PG&E *Research and Development*

Evaluation of Residential Evaporative Condensers In PG&E Service Territory

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California statistics show that residential air conditioners consume 9% of total residential energy use, yet contribute 58% to peak summer demand (CEC, 1989). To address this problem, PG&E initiated several projects to investigate emerging technologies that apply principals of evaporative cooling to reduce air conditioner energy demand.

Two evaporatively cooled condensing units were selected for detailed study. The "Evapcon" uses a conventional air-cooled condenser surrounded by wetted evaporative media which pre-cools air drawn through the finned-tube condenser coil. The "AC2" uses similar evaporative media to cool water in a manner similar to a cooling tower. While both evaporative condenser (EC) technologies benefit from the dry outdoor conditions common to California, the AC2 offers the added advantage of direct refrigerant to water heat exchange by immersing the copper tube condenser coil in the water sump.

PG&E's Technical and Ecological Services (TES) laboratory in San Ramon tested conventional air-cooled 10 and 12 SEER condensers and the two EC systems under varied outdoor conditions. To validate the laboratory test results, which demonstrated "high temperature" condensing unit efficiencies up to twice as high as a 10 SEER unit, further field monitoring was completed on five residential and one small commercial site.

This report synthesized the detailed laboratory and field test results and developed performance relationships for an hourly computer model used to predict annual energy use for each system type. The key objectives of the study were to identify customer energy and operating cost savings, and to determine at what incremental cost EC technologies are cost-effective without any utility incentives.

The DOE-2.2 building simulation tool was used to model four residential and one small commercial building type. These buildings were simulated with 10 and 12 SEER air-cooled condensers, and EvapCon and AC2 EC system types. The buildings were evaluated in six California climate zones representing a range of mild coastal to hot inland climate conditions.

Results indicate favorable EC performance compared to air-cooled condensing units. On average the EvapCon is projected to save nearly twice the energy as a SEER 12 system, with an AC2 saving over five times the energy. In benchmarking performance to standard 10 SEER equipment, full-season "SEERs" as high as 11.9 (EvapCon) and 16.1 (AC2) are projected. An additional utility (and customer first cost) benefit is the average 12% downsizing potential (~1/2 ton) for EC systems due to their stable capacity at high outdoor temperatures.

Results of this study, combined with field and laboratory monitoring, suggest that the potential for ECs to succeed in California is substantial. With current incremental cost assumptions, paybacks as short as 5 years for the office case and 6 years for residential, can be realized in hot climate areas. Favorable customer economics, and the opportunity to decrease cost of service by improving utility load factors, make ECs worthy of continuing market transformation efforts.

1.0. BACKGROUND

Residential air conditioning has become commonplace over the last several decades in much of the country as comfort demands have increased and cooling equipment costs have fallen. Vapor compression cooling is well suited to warm moist climates where dehumidification is needed, but the performance of air-cooled condensing units degrades significantly under the high dry bulb temperatures experienced in much of the Pacific Gas & Electric Co. service territory. As refrigerant condensing temperatures rise with increasing outdoor temperature, air-cooled condenser electrical demand increases and cooling capacity and operating efficiency falls.

Two factors favor the use of evaporative technology in California's residential and small commercial buildings: (1) low nighttime temperatures experienced in most California climate zones attenuate the concentration of loads in afternoon periods, resulting in poor load factor for air-cooled systems, and (2) dry conditions (and low wet-bulb temperatures) usually accompany hot weather events and periods of high system demand. Air conditioning condensers that are evaporatively cooled maintain peak condensing temperatures as much as 30-40°F lower, thereby substantially reducing demand and potentially improving load factor.

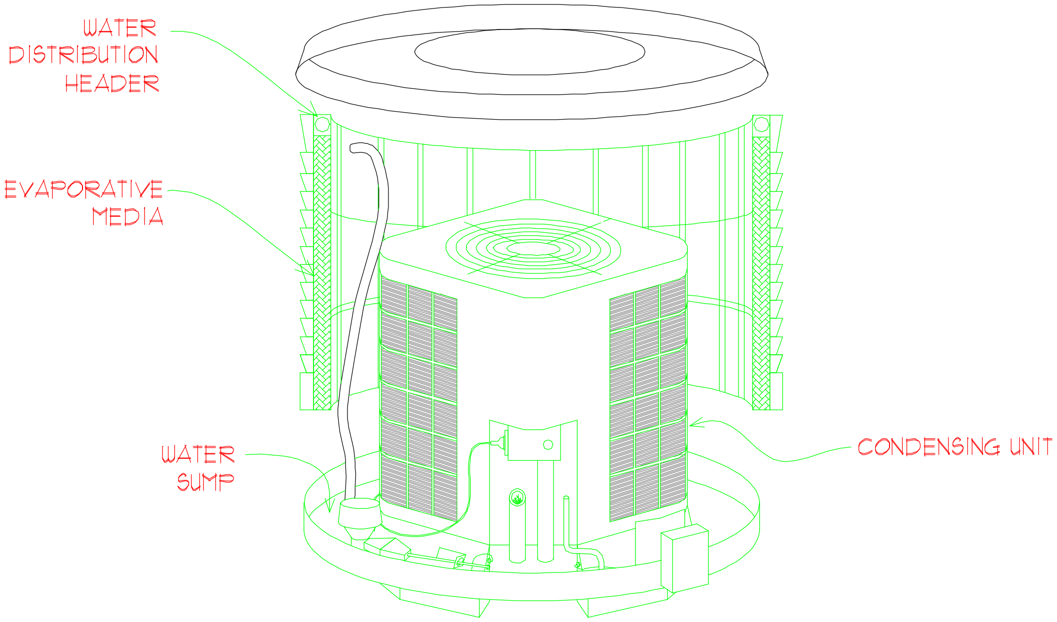
Evaporative condensers (ECs), which have long been used in the commercial sector, are an emerging residential technology. They operate by rejecting condenser heat to a medium (either air or water) that is cooled by the evaporation of water. PG&E is interested in determining the performance benefits that ECs offer, as well as the projected customer economics for this new technology.

2.0. EVAPORATIVE CONDENSER TECHNOLOGY DESCRIPTION

Two commercially available, residential-scale evaporative condensers were evaluated in this project. The first generation unit ("EvapCon"), an evaporative condenser pre-cooler, utilizes wrap-around evaporative media supported by a fiberglass frame to pre-cool air entering a conventional condensing unit. As shown in Figure 1, the pump located in the water sump at the base of the unit distributes water to the evaporative media. By drawing outdoor air through the wetted media, the condenser inlet temperature is reduced, improving cooling system capacity and efficiency, and reducing electrical demand.

The EvapCon was previously installed and monitored in two utility-sponsored residential integrated design projects. As part of Pacific Gas and Electric Company's Advanced Customer Technology Test, EvapCon units were monitored at sites in Stockton, CA (PG&E, 1994) and in Walnut Creek, CA from 1993 to 1996. Two installations in the Palm Springs area were also monitored under a Southern California project. The Palm Springs study demonstrated a 21% EvapCon efficiency improvement relative to the same condensing unit without EvapCon at an outdoor dry bulb temperature of 100°F (CIEE, 1995).

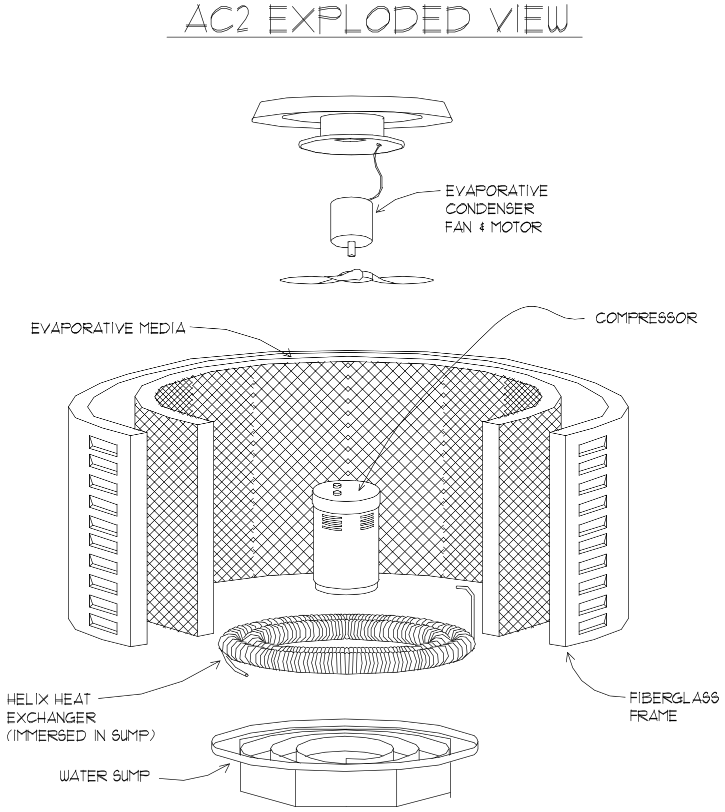
Figure 1: "Evapcon" Evaporatively Cooled Condenser



The second generation EC unit, the "AC2", is a true evaporative condenser. Introduced in 1997, the AC2 replaces the fin-tube air-cooled condenser coil with an immersed refrigerant-to-water helical copper heat exchanger. As shown in the exploded view in Figure 2, water is circulated through a counterflow heat exchange path in the sump containing the condenser coil, then over the evaporative media, and back to the sump. A fan draws outdoor air through the wetted evaporative media, cooling sump water to within 5-10^{0}F of the outdoor wet bulb temperature. The immersed heat exchanger offers significant performance benefits due both to improved refrigerant-to-water heat transfer and to lower condensing.

An air-cooled condenser operating at 100°F outdoor dry bulb temperatures will have a refrigerant condensing temperature of about 120°F. An AC2 unit operating under similar conditions will have a condensing temperature of only about 90°F. This 30°F advantage translates into increased EC capacity and efficiency at higher temperatures since the compressor does not have to work as hard to reject the heat.

Figure 2: "AC2" Evaporatively Cooled Condenser



Both of the EC technologies evaluated in this study perform best in relation to air-cooled condensing units when operated in climates with low outdoor relative humidity, or more precisely, low outdoor wet bulb temperature. For example, the EC performance advantage over conventional air-cooled equipment is greater in California's Central Valley, where summer conditions of 100°F dry bulb and 70°F wet bulb are typical, relative to Atlanta, where summer conditions of 90°F dry bulb and 75°F wet bulb are common.

3.0. OBJECTIVES AND STRATEGY

The primary objective of this study was to identify cost-effectiveness of EC systems applied to a range of climate zones and building types. The DOE-2 building energy simulation program was used to develop this information.

The general approach to the project included:

1. Developing cost estimates of EC technologies relative to conventional air-cooled units.
2. Utilizing manufacturer and laboratory test data to generate performance curves for the DOE-2.2 simulation.

3. Evaluating customer cost-effectiveness of SEER 12 and EC systems.
4. Comparing laboratory test data with field monitoring data at five residential and one small commercial site in Northern California.

4.0. METHODOLOGY

4.1 Cooling System Performance Testing

In 1997 Pacific Gas and Electric Company initiated laboratory testing of conventional and evaporatively cooled residential split system air conditioners (PG&E, 1998). Four condensing units were tested at PG&E's Technical and Ecological Services (TES) lab, located in San Ramon, California. Table 1 lists the equipment manufacturer and nominal capacity for the four units tested. Testing was completed to compare system capacity, demand, and efficiency characteristics through a range of operating conditions. All four units were rated at 3 ton capacity, although the AC2 had a 2.5 ton compressor and the EvapCon a 2.0 ton compressor. (The EC manufacturer specifies 3 ton equivalence with air-cooled condensers based on the ECs level capacity at varying air temperatures, relative to air-cooled condensers.)

Table 1: Condensing Units Tested by PG&E

Type	Nominal Capacity	Manufacturer
10 SEER	3 tons	Janitrol
12 SEER	3 tons	Heil
EvapCon	2 tons	RTI
AC2	2.5 tons	RTI

Condensing units were tested in an environmentally controlled chamber. The indoor unit was connected to a "load" duct supplied with 80°F air. A supply fan, heater and humidifier were used to control the condition of air supplied to the test chamber. The environmental chamber supply air wet and dry bulb temperatures were monitored at four positions around the condensing units. Total condensing unit electrical demand was also monitored for all four units, as was water consumption for the two evaporative technologies. Indoor fan power was not monitored, therefore reported demand and efficiencies do not include indoor fan energy.

During testing, chamber temperatures were increased in 10° increments from 85^0F to 115^0F and relative humidity was maintained in the 10-40% range. All four units were operated at full load conditions and under part load conditions of 20%, 50% and 75% for cycle intervals of 10, 20, and 30 minutes. A total of 53 tests were completed.

Difficulties in obtaining reliable latent cooling measurements resulted in reporting of sensible capacities only. However, since much of the testing was done in the Fall, necessary heating of the return (outdoor) air resulted in very dry conditions, and therefore little latent cooling. Some of the early SEER 10 and EvapCon unit testing was performed during late-summer periods when the 80°F return (outdoor) temperature could not be maintained due to high inlet air temperatures. Test results were mathematically "adjusted" using an empirically derived heat exchanger calculation to be consistent with the 80°F return temperature.

4.2 Determination of Performance Curves

PG&E laboratory data and manufacturers' performance data were used to develop performance relationships for the four cooling systems for use in the hourly DOE-2.2 building energy simulation. DOE-2.2 characterizes residential cooling system capacity and electric input ratio (condensing unit energy input per unit of delivered cooling) with bi-quadratic functions of outdoor dry bulb temperature and return air wet bulb temperature according to the following equations:

$$\mathrm{CAP} = a + b*T_{ci} + c*T_{ci}^2 + d*T_{iwb} + e*T_{iwb}^2 + f*T_{ci}*T_{iwb} \qquad \text{(Eqn. 1)}$$

$$\mathrm{EIR} = g + h*T_{ci} + i*T_{ci}^2 + j*T_{iwb} + k*T_{iwb}^2 + m*T_{ci}*T_{iwb} \qquad \text{(Eqn. 2)}$$

where, a-m = constants, T_{ci} = condenser inlet temperature, T_{iwb} = indoor wet bulb temperature.

Since the PG&E laboratory data set did not have sufficient data points necessary for development of the curves, manufacturer's data were also used. The process involved developing bi-quadratic curves using a least-squares fit of the manufacturer's test data and then adjusting the intercept (e.g. "*a*" in Equation 1 and "*g*" in Equation 2) to minimize the Chi-squared difference between the manufacturer's data curve and the data points calculated using the laboratory results. This approach used manufacturer's data to determine the curve "shape", while minimizing differences between the two data sets by adjusting the intercept. On average, for the four systems tested, the average manufacturer's EER was reduced by 0.52 points (range of 0.02 to 1.04) and the average manufacturer's rated cooling capacity was increased by 1225 Btu/hour (range of –2710 to +4500 Btu/hour).

Since the capacities and efficiencies of the two evaporative condenser models are based on entering condenser wet bulb temperature, EC technologies utilized the DOE-2.2 evaporative pre-cooler model to allow characterization of performance relative to outdoor wet bulb. Efficiency and capacity curves based on outdoor wet bulb and a pre-cooler effectiveness of 100% were used to model the EC units. Because the pre-cooler model cannot model less than a 3 degree wet bulb approach, the AC2 performance curves were adjusted to account for this offset.

4.3 Modelling Cases

Five building types were developed to generate performance projections: three prototype residential new construction buildings (1,650 ft^2 and 2,000 ft^2 single-story houses, and a 2,500 ft^2 two-story house), an 1,190 ft^2 small commercial office building (to represent the commercial site where an AC2 unit was monitored during 1997-98), and a retrofit house with characteristics which vary by region (as defined by PG&E RASS data).

Each of the buildings were run with the four cooling system types in six California climate zones representing climates ranging from mild coastal-transitional to inland Central Valley climates. Table 2 summarizes the ASHRAE cooling design information by climate zone.

Table 2: Climate Zone Summary

		Cooling Design Temperatures		
Climate Zone	Location	Design Dry Bulb	Coincident Wet Bulb	Design Wet Bulb
2	Santa Rosa	96	68	69
4	San Jose	86	66	68
11	Redding	103	68	70
12	Sacramento	100	70	71
13	Fresno	101	71	73
16	Mt. Shasta	89	61	63

The new home cases were modelled as complying with the California Residential Building Energy Standards (CEC, 1995), while the small office was based on the actual construction of the office monitored. Table 3 summarizes the new construction characteristics including insulation levels, glazing percentages, and whether shadescreen was assumed to be installed. Table 4 presents the retrofit house characteristics based on assumptions listed in PG&E's RASS data. (Note that for the retrofit cases, the floor area and envelope parameters vary considerably with location.) Both the new construction and retrofit assumptions are felt to result in conservative (low) cooling energy use estimates, since shadescreen is rarely installed in production housing and the retrofit envelope assumptions seem overly optimistic.

Table 3: New Construction Building Characteristics

Climate Zone	Wall R-value	Ceiling R-value	Glazing (% of floor area)	Glazing U-value	Glazing Shading
2	13	30	16%	0.65	None
4	13	30	20%	0.75	None
11	19	38	16%	0.65	E & W
12	19	38	16%	0.65	E & W
13	19	38	16%	0.65	E & W
16	21	38	16%	0.60	None

Table 4: Retrofit Building Characteristics

Climate Zone	Floor Area (ft^2)	Glass Area (as % of floor area)	Average R-value Roof	Average R-value Wall	Glazing Properties U-value	Glazing Properties SC
2	1904	11.5	28.0	14.7	0.91	0.89
4	1904	11.5	28.0	14.7	0.91	0.89
11	1665	12.3	22.9	15.5	0.98	0.91
12	1640	10.9	18.6	11.5	1.12	0.96
13	1665	12.3	22.9	15.5	0.98	0.91
16	1809	10.0	26.4	18.8	0.86	0.88

For the residential simulations, two load cases were run for each of the above scenarios with the following thermostat setpoints: “typical load” - 78°F (6 PM to 10 AM) with 82°F the remainder of the day, and “high load” – constant 76°F setpoint. For the small office simulations, the “typical load” case assumed 76°F setpoints during weekday occupancy period of 8 AM to 5 PM; “high load” assumed 74°F setpoints for all days except Sunday, 7 AM to 6 PM.

Manual J sizing calculations were completed for each of the building type/climate zone combinations to determine both conventional and EvapCon/AC2 equipment sizing for all analyzed cases.

4.4 Projected HVAC System Costs

A key factor affecting the viability of any new technology is cost. Many promising new technologies never fully realize their potential because they are penalized by high equipment costs (due to low production volumes) and/or by high installation costs. The latter factor is often due to conservative pricing by contractors unfamiliar with the technology, or contractors trying to maximize profits by charging premium prices for the “latest technology”.

For this study, costing for the air-cooled system options was completed at two cost points: standard builder model costing which represents volume HVAC contractors that compete at a commodity level, and high-end contractors who typically sell “premium” quality HVAC units. Installed cost estimates for new construction cases were developed to represent competitive contractor pricing for a subdivision where a minimum of 100 units were being installed.

Resources utilized in developing the cost estimates included information provided by a major Northern California high-volume HVAC contractor (for 10 and 12 SEER equipment), the Northern California AC2 distributor (for cost information on premium 10 and 12 SEER units and the AC2), and EvapCon contractor pricing information from RTI (the manufacturer of both EC system types). Since ECs have not yet had a major presence in the California market, installed cost estimates were developed directly from contractor and distributor pricing sources.

For the new construction cases, cost-effectiveness was determined based on the difference between projected annual cooling cost savings and the amortized incremental cost of the system (30 year loan period with an 8% interest rate). For the retrofit cases, two economic criteria were developed. The first is the incremental simple payback for each technology relative to the cost and savings of the standard SEER 10 replacement unit. The second criteria is similar to the new construction case and assumes the replacement HVAC unit is purchased with a 10 year, 10% home equity loan. The shorter time scale and higher interest rate for the retrofit case makes it more difficult to justify the cost of the alternative cooling systems. In all the economic calculations presented in this study, no credit was taken for any tax benefits from the additional interest payments. This approach is conservative, but is partly offset by EC water costs, which were not accounted for. (A worst case estimate of residential water costs at a high rate of $2.25 per 100 ft^3 results in an annual water cost increase of $12/year.)

A final element in the economic evaluation of ECs was the determination of what incremental cost would be necessary to achieve a 2 year payback for the new construction cases evaluated.

4.5. Analysis of Field Monitoring Data

During the summer of 1998, Proctor Engineering Group monitored five AC2 units in existing residences located throughout PG&E territory. In addition, Davis Energy Group monitored the performance of a 2.5 ton AC2 unit serving the second floor (1190 ft^2) of its office building between September 1997 to October 1998. Monitoring data included system latent and sensible capacity, energy and water use, and indoor and outdoor conditions. Table 5 summarizes location and nominal size of each unit. Data were analyzed by Davis Energy Group in a manner consistent with that presented in section 4.2.

Table 5: AC2 Field Monitoring Sites

Site	Location	Building Type	Nominal tons
1	Auburn	Residential	4
2	Concord	“	3
3	Davis	“	3
4	Fresno	“	3
5	Tracy	“	4
6	Davis	Small Office	2.5

5.0. RESULTS

Due to the large number of simulation cases (5 building types, 6 climate zones, 4 system types, 2 load types), abbreviated results are presented in this section; detailed results are tabulated in Appendix A. Results listed below are averaged for each climate zone and are presented as “annual cost savings per 1000 ft^2 of conditioned floor area. A brief comparison of field monitoring results is provided in Section 5.2. Appendix B presents key information relating to the DOE2 performance curves developed from the data.

5.1. Simulation Results

Table 6 shows Manual J sizing results for the four building types, six climate zones, and three systems (conventional air cooled AC, EvapCon, and AC2). Manual J loads were compared to system capacity to verify equipment sizing. Since air conditioner capacity is typically in half-ton increments, system sizing was based on rounding up to the next half ton.

Sizing results are only listed for air cooled units (10 and 12 SEER); AC2 and EvapCon sizing is included in Appendix A. Averaging all cases, the EvapCon provides an average 13.2% installed capacity reduction, while AC2 results in an average 11.8% downsizing potential. (For example, for the Climate Zone 4 2500 ft^2 house case, a 3.5 ton conventional unit is called for; for the evaporative condenser systems a 3.0 ton EvapCon and a 3.5 ton AC2 would be appropriate.) In reviewing EC sizing data in Appendix A, it should be noted that the actual capacity increments for the EC equipment are not in uniform half ton increments as is typically the case for air cooled equipment. In some cases, EvapCon sizing resulted in a half-ton downsizing while AC2 sizing did not; in other cases the reverse was true.

Table 6: Manual J Sizing Results (nominal tons)

Climate Zone	Building Type 1650 ft^2	2000 ft^2	2500 ft^2	Small Office
2	3.0	3.5	4.0	3.5
4	2.5	3.0	3.5	2.5
11	3.5	4.0	5.0	4.0
12	3.0	3.5	5.0	4.0
13	3.5	3.5	5.0	4.0
16	2.5	3.0	3.5	3.0

Table 7 summarizes incremental costs relative to the 10 SEER base case averaged over all climate zones and building types. Based on information collected for this study, the incremental cost for a premium 10 SEER unit is $85/ton. 12 SEER equipment carries a $153-$245 per ton incremental cost vs. the base case equipment. Both EvapCon ($179-$197/ton) and AC2 ($317-$349/ton) are projected to have smaller cost ranges, because the equipment is the same for both “builder” and “premium” model HVAC contractors. For the EC units, cost is more sensitive to contractor perception of risk than to volume differences. Detailed cost estimates are included in Appendix A.

Table 7: Average Projected Installed Costs and Incremental Costs

		Incremental Cost vs. 10 SEER Base Case			
		Builder Model		Premium Model	
Equipment Description	Cost	Total $	Per ton	Total $	Per ton
10 SEER builder model	$2413	n/a	n/a	n/a	n/a
10 SEER premium model	$2719	$306	$85	n/a	n/a
12 SEER builder model	$2965	$552	$153	n/a	n/a
12 SEER premium model	$3602	n/a	n/a	$883	$245
EvapCon builder model	$3056	$643	$179	n/a	n/a
EvapCon premium model	$3426	n/a	n/a	$708	$197
AC2 builder model	$3555	$1142	$317	n/a	n/a
AC2 premium model	$3975	n/a	n/a	$1257	$349

Table 8 summarizes base case (SEER 10) annual energy use projections. Residential results for the new construction cases were averaged for the three building types with all presented as “energy use per 1000 ft^2 of conditioned floor area”. Results indicate highest usage in the Fresno climate (CZ 13) and lowest usage for Mt. Shasta (CZ 16), with a range of approximately 300%. Interestingly, in the milder climate zones (2, 4, and 16) energy use is about 9% lower for retrofit cases than for new construction. This is likely due to the assumed increased tree shading in established areas and the lower glazing percentages for the retrofit cases. In the three hotter climate zones, the poorer envelope characteristics overwhelm the shading benefits, resulting in usage about 23% higher than for new construction.

Small office results, also presented per 1000 ft^2, demonstrate cooling energy consumption 2 to 4 times higher than the residential cases, due to the higher internal gains and lower cooling setpoints.

Average energy savings projections for the residential and small office cases are presented in Table 9. EvapCon savings are roughly double those projected for SEER 12, and AC2 savings are about 5 to 6 times higher. Percentage savings for the residential and small office cases are fairly consistent, with the exception of EvapCon savings, which decrease several percentage points for the small office case. A likely explanation for this trend is more cooling operation at lower outdoor temperatures for the office case, where EC savings are less dramatic due to the reduced wet bulb depression.

Table 8: Projected SEER 10 Annual Cooling Energy Use (per 1,000 ft^2 of Conditioned Floor Area)

Climate Zone	Residential New Construction Med Load	Residential New Construction High Load	Residential Retrofit Med Load	Residential Retrofit High Load	Small Office Med Load	Small Office High Load
2	591	962	534	912	2715	3708
4	516	1006	456	893	2316	3350
11	1147	1634	1452	2021	3313	4516
12	733	1176	981	1515	3103	4209
13	1764	2386	2100	2765	4255	5597
16	446	706	405	641	1651	2334

Table 9: Projected Cooling Energy Savings (%)

System Type	Residential New Construction	Residential Retrofit	Small Office
SEER 12	6.6%	6.6%	6.4%
EvapCon	12.5%	12.4%	10.6%
AC2	35.1%	34.9%	34.0%

Although significant savings are projected for evaporative condenser technologies, cooling energy cost savings must be sufficient to offset incremental system costs for the technology to succeed in the marketplace. Table 10 lists projected annual "medium load" cost savings (per 1000 ft^2 of floor area) by climate zone for each of the alternative cooling technologies at an average rate of $.12/kWh. Climate zones 13 and 11 demonstrate the highest savings potential. On average, small office savings are nearly three times higher per square foot than the projected residential savings. The "high load" scenario increases the Table 10 projected savings by 56-67% for the residential cases and 36-38% for the office cases.

Table 10: Projected Savings per 1,000 ft^2 of Conditioned Floor Area (Medium Load)

	Res New Construction			Small Office			Res Retrofit		
CZ	SEER12	EvapCon	AC2	SEER12	EvapCon	AC2	SEER12	EvapCon	AC2
2	$ 5	$ 9	$ 25	$ 21	$ 32	$ 109	$ 4	$ 8	$ 23
4	$ 4	$ 5	$ 19	$ 18	$ 21	$ 88	$ 4	$ 4	$ 17
11	$ 9	$ 22	$ 52	$ 26	$ 49	$ 141	$ 12	$ 27	$ 65
12	$ 6	$ 12	$ 32	$ 24	$ 41	$ 128	$ 8	$ 16	$ 43
13	$ 15	$ 32	$ 80	$ 33	$ 66	$ 184	$ 18	$ 38	$ 95
16	$ 3	$ 5	$ 17	$ 13	$ 19	$ 66	$ 3	$ 5	$ 16

Table 11 summarizes those cases which demonstrate cost-effectiveness given the indicated cost and performance assumptions. (A “B” denotes favorable economics only under the budget HVAC pricing scenario.) No SEER 12 cases were projected to be cost-effective. AC2 and EvapCon were found to be cost-effective for most small office cases, due to the much higher loads (and savings) per ton of installed capacity. For residential new construction, AC2 was found to be consistently cost-effective in the Central Valley climates (11, 12, 13), with reduced cost-effectiveness in the milder zones. AC2 economics were consistently better than those projected for EvapCon. From the retrofit perspective, only the high load CZ13 scenario generated a positive cash flow using the 10 year home equity loan assumption.

Table 11: Summary of Cases with Positive Cash Flow

	System Type					
Climate		AC2			EvapCon	
Zone	Res. New	Res. Retro	Office	Res. New	Res Retro	Office
2	High(B)		All cases			
4	High(B)		“			
11	Med/high		“	Med/high		Med/high
12	High(B)		“	High		High
13	Med/high	High(B)	“	Med/high		All cases
16						

Table 12 indicates how far two years worth of energy savings would go towards paying off the incremental system costs for the new construction cases. Results are averaged for the medium and high load cases and are again presented per 1000 ft^2 of conditioned floor area. With projected residential savings of $190 per 1000 ft^2 (CZ 13 AC2), a 1700 ft^2 Fresno household could pay roughly $320 incremental cost for an AC2 to achieve a 2 year simple payback. With current estimated incremental AC2 costs of about $1200 (see Appendix A), nearly eight years of savings are required before a positive cash flow is achieved.

Table 12: Maximum Incremental Cost for 2 Year Simple Payback (per 1000 ft^2)

	System Type					
Climate	SEER 12		EvapCon		AC2	
Zone	Res. New	Office	Res. New	Office	Res. New	Office
2	$ 12	$ 50	$ 23	$ 76	$ 65	$ 257
4	$ 13	$ 43	$ 16	$ 52	$ 58	$ 215
11	$ 22	$ 62	$ 52	$ 115	$ 126	$ 331
12	$ 16	$ 57	$ 31	$ 96	$ 83	$ 301
13	$ 34	$ 27	$ 75	$ 152	$ 187	$ 423
16	$ 9	$ 31	$ 14	$ 45	$ 46	$ 157

Economics for the office case benefit from the higher projected energy savings. For an 1190 ft^2 Fresno office space, two years of energy savings could contribute roughly $500 towards the AC2 incremental cost. With current estimated incremental costs of about $1200; slightly less than five years of savings are required before a positive cash flow is achieved for the AC2.

Table 13 presents simple payback ranges for retrofit cases relative to a 10 SEER condenser, which is the most typical replacement option. The low end of the range represents “high load” savings and “budget” HVAC pricing, while the high end of the range represents “medium load” savings and “premium” HVAC pricing. In all cases, AC2 offers the best incremental payback relative to 10 SEER with paybacks as favorable as 6 to 9 years for climate zone 13. EvapCon is projected to provide paybacks comparable to AC2 in the two hottest zones (11 and 13), with much longer paybacks in the milder zones. SEER 12 cases are projected to have considerably longer paybacks than either EC system.

Table 13: Projected Retrofit Simple Paybacks (years)

Climate	System Type		
Zone	SEER 12	EvapCon	AC2
2	40-106	24-44	15-28
4	34-112	36-86	17-38
11	23-48	11-15	8-11
12	28-66	16-26	11-18
13	15-30	9-12	6-9
16	53-150	44-81	25-44

5.2. Field Monitoring Results

Detailed reporting of the residential field test results are available in a separate report prepared by Proctor Engineering (Dec 1998), while results from the small office monitoring project can be found in the DEG monitoring report. This section reviews full-season summary data from the monitoring sites, and compares them to projections generated by DOE-2.2. Variations in field monitored performance can be due to differences in system configuration (ducting, type of expansion device, coil size, etc.), homeowner operating patterns, weather conditions, and monitoring measurement inaccuracies.

The delivery system (duct system and air handler) is probably the greatest source of difference between simulated and actual HVAC system performance. DOE-2.2 simulation models assumed duct efficiencies of 75% and standard ARI fan power assumptions of 365 Watts per 1000 cfm of supply air. This compares with in-situ conditions where fan power may be as much as twice as high as the ARI assumption and duct distribution efficiency is unknown. These discrepancies make direct comparisons of laboratory and field results more difficult. Table 14 compares EERs for monitored vs. simulated performance. To accommodate the discrepancies previously addressed, monitoring results are presented three ways:

1. directly monitored condenser and fan energy use
2. directly monitored condenser energy plus fan energy based on the ARI standard
3. monitored energy use normalized to the ARI standard rating point (70°F outdoor wet bulb and 80°F/67°F return air dry bulb/wet bulb) using the regression curve of the full load data for that site.

Simulated seasonal EERs for SEER 10 equipment are also provided in Table 14 for comparison to the AC2 data.

Table 14 residential results indicate a nearly 50% range between the calculated EERs for Concord and Tracy, although the Tracy data is considered suspect. In adjusting field-measured fan power to the ARI assumption, EERs increase an average of 0.7 EER points. Finally, in calculating an EER at the ARI rating point conditions, efficiencies increase on average by another 1.8 EER points. Comparing the residential field data with that collected at the Davis office shows generally higher EERs at the office site, which is likely due to reducing cycling and operation at more favorable outdoor conditions.

Table 14: Comparison of Monitored and Simulated EERs

Case	Full-season Actual Fan Power	Full-season ARI Fan Power	ARI Standard Rating Point
Monitored			
Auburn-#1	11.7	13.3	13.4
Concord-#2	12.7	13.1	15.6
Davis-#3	9.8	10.1	13.2
Fresno-#4	11.7	12.3	13.8
Tracy-#5	8.5	9.2	n/a
Average of #1-4	11.5	12.2	14.0
DEG Office-#6	12.4	13.3	16.4
Simulated			
AC2 (Residential)	n/a	10.5-14.0 (1)	16.1
SEER 10 (Residential)	n/a	6.7-8.9 (1)	n/a
AC2 (Small Office)	n/a	12.7-14.9 (1)	16.1
SEER 10 (Small Office)	n/a	8.4-9.8 (1)	n/a

Notes: (1) EER range denotes efficiency with and without duct losses

It is important to note that field monitoring of cooling capacity and efficiency does not fully account for duct system inefficiencies. Supply air flow is measured at the registers after any leakage has occurred, but the supply and return temperature and enthalpy measurements used for total cooling calculations are recorded in close proximity to the air handling unit, so downstream losses are not accounted for. Therefore, to compare monitored EERs with simulation projections requires that the DOE2 EER results be presented both "with and without" duct losses. Table 14 results show that average full-season ARI EERs land roughly in the middle of the DOE-2 simulation results. Interestingly, small office simulation results also indicate higher average EERs in comparison to the residential results, reinforcing the hypothesis that more favorable operating conditions contribute to better AC2 performance.

6.0. CONCLUSIONS

Key conclusions drawn from this study are as follows:

1. Full-year savings energy of 12% and 35% are projected relative to a 10 SEER system for EvapCon and AC2, respectively. SEER 12 systems are projected to save 6-7% vs. 10 SEER systems.
2. Based on the assumption that a 10 SEER unit actually operates at that efficiency level, a 12 SEER unit is projected to have a relative SEER rating of 10.7, an EvapCon 11.3, and an AC2 15.3 based on an average of the DOE2 simulations performed in this study. EvapCon and AC2 "SEERs" as high as 11.9 and 16.1, respectively, are projected for the hot valley zones.
3. Incremental costs for the alternative systems, relative to 10 SEER equipment, are estimated at $190/ton for EvapCon, $200/ton for 12 SEER, and $330 per ton for AC2. The incremental costs for the EC systems include cost credits for system downsizing which amount to an average 12% nominal capacity reduction (~1/2 ton) vs. air-cooled equipment.
4. Both the AC2 and EvapCon offer more favorable customer economics than 12 SEER cooling systems. 12 SEER systems were not found to be cost-effective (from a 30 year amortized new construction perspective) in any of the cases evaluated. AC2 was found to generate positive cash flow for virtually all small office cases and many of the residential cases. EvapCon demonstrated cost-effectiveness in only the hotter Valley climate zones. For retrofit cases, using a 10 year amortization, only one AC2 scenario was found to be cost-effective.
5. The Central Valley climates offer the best EC economics. EC systems are not cost-effective at current cost levels in mild climates or low load situations.
6. At current equipment pricing and with no incentives, paybacks are likely to be greater than two years for EC technologies.
7. Field monitoring data indicates average seasonal EERs generally consistent with the DOE2 projections.
8. Full-season field monitored efficiencies are likely to be lower than simulation projections since indoor fan power is often much higher than the standard ARI fan power assumption. ARI rating point EERs are even higher since the rating condition doesn't account for cycling effects and the higher field fan power.

7.0. RECOMMENDATIONS

ECs, especially the second generation AC2, offer significant promise as a cost-effective alternative to conventional air-cooled condensing units. In addition to favorable customer economics under higher load situations, these systems provide utility value through peak load reduction and improved load factor.

Before EC technologies can achieve a significant share of the market, they must demonstrate the following:

- consistent operational reliability and minimal maintenance
- reduced installation costs
- increased contractor familiarity and confidence in EC technologies

Emerging technologies require greater marketing efforts to build product confidence, and investments in the infrastructure needed to support installation and service than mature technologies. Manufacturers must cover these costs by applying high margins. In addition, the circular relationship between sales volume and production cost precludes competitive pricing. The manufacturer of the EC technologies studied may survive by exploiting niche markets, but higher sales volumes resulting from success in the merchant housing market will likely not occur without “pump priming” in the form of demonstration programs, builder incentives, and contractor training.

The following actions are recommended to advance the market for EC technologies:

1. Continue market transformation programs, such as the Home Cooling Program, as a vehicle to market the AC2 technology to developers and builders in PG&E territory. Securing multi-family or subdivision projects throughout Northern California is an important step in developing a critical mass that could spur the industry.
2. Pursue small commercial projects (e.g. retail or office) as target areas, since simulation results seem to indicate more favorable performance for higher cooling load applications such as these.
3. Maintain contact with existing EC installations and installing HVAC contractors over the next several years to develop an information base on maintenance requirements and costs, and to identify product improvements that could reduce maintenance.
4. Support the inclusion of an evaporative condenser compliance method in the California Residential Building Energy Standards.
5. Evaluate the merit of manufacturer or distributor incentives as a means to reduce system first cost.
6. Consider targeting high cooling load areas where paybacks of 5-10 years exist with current EC pricing and no utility incentives.
7. To leverage EC incentive investments, consider targeting growth areas which are capacity limited by T&D system limitations.

8.0. REFERENCES

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