Implementation and Operation of an ''Integrated Design'' Desert House

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A detailed evaluation methodology, originally developed for PG&E's ACT[2] Project, was used to design cost-effective packages of energy efficiency measures (EEM's) for two residential sites in the Coachella Valley desert region of Southern California. Design of the packages was based on ''mature market'' cost assumptions, which assume that the EEM has achieved volume production and widespread application in the marketplace. EEM packages were installed at the two sites (one new construction and one retrofit) and monitored for nine months during 1995. Monitoring data were used to update the original performance projections and revise cost-effectiveness projections.

This paper focuses on the analysis methodology and cost-effectiveness evaluations of four key EEM's installed at the new construction site in Palm Desert, California. The four EEM's (condensing unit evaporative pre-cooler, night evaporative underfloor cooling system, improved ducts in conditioned space, and photovoltaic pool pumping) were found to be cost-effective under the original performance and mature market cost (MMC) assumptions used in the design phase. Revised analysis based on monitoring results, indicated three of the four EEM's were cost-effective under MMC assumptions and two of four under current cost assumptions. Ducts in conditioned space were found to be the most cost effective of the four, since a significant portion of the incremental cost could be offset by cost reductions due to air conditioner downsizing.

INTRODUCTION

The Coachella Valley Project (CVP) was initiated in 1994 by the Southern California Edison Company (Edison) as a major research and development effort to scientifically test the hypothesis that efficient residential end-use technologies can generate energy savings at costs less than new energy supply. The CVP was patterned after the Advanced Customer Technology Test (ACT[2]) developed by the Pacific Gas and Electric Company which evaluated cost-effectiveness of end-use technologies at four residential and two commercial sites in Northern California. Since many potential energy-efficiency measures (EEM's) are not yet fully commercialized, the ACT[2] and CVP rely on ''mature market'' EEM cost estimates to ensure a level playing field between mature and emerging technologies.

The CVP was designed to evaluate the limits of cost-effective energy efficiency in both a new and a retrofit site in California's Coachella Valley. The Coachella Valley is of particular interest to Edison because of both the severe summer climate and the utility's interest in finding cost-effective solutions for their customers. The project was intended to select representative homes, develop integrated energy-efficient designs, implement the designs, commission the completed installations, monitor the occupied homes, and draw conclusions on viability of the technologies based on monitoring data.

Project sites included a new home at the La Paloma development in Palm Desert, and a retrofit site in neighboring Rancho Mirage. The La Paloma house is a 2,356 ft^2 one-story home built by Desert Southwest Developers. The base case home, designed and planned for construction at the site before involvement of the CVP team, had 470 ft^2 of glazing, with 244 ft^2 located on the southeast facing back wall. A pool and integral spa were specified in the base case design. The Rancho Mirage retrofit site was a 1,645 ft^2 one-story home built in the mid-70's and occupied by a couple. The house included a pool but no spa. Natural gas service was available at both sites.

Construction and installation activities were completed at both sites in February 1995. After EEM and monitoring system commissioning, operation began in March 1995. Operation was monitored through November 30, 1995. Original Edison project funding included calibration of computer models based on the monitoring data and completion of EEM impact evaluations, but subsequent budget reductions curtailed these tasks. A companion project, funded by Edison through the California Institute for Energy Efficiency, allowed for the detailed EEM impact evaluation work reported here and presented in detail in the Advanced Residential Technologies Project (ARTP) final report (CIEE 1995).

The primary CVP objective was to achieve and verify maximum cost-effective energy-efficiency using sets or ''packages'' of energy-efficiency measures under mature market cost assumptions. Secondary objectives were to:

(1) Use detailed computer simulations to design an optimal EEM package

(2) Install and commission the selected EEM's

(3) Perform continuous detailed EEM monitoring

(4) Document and report all project activities

The ARTP project furthered the CVP work by pursuing detailed impact evaluations of all EEM's based on the accumulated monitoring data. Project results in this paper are limited to the evaluation methodology and impact evaluation results for four key EEM's at the new construction site.

METHODOLOGY

The results presented here combine the methodology and mature market costing used in the CVP project with the monitoring-based impact evaluation performed in the ARTP. The ARTP evaluation differed from the CVP sequential analysis methodology in that EEM cost-effectiveness evaluations were relative to a fixed base case house, as compared to the ''rolling base case'' utilized in final design. This approach was undertaken to reflect real world projects where typically only a few EEM's would be implemented, instead of the more costly full-blown integrated design.

All EEM evaluations utilized energy savings projections from detailed simulation modelling in conjunction with a life-cycle economics methodology to determine EEM cost-effectiveness based on incremental costs and estimated equipment replacement schedules. A cost-effective ''package'' of EEM's was developed based on this methodology. Design documents and construction specifications were then developed for incorporation in the final plans. Davis Energy Group worked with contractors in procuring specialty EEM's, providing construction supervision, and in commissioning EEM's prior to occupancy. Monitoring hardware was installed to provide detailed data necessary for impact evaluations.

The following sections provide the reader with background information on the economic assumptions, modelling methodology, EEM commissioning and monitoring requirements, and descriptions of the key EEM's.

Economics

All economic evaluations completed in this project were based on a modified version of the Economic Analysis Spreadsheet developed in PG&E's ACT[2] Project (PG&E 1991). The Economic Analysis Spreadsheet computes 30 year life cycle net present value ''benefits'' and ''costs'' to determine an overall benefit-cost-ratio (BCR). The approach was developed to assess life cycle economics based on avoided cost for both electricity and natural gas. If the calculated BCR is greater than one, the utility can theoretically purchase, operate, and maintain the EEM, while generating a positive net present value assuming revenues equal to the unimproved base case have been collected from the customer.

Benefits were computed based on the projected annual gas and electric energy savings factored by the 30 year ''value'' of a therm or kWh. The 30 year value sums the discounted annual projected marginal costs, and was calculated to be $.891/kWh and $5.27/therm, based on data provided from Edison. EEM costs were determined by adding initial incremental costs to discounted future equipment replacement costs. Using a life cycle costing approach accounts for EEM's with different equipment lifetimes than the base case. For example, fluorescent lighting with electronic ballasts will certainly have higher initial costs than incandescent fixtures, but over a 30 year lifetime, incandescent bulb replacement costs may result in a higher base case LCC. All economic evaluations assumed a 10% nominal utility discount rate.

EEM energy savings projections and incremental cost estimates were inputs to the spreadsheet. Cost estimates included initial material, labor, and markups; and replacement costs at the assumed end of service life. Base case and EEM maintenance estimates were also included where appropriate. Table 1 summarizes service life for key EEMs based on data provided in an annual appliance industry survey (Appliance 1993).

ARTP economics were evaluated under both ''current'' and ''mature market cost'' (MMC) scenarios. Current EEM costs were developed from actual materials costs and estimated labor costs. Actual project material costs may have been adjusted if alternate suppliers or products were identified subsequent to the construction phase. Labor estimates were based on information provided by installing contractors. Since actual subcontractor bids included ancillary costs such as provisions for monitoring equipment and were not obtained competitively, actual costs were only used to influence ''current'' costs developed for the analyses.

Mature market costs are intended to represent future costs when the technology achieves widespread implementation. The primary assumptions in developing MMC's is that no further cost savings can occur due to increased EEM production volume, and that the EEM is priced to compete in the marketplace. Many current high efficiency technologies have

Table 1. *Equipment Lifetimes*

Measure	Lifetime (yrs)
Clothes Dryer	13
Clothes Washer	13
Refrigerator	16
Dishwasher	10
Water Heater (gas)	11
Central Furnace	19
Split System AC	15
Envelope component	>30
Pumps	10

high current costs, because of low production volume, sunk development costs, and a pricing strategy directed toward the high-end market. MMC's are intended to represent ''what could happen'' vs. ''what will happen'', since not all EEM's will achieve mature market status. Examples of products which have the made the transition from initial premium pricing to mature market status include calculators and home personal computers.

Sources of information used in compiling cost information include subcontractor estimates, the 1994 National Construction Estimator (NCE 1994), industry experts, and Davis Energy Group estimates.

Modelling

The base case DOE-2.1E house model was derived from the builder's base case construction documents. Occupancy schedules were selected to reflect typical California occupancy patterns with assumed thermostat settings of 68°F heating (60°F night setback) and 80°F cooling. The base case model included R-38 ceiling, R-21 2x6 walls, and aluminum-framed, dual-glazed windows. The proposed base case HVAC system was a conventional forced-air gas furnace (80% AFUE) with central air conditioning (10 SEER) and R-4.2 insulated attic ductwork. Water heating was provided by a high-efficiency, 39-gallon gas water heater (Energy Factor 0.63). An electric oven with gas cooktop and electric clothes drying were also included in the base case.

A list of 83 candidate EEM's were sorted into envelope (EN), space conditioning (SC), water heating (WH), appliance (AP), lighting (LT), and miscellaneous (MI) categories, and were evaluated for both performance and life-cycle economics. DOE2.1E performance analyses were completed for space conditioning EEM's, where possible; water heating EEM's were evaluated using Davis Energy Group's HWSIM simulation. Appliance and pool/spa end use estimates were evaluated using unit energy consumption data provided by Edison (SCE 1991). EEM savings projections and estimated mature market costs were input to the Economic Analysis Spreadsheet to determine life-cycle cost and overall benefit/cost ratios. EEM's were then ranked and either rejected ($BCR < 1$) or held for potential inclusion in the final EEM package.

Using the ranked EEM lists, multiple EEM packages were designed based on sequential analyses. This process considers interactive effects by incrementally adding the most cost-effective EEM and then re-evaluating remaining EEM's. The package was complete when no further cost-effective EEM's existed. Two packages were developed. The more conventional approach featured conventional air conditioning, while the second substituted two-stage evaporative cooling.

Based on builder and utility review the more conventional package was selected to minimize builder marketing concerns. Final design activities included revising package and economic projections, preparing construction documents, and completing a final design report.

Construction, EEM Commissioning, and Performance Monitoring

Construction of the La Paloma house occurred from October 1994 to February 1995. Prior to construction, Davis Energy Group reviewed all EEM's with the local building department to gain their approval. Although there were no significant delays due to EEM procurement, several construction tasks were rescheduled to keep project completion on schedule. Lead time associated with the high performance glazing units was particularly lengthy resulting in the vinyl window frames (without glass) being installed first to allow stucco work to continue.

Commissioning plans were developed for EEM installations at both houses prior to beginning work. Each commissioning plan specified EEM installation inspection requirements and functional performance requirements for key operating components. The plans also provided commissioning status forms for documenting all commissioning activities, including monitored EEM performance relative to performance targets. Commissioning work was completed prior to occupancy to verify proper installation and operation of all specified EEM's. A commissioning report was prepared and submitted to Edison after completion of EEM commissioning.

Monitoring hardware requirements and data point lists were developed prior to EEM installation. Two dataloggers and 56 sensors were installed at the La Paloma site. Telephone modems were installed to allow for daily data transfer to the host computer in the Davis Energy Group home office. The raw data was routinely scanned to verify that all sensor readings were within the expected range. Monthly reports summarized sensor readings and provided pie charts showing electricity and gas use by function, and bar charts comparing measured end use to estimated base case energy consumption. Monthly reports were provided to Edison for the months of March through November 1995.

Description of Key EEM's

Only four of the 25 EEM's installed at La Paloma are highlighted in this paper to allow for a more detailed review of performance and cost-effectiveness issues presented in the ARTP. Descriptions of the four EEM's follows:

Condensing Unit Evaporative Pre-Cooler. Evaporative pre-coolers utilize wetted media to pre-cool outdoor air passing across the condenser coils. Reducing condensing temperature improves the performance of a vapor compression cooling system by reducing power and increasing cooling capacity. Evaporative pre-coolers are most effective in hot, dry climates where the wet bulb depression is large and potential cooling savings are high. As with evaporative coolers, annual maintenance is required to minimize mineral deposits which reduce effectiveness and condenser airflow over time.

An evaporative cooler manufacturer in the Southwestern U.S. produced the custom fabricated pre-cooler to fit the two-speed condensing unit specified for the project. The pre-cooler unit included a fiberglass bottom section (which supports the condensing unit and serves as a water sump), expanded cellulose evaporative media protected by a plastic grille surrounding the condensing unit, and a fiberglass top which retains the media and connects to the top of the condensing unit. A small loop of refrigerant tubing rests in the sump to provide additional refrigerant precooling.

The pre-cooler units for the CVP project were much more expensive than standard pre-cooler units because custom fiberglass molds had to be developed. Additional costs at the new construction site were incurred for modifications to interface the unit with the Night Evaporative Underfloor Cooling System (see description below). Current and mature market costs used in the economic evaluation assumed use of standard, commercially available equipment, and were therefore not burdened with the custom nature of the unit installed.

Pre-cooler performance evaluations were based on monitored cooling system performance vs. outdoor dry bulb temperature with both the pre-cooler installed and removed. Data were taken between August 18 and September 18 with the pre-cooler removed, providing a comparative basis for determining pre-cooler performance. Capacity and power data during 15-minute periods with continuous cooling system operation were used to develop regression curves vs. outdoor temperature. The modified condenser performance curves were then incorporated into DOE2.1E. A representative indoor temperature setpoint of 80°F was used in the DOE2 analysis.

Night Evaporative Underfloor Cooling System (NEUCS). The NEUCS installed at La Paloma utilizes night evaporative cooling to chill water circulated through plastic tubing under the floor slab. Nighttime evaporative cooler operation is more effective than daytime operation since outdoor wet bulb temperatures are lower, typically reaching a minimum close to sunrise. A separate slab circulation pump located in the water sump allows night slab cooling to operate independently of daytime condenser pre-cooling. Water temperatures supplied to the floor are typically in the 58-66°F range. The cooled slab absorbs heat throughout the day, displacing or eliminating air conditioner use.

NEUCS technology appears most viable as a cooling load reduction measure in climates with high cooling loads and favorable night wet bulb temperatures. Alternatively, in transitional cooling climates with relatively low cooling loads, NEUCS offers the potential of eliminating mechanical cooling. In the latter case, the NEUCS could employ a dedicated direct evaporative cooler which cools the slab at night and also provides evaporatively cooled air to the house. This configuration was installed as a stand-alone cooling system at a PG&E ACT[2] project site in Northern California (PG&E 1993) with a 0.5% cooling design temperature of 104°F.

The NEUCS system requires installation of polyethylene tubing in the sand layer approximately 3 inches below the concrete floor slab. At the 2,350 ft^2 La Paloma house, 1,000 ft of 1.25'' diameter tubing was installed in two circuits with the ends terminating at the condensing unit. Tubing installation was completed in a few hours. Davis Energy Group was responsible for final plumbing connections and integrating custom controls with the pre-cooler and condenser fan.

A detailed two-dimensional finite difference model was developed with the assistance of Lawrence Berkeley National Laboratory to model thermal interactions between the house, the floor slab, the ''deep earth'' below, and the soil mass located near the house perimeter. The model incorporated the NEUCS tubing array modelled as point cooling sources, and an evaporative cooler algorithm to simulate summer night cooling. The algorithm calculates slab inlet water temperature based on outdoor wet bulb temperature. Due to the complexity of the NEUCS finite difference model, it was necessary to compile the program code with a research version of the MICROPAS4 hourly simulation instead of developing a DOE2 user-defined function. The NEUCS model was calibrated with La Paloma site monitoring data before full-year performance simulations were completed.

Improved Ducts in Conditioned Space. Studies show that national average duct efficiency in attics and crawlspaces may be as low as 60-70% (Obst 1993). Duct performance is particularly bad during peak cooling periods when attic temperatures can exceed outdoor temperatures by 20-30°F. Duct loss occurs by thermal conduction through duct walls to attic and basement air, and by leakage at connections and seams. Leakage can account for substantial increases in house infiltration rates, particularly if interior doors are closed, since room-to-room pressure imbalances may occur. Efficient duct systems decrease system heating and cooling loads and may allow for downsizing of heating and air conditioning systems. The California Energy Commission specifies efficiencies of 83% (heating) and 81% (cooling) to the R4.2 insulated attic flex ducts typical of California residential construction (CEC 1992).

La Paloma duct improvements included placement of ducts inside the insulated envelope, and mastic and mechanical sealing of duct connections. Existing soffits and drop ceiling space resulted in minimal additional cost, especially after accounting for a 40% reduction in duct length from the base case design with the revised duct design and a half ton reduction in cooling system capacity.

For the new construction ‘‘current cost’’ scenario, projected EEM costs are higher to cover construction modifications necessary to create a duct layout within conditioned space. However, in a ‘‘mature market’’, incremental costs should be minor because duct location would be an early architectural design consideration. Cost-effectiveness should also improve in two-story houses where it is typically easier to place the ducts within both the conditioned thermal and pressure boundary of the house.

Duct efficiency was modeled in DOE2 using both conductive and leakage loss components. Base case duct losses were based on the original duct design and CEC standard leakage assumptions (180 cfm per 100 ft^2 of duct surface area). Original projections assumed zero duct losses for this EEM; however this assumption was modified based on actual La Paloma construction which placed the ducts below the insulation but above the drywall, allowing duct air leakage to pass through the insulation and into the attic. Locating as much ducting as possible with both the thermal and pressure boundaries of the house is preferred.

Photovoltaic Pool Pumping. In Edison territory, pool pumping energy uses an average of 2,105 kWh/year (SCE 1991), and depending on pool configurations and installation can exceed 4,000 kWh/year. Modern pools are typically outfitted with oversized (2 HP) pumps operated 4 to 10 hours per day. The resulting high energy use can be eliminated by employing a DC filtration pump powered by photovoltaic (PV) panels. Solar power is well suited to pool filtration in sunny areas such as the Coachella Valley, because the need for filtration is greatest during summer months when the solar panels generate the greatest output. Because pools equipped with PV pumps can be filtered continuously during daylight hours, smaller pumps delivering lower flow rates than conventional pumps can be used to provide equivalent average filtration levels.

The installed PV pumping system used ten 53 watt ground-mounted panels, a 1/2 HP DC pump, and a low pressure drop cartridge filter. Incremental costs were based on the difference between a standard filtration system with 2 HP pump, and the PV system with 1/2 HP DC pump. Except for PV panel wiring, electrical connection costs were assumed to be equal. Mature market assumptions included $1.50 per peak watt for the PV panels, and DC pump costs equal to those of the larger AC pumps they replaced.

Complete elimination of grid electrical energy use does not insure EEM success, particularly if the quality of filtration is sacrificed. To confirm the adequacy of filtration provided by the PV pumping systems, an analysis was completed to compare PV system ‘‘turnover rate’’ with the pool industry standard of one turnover per day. Regression equations developed from monitoring data were applied to full year Cathedral City solar radiation data to calculate an average daily turnover rate for each month.

RESULTS

Results include presentation of the CVP final design package which sequentially lists all implemented EEM's, and detailed ARTP impact evaluation results for the four highlighted EEM's. The ARTP results are highlighted, since monitoring results and current cost data are combined in the impact evaluation process.

Final Design Sequential Analysis Results

Table 2 lists the 25 selected final design EEM's in decreasing cost-effectiveness order. The first EEM was implemented on the base case, which was then continually revised as

Table 2. La Paloma Final Design Sequential EEM Order (Mature Market Costs)

EEM	Description	Savings kWh	Savings Therms	NPV/BCR
EN19	Improve Building Orientation	54	3.0	$ 64
EN5	Engineered Wall Framing	1123	23.0	$1,750
EN7	Light Roof Cover	1778	− 12.0	$1,569
AP8	Energy Efficient Dishwasher	0	6.6	$ 233
SC17	Condenser Relocation/Shading	210	0.0	$ 187
EN6	Light Wall Color	140	− 1.0	$ 119
WH3	Low Flow Showerheads	0	14.5	$ 76
WH10	Anti-Convection Valves	0	6.4	9.4
WH15	Recirculation Time/Temperature Control	0	78.0	8.2
AP2	Horizontal Axis Clothes Washer	125	24.4	7.4
AP5	Gas Dryer	1224	− 49.0	6.6
LT2	Outdoor Lighting Control	181	0.0	5.2
EN15	Improved Windows and Glazing	2767	− 6.0	2.3
SC9a	Evaporatively Pre-Cooled AC w/NEUCS	1854	0.0	1.8
WH2	Low Temperature Dishwashing	0	18.2	2.1
LT7	Builder-Supplied Lighting Modifications	1734	− 9.0	2.1
LT8	Owner-Supplied Lighting Modifications	433	− 3.0	1.9
AP9	Efficient Exhaust Fan	60	0.0	1.7
EN9	Attic Radiant Barrier	215	0.0	1.5
MI4	Photovoltaic Pool Pump	2105	0.0	1.2
WH16	Heat Pump Water Heater	− 446	125.9	1.2
MI2	Solar Pool Heating	0	560.0	1.1
SC16	Variable Speed High Efficiency AC	1050	0.0	1.1
SC10	Ducts in Conditioned Space	525	12.0	1.1
MI3	Efficient Spa Design	− 12	122.1	0.9
	TOTALS	15120	914	2.3

additional EEM's were added. Economic results are presented in terms of 30 year net present value (NPV) or BCR. NPV is reported for those EEM's which are projected to have a life cycle incremental cost (LCIC) less than zero; the first seven EEM's fall into this category. Some EEM's, like Engineered Wall Framing, are projected to have a lower LCIC because under a mature market cost scenario the EEM benefits from substantially lower material costs. (Current costing for the manufactured framing material and rigid wall insulation indicates a cost premium over conventional framing.) Many of the EEM's with high projected savings fall towards the end of Table 2, since they are burdened by relatively high costs. Often a more cost-effective EEM will enter the package, further reducing the cost-effectiveness of the remaining ''big impact'' EEM's.

Annual projected savings of 15,120 kWh and 914 therms result in homeowner cost savings of about $2,500 per year. The mature market LCIC for all EEM's was estimated at just under $9,000, resulting in an overall package BCR of 2.3.

Table 3 summarizes estimated annual base case energy use by end use and the projected savings of the final EEM package. For end uses utilizing both electricity and gas, total

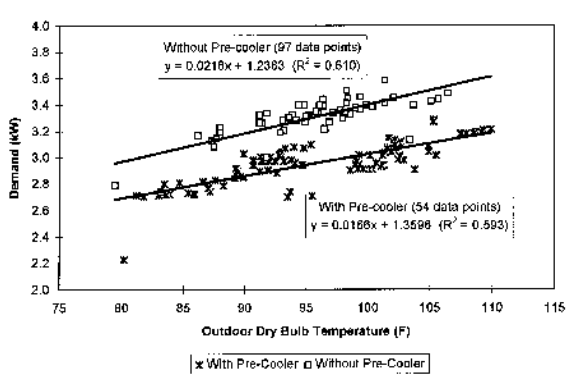
Table 3. Projected Package Energy Savings By End Use			
End Use	Projected Base Case Annual Energy Use kWh	therms	La Paloma Projected Savings
Cooling	11823	0	84%
Heating	54	62	33%
Lighting	2596	0	81%
Water Heating	0	277	78%
Pool / Spa	2418	743	91%
Appliances/Misc	3781	13	53%
TOTAL	20672	1095	77%

energy use is calculated based on an assumed average heat rate of 8000 Btu/kWh. Pool/Spa savings were the highest since all pool heating and pumping energy use was eliminated with the implementation of photovoltaic pool pumping and solar pool heating. Heating savings, at 33%, represented the lowest end use savings since limited savings potential existed with such low base case heating loads. Overall package energy savings of 77% were projected.

Performance of Key EEM's

Condensing Unit Evaporative Pre-Cooler. Monitoring data was filtered to generate two datasets: continuous 15 minute operating data with the pre-cooler installed and the pre-cooler removed. Figure 1 shows condensing unit demand vs. outdoor dry bulb temperature for both cases. The data

Figure 1



indicate that in 100°F outdoor air, condensing unit power was reduced about 12% and total cooling capacity increased 6% for the nominal 3 ton cooling system.

The modified performance relationships were input into DOE2.1E for full-year impact evaluation. Current and mature market installed incremental cost estimates for the pre-cooler were $425 and $227, respectively, including a small credit ($75) for potential cooling system downsizing. A 15 year equipment life was estimated for the pre-cooler, with pump and media replacement scheduled at 5 year intervals.

Night Evaporative Underfloor Cooling System (NEUCS). Current costs were estimated by adding standard pre-cooler costs (no custom fabrication required), plumbing contractor installation costs, and custom control costs, for an incremental installed cost of $2040. The $977 mature market NEUCS incremental installed cost assumes a reduction in both plumbing and pre-cooler costs and a significant reduction in system controls costs[1]. A 1/2 ton AC capacity downsizing credit was assumed in all NEUCS economics evaluations. Life cycle costing assumes replacement of pre-cooler, NEUCS pump, and controls at 15 years.

NEUCS monitoring data were used to develop a relationship between the temperature of water entering the slab and outdoor wet bulb temperature. For wet bulb temperatures in the 55-60°F range, slab inlet water temperatures were typically 5-6°F higher than wet bulb. Combined power consumption of the condenser fan (low speed) and slab circulating pump was measured at about 0.35 kW with average slab cooling rates of about 12,000 Btu/hour.

Figure 2

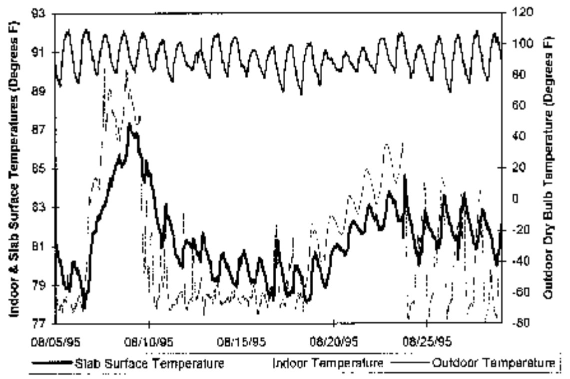


Figure 2 demonstrates the impact of the NEUCS on slab surface temperatures during the month of August. Maximum outdoor dry bulb temperatures during this period ranged from the upper 90's to near 110°F. The first several days indicate the NEUCS system operating and maintaining slab surface temperatures in the range of 78-81°F. On August 7, the air conditioner compressor failed disabling both the forced air cooling and the NEUCS for a three day period. During this time both indoor and slab surface temperatures rose to the high 80's. The unit was repaired on August 9 and during the next week the NEUCS system again reduced slab temperatures to the levels maintained during the first few days of August. On August 18, the NEUCS was disabled (to allow for comparative monitoring data without both the NEUCS and evaporative pre-cooler) and slab temperatures reached an equilibrium in the 80-84°F range, or approximately 2-3°F higher than with the NEUCS operating.

Improved Ducts in Conditioned Space. Monitoring of duct performance was limited to measurement of supply and return temperatures and relative humidities. Final DOE2.1E performance projections were based on the improvement between the assumed CEC typical duct leakage and the duct leakage measured during EEM commissioning. Design specifications called for a duct leakage performance standard of 150 CFM at 50 Pascals static pressure. Final simulation runs conservatively assumed that all duct leakage (measured at 18% of the assumed base case CEC value) entered the attic.

Photovoltaic Pool Pumping. Short-term insolation and flow monitoring of the PV pumping installation at La Paloma generated a regression curve plotting hourly pump flow as a function of insolation levels. The curve was combined with local hourly insolation data to generate an average pool turnover rate for the twelve months of the year. The average annual rate shown in Figure 3 is slightly less than the one turnover per day target, however for the prime pool use months of April through October, the turnover target is nearly achieved. Pool turbidity was never an issue with the homeowners during the first year of operation, indicating that the industry standard filtration recommendation is likely overly conservative.

Final EEM Cost-Effectiveness Projections

Table 4 summarizes ARTP performance and cost-effectiveness projections for the four highlighted EEM's with energy savings and LCIC relative to the base case La Paloma house.

Under the current cost scenario, both ducts in conditioned space and the evaporatively pre-cooled AC are projected to have life cycle BCR's greater than 1.0. NEUCS cost-effectiveness does not quite achieve the 1.0 BCR target under current cost economics and PV pool pumping is far from being cost-effective with a 0.3 BCR.

Mature market economic assumptions improve the situation dramatically. For ducts in conditioned space, mature market costs assume that the location of soffits and drop ceilings suitable for duct runs is considered early in the architectural design process. Given the current lack of thought concerning integration of the HVAC system with the building, the improved duct design would require a significant change in the overall design process. The very low mature market LCIC ($19) indicates a small initial incremental cost for duct sealing and drywall above the ducts, largely offset by a one ton reduction in the required cooling capacity. NEUCS economics also improve significantly due to large reductions in both pre-cooler and system control costs. PV pool pumping, at a mature market cost of $1.50 per peak Watt, nearly achieved the 1.0 BCR target for the average Edison pool

Figure 3

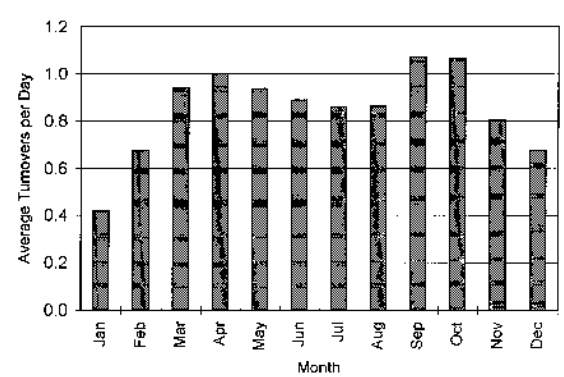


Table 4. EEM Performance and Economics Summary

Description	Energy Savings kWh	Energy Savings therms	Current Cost LCIC	Current Cost BCR	MMC LCIC	MMC BCR
Ducts in Conditioned Space	2671	12.0	$ 307	6.5	$ 19	106.1
Evaporatively Pre-Cooled AC	1769	0.0	$ 901	1.1	$ 607	2.6
NEUCS	3204	− 12.0	$2641	0.8	$1322	2.1
Photovoltaic Pool Pump	2105	0.0	$5473	0.3	$2186	0.9

owner; high use customers would have correspondingly higher BCR's.

Table 5 summarizes projected undiversified demand savings for the 113°F peak outdoor dry bulb temperature on the Cathedral City weather tape. PV pool pumping demand savings is based on displacing the base case 2 hp pool pump assumed to be operating during the utility peak load period. The three cooling EEM's reflect cooling demand savings during the peak hour when the air conditioner is operating less efficiently than at the standard 95°F EER rating point.

CONCLUSIONS

Key project conclusions include:

(1) An integrated design process, such as the one implemented in the Coachella Valley Project, recognizes the synergy inherent in creating EEM packages. High efficiency glazing units, engineered wall framing, ducts in conditioned space, attic radiant barrier, NEUCS, and an indoor heat pump water heater all contribute to lower cooling loads, allowing for cooling system cost savings.

Table 5. Peak Demand Impacts

Description	Undiversified kW Savings
Photovoltaic Pool Pump	2.60
Evaporatively Pre-Cooled AC	1.12
NEUCS	0.88
Ducts in Conditioned Space	1.52

(2) Life cycle costing is essential in fully evaluating EEM benefits. For example, ducts in conditioned space not only reduce initial cooling system capacity cost and generate annual energy savings, but also reduce cooling system replacement costs.

(3) Implementation of many EEM's are hampered by high costs due to a combination of low production volume and lack of contractor familiarity (resulting in high installation costs). Commonplace technologies, such as split system air conditioning units, have truly achieved mature market status through standardization and production optimization, reducing the viability of competing EEM's.

(4) Two of the four highlighted EEM's, ducts in conditioned space and the evaporative pre-cooler, are cost-effective using current cost and typical usage assumptions in the Coachella Valley. NEUCS is projected to achieve a BCR$>$2 under mature market cost assumptions.

FURTHER WORK

The results from Edison's Coachella Valley Project and PG&E's ACT2 Project indicate the synergistic value of an integrated design approach with careful EEM commissioning. Many of the EEM's implemented in the field are cost-effective now and could be integrated into current building practice. The California Energy Commission has formed a collaborative with the California building industry, utilities, and other interested parties with the goal of improving the quality and energy efficiency of new homes being built. Utilities can also play a vital role in the implementation of cost-effective EEM's by directly providing technology transfer assistance to builders and subcontractors. More innovative technologies such as NEUCS, require additional field R&D before configuration and implementation details have been optimized for various California applications.

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ENDNOTES

1. Current costs include $1,060 for materials (evaporative pre-cooler, two-speed condensing unit fan, custom controls, and 1-1/4'' tubing), $465 for labor (installing tubing, pre-cooler, two-speed fan, custom controls, and supply water piping to pre-cooler), and the remainder for contractor and builder overhead and profit. Mature market costs assume pre-cooler, two-speed fan, and controls are integrated with the condensing unit, reducing total material costs to $620. Labor is also reduced (to $235) by the availability of a pre-packaged unit. Overhead and profit, as a fixed percentage of labor and materials, is estimated at $250. Both current and mature market scenarios assume a $140 air conditioner downsizing cost savings due to NEUCS.

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