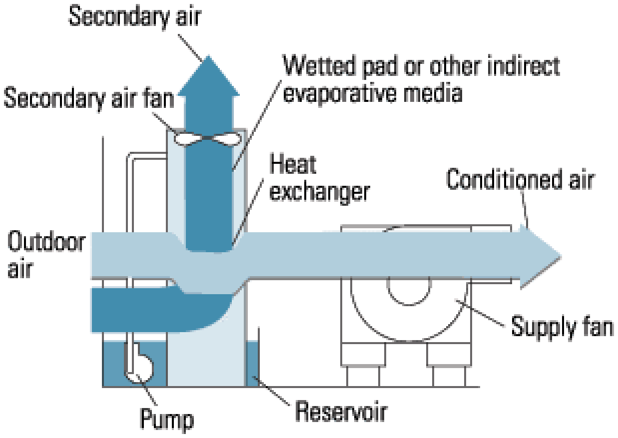


Source: Munter

Modern evaporative coolers couple high-performance media with low-velocity air flow. They maximize moisture transfer as the air traverses the media to enhance "direct saturation effectiveness," which is analogous to cooling efficiency. Direct evaporative cooler performance is measured relative to the wet bulb "depression." Well-designed systems with thick (10 to 12 inches or more) media operating properly can achieve 93% effectiveness, whereas older style systems that typically use two inches of excelsior may achieve effectiveness of 50% to at most 80%. We do not recommend their use, although they are less expensive, because these less efficient units also tend to waste water.

"Indirect**"** evaporative coolers take advantage of evaporative cooling effects, but cool without raising indoor humidity. Figure 4 shows a common configuration of indirect cooling that makes use of an air-to-air heat exchanger. The main fan supplies outside air through the dry passages of a heat exchanger into the dwelling, while a secondary fan delivers exhaust air from the dwelling, fresh air, or some combination through wetted passages in thermal contact with the dry passages of the heat exchanger. A variation, called "indirect/direct," adds a second stage of evaporative cooling before the conditioned air enters the dwelling to further lower the temperature of the incoming air. Efficient indirect/direct units can deliver air that is cooler than the outside wet bulb temperature.

Figure 4. Indirect Evaporative Cooling



Source: Platts

Table 1 shows delivery temperature at 85% saturation effectiveness (corresponding to a good-quality direct cooler) and delivery temperature at 105% (corresponding to a good-quality indirect/direct two stage evaporative cooler) for seven Southwestern cities.

Table 1. Delivery Temperatures for Selected Cities in the Southwest

City	Dry bulb ambient temp (ºF)	Wet bulb ambient temp (ºF)	Depression (ºF)	Temp delivered @ 85% effectiveness (ºF)	Temp delivered @ 105% effectiveness (ºF)
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 that these delivery temperatures shown in the table are under severe conditions. During 99 percent of the typical cooling season, ambient temperatures (and delivery temperatures) are lower than those shown in the table.

Water Issues

Evaporating a pound of water yields about 1,061 Btu of cooling. Accordingly, if the process were 100% effective, a gallon of water could yield 8,700 Btus of evaporative cooling. Water is used to thoroughly wet a medium in the air stream, which tends to dry the medium and cool the air. Ideally, 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 is evaporated. However, some extra water is important to flush 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 make-up water in the reservoir (sump), the residue going down an overflow drain. This "bleed" system continuously 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. Instead of continuous dilution, after an elapsed running time of the cooler of several hours, the reservoir is drained and flushed automatically. 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 is used to provide cooling. In all events, the discharged portion 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.

While an evaporative cooler does consume a significant amount of water, it also saves water consumed at the power plant (assuming a less energy-efficient compressor-based air conditioner would be used for cooling if the evaporative cooler were not used). Generating a kWh of electricity with a new coal plant in the Southwest uses about 0.67 gallons of water, while a new natural-gas-fired plant consumes about 0.33 gallons of water per kWh generated. For the analysis that follows, we estimate the mix at 0.5 gallons/kWh for the Southwest. Since conventional direct expansion (DX) air conditioning systems use substantially more energy than do evaporative coolers, water use at the power plant (source) is proportionally greater.

Simulations were conducted to estimate energy and water use (Table 2). The homes modeled are efficient 1800 square foot structures whose overall energy use is 48 percent lower than homes that just meet the requirements of the year 2000 International Energy Conservation Code for the weather conditions associated with each city. We assumed 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 set point of 76 degrees F. We also assumed a run time of the evaporative coolers to exceed that of the replaced conventional compressor-based air conditioning systems by 43% at an average power consumption of 800 watts.

Table 2. Water and Energy Use in the Southwest

City	Cooling Energy DX (kWh/yr)	Cooling Energy Evap (kWh/yr)	Energy Saved (kWh/yr)	DX Source Water Use (gal)	Evap Source Water Use (gal)	Water Saved at Source (gal)	Evap Site Water Use (gal)	Net Evap Water Use (gal)	Annual increase HH water use due to evap cool (%)
Albuquerque	2,487	334	2,153	1244	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	2361	249	2,112	6,696	4,583	2.6%
Phoenix	6,043	574	5,469	3022	287	2,735	8,619	5,884	5.1%
Salt Lake City	2,839	357	2,483	1420	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%

According to this analysis, modern residential evaporative coolers in the Southwest use an average of 5,754 gallons of water per year at the site, ranging from 1,692 gallons in Cheyenne to 8,619 gallons in Phoenix. For single family households, this amount of water use represents an average of only 3.3% of annual water use. However, from the overall environmental point of view that takes into account water used at the power station, net water use averages 3,941 gallons of water per year, ranging from 2,435 gallons in Cheyenne to 5,884 gallons in Phoenix. On average in the Southwest, net water use is 68% of the water used at the site.

Most important by far is the savings in electricity use—and cost—achieved by using evaporative instead of DX-based cooling. An examination of operating cost figures is shown in Table 3. This shows annual cost to the end user of cooling 1800 square foot new homes in five Southwestern cities that slightly exceed ENERGY STAR® standards, comparing DX and evaporative cooling. 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.

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

Annual water costs for evaporative cooling average $12 per year in the efficient homes analyzed in the Southwest, ranging from $5 in Albuquerque, Denver, and Salt Lake City to $20 in Phoenix. On average, water costs with evaporative cooling diminish energy saving dollars by only about 4%. Even accounting for water costs, overall cooling season savings average $287 per year in energy efficient homes in the Southwest, ranging from $116 in Denver to $434 in Phoenix. Further, lower electricity demand may help delay building new power plants with their associated water use, air pollution, and fossil fuel consumption (provided that they are designed and installed in a way that they effectively reduce peak cooling loads even during the monsoon seasons in areas where they occur.)

First Costs

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

The equipment for single-stage evaporative cooling systems with a saturation effectiveness of greater than 80% under all operating conditions, variable (or at least two) speed motors, and a sump-dump feature for effective cleaning with minimal water use, range in cost from $600 to $1,120, depending on saturation effectiveness and blower horsepower. Blower horsepower is the principal determining factor in air flow rates. Equipment for two-stage (indirect/direct) evaporative coolers whose saturation effectiveness is in the 105% to 110% range is $1,700 to slightly less than $3,000. Installation costs are lower than they are for central air conditioning systems in large measure because of substantially simplified ducting. Installations on a concrete pad next to a home run from $600 to $1000 while attic installations run from $800 to $1,400, depending on the number of up-ducts that must be installed and other factors like 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 to $2,200. The total installed cost for an efficient two-stage evaporative cooler is on the order of $2,500 to $3,500. In general, installed costs of efficient evaporative equipment are lower than installed costs for comparable compressor-based central cooling systems. Lifetime (20 year) costs are much less, on the order of $5,500 in the Southwest.

Choosing Efficiency

As with conventional air conditioning systems, evaporative coolers that deliver more cooling cost more to purchase, cost more to operate, and make more noise (because they must move more air than those which deliver less cooling energy.) To optimize economic and energy performance, as well as to maximize comfort, it is best to ensure that:

- the home's envelope is well insulated and air sealed;
- windows have low solar heating gain coefficients (SHGC); and
- effective exterior shading devices (overhangs, fins, shutters, louvers, strategically-located vegetation) are employed to block direct beam sunshine during the cooling season.

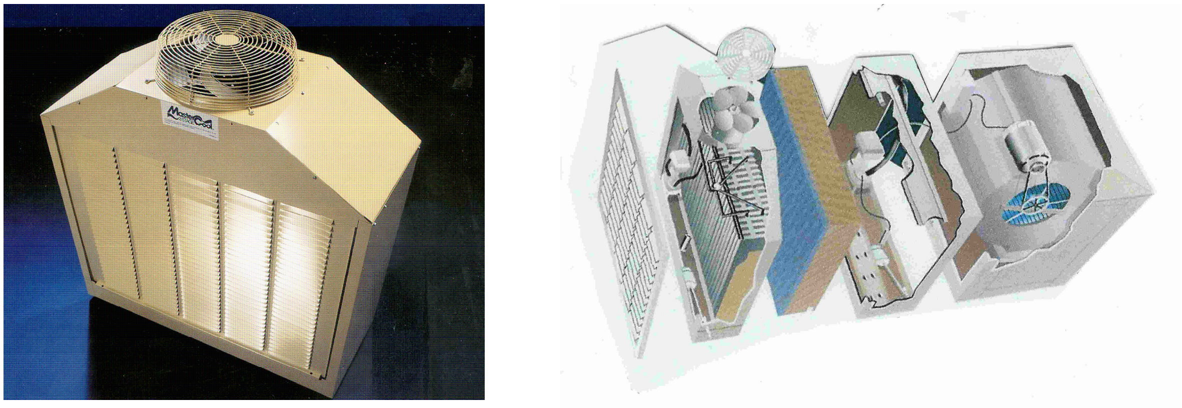
These strategies will lower the cooling load and enable smaller, less-expensive cooling equipment to be used.

In general, low-end, direct systems that use only several inches of media (that must be replaced frequently) are inefficient and waste water. Although their low cost makes them attractive for some uses, they are generally a bad choice for the long term. Better by far are single-inlet systems with thick media resulting in saturation effectiveness of at least 80% under all operating conditions, variable speed motors, a sump-dump feature for effective cleaning with minimal water use, and thermostatic controls.

Indirect/direct evaporative coolers can achieve comfort in a wider range of climate zones than direct machines because they are capable of delivering air that is several degrees below wet bulb temperature, and that is drier than the air delivered by direct coolers. As a consequence, they are well matched to climates in such fast-growing areas as Las Vegas, Tucson, and Phoenix.

Only two manufacturers are currently producing indirect/direct evaporative coolers for the residential market in the U.S. AdobeAir's Model 6500 Master Cool unit has been in the market for almost a decade. As shown in Figure 4, one or two indirect cooling stages may be added to the outside air side of a direct evaporative cooling unit. It uses 12 inch thick media and a 1 horsepower blower to deliver conditioned air that is several degrees below outside air wet bulb temperature under most circumstances. Each indirect module has its own small fan to move air through the wet passages. According to the company's product literature, on a hot day in which dry bulb temperature is 104ºF and wet bulb is 69ºF, AdobeAir's MasterCool direct system with no indirect cooling module delivers 75ºF air to the conditioned space and has 33,600 Btu/hour cooling capacity. With the addition of one indirect cooling module, the system produces 68ºF air delivering 56,400 Btu/hour, and with two indirect cooling modules, 66ºF air delivering 81,600 Btu/hr of cooling energy. Compared with a conventional A/C unit with a SEER of 12, operating costs (energy plus water) are at least 70% lower for AdobeAir's indirect/direct system in most hot climate zones.

Figure 4. AdobeAir's MasterCool Indirect/Direct Evaporative Cooler

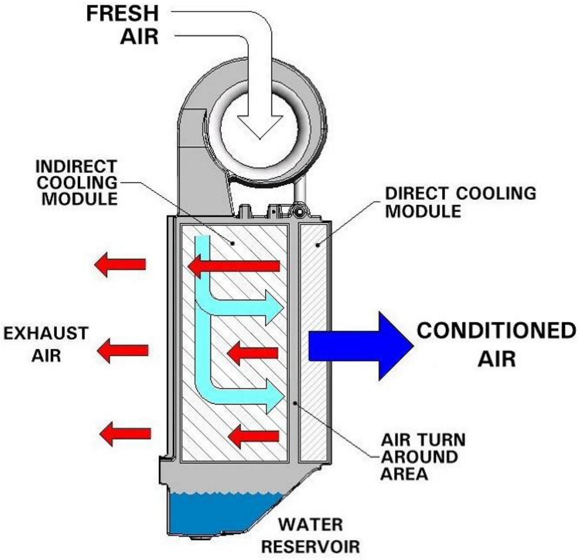


Source: AdobeAir

Speakman CRS (for "Clean, Renewable, Sustainable") is a branch of the Speakman Company, a Delaware firm that has been producing shower heads and other water-related products for more than 130 years. The company is a newcomer to the evaporative cooler field, but is now manufacturing and distributing a newly-modified indirect/direct evaporative cooler called the OASys, that was developed by the Davis Energy Group in Davis, California.

As shown in Figure 5, the system uses a single blower that pulls in outside air and directs most of it (about 73%) through the dry side of a heat exchanger that uses 14 inch thick media to efficiently indirectly cool the air stream without adding moisture. This partially-cooled air then passes through a direct cooling module before being directed into the home. About 27% of the outside air stream is used in the other (wet) side of the counter-flow heat exchanger, where it is cooled, gathers moisture, and then is discharged to the outdoors. Water from both the indirect and direct cooling processes gathers in a single reservoir where it is purged with a frequency reflective of the amount of scale in local tap water and the rate of water use by the system (which depends on the blower speed that is controlled by a thermostat).

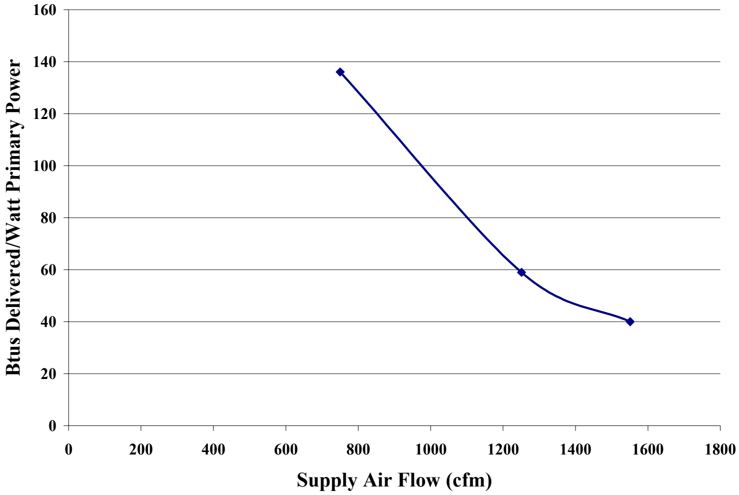
Figure 5. OASys Air Flow



Source: Davis Energy Group

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 efficiency. Figure 6 shows how system efficiency varies with fan speed. 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.

Figure 6. OASis Measured Performance at Three Supply Air Flow Fates



Source: Davis Energy Group; Lawrence Berkeley National Laboratory

Engineers at the Davis Energy Group took these and other test results and performed simulations of a very efficient 1600 square foot home in eight of California's climate zones. It is useful to examine the results for Fresno, which has a hot, arid climate not unlike many locations in the Southwest (1% dry bulb temp 101ºF, wet bulb 70ºF). The base-case home with a conventional DX air conditioning system rated at 12 SEER uses 1886 kWh/yr with a peak of 3 kW, while the OASys uses 135 kWh/yr with a peak of 0.52 kW. This amounts to an annual energy savings of 93% and a peak demand savings of 83%. Simulation results reflect a thermostat setting of 80ºF for the conventionally air conditioned home, but 78ºF for the evaporatively cooled home to compensate for higher indoor humidity in the latter case.

The Market

This kind of savings points the way to potentially very cost-effective use of energy-efficient evaporative cooling systems in those regions in which 99 percent of the time wet bulb temperatures are 72ºF or below. This applies to new home construction as well as retrofit. Yet the disturbing market trend is moving toward more compressor-based air conditioning. The market penetration of whole- house evaporative coolers in new construction is no more than 4 percent throughout the Southwest region (including California). The retrofit market is largely similar. Home owners without cooling tend to select conventional A/C systems when upgrading, rather than evaporative coolers. Further, many home owners with old-style evaporative units tend to upgrade to A/C units rather than to more efficient evaporative coolers.

The greatest barriers to acceptance of the newly-improved evaporative cooling technology appear to be misperceptions based on the performance of old technology and the lack of awareness on the part of the buying public—and the builders who serve them. For the vast majority of the public—and the building profession—evaporative cooling means unsightly, low-tech, and often poorly-performing swamp coolers that waste water. With modern coolers, none of these shortcomings hold. However, a major education and awareness-building effort is needed to convince homeowners and builders that evaporative cooling can be a high-performance alternative to conventional air conditioning systems—it is potentially much less costly over its lifetime, and can be designed to be at least as comfortable as the alternative.

Savings Potential

Toward evaluating options, it is useful to examine potential savings in the fast-growing states in the Southwest. Projections are that there will be about 2.9 million new housing units built in the Southwest between 2000 and 2020, 17% of the U.S. total. Of these new housing units, 23% are projected to be in multi-family buildings, the remainder in single-family structures. Table 4 shows electric and demand savings achieved in the year 2020 under two penetration rates of energy-efficient evaporative coolers versus SEER 13 A/C units: 20% and 40% penetration rates.

This analysis is quite conservative, for it assumes a high level of energy-efficient homes (that is, savings would be greater to the degree that new homes are not as efficient as assumed.) Estimates of energy savings under the 40% scenario translate to a dollar savings in the year 2020 of $335 million, a figure that also accounts for water use. The demand savings is equivalent to avoiding the building of four 700 MW power stations. This is a key reason some utilities in the region are conducting incentive programs to stimulate the adoption of evaporative cooling in new and retrofit homes.

Table 4. Electric Energy and Demand Savings in 2020 Versus SEER 13 A/C under Two Scenarios of Evaporative Cooling Market Penetration in New Homes built between 2000 and 2020

State	New Housing units between 2000 and 2020 (thousands)	Elec Savings in 2020 @ 20% Evap Cool (GWh)	Demand Savings in 2020 @ 20% Evap Cool (MW)	Elec Savings in 2020 @ 40% Evap Cool (GWh)	Demand Savings in 2020 @ 40% Evap Cool (MW)
Arizona	1,127	1,233	563.5	2,466	1127
Colorado	617	204	308.5	409	617
Nevada	399	337	199.5	674	399
New Mexico	351	151	175.5	302	351
Utah	380	189	190	377	380
Totals	2,874	2,114	1,437	4,228	2,874

Recommendations

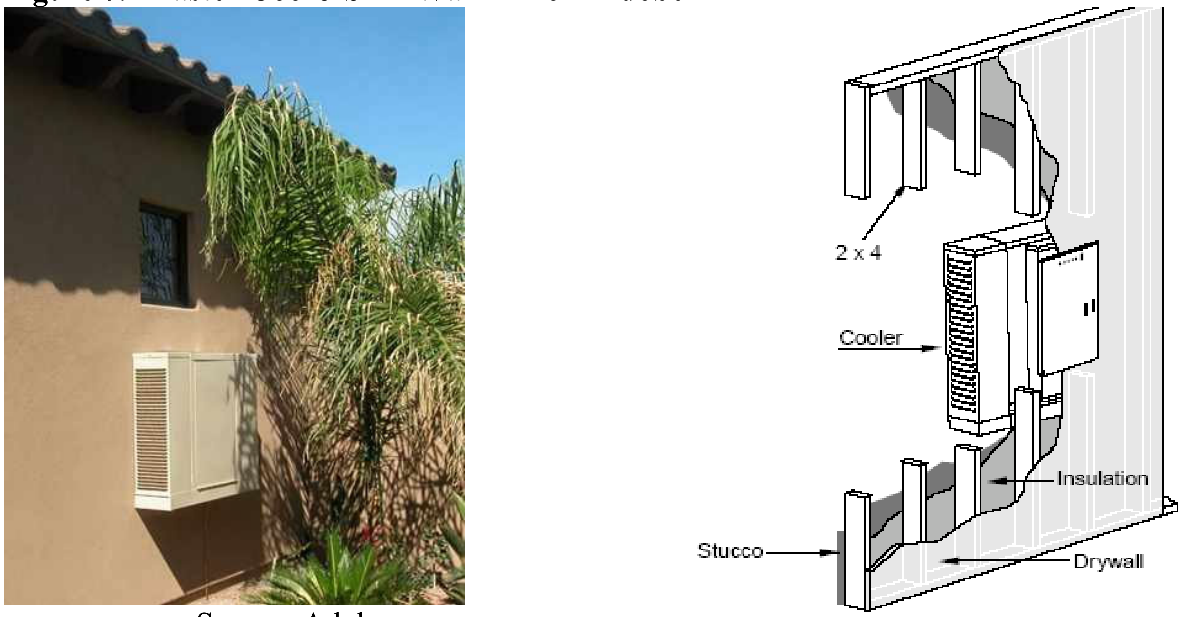
Utility companies in the region have the opportunity to play an important role by providing cash incentives for the purchase of high-efficiency evaporative coolers and publicizing their advantages both to the public at large and to the building community. Incentive levels of $500 for high-efficiency direct coolers and $1,000 for indirect/direct coolers would have a strong effect in ensuring market transfer toward high-quality units.

Forming partnerships between local utility companies and production builders to construct model homes that illustrate the advantages of excellent evaporative cooling will help establish the credibility of modern evaporative cooler systems appropriately integrated into a well-designed home.

Building a tight, well-insulated model home with careful attention to fenestration (shading, appropriate solar heat gain coefficients versus orientation) is fundamental, of course, as are techniques that both reflect and reradiate sunlight striking the roof. Installing a high-quality evaporative cooler in the attic (or at the side of a home, as with Adobe's new product, Figure 7) in conjunction with well-insulated up-ducts and intelligent controls will meet the cooling needs of the home quite efficiently while maintaining a high degree of comfort and indoor air quality. The home could then be heated via a hydronic system, optimally via a radiantly-heated slab, a system which is becoming less costly and is quite reliable. A solar hot water system could supply domestic hot water as well as a substantial portion of the low-temperature needs of the hydronic heating system in the sunny Southwestern climates, with back-up from an efficient, tankless boiler. The result would eliminate conventional duct systems with their associated economic and energy inefficiencies and achieve excellent overall cost effectiveness—as well as health, safety, and comfort.

There is a need on the part of designers and builders 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 coupled with ensuring that there is no 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 which 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, and several companies are working to develop more efficient systems which require less pressure drop across indirect media while achieving more effective cooling.

Figure 7. Master Cool® Slim Wall™ from Adobe



Source: Adobe

Acknowledgements

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