Advanced Customer Technology Test for Maximum Energy Efficiency (ACT^2) Project: The Final Report

Lance E. Elberling, Pacific Gas & Electric Company, San Ramon, CA
Grant J. Brohard, Pacific Gas & Electric Company, San Ramon, CA
Merwin L. Brown, Battelle, Richland, WA
Ralph Cavanagh, Natural Resources Defense Council, San Francisco, CA
George R. Hernandez, Bentley Engineering Company, Walnut Creek, CA
Amory Lovins, Rocky Mountain Institute, Snowmass, CO
Arthur H. Rosenfeld, Department of Energy, Washington, D.C.

ABSTRACT

In 1990, a large utility initiated a Research & Development project entitled the Advanced Customer Technology Test for Maximum Energy Efficiency (ACT^2) to determine the maximum energy savings achievable in a utility customers' facility using an integrated design approach. The hypothesis was that much more energy can be saved through the synergistic interaction of individual energy efficient measures than would be realized if the measures were implemented individually. For example, a superior building shell and/or glazing will decrease the required size of an air conditioning system such that a smaller, more efficient system can be installed for the same or lower cost than the larger less efficient system. By combining the two energy efficient measures (glazing and a new A/C system), the resulting energy consumption is less than it would be if the measures were evaluated and implemented separately. Seven facilities were selected as part of the project, both new construction and retrofit, residential and commercial, and a minimum of two years of energy monitoring data was collected and analyzed for each site. The evaluations of the sites were completed in 1997. Energy savings ranged from 40% to 50% of baseline energy consumption for the retrofit projects and 50% to 65% of the projected energy consumption for the new construction sites assuming they had been built merely to satisfy California's Title 24 energy standards. This paper presents the findings for each site and discusses some of the major lessons learned and market barriers encountered.

Introduction

Pacific Gas & Electric Company initiated the ACT^2 Project to determine the maximum energy savings achievable in customers' facilities, at or below the 1992 utility supply costs (roughly equivalent to $0.43/therm and $0.064/kWh), using integrated packages of state-of-the-art energy efficient measures. This is a unique project, the first of its kind to use real-world economics in applying designs specifically relying on integrated engineering and design. As such, we discovered important lessons relating to the application of integrated engineering and design and to industry-wide problems relating to adopting energy-efficient designs in general.

An internationally renowned Steering Committee made up of experts in energy efficiency was assembled to guide the conduct of the research. An internal committee was formed from various departments within the utility to ensure the results of the project were consistent with established financial and business criteria. Then several sites were selected as representative of new and existing building techniques in northern and central California, both commercial and residential. Extensive monitoring systems were installed in the retrofit and the new building sites; allowing for very accurate tracking of the actual energy savings achieved. The data was used to calibrate a DOE 2 building energy simulation model for each site. The model was used to test the effectiveness of each energy efficiency measure as it was applied to the total package.

This paper provides a short case-study of each site and discusses the lessons learned from conducting the research.[1]

Project Results

Four Retrofit Sites

The Sunset Building. The Sunset building, PG&E's R&D leased space in the San Francisco Bay Area (San Ramon), was the pilot demonstration site of the ACT^2 Project. Since we had not completed the project plan at the time, we chose only a portion of a complete building (22,000 square feet out of 420,000 square feet total) to retrofit. Despite this handicap, the retrofitted site consumed 56% less energy than the preretrofitted condition. The retrofit consisted of a double-effect evaporative cooling system with variable-speed fans throughout, low-air-velocity, high-coolant-velocity central system, high-efficiency HVAC motors, DDC retrofit of the HVAC controls, high-efficiency T-8 lamps and dimmable ballasts controlled by motion sensors, occupancy sensors and manual dimmers, specular silver reflectors, high-efficiency task lighting, new high performance window system on south-facing walls, and variable-speed reciprocating chillers with oversized heat exchanger barrel and an evaporative condenser for peak-load days.

As a pilot site the Sunset building was immensely successful. We learned numerous lessons on how not to perform the ACT^2 test at this site at the other sites: 1) not to attempt an integrated design on only part of a building (too hard to isolate systems and effects), 2) pick a universally accepted economic model (we tried to use a utility economic system which confused the A&E design firms), 3) some technologies which are novel and not widely used can make the best energy efficiency measures (the double indirect evaporative cooling system saved 90% of the HVAC load and except for some inappropriate control coding worked flawlessly), and 4) use an experienced building simulation modeler (modeling is extremely difficult and complex).

VeriFone Commercial Retrofit. The Verifone office building is a 7,329 ft^2, single-story structure located in Auburn, California. Auburn is located in the foothills of the Sierra Nevada mountains at about 1,300 ft. elevation. Walls were uninsulated concrete masonry, and the dropped ceiling was insulated on top with fiberglass batts. Window area was relatively small, and the glass type was single-pane with a bronze tint. Cooling and heating were provided by two 7.5 ton packaged air conditioners with electric space heaters used in some spaces. The predominant lighting type was T-12 lamps with magnetic ballasts. The retrofit consisted of 21 individual energy efficiency measures in an integrated design. The final installed package included interior wall sheathing and insulation, skylight tubes, an economizer system, reduced hot water temperature with heat recovery from the refrigerator, improved ceiling insulation, high-efficiency exhaust fans, duct sealing, hydronic heating, high-efficiency blower

[1] This paper was shortened due to paper length constraints, please read the full text at www.pge.com/customer_services/other/pec/act2/act2over.html.

fans, occupancy sensors, high-efficiency lighting, and cooling augmentation provided by a nighttime roof spray/thermal storage system where cooling water stored in an underground tank is circulated to sprayheads on the roof at night to cool it for use in the hydronic system during the day.

The whole building achieved savings are 42% of the energy that was being consumed by the building in the basecase year. These savings were adjusted for typical meteorological year weather conditions using a calibrated DOE2 model (weather-normalized). The basecase energy, EEM package energy, and savings predicted in the design phase of the project and the actual measured savings by end-use from the Impact Evaluation Report (Eley, 1997) are summarized in Table 1 below.

Table 1. Verifone Commercial Retrofit

Electricity Consumption and Savings by End Use

End Use	Base Case (kWh/y)		EEM Package (kWh/y)		Savings (kWh/y)		Savings (%)		Variance in Savings (kWh/y)
	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	
Cool	37,478	47,251	9,327	21,353	28,151	25,898	75%	55%	-2,253
Heat	7,495	8,987	198	890	7,297	8,097	97%	90%	800
Fans	5,571	22,325	1,561	14,371	4,010	7,954	72%	36%	3,944
Lights	55,965	55,965	13,378	18,841	42,587	37,124	76%	66%	-5,463
Misc.	63,276	62,824	41,609	59,585	21,667	3,239	34%	5%	-18,428
Total	169,785	197,352	66,073	115,040	103,712	82,312	61%	42%	-21,400

Gas Consumption and Savings by End Use

End Use	Base Case (therms/y)		EEM Package (therms/y)		Savings (therms/y)		Savings (%)		Variance in Savings (therms/y)
	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	
Heat	1,197	3,036	699	1,755	498	1,281	42%	42%	783

Stockton Residential Retrofit. The Stockton, California site is a 2,200 ft^2 single story residential home built in 1979 in California's Central Valley, a climate of very hot summers in the 95 to105^{0}F range and winter lows down to freezing. The original home was constructed to 1979 Title-24 standards (California State energy codes) which required R-19 ceiling insulation and R-13 wall insulation. The retrofit equipment installed consisted of krypton lamps, efficient computer/printer, attic vent fan elimination, programmable electronic thermostat, high efficiency dryer, DHW anti-convection valves, spa heater pilotless ignition device, evaporative pre-condenser, Super Energy Efficient Refrigerator Program (SERP) refrigerator, occupancy sensors, efficient pool pump, hot water heater pressure temperature valve improvements, baseboard hydronic heating with condensing water heater, halogen PAR lamps, low-flow bathroom faucets, screw-in compact fluorescent lamps, T8 fluorescent lamps with electronic ballasts, efficient spa pump, linear fluorescent hard-wired compact fluorescent lamps, and attic/fireplace/duct improvements.

The whole house achieved (weather-normalized) savings of 54.2% of the energy that was being consumed by the home in the basecase year. The basecase energy, EEM package energy, and savings predicted in the design phase of the project and the actual measured savings by end-use from the Impact Evaluation Report (Eley, 1996) are summarized in Table 2 below.

Table 2. Stockton Residential Retrofit

Electricity Consumption and Savings by End Use

	Base Case (kWh/yr)		EEM Package (kWh/yr)		Savings (kWh/yr)		Savings (%)		Variance in Savings
	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	(kWh/yr)
Heat	494	732	121	304	373	428	76%	59%	55
Cool	1347	1534	326	494	1021	1040	76%	68%	19
DHW	0	0	0	65	0	-65	-100%	-100%	65
Refrigerator	1843	1843	450	601	1393	1242	76%	67%	151
Interior Misc.	--	3664	--	1322	--	2341	--	64%	--
Exterior Misc.	--	4633	--	2782	--	1852	--	40%	--
Misc Subtotal	8080	8297	3858	4104	4222	4193	52%	51%	29
Total	11764	12406	4755	5567	7009	6839	60%	55%	170

Gas Consumption and Savings by End Use

	Base Case (therm/yr)		EEM Package (therm/yr)		Savings (therm/yr)		Savings (%)		Variance in Savings
	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	(therm/yr)
Heat	1015	904	403	478	612	427	60%	47%	185
DHW	180	144	99	76	81	68	45%	47%	13
Dryer	0	0	0	18	0	-18	--	-100%	18
Spa & Pool	280	264	59	40	221	224	79%	85%	3
Total	1475	1312	561	611	914	701	62%	53%	213

Because the Stockton site is an existing house, little could be cost effectively done to the building shell. The only shell improvements that were cost effective consisted of increasing attic insulation from R-19 to R-30, air duct sealing, increasing duct insulation to R-30, and sealing several ceiling penetrations. These improvements resulted in combined savings of 689 kWh and 261 therms.

The HVAC system offered several opportunities for improving efficiency. First, the conventional 3 ton air conditioner was replaced with an evaporative pre-condenser unit which had an EER of 13.5 as compared to the basecase EER of 8.9. This measure saved 442 kWh/yr and reduced peak demand by 1.8 KW. The forced air heating system was replaced with a baseboard hydronic heating system which used a single high efficiency hot water heater to provide both space and water heating. This improvement resulted in annual electricity savings of 189 kWh and gas savings of 308 therms.

Significant savings were achieved in the lighting, equipment, and appliance end-uses. The lighting EEMs were implemented throughout the house and consisted of reduced wattage ceiling fan lights, occupancy sensors, conversion of T-12 fluorescent lamps and magnetic ballasts to T-8 lamps and electronic ballasts, use of compact fluorescent lamps (CFLs) in portable lamps, substitution of incandescent fixtures with T-8 and electronic ballasts, replacement of incandescent fixtures with hardwired CFLs, and halogen PAR lamps in place of conventional incandescent PAR lamps. The combined savings were 2,312 kWh annually; but these measures also resulted in an increase in gas usage of 45 therms annually. The equipment measures were applied to a spa, pool, and home office computer. The spa heater which had a standing pilot light which was replaced with a heater having an intermittent ignition device pilot resulted in savings of 140 therms annually while the heater's controls increased electric usage by 85 kWh per year. An efficient spa pump was installed saving 303 kWh annually. The pool filtration EEM reduced pumping pressure losses, allowed a 75% reduction in pump motor size. This provided 908 kWh per year in energy savings. Ninety kWh were saved by installing software on the home office computer that turned the monitor off when not in use. Two major appliances were replaced as part of the retrofit. An efficient gas dryer replaced an electric dryer, saving 622 kWh per year and increasing gas consumption by only 18 therms per year. A SERP refrigerator was installed resultling in electricity savings of 1,263 kWh annually and a 40 therm per year increase in gas usage.

Walnut Creek Residential Retrofit. The Walnut Creek, California site is a 1,578 ft^2 single-story residential home built in 1969 in California's "transition zone." Transition zone temperatures range from 75 -105 degrees F in the summers and 35 to 50^0F in the winter. The home was constructed in 1969 before Title-24 standards (California State energy codes) were instituted. Attic insulation had been added to achieve R-19 and the original single-pane windows had been replaced with aluminum frame dual-pane windows. A conventional gas forced-air furnace and 3 ton air conditioner provided heating and cooling. The retrofit equipment installed consisted of horizontal axis clothes washer, high efficiency freezer, gas clothes dryer, high-efficiency showerheads, outdoor halogen lamps, combined refrigerator water heater, screw-in compact fluorescent lamps, DHW anti-convection valves, baseboard hydronic heating with condensing water heater, T-8 fluorescent lamps with electronic ballasts, hard-wired compact, fluorescent lamps, high-efficiency faucets, exterior wall insulation, and evaporative pre-cooled condenser.

The whole house achieved (weather-normalized) savings of 51% of the energy that was being consumed by the home in the basecase year. The basecase energy, EEM package energy, and savings predicted in the design phase of the project and the actual measured savings by end-use from the Impact Evaluation Report (Eley, 1997) are summarized in Table 3 below.

Table 3. Walnut Creek Retrofit Residential

Electricity Consumption and Savings by End Use

End Use	Base Use (kWh/yr)		EEM Use (kWh/yr)		Savings (kWh/yr)		Savings (%)		Variance in Savings (kWh/yr)
	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	
Heat	142	158	41	88	101	70	71%	45%	-31
Cool	908	1,720	170	438	738	1,282	81%	75%	544
DHW	0	0	0	58	0	-58	0%	0%	-58
Int. Lighting	–	*1,248*	–	*361*	–	*887*	–	*71%*	–
Ext. Lighting	–	*801*	–	*270*	–	*531*	–	*66%*	–
Sbtl. Lighting	2052	2,049	634	631	1,418	1,418	69%	69%	0
Refrigerator	*1565*	*1,478*	*765*	*832*	*800*	*646*	*51%*	*44%*	*-154*
Freezer	*1382*	*1,612*	*425*	*483*	*957*	*1,129*	*69%*	*70%*	*172*
Sbtl. Refrigerators	2947	3,090	1190	1,315	1,757	1,775	60%	57%	18
Clothes Dryer	2021	1,928	384	138	1,637	1,790	81%	93%	153
Misc. Plug	1721	2,322	1601	1,956	120	366	7%	16%	246
Total	9,791	11,267	4,020	4,623	5,771	6,644	59%	59%	873

ᵀPredicted numbers are taken from the Final Design Report [6] for comparison

Gas Consumption and Savings by End Use

End Use	Base Use (therm/yr)		EEM Use (therm/yr)		Savings (therm/yr)		Savings (%)		Variance in Savings (therm/yr)
	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	
Heat	294	339	124	162	170	177	58%	52%	7
DHW	224	220	70	113	154	106	69%	48%	-48
Cook & Dryer	25	5	74	68	-49	-63	0%	0%	-14
Total	543	564	268	343	275	220	51%	39%	-55

As an existing home the Walnut Creek site again offered limited opportunities to improve building shell performance. However, several EEMs were installed that did improve shell performance and when combined with an evaporatively pre-cooled 2 ton air conditioner saved 815 kWh and 51 therms annually. These measures consisted of increasing attic insulation from R-19 to R-30, adding an attic radiant barrier, adding R-11 wall insulation, deciduous shade trees over west windows, insulated front door, and controlled ventilation crawl space with insulated foundation.

The forced-air furnace was replaced by a hydronic baseboard heating system using a single, high- efficiency water heater to provide space and water heating. This EEM resulted in annual savings of 51 kWh and 219 therms.

Lighting improvements consisted of replacing interior and exterior incandescent lamps with screw-in compact fluorescent lamps (CFLs), the replacing of T-12 fluorescent fixtures with T-8s, bathroom incandescent lamps with T-8 fixtures, outdoor incandescent lamps with halogen lamps, and various indoor incandescent fixtures and portable lamps with hard-wired CFL fixtures and lamps. These EEMs combined to provide 1,509 kWh in annual savings while increasing gas consumption by only 16 therms.

Several major appliance EEMs delivered 4,215 kWh and 3.8 therms in annual savings while increasing gas consumption by 71 therms. The greatest electric savings came from the replacement of an electric dryer with a high-efficiency gas dryer; this EEM saved 1,129 kWh/yr. and increased gas usage by 63 therms for a net source energy saving of 8.0 MBtus annually. The horizontal-axis washing machine saved 120 kWh and 3.8 therms annually. A 19 ft^3 freezer located in the garage was replaced with a high-efficiency refrigerator/freezer saving 1,129 kWh per year. Finally, the refrigerator water heater EEM saved 1,175 kWh and 18 therms of usage annually. However, the gas consumption rose 26 therms per year due to the reduction in electricity consumption in the kitchen for a net saving of 8 therms of gas annually.

Three New Construction Sites

CSAA Commercial New Construction. The California State Automobile Association (CSAA) building is a 15,704 ft^2 commercial office building located in Antioch, California and built in 1994. Antioch is located in California's Central Valley, with measured heating degree days of 2,343 and cooling degree days of 1,170, both against a 65^{0}F base.

The weather-normalized savings for the total EEM package savings are 218,975 kWh/yr and 3,028 therms/yr, or 64% of the energy that would have been consumed by the Title-24 compliant basecase building. The package reduces summer maximum peak electricity demand from 144 kW to 44 kW. The mature market cost of the EEM package is estimated to be $114,993. The present value of energy savings is $224,753, using PG&E's economics. Therefore, the overall benefit-cost ratio for the entire package is 1.95, slightly lower than the predicted value of 2.24. The basecase energy, EEM package energy, and savings predicted in the design phase of the project and the actual measured savings by end-use from the Impact Evaluation Report (Eley, 1997) are summarized in Table 4 below.

Table 4. CSAA New Construction Commercial

Electricity Consumption and Savings by End Use

End Use	Base Case (kWh/y)		EEM Package (kWh/y)		Savings (kWh/y)		Savings (%)		Variance in Savings (kWh/y)
	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	
Cool	58,632	65,002	14,257	21,870	44,375	43,133	76%	66%	-1,242
Heat	5,655	5,516	0	0	5,655	5,516	100%	100%	-139
Fans	36,833	33,974	4,288	9,945	32,545	24,028	88%	71%	-8,517
Lights	120,908	120,910	25,321	27,297	95,587	93,612	79%	77%	-1,975
DHW	5,992	900	2,696	72	3,296	828	55%	92%	-2,468
Misc.	123,352	123,352	59,818	71,494	63,534	51,858	52%	42%	-11,676
Total	351,372	349,654	106,380	130,679	244,992	218,975	70%	63%	-26,016

Gas Consumption and Savings by End Use

End Use	Base Case (therms/y)		EEM Package (therms/y)		Savings (therms/y)		Savings (%)		Variance in Savings (therms/y)
	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	
Heat	4,327	4,221	1,320	1,193	3,007	3,028	69%	72%	21

The CSAA office building basecase was a typical CSAA office building in a two-story structure with a floor area of 17,310 ft^2. The first EEM, Siting and Form, changed the structure to a single story, eliminating the need for an elevator, stairs, and a second set of bathrooms. Eliminating the extra spaces reduced the floor area to 15,704 ft^2. The one-story design made possible the inclusion of skylights for daylighting, skylight louvers, daylighting controls, barometric relief dampers and spectrally-selective windows. These improvements accounted for 33% of the total package savings. Other EEMs installed were a dual fan dual-duct HVAC system, HVAC DDC control system, "Energy Star" computers and monitors and occupancy sensors.

Davis Residential New Construction. The Davis, California site is a 1,656 ft^2 single-story home constructed in 1993 on a level lot on a north-facing street side in a new subdivision. Davis is located in California's Central Valley, a climate of very hot summers in the 95 to105^{0}F range and winter lows around freezing. Approximately 20 EEMs were implemented in the home consisting of schematic design, efficient window frames, light colored roof surface , engineered wall framing, radiant subpackage, low-flow showerheads, high-efficiency exhaust fans, DHW anti-convection valves, high-efficiency clothes washer, parallel piping for domestic hot water, water heater pressure and temperature valve improvements, low-flow lavatories, portable lighting fixture improvements, high-efficiency refrigerator, built-in lighting improvements, efficient oven, extra DHW tank insulation, refrigerator water heater, and cooling elimination subpackage.

The achieved whole house (weather-normalized) savings for all energy measures were 52 percent when compared with a typical new home meeting all of California's 1992 energy codes. The basecase energy, EEM package energy, and savings predicted in the design phase of the project and the actual measured savings by end-use from the Impact Evaluation Report (Eley, 1996) are summarized in Table 5 below.

Table 5. Davis Residential New Construction

Electricity Consumption and Savings by End-Use

End-Use	Base Use (kWh/yr)		EEM Use (kWh/yr)		Savings (kWh/yr)		Savings (%)		Variance in Savings (kWh/yr)
	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	
Heat	115	98	61	37	54	61	47%	62%	7
Cool	796	762	0	0	796	762	100%	100%	-34
DHW	0	0	20	52	-20	-52	0%	0%	-32
Int. Lighting	--	*574*	--	*199*	--	--	--	--	--
Ext. Lighting	--	*178*	--	*39*	--	--	--	--	--
Refrigerator	--	*1,465*	--	*852*	--	--	--	--	--
Sbtl. Lgt. & Ref.	3,051	2,218	847	1,090	2,204	1,128	72%	51%	-1,076
Misc.	2,034	1,832	1,910	1,860	124	-28	6%	-2%	-152
Total	**5,996**	**4,910**	**2,838**	**3,039**	**3,158**	**1,871**	**53%**	**38%**	**-1,287**

Gas Consumption and Savings by End-Use

End-Use	Base Use (therms/yr)		EEM Use (therms/yr)		Savings (therms/yr)		Savings (%)		Variance in Savings (therms)
	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	
Heat	275	248	57	86	218	162	79%	65%	-56
DHW	189	230	38	61	151	169	80%	74%	18
Misc.	75	61	72	60	3	2	4%	3%	-1
Total	**539**	**539**	**167**	**206**	**372**	**332**	**69%**	**62%**	**-40**

Stanford Ranch Residential New Construction. The Stanford Ranch home is a 1,782 ft^2, single-story slab-on-grade single-family detached home in a large planned tract development. It is located in California's Sierra foothills east of Sacramento, and has a climate similar to the Davis home, with the exception of daytime summer temperatures that are approximately 2^0F higher, reaching 107^0F, and at night do not normally fall below 70^0F. The energy efficiency measures installed were schematic design, engineered wall framing, low flow showerheads, light colored wall surface, insulated doors, high efficiency exhaust fans, water heater relocation, tuned glazing: southwest low-*e* coating, forced air hydronic heating with condensing water heater , DHW anti-convection valves, improved ducts, argon filled glazing (clear glass), high-efficiency refrigerator, evaporative underfloor cooling with forced air delivery, outdoor light motion sensor, parallel piping for domestic water, high-efficiency clothes washer, built-in lighting improvements, water heater pressure/temperature valve improvements, low-flow fixtures, dryer heat recovery, high-efficiency blower motor and fan, portable lighting improvements, extra water heater tank insulation, high-efficiency dishwasher, and slab edge insulation.

The achieved (weather-normalized) whole house savings for all energy measures were 54% of the energy that would have consumed had the house been built to California's Title-24 building energy standards. The basecase energy, EEM package energy, and savings predicted in the design phase of the project and the actual measured savings by end-use from the Impact Evaluation Report (Eley, 1996) are summarized in Table 6 below.

Table 6. Stanford Ranch New Construction Residential

Electricity Consumption and Savings by End Use

End Use	Base Use (kWh/yr)		EEM Use (kWh/yr)		Savings (kWh/yr)		Savings (%)		Variance in Savings (kWh/yr)
	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	
Heat	138	166	82	279	56	-113	41%	-68%	-169
Cool	2679	2648	357	403	2322	2245	87%	85%	-77
DHW	0	0	0	157	0	-157	0%	0%	-157
Int. Lighting	--	1484	--	416	--	1068	--	72%	--
Ext. Lighting	--	454	--	92	--	362	--	80%	--
Sbtl. Lighting	1938	1938	508	508	1430	1430	74%	74%	0
Refrigerator	1462	1462	667	542	795	920	54%	63%	125
Misc.	2655	2646	2563	2560	92	86	3%	3%	-6
Total	**8872**	**8860**	**4177**	**4450**	**4695**	**4410**	**53%**	**50%**	**-285**

Gas Consumption and Savings by End Use

End Use	Base Use (therm/yr)		EEM Use (therm/yr)		Savings (therm/yr)		Savings (%)		Variance in Savings (therm/yr)
	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	
Heat	312	392	78	157	234	234	75%	60%	0
DHW	160	160	52	61	108	99	68%	62%	-9
Total	**472**	**552**	**130**	**218**	**342**	**334**	**72%**	**60%**	**-9**

Lessons Learned

The PG&E R&D Team not only learned how to design and construct integrated energy efficient buildings, but also how to put together a successful multi-million dollar R&D project on integrated energy efficiency design. Each of these endeavors was a first-of-its-kind effort and many lessons were learned.

The Design Team. If we were to set out to design an ACT^2 building today, we would pick a design team based on its demonstrated ability to design very efficient buildings and its willingness and desire to create an exemplary facility. The personal drive of the lead project manager or designer can more than make up for less than perfect information on the latest technology. A reasonable amount of networking and access to a good energy efficiency data source can be a much more cost effective solution than hiring the best designers in the country. The personalities of top-notch design experts who have not worked together as a team before can actually end up making the entire process worse, both from a monetary standpoint and from a design standpoint. Plenty of teamwork and give and take is required among the team members to end up with a successful final design which will work.

Design Constraints. As a research project we required the design firms to spend time and effort to "prove" why many potential EEMs were screened out of consideration. The design firms felt that in many cases they could have used their own expert judgment in dropping EEMs and not affected the outcome of the final design.

Equipment Selection. The project installed several near-commercial technologies. Many of these required extensive baby-sitting or replacement. All equipment must be rugged and reliable with an extensive infrastructure to support it. We found that inadequate supporting infrastructure (firms which carry, maintain, upgrade and repair a particular vendor's equipment), can be the Achilles heel of good new technology.

Another consideration in the selection of an EEM is the lead time associated with the device or system to be included as part of the design. For example, when the windows were chosen for one of the sites, the first choice had to be abandoned and substituted during the construction phase because the supplies could not be delivered when needed. Although this may seem like a trivial and obvious task that is routine for a general contractor, the product supplier had quoted an acceptable delivery time during the design phase. The lesson here is to be prepared for this type of incident when working with suppliers of new technologies. A possible solution is to allow additional time for delivery of such products.

The General Contractor and Sub-Contractors. No matter how good the design is, an uninformed, inexperienced or poor contractor can sink the project. The company's experience and size seem to be key when evaluating its capabilities. For instance, has the contractor demonstrated the ability to install advanced technologies properly and will the contractor be around in the future to handle potential warranty issues? Many of the best new technologies will also be unfamiliar to the end-user, so it is even more critical that the contractor knows how to make sure the equipment works properly when installed and can service it as required. If the end-user is frustrated by the technology and can't get satisfaction from the contractor, the technology will not attain market acceptance. This is closely tied to the notion above about the infrastructure supporting new technology. The contractor becomes an integral part of that infrastructure. New technologies are going to take more service calls and callbacks than mature technologies. Contractors and vendors must factor that in when specifying and installing such equipment. Future market transformation programs may need to address the specific issue of increased callbacks for new technologies.

Commissioning. One misconception we uncovered was that a commissioning plan can simply have check-offs such as "Check the control sequence of the chiller" or "Verify the temperature sensor output." Invariably check-offs were noted as "complete," when in actuality the items were not commissioned. Sensors are a good example. A true commissioning plan needs the details on the correct method for checking each item. So the commissioning plan needs a dimensioned map to insure proper location of the sensor, the method to check if the wiring all the way from the sensor to the appropriate control system input is correct, and the appropriate checking method written out for the technician to follow and "as found" and "as left" boxes to be filled in. The sensor needs to be checked all the way through the system as well. Obtaining just the millivolt or amp readings at one temperature isn't sufficient. You must check the control system readings for the sensor at several temperatures. The sensor output could be correct but the control system may be miscalibrated resulting in incorrect readings.

Operation and Maintenance. It is essential to have service contracts with knowledgeable service firms or train the ones that are hired. Don't expect a service and/or repair company (including in-house staff which are subject to change) to service and/or repair new equipment properly.

Residential New Construction Design Considerations. Home energy consumption is primarily weather-driven, and in California solar loads have by far the greatest impact. Consequently, the first energy efficiency measures taken should be those that promote solar heat gain in the winter and solar gain reduction in the summer. Since the majority of these measures are building-shell- related (glazing, insulation, reflective roofs and walls, building orientation etc.), and since these measures are either implemented or missed for the life of the building all shell energy efficiency measures should be the first measures incorporated into the design..

Energy Performance Modeling. The main lesson learned from ACT^2's modeling effort is that the choice of the modeler, and not the firm, is critical. The person who actually "turns the knobs" is the person on whom the results of the model depend. Additionally, the mathematical algorithms that represent the individual components in the model engine need to be improved so that they accurately reflect the component under consideration. This is very difficult when you are trying to get the model to represent a new technology. It is imperative that some type of calibration be performed on the model using metered data. This will help eliminate errors introduced by the modeler using inaccurate assumptions.

The ultimate modeling lesson learned is that accurate, easy to use models must be developed and more people must be trained in all aspects of energy simulation modeling.

Conclusions

The concept of using whole-building integrated designs is sound and has been proved successful in creating larger energy savings at lower costs. Energy savings in the ACT^2 Project ranged from 40-65% in both commercial and residential buildings. Many obstacles have to be overcome to get this practice to be implemented regularly in the industry (market transformation). Further research should be done to identify, characterize and promote new energy efficient technologies that are cost effective, commercially available and reliable. Hopefully we can all build on the evidence provided by this project and others similar to it so that future buildings and retrofits incorporate integrated design principles to make all facilities simultaneously more comfortable, much more efficient, and less costly.

References

SBW Consulting, Inc. 1991. Advanced Customer Technology Test (ACT2) for Maximum Energy Efficiency Project Plan and Hand Books. Prepared for the Research and Development Department, Pacific Gas and Electric Company, San Ramon, California.

Eley Associates. 1997. ACT^2 Verifone Commercial Site Impact Evaluation Report (Draft). Prepared for the Research and Development Department, Pacific Gas and Electric Company, San Ramon, California.
URL: http://www.pge.com/customer_services/other/pec/act2/act2over.html

Eley Associates. 1996. ACT[2] Stockton Residential Site Impact Evaluation Report (Draft). Prepared for the Research and Development Department, Pacific Gas and Electric Company, San Ramon, California. URL: http://www.pge.com/customer_services/other/pec/act2/act2over.html

Eley Associates. 1997. ACT[2] Walnut Creek Residential Site Impact Evaluation Report (Draft). Prepared for the Research and Development Department, Pacific Gas and Electric Company, San Ramon, California. URL: http://www.pge.com/customer_services/other/pec/act2/act2over.html

Eley Associates. 1997. ACT[2] CSAA Commercial Site Impact Evaluation Report (Draft). Prepared for the Research and Development Department, Pacific Gas and Electric Company, San Ramon, California. URL: http://www.pge.com/customer_services/other/pec/act2/act2over.html

Eley Associates. 1996. ACT[2] Davis Residential Site Impact Evaluation Report (Draft). Prepared for the Research and Development Department, Pacific Gas and Electric Company, San Ramon, California URL: http://www.pge.com/customer_services/other/pec/act2/act2over.html

Eley Associates.1996. ACT[2] Stanford Ranch Residential Site Impact Evaluation Report (Draft). Prepared for the Research and Development Department, Pacific Gas and Electric Company, San Ramon, California. URL: http://www.pge.com/customer_services/other/pec/act2/act2over.html