Research and Development

ACT^2 Davis Residential Site EEM Impact Analysis

Customer Systems

File

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1. Executive Summary

Measured data and a calibrated simulation model are used to estimate the actual savings and cost effectiveness of energy efficiency measures (EEMs) installed at the Davis residential site. The base case for comparison with both predicted and measured savings complies with the 1992 California Title 24 energy code and thus should already include measures cost-effective from a societal perspective.

The weather-normalized savings for the total EEM package are estimated to be 52% compared to a typical new home, and the package reduces peak electricity demand from about 3.6 kW to 2.0 kW. These savings reflect no improvement in the small appliances that the occupants bring with them and that used roughly one-quarter of the base case electricity. Excluding all plug loads (except lighting and refrigerator), the savings were 80% predicted and 67% measured.

Table 1
End-Use Savings Summary

End-Use	Electricity Savings (%)		Gas Savings (%)		Source Energy Savings (%)	
	Predicted	Measured	Predicted	Measured	Predicted	Measured
Heat	47%	62%	79%	65%	78%	65%
Cool	100%	100%	--	--	100%	100%
DHW	0%	0%	80%	74%	79%	72%
Lgt. and Refr.	72%	51%	--	--	72%	51%
Misc.	6%	-2%	4%	3%	5%	0%
Total	**53%**	**38%**	**69%**	**62%**	**61%**	**52%**

The building is a 1,656 ft^2 (net) single family residence located in Davis, California. Heating is provided by a hydronic radiant floor system based on a high efficiency water heater for combined space heating and domestic hot water duty. The house requires no compressor cooling due to a package of measures that reduces cooling loads, using mechanical venting at night and employing ceiling fans to improve comfort. Other measures include an R-26 engineered wall system, high performance windows, light-colored roof, a high efficiency refrigerator with heat recovery for water heating, efficient appliances and high efficiency showerheads and faucets.

The most cost effective measure is the Schematic Design, which reduces perimeter length and changes window area and orientation. The Radiant Subpackage, which includes the radiant floor system and efficient water heater, provides roughly one-half of the total energy savings. It reduces space heating fuel consumption by 45% and water heating fuel consumption by 36%.

The savings are compared to estimates developed by the Design/Build Team and reported in the Final Design Report [3]. The measured estimate of 52% savings is lower than the 62% estimated in the Final Design Report. Three types of changes each account for roughly one-third of the total savings difference. They include 1) design changes, 2) use of measured operating patterns in the simulation, and 3) adjusted modeling parameters.

The most significant design change is the substitution of a less efficient refrigerator at the request of the homeowners, accounting for about 40% of the difference in electricity savings.

Use of measured operation patterns results in a significant drop in lighting savings because the actual lighting operating hours are roughly one-half of the predicted hours. This change also accounts for nearly 40% of the difference between predicted and measured electricity savings.

A change in the slab floor model parameters is responsible for nearly all of the drop in gas savings. The new method is based on a finite element heat loss model developed specifically for the slab floor of the Davis house.

In the mature market, the EEM package is estimated to cost $4,490 less than the base case house. The present value of energy savings is $3,845. Therefore, the net present value of the EEMs, based on PG&E's economic perspective, is $8,335. Due to the large negative cost of the schematic design EEM, the average electricity cost of conserved energy (CCE) is -$2.33/kWh. The average CCE for gas dominated EEMs is also negative: -$0.79/therm. The marginal CCEs, for the least cost-effective measures are $0.08/kWh and $0.53/therm.

2. ACT² Overview

PG&E's Advanced Customer Technology Test for Maximum Energy Efficiency (ACT²) is a project to design, implement and measure integrated packages of technologies which are optimized for maximum energy efficiency at selected PG&E customer facilities. ACT² demonstrations are carried out at both commercial and residential sites, including new construction and existing buildings. The ACT² mission is as follows:

> To provide scientific field test information, for use by PG&E and its customers, on the maximum energy savings possible, at or below projected competitive costs, by using modern high-efficiency end-use technologies in integrated packages acceptable to the customer.

The groups involved in implementing and evaluating the energy efficiency measures (EEMs) include:

1. *Design/Build Team*: performs EEM analysis and design, performs or oversees construction, and commissions EEMs.
2. *Site Data Collection and Impact Evaluation (SDCIE) Team*: develops base-case models, develops measurement plans, implements monitoring, evaluates EEM savings after one year of building operation. Measures and evaluates one year of pre-installation data for retrofit projects.

This report, the EEM Impact Analysis, is produced by the SDCIE team after the energy efficiency measures have been in operation for at least one year.

The Davis house is one of the residential new construction demonstrations. The following is a list of ACT² sites.

Table 2
ACT^2 Demonstration Sites

Project	Location	Type
Sunset Building	San Ramon	commercial office retrofit (pilot project)
Residence	Davis	single family new construction
Residence	Stockton	single family retrofit
CSAA	Antioch	commercial office new construction
Residence	Walnut Creek	single family retrofit
Stanford Ranch	Rocklin	single family new construction
Verifone	Auburn	commercial office retrofit
Restaurant	Pleasanton	restaurant retrofit

3. Introduction

In this analysis, the calibrated operations model is used to provide the following results for the ACT^2 Davis Residential Site:

1. Energy and demand savings for the whole site and for each EEM, monthly and by end-use,
2. EEM installed cost estimates, based on actual data,
3. Energy efficiency supply curve based on the Cost of Conserved Energy (CCE),
4. Information about the persistence and reliability of the EEMs.

This analysis builds on the work of the Residential Design/Build Team (RDBT) and other members of the Site Data Collection and Impact Evaluation (SDCIE) Team. Prior to this analysis the DOE2 simulation model has evolved from design model to as-built model to sequential analysis model. The sequential analysis model was modified during operations model calibration.

Monitored energy consumption is summarized in the *Davis Postcondition Data Report* [1].

4. Method

The starting point for the analysis is the calibrated operations model, described in the *Operations Model Calibration Report* [9]. Energy efficiency measures (EEMs) are removed from the calibrated model to create the base case. Then savings are determined by adding the measures one-by-one, both individually and sequentially, to that base case. The EEMs are described in the Results section of this report, along with a discussion of calculation methods and results.

More information about the ACT^2 design and evaluation method is included in the *ACT^2 EEM Evaluation Handbook* [10] and the *ACT^2 Project Plan* [11].

4.1 Simulation Program

The simulation program used for the analysis is PC DOE2.1E-W79, developed by J.J. Hirsch.

4.2 Weather

The impact analysis simulations use the standard California Energy Commission TMY weather file for Climate Zone 12 (Sacramento). While the operations model is calibrated with measured weather data, the EEM analysis employs typical weather data so that the results can be generalized to a typical year.

4.3 Base Case House

The base case house complies with California's Title 24 energy efficiency standard, which covers shell insulation, window shading and conductance, space heating, cooling and water heating equipment efficiency, and lighting efficiency in kitchens and bathrooms. The code is designed to include measures that are cost-effective from a societal perspective. Therefore, the base case house is already an efficient building.

Features of the base case design include R-13 wall insulation, R-38 ceiling insulation, double-pane windows, an uninsulated slab-on-grade floor, a gas furnace with AFUE of 78%, an air conditioner with SEER of 10.0, and a standard gas water heater.

4.4 Modeling Assumptions

Measured data are used for some modeling inputs, while in other cases typical assumptions are employed. Measured data are used where they are expected to provide better accuracy than the schedules originally used to predict savings. The following model inputs are based on measured data:

1. plug loads
2. appliance operating schedules
3. lighting schedules
4. hot water consumption schedules
5. occupancy schedules

Ideally, the schedules listed above would be typical of average occupants. However, usage varies widely in residences, and “standard” schedules are not available for all the model inputs used here. The modeling procedures for compliance with California’s Title 24 do not include a breakdown of end-use schedules for residences. Therefore, the measured usage for this house was judged to be more accurate than schedules based on assumed operating patterns.

The following inputs are based on typical conditions rather than monitored data:

1. thermostat setpoint schedules
2. weather

Typical year weather data are used to reduce the impact of varying weather conditions on the results.

DOE2 is used to calculate heating and cooling savings. The direct savings for many measures such as water heating, lighting and appliances are calculated outside of the DOE2 simulation. Where the energy used by those measures impacts the heating and cooling load, then that impact is included in the simulation.

4.5 EEM Cost Review Method

The cost assumptions in the final design report are reviewed and compared to "as-built" cost data. As-built data are available in the form of the builder's cost estimates for each EEM, which were negotiated before construction and are equal to the incremental cost paid by PG&E. Unfortunately, the builder's estimates include costs specific to ACT^2, such as extra labor that may be required for an unfamiliar procedure. Since those costs are not broken down, it is difficult to figure out an appropriate adjustment to the mature market cost. Therefore, the result of the review is that the original design estimates for mature market costs are accepted in all cases. These costs may be lower or higher than "actual" mature market costs, but not enough evidence exists to make accurate adjustments. For information purposes, the final design estimates and the builder estimates are compared for each measure described in this report.

In other words, actual costs reflect those peculiar to a unique experiment. A conscientious effort was made by the design/build team to estimate what such a house would cost to build if this sort of construction were widely practiced. However, this mature market cost can be empirically validated only by trying that experiment as well, i.e., building a lot of Davis-like houses.

5. Summary of Results

5.1 EEM Package Results

The EEM package reduces electricity consumption from a typical house by 37%, from 4,814 kWh/yr to 3,039 kWh/yr. Figure 1 compares monthly electricity usage for the base case and the whole package.

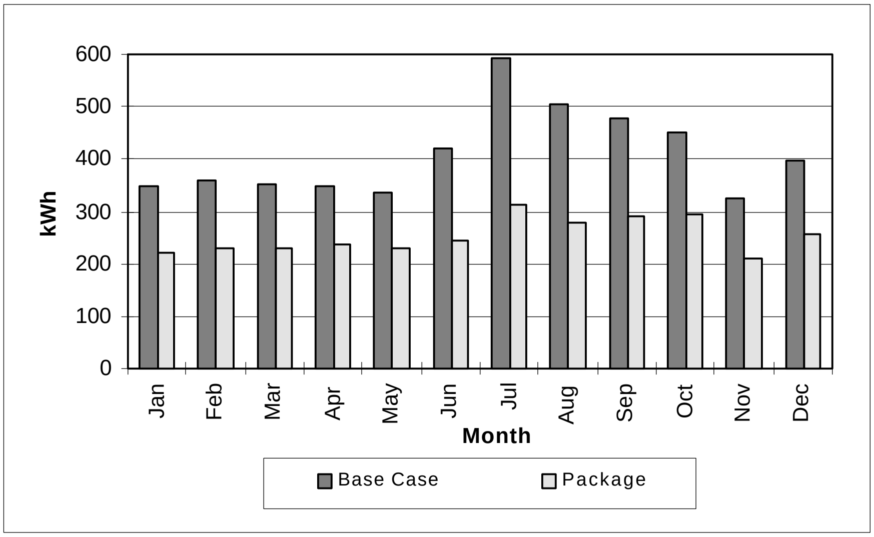

Figure 1
Monthly Electricity Comparison of Base Case to EEM Package

The package reduces gas consumption by 62%, from 539 therms/yr to 206 therms/yr. Figure 2 compares monthly gas consumption for the base case and the whole package.

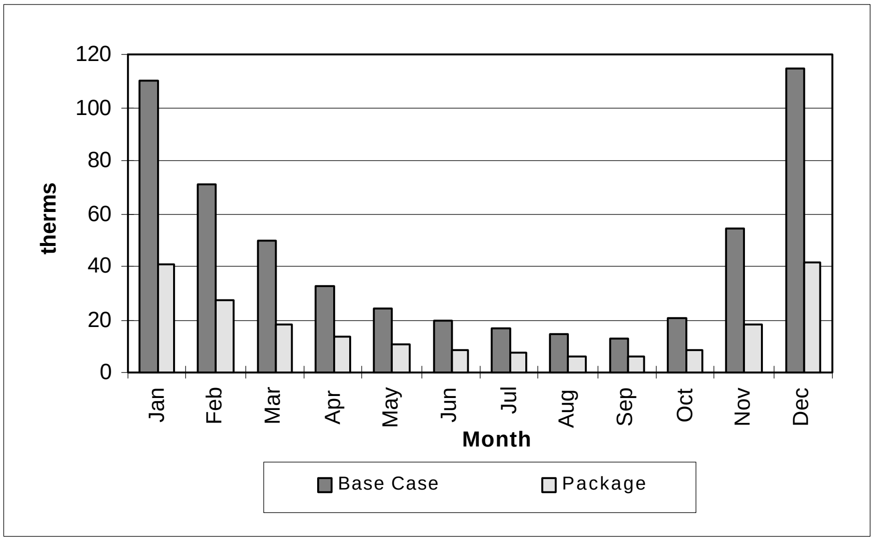

Figure 2
Monthly Gas Comparison of Base Case to EEM Package

The package reduces total source energy consumption by 52%, from 55.8 MBtu/yr to 27.1 MBtu/yr. Figure 3 compares monthly source energy consumption.

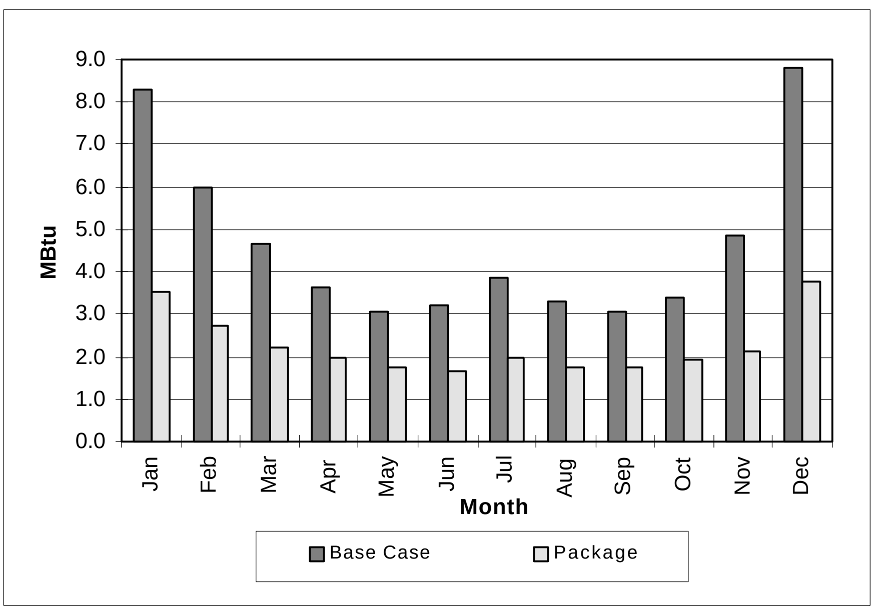

Figure 3
Monthly Source Energy Comparison of Base Case to EEM Package
(1 kWh = 8000 source Btu)

The following three tables show electricity and gas savings by end-use. Total measured electricity savings are 38% and gas savings are 62%, compared to predicted savings of 53% and 69%. Total measured source energy savings are 52% while the predicted savings were 61%. Some of the reasons for the reduced savings are discussed later in Section 5.5; the largest differences occur in the refrigerator and interior lighting savings. The predicted savings are taken from the Final Design Report [3].

Table 3
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**

Table 4
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**

Table 5
Source Energy Consumption and Savings by End-Use
(1 kWh = 8000 source Btu)

End-Use	Base Use (MBtu/yr)		EEM Use (MBtu/yr)		Savings (MBtu/yr)		Savings (%)		Variance in Savings (MBtu)
	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	
Heat	28.4	25.6	6.2	8.9	22.2	16.7	78%	65%	-5.55
Cool	6.4	6.1	0.0	0.0	6.4	6.1	100%	100%	-0.27
DHW	18.9	23.0	4.0	6.5	14.9	16.5	79%	72%	1.52
Int. Lighting	--	*4.6*	--	*1.6*	--	--	--	--	
Ext. Lighting	--	*1.4*	--	*0.3*	--	--	--	--	
Refrigerator	--	*11.7*	--	*6.8*	--	--	--	--	
Sbtl. Lgt. & Ref.	24.4	17.7	6.8	8.7	17.6	9.0	72%	51%	-8.61
Misc.	23.8	20.8	22.5	20.8	1.3	-0.1	5%	0%	-1.34
Total	**101.9**	**93.1**	**39.4**	**44.9**	**62.5**	**48.2**	**61%**	**52%**	**-14.25**

Figure 4 compares the simulated peak electricity demand profile for the base case and the EEM package. These results use the calibrated simulation model and correspond to the "measured" savings listed in the preceding tables. Two days are shown: August 1 was chosen because it corresponds to PG&E's system peak in 1995, and August 7 is the peak for the base case model. Figure 5 provides a better picture of the EEM package; it shows the simulated average electric demand profile for the period of July through September. The base case average reaches 3.1 kW, while the EEM package case peak is 0.7 kW.

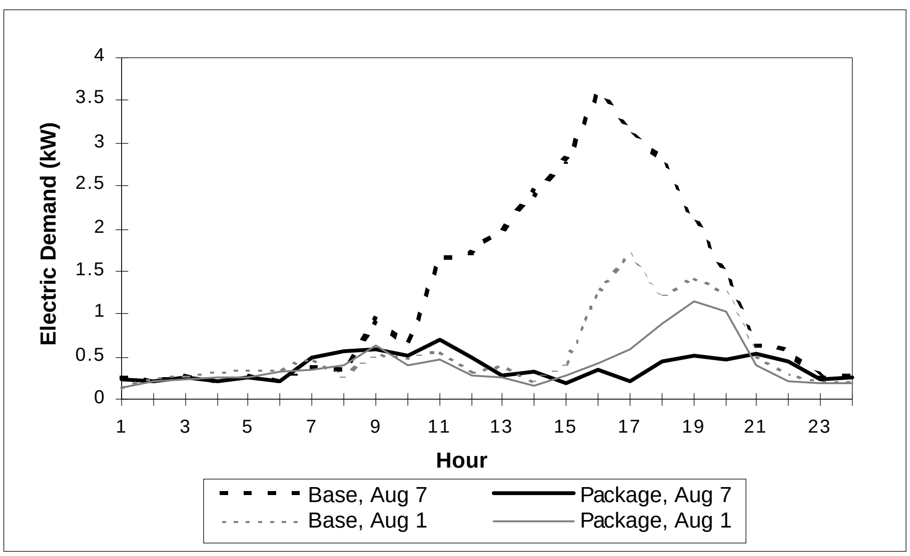

Figure 4
Comparison of Peak Electric Demand, Base vs. EEM Package.

Simulated Demand using Calibrated Model and Normalized Weather, August 1 & 7

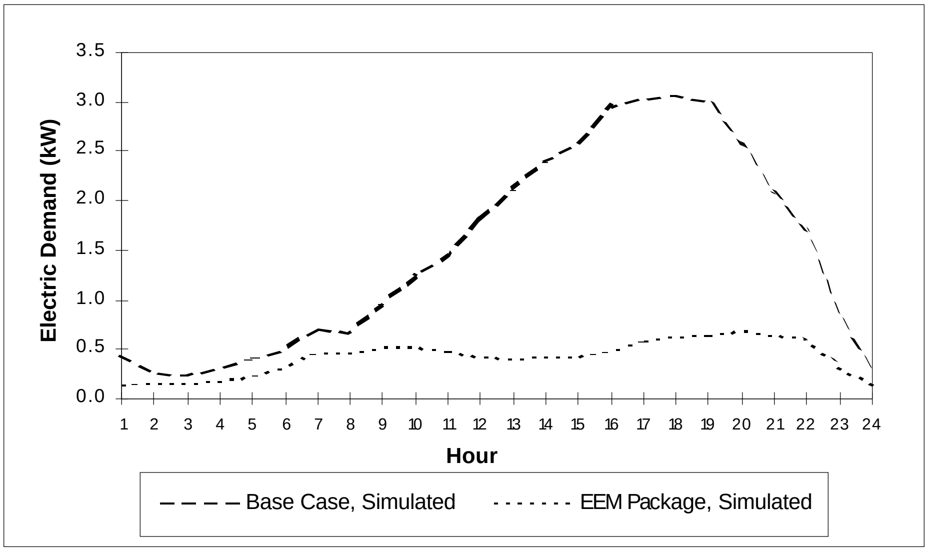

Figure 5
Comparison of Summer Electric Demand, Base vs. EEM Package.
Simulated Demand using Calibrated Model and Normalized Weather.
Average kW for July through September.

Figure 6 shows the monthly peak electric demand for the base case and the EEM package. The results are based on simulations using typical weather data.

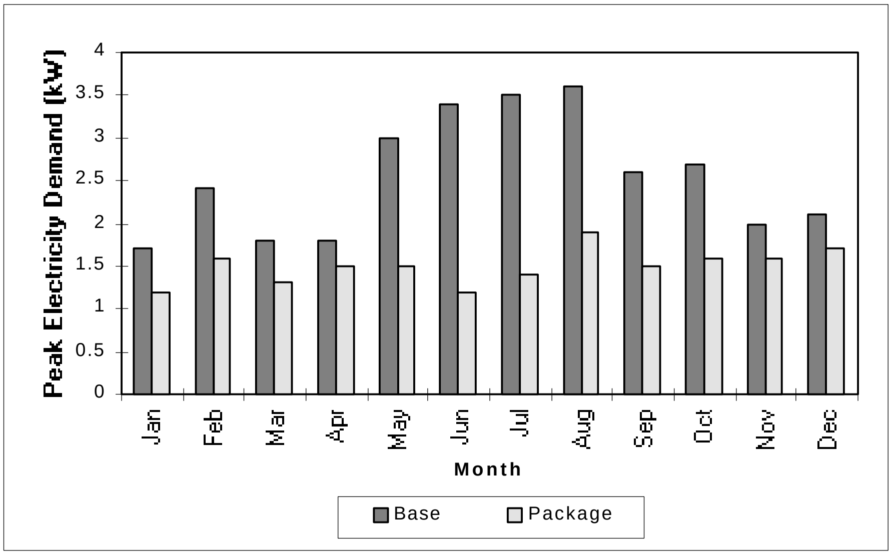

Figure 6
Comparison of Monthly Peak Electric Demand.
Simulated Demand using Calibrated Model and Normalized Weather.

5.2 Sequential EEM Results

Table 6 shows the results of the economic analysis for each EEM. The measures are ranked according to the order of measures in the *Sequential Analysis* [6]. In that report, the measures were ranked from highest to lowest benefit-cost ratio (BCR), except for the measures with negative first cost, which are ranked by net present value (NPV). The results here are slightly different because energy savings change with the calibrated model. Therefore, the order of EEMs in the list would be different if the sequential analysis were to be repeated. However, the difference in savings results would be small for the individual measures and would not change for the package as a whole.

Savings for three measures have dropped to the point that they are no longer cost-effective. The BCR for the hardwired lighting measure drops from 1.50 to 0.69. The dishwasher BCR drops to 0.18. The combined refrigerator water heater, drops from being marginally cost effective with a BCR of 1.0 to a BCR of 0.32. For a fourth measure, the cooling elimination subpackage, cost effectiveness drops slightly from a BCR of 0.70 to 0.65. This measure was included at the discretion of PG&E even though it was somewhat under the BCR limit. Each of these EEMs is discussed in more detail in Section 6.

Table 6
EEM Economic Results and Incremental Energy Savings

		Measured							Predicted (Final Design Report)						
		NPV	CCE		Annual Energy Savings			Cum	NPV	CCE		Annual Energy Savings			Cum
No.	Description	BCR	$/kWh	$/therm	therms	kWh	MBtu	%	BCR	$/kWh	$/therm	therms	kWh	MBtu	%
1	Schematic Design (peri. & glzg)	5,332	-0.50		25	344	5.3	6%	5,198		-2.48	101.0	231	11.9	12%
2	Radiant Sub-Package	1,275		-0.05	183	-9	18.2	25%	1,439		-0.06	167.7	247	18.7	30%
3	Engineered Wall Framing	696		-0.78	38	11	3.9	29%	677		-0.81	38.5	-11	3.8	33%
4	High efficiency refrigerator	590	0.00		-9	688	4.6	34%	1.90	0.04		-13.2	1266	8.8	42%
5	High R Window Frames	397		-1.71	10	31	1.2	36%	397		-1.55	13.3	17	1.5	43%
6	Roof Surface Characteristics	109	-0.23		-2	49	0.2	36%	130	-0.17		-4.4	86	0.2	44%
7	Low flow showerheads	207		0.00	33	0	3.3	39%	63		0.00	10.1	0	1.0	45%
8	High efficiency exhaust fans	7	0.00		0	8	0.1	39%	11	0.00		0.0	12	0.1	45%
9	Horizontal axis clothes washer	2.94		0.17	11	29	1.3	41%	3.60		0.13	14.0	32	1.7	46%
10	Parallel piping	3.43		0.12	3	0	0.3	41%	2.80		0.15	2.8	0	0.3	47%
11	PTV improvements	4.88		0.09	5	0	0.5	42%	2.80		0.15	2.8	0	0.3	47%
12	High efficiency lavatory faucets	2.78		0.15	8	0	0.8	43%	2.20		0.19	6.7	0	0.7	48%
13	Owner lamp retrofit	2.32	0.03		-1	127	0.9	44%	2.00	0.03		0.0	107	0.9	48%
14	Built-in Lighting Improvements	0.69	0.10		-7	523	3.5	47%	1.50	0.04		-5.0	1062	8.0	56%
15	Improved oven	1.06		0.45	1	2	0.1	47%	1.20		0.35	1.7	0	0.2	56%
16	Added DHW tank insulation	1.18		0.36	5	0	0.5	48%	1.10		0.39	4.4	0	0.4	57%
17	Cooling elimination subpackage	0.65		0.79	20	71	2.5	51%	0.70	0.08		7.4	161	2.0	59%
18	Refrigerator water heater	0.32		1.26	8	-5	0.7	51%	1.00		0.48	18.0	18	1.9	61%
19	Energy efficient dishwasher	0.18		2.34	3	0	0.3	52%	1.10		0.53	6.1	42	0.9	62%

Table 7
Energy Consumption by End-Use as EEMs are Added Sequentially to Base Case (Measured)

		Gas (therms)			Electricity (kWh)							Totals		
No.	Description	Heat	DHW	Misc.	Heat	Cool	DHW	Int. Lgt	Ext. Lgt	Refr.	Misc.	Gas (therms)	Elec. (kWh)	Source (MBtu)
	Base Case	248	230	61	98	762	0	574	178	1,465	1,832	539	4,910	93.1
1	Schematic Design	222	230	61	87	429	0	574	178	1,465	1,832	513	4,566	87.8
2	Radiant Subpackage	122	147	61	53	419	52	574	178	1,465	1,832	331	4,574	69.7
3	Engineered Wall Framing	84	147	61	37	425	52	574	178	1,465	1,832	293	4,563	65.8
4	High efficiency refrigerator	93	147	61	41	347	52	574	178	852	1,832	302	3,876	61.2
5	High R Window Frames	84	147	61	36	320	52	574	178	852	1,832	292	3,845	60.0
6	Roof Surface Characteristics	86	147	61	37	269	52	574	178	852	1,832	294	3,794	59.8
7	High efficiency shower heads	86	114	61	37	269	52	574	178	852	1,832	261	3,794	56.5
8	High efficiency exhaust fans	86	114	61	37	269	52	574	178	852	1,824	261	3,786	56.4
9	High efficiency clothes washer	86	103	61	37	269	52	574	178	852	1,794	251	3,757	55.1
10	Parallel piping	86	101	61	37	269	52	574	178	852	1,794	248	3,757	54.8
11	PTV improvements	86	96	61	37	269	52	574	178	852	1,794	243	3,757	54.3
12	High efficiency lavatory faucets	86	87	61	37	269	52	574	178	852	1,794	234	3,757	53.5
13	Lighting level II improvements	87	87	61	38	266	52	574	178	852	1,671	235	3,630	52.6
14	Lighting level I improvements	94	87	61	41	254	52	199	39	852	1,671	242	3,108	49.1
15	Improved oven	94	87	60	41	251	52	199	39	852	1,671	241	3,105	49.0
16	Added DHW Tank Insulation	94	83	60	41	251	52	199	39	852	1,671	236	3,105	48.5
17	Cooling Elimination Subpackage	75	83	60	32	0	52	199	39	852	1,860	217	3,034	46.0
18	Refrigerator water heater	86	64	60	37	0	52	199	39	852	1,860	209	3,039	45.2
19	Dishwasher	86	61	60	37	0	52	199	39	852	1,860	206	3,039	44.9

Table 8
Incremental Savings for Each EEM by End-Use (Measured)

		Gas (therms)			Electricity (kWh)							Totals		
No.	**Description**	**Heat**	**DHW**	**Misc.**	**Heat**	**Cool**	**DHW**	**Int. Lgt**	**Ext. Lgt**	**Refr.**	**Misc.**	**Gas (therms)**	**Elec. (kWh)**	**Source (MBtu)**
1	Schematic Design	25	0	0	11	333	0	0	0	0	0	25	344	5.3
2	Radiant Subpackage	100	82	0	34	10	-52	0	0	0	0	182	-8	18.2
3	Engineered Wall Framing	38	0	0	16	-6	0	0	0	0	0	38	11	3.9
4	High efficiency refrigerator	-9	0	0	-4	78	0	0	0	613	0	-9	687	4.6
5	High R Window Frames	10	0	0	4	27	0	0	0	0	0	10	31	1.2
6	Roof Surface Characteristics	-2	0	0	-1	51	0	0	0	0	0	-2	50	0.2
7	High efficiency shower heads	0	33	0	0	0	0	0	0	0	0	33	0	3.3
8	High efficiency exhaust fans	0	0	0	0	0	0	0	0	0	8	0	8	0.1
9	High efficiency clothes washer	0	11	0	0	0	0	0	0	0	29	11	29	1.3
10	Parallel piping	0	3	0	0	0	0	0	0	0	0	3	0	0.3
11	PTV improvements	0	5	0	0	0	0	0	0	0	0	5	0	0.5
12	High efficiency lavatory faucets	0	8	0	0	0	0	0	0	0	0	8	0	0.8
13	Lighting level II improvements	-1	0	0	0	3	0	0	0	0	124	-1	127	0.9
14	Lighting level I improvements	-7	0	0	-3	12	0	375	140	0	0	-7	523	3.5
15	Improved oven	-1	0	2	0	3	0	0	0	0	0	1	2	0.1
16	Added DHW Tank Insulation	0	5	0	0	0	0	0	0	0	0	5	0	0.5
17	Cooling Elimination Subpackage	20	0	0	9	251	0	0	0	0	-189	20	71	2.5
18	Refrigerator water heater	-11	19	0	-5	0	0	0	0	0	0	8	-5	0.7
19	Dishwasher	0	3	0	0	0	0	0	0	0	0	3	0	0.3

Table 9
Cumulative Savings for Each EEM by End-Use (Measured)

		Gas (therms)			Electricity (kWh)							Totals		
No.	Description	Heat	DHW	Misc.	Heat	Cool	DHW	Int. Lgt	Ext. Lgt	Refr.	Misc.	Gas (therms)	Elec. (kWh)	Source (MBtu)
1	Schematic Design	25	0	0	11	333	0	0	0	0	0	25	344	5.3
2	Radiant Subpackage	126	82	0	45	343	-52	0	0	0	0	208	336	23.5
3	Engineered Wall Framing	163	82	0	62	337	-52	0	0	0	0	246	347	27.3
4	High efficiency refrigerator	155	82	0	58	415	-52	0	0	613	0	237	1,034	31.9
5	High R Window Frames	164	82	0	62	442	-52	0	0	613	0	246	1,065	33.2
6	Roof Surface Characteristics	162	82	0	61	493	-52	0	0	613	0	244	1,115	33.3
7	High efficiency shower heads	162	115	0	61	493	-52	0	0	613	0	277	1,115	36.6
8	High efficiency exhaust fans	162	115	0	61	493	-52	0	0	613	8	277	1,123	36.7
9	High efficiency clothes washer	162	126	0	61	493	-52	0	0	613	37	288	1,153	38.0
10	Parallel piping	162	129	0	61	493	-52	0	0	613	37	291	1,153	38.3
11	PTV improvements	162	134	0	61	493	-52	0	0	613	37	296	1,153	38.8
12	High efficiency lavatory faucets	162	142	0	61	493	-52	0	0	613	37	304	1,153	39.6
13	Lighting level II improvements	161	142	0	60	497	-52	0	0	613	161	303	1,279	40.5
14	Lighting level I improvements	154	142	0	57	508	-52	375	140	613	161	296	1,802	44.0
15	Improved oven	153	142	2	57	511	-52	375	140	613	161	297	1,805	44.2
16	Added DHW Tank Insulation	153	147	2	57	511	-52	375	140	613	161	302	1,805	44.6
17	Cooling Elimination Subpackage	173	147	2	66	762	-52	375	140	613	-28	322	1,875	47.2
18	Refrigerator water heater	162	166	2	61	762	-52	375	140	613	-28	329	1,871	47.9
19	Dishwasher	162	169	2	61	762	-52	375	140	613	-28	332	1,871	48.2

Table 10
Monthly Electricity Consumption as EEMs are Added Sequentially to Base Case, kWh (Measured)

No.	EEM Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	Base Case	348	360	351	349	336	420	592	505	476	452	324	397	4,910
1	Schematic Design	344	358	350	350	309	353	492	422	424	448	322	393	4,566
2	Radiant Subpackage	337	355	353	352	313	355	495	424	427	453	321	388	4,574
3	Engineered Wall Framing	332	352	351	351	313	353	493	420	433	461	320	383	4,563
4	High efficiency refrigerator	304	313	303	291	270	295	403	346	332	375	286	356	3,876
5	High R Window Frames	303	313	303	291	269	292	395	340	328	371	286	355	3,845
6	Roof Surface Characteristics	303	313	303	291	268	283	378	327	321	365	286	355	3,794
7	High efficiency shower heads	303	313	303	291	268	283	378	327	321	365	286	355	3,794
8	High efficiency exhaust fans	302	312	302	291	268	282	378	327	321	364	285	354	3,786
9	High efficiency clothes washer	300	309	300	288	265	280	375	325	319	361	282	352	3,757
10	Parallel piping	300	309	300	288	265	280	375	325	319	361	282	352	3,757
11	PTV improvements	300	309	300	288	265	280	375	325	319	361	282	352	3,757
12	High efficiency lavatory faucets	300	309	300	288	265	280	375	325	319	361	282	352	3,757
13	Lighting level II improvements	289	299	289	279	255	270	364	314	310	350	272	340	3,630
14	Lighting level I improvements	237	239	237	240	223	242	335	280	274	311	218	271	3,108
15	Improved oven	237	239	237	240	223	242	335	280	273	310	218	272	3,105
16	Added DHW Tank Insulation	237	239	237	240	223	242	335	280	273	310	218	272	3,105
17	Cooling Elimination Subpackage	220	229	230	235	230	244	312	280	292	295	211	255	3,034
18	Refrigerator water heater	222	230	231	235	230	244	312	280	292	295	212	257	3,039
19	Dishwasher	222	230	231	235	230	244	312	280	292	295	212	257	3,039

Table 11
Monthly Incremental Electricity Savings, kWh (Measured)

No.	EEM Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Schematic Design	4	2	1	-1	27	67	100	83	52	4	2	4	344
2	Radiant Subpackage	7	3	-3	-3	-4	-3	-3	-2	-3	-5	0	5	-8
3	Engineered Wall Framing	4	3	2	1	1	2	2	3	-6	-8	2	4	11
4	High efficiency refrigerator	29	39	48	60	43	58	90	74	101	86	33	27	687
5	High R Window Frames	1	1	1	0	1	4	8	7	4	4	0	1	31
6	Roof Surface Characteristics	0	0	0	0	1	8	17	12	7	6	0	0	50
7	High efficiency shower heads	0	0	0	0	0	0	0	0	0	0	0	0	0
8	High efficiency exhaust fans	1	1	1	1	0	1	1	0	0	1	1	0	8
9	High efficiency clothes washer	3	2	2	2	3	3	3	2	2	2	3	3	29
10	Parallel piping	0	0	0	0	0	0	0	0	0	0	0	0	0
11	PTV improvements	0	0	0	0	0	0	0	0	0	0	0	0	0
12	High efficiency lavatory faucets	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Lighting level II improvements	11	10	11	10	10	10	11	11	10	11	11	12	127
14	Lighting level I improvements	52	60	52	39	32	27	28	34	36	39	54	68	523
15	Improved oven	0	0	0	0	0	0	0	0	1	1	0	0	2
16	Added DHW Tank Insulation	0	0	0	0	0	0	0	0	0	0	0	0	0
17	Cooling Elimination Subpackage	16	10	7	5	-7	-2	23	0	-19	15	7	16	71
18	Refrigerator water heater	-1	-1	0	-1	0	0	0	0	0	0	-1	-1	-5
19	Dishwasher	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 12
Monthly Cumulative Electricity Savings, kWh (Measured)

No.	EEM Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Schematic Design	4	2	1	-1	27	67	100	83	52	4	2	4	344
2	Radiant Subpackage	11	5	-2	-4	23	64	97	81	49	-1	2	9	336
3	Engineered Wall Framing	15	8	0	-2	24	66	99	85	44	-9	4	14	347
4	High efficiency refrigerator	44	47	48	57	66	124	189	159	144	77	37	41	1034
5	High R Window Frames	45	47	48	58	67	128	197	166	148	81	38	42	1065
6	Roof Surface Characteristics	45	47	48	58	68	136	214	178	155	87	38	42	1115
7	High efficiency shower heads	45	47	48	58	68	136	214	178	155	87	38	42	1115
8	High efficiency exhaust fans	45	49	49	58	68	137	215	178	155	88	39	42	1123
9	High efficiency clothes washer	48	51	51	60	71	140	218	180	157	90	41	45	1153
10	Parallel piping	48	51	51	60	71	140	218	180	157	90	41	45	1153
11	PTV improvements	48	51	51	60	71	140	218	180	157	90	41	45	1153
12	High efficiency lavatory faucets	48	51	51	60	71	140	218	180	157	90	41	45	1153
13	Lighting level II improvements	59	61	62	70	81	150	229	191	167	101	52	57	1279
14	Lighting level I improvements	111	121	114	109	113	177	257	225	203	141	106	125	1802
15	Improved oven	111	121	114	109	113	177	258	226	203	142	106	125	1805
16	Added DHW Tank Insulation	111	121	114	109	113	177	258	226	203	142	106	125	1805
17	Cooling Elimination Subpackage	127	131	121	114	106	176	280	225	184	157	113	141	1875
18	Refrigerator water heater	126	130	120	114	106	176	280	225	184	157	112	140	1871
19	Dishwasher	126	130	120	114	106	176	280	225	184	157	112	140	1871

Table 13
Monthly Gas Consumption as EEMs are Added Sequentially to Base Case, therms (Measured)

No.	EEM Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	Base Case	109.8	70.7	49.4	32.3	24.1	19.6	16.4	14.4	12.8	20.2	54.4	114.5	538.5
1	Schematic Design	101.2	66.5	47.9	34.8	24.1	19.6	16.4	14.4	12.8	20.1	49.5	105.8	513.1
2	Radiant Subpackage	63.5	41.2	29.0	20.9	17.4	14.1	12.4	10.5	9.1	14.1	31.0	67.6	330.8
3	Engineered Wall Framing	53.3	35.0	24.3	18.2	17.4	14.1	12.4	10.5	9.1	14.0	26.8	57.7	292.9
4	High efficiency refrigerator	55.0	36.8	26.0	19.6	17.4	14.1	12.4	10.5	9.1	14.1	27.5	59.3	301.8
5	High R Window Frames	52.4	35.2	24.8	18.8	17.4	14.1	12.4	10.5	9.1	14.1	26.6	56.7	292.2
6	Roof Surface Characteristics	52.9	35.5	25.2	19.3	17.4	14.1	12.4	10.5	9.1	14.1	26.7	57.1	294.3
7	High efficiency shower heads	48.5	32.3	22.5	17.1	14.7	12.1	11.1	9.3	8.3	12.4	23.2	49.8	261.4
8	High efficiency exhaust fans	48.5	32.3	22.5	17.1	14.7	12.1	11.1	9.3	8.3	12.4	23.2	49.8	261.4
9	High efficiency clothes washer	46.8	31.2	21.4	16.4	13.7	11.5	10.7	9.0	8.0	11.9	22.0	47.9	250.5
10	Parallel piping	46.5	30.9	21.0	16.1	13.5	11.3	10.6	8.8	7.8	11.7	21.8	47.6	247.8
11	PTV improvements	46.0	30.3	20.5	15.7	13.1	11.0	10.3	8.6	7.6	11.4	21.3	47.1	242.9
12	High efficiency lavatory faucets	44.9	29.5	19.8	15.2	12.4	10.5	10.0	8.3	7.4	11.0	20.3	45.2	234.5
13	Lighting level II improvements	45.1	29.7	19.9	15.3	12.4	10.5	10.0	8.3	7.4	11.0	20.4	45.5	235.5
14	Lighting level I improvements	46.4	31.4	20.9	15.9	12.4	10.5	10.0	8.3	7.4	11.0	20.8	47.4	242.4
15	Improved oven	46.4	31.3	20.9	15.8	12.2	10.4	9.9	8.2	7.3	10.8	20.7	47.3	241.2
16	Added DHW Tank Insulation	45.9	30.8	20.3	15.4	11.8	10.1	9.6	7.9	7.0	10.5	20.2	46.8	236.5
17	Cooling Elimination Subpackage	40.3	27.1	18.6	14.2	11.8	10.1	9.6	7.9	7.0	10.5	18.6	41.1	216.8
18	Refrigerator water heater	41.3	27.6	18.6	14.0	10.7	8.4	7.7	6.4	5.8	8.5	18.1	42.0	209.1
19	Dishwasher	41.0	27.2	18.3	13.8	10.4	8.2	7.6	6.3	5.7	8.3	17.8	41.5	206.1

Table 14
Monthly Incremental Gas Savings, therms (Measured)

No.	EEM Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Schematic Design	8.6	4.2	1.4	-2.5	0.0	0.0	0.0	0.0	0.0	0.2	4.9	8.7	25.4
2	Radiant Subpackage	37.7	25.3	19.0	13.9	6.7	5.5	4.0	3.9	3.7	5.9	18.5	38.2	182.3
3	Engineered Wall Framing	10.2	6.2	4.6	2.7	0.0	0.0	0.0	0.0	0.0	0.1	4.1	9.9	37.9
4	High efficiency refrigerator	-1.7	-1.8	-1.6	-1.4	0.0	0.0	0.0	0.0	0.0	-0.1	-0.7	-1.6	-8.9
5	High R Window Frames	2.6	1.7	1.1	0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.5	9.7
6	Roof Surface Characteristics	-0.5	-0.3	-0.4	-0.4	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	-0.4	-2.2
7	High efficiency shower heads	4.4	3.1	2.7	2.2	2.8	1.9	1.3	1.2	0.8	1.7	3.6	7.3	32.9
8	High efficiency exhaust fans	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	High efficiency clothes washer	1.6	1.1	1.1	0.7	1.0	0.7	0.5	0.3	0.3	0.5	1.1	1.9	10.9
10	Parallel piping	0.3	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.3	0.3	2.7
11	PTV improvements	0.5	0.6	0.6	0.4	0.4	0.3	0.2	0.2	0.3	0.3	0.5	0.5	4.9
12	High efficiency lavatory faucets	1.1	0.8	0.7	0.5	0.7	0.5	0.3	0.3	0.2	0.4	0.9	1.9	8.4
13	Lighting level II improvements	-0.2	-0.2	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.3	-1.0
14	Lighting level I improvements	-1.3	-1.7	-1.0	-0.6	0.0	0.0	0.0	0.0	0.0	0.0	-0.4	-1.9	-6.9
15	Improved oven	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	1.2
16	Added DHW Tank Insulation	0.5	0.5	0.5	0.4	0.4	0.3	0.2	0.2	0.2	0.3	0.5	0.5	4.7
17	Cooling Elimination Subpackage	5.6	3.7	1.7	1.2	0.0	0.0	0.0	0.0	0.0	0.1	1.6	5.7	19.6
18	Refrigerator water heater	-1.1	-0.5	-0.1	0.2	1.1	1.7	2.0	1.5	1.2	2.0	0.6	-0.9	7.8
19	Dishwasher	0.4	0.4	0.4	0.2	0.3	0.2	0.1	0.1	0.1	0.2	0.2	0.5	3.0

Table 15
Monthly Cumulative Gas Savings, therms (Measured)

No.	EEM Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Schematic Design	8.6	4.2	1.4	-2.5	0.0	0.0	0.0	0.0	0.0	0.2	4.9	8.7	25.4
2	Radiant Subpackage	46.3	29.4	20.4	11.3	6.7	5.5	4.0	3.9	3.7	6.1	23.4	46.9	207.7
3	Engineered Wall Framing	56.5	35.6	25.0	14.1	6.7	5.5	4.0	3.9	3.7	6.2	27.6	56.9	245.6
4	High efficiency refrigerator	54.8	33.8	23.4	12.7	6.7	5.5	4.0	3.9	3.7	6.1	26.8	55.3	236.7
5	High R Window Frames	57.4	35.5	24.5	13.4	6.7	5.5	4.0	3.9	3.7	6.1	27.8	57.8	246.4
6	Roof Surface Characteristics	56.9	35.2	24.1	13.0	6.7	5.5	4.0	3.9	3.7	6.1	27.6	57.4	244.2
7	High efficiency shower heads	61.3	38.3	26.9	15.1	9.5	7.4	5.3	5.1	4.5	7.8	31.2	64.7	277.2
8	High efficiency exhaust fans	61.3	38.3	26.9	15.1	9.5	7.4	5.3	5.1	4.5	7.8	31.2	64.7	277.2
9	High efficiency clothes washer	62.9	39.5	28.0	15.9	10.4	8.1	5.7	5.4	4.9	8.3	32.3	66.6	288.0
10	Parallel piping	63.2	39.8	28.3	16.1	10.7	8.3	5.9	5.5	5.0	8.5	32.6	66.9	290.8
11	PTV improvements	63.7	40.3	28.9	16.5	11.1	8.6	6.1	5.8	5.3	8.8	33.1	67.5	295.7
12	High efficiency lavatory faucets	64.8	41.1	29.6	17.1	11.8	9.1	6.4	6.1	5.5	9.2	34.1	69.3	304.1
13	Lighting level II improvements	64.6	40.9	29.4	17.0	11.8	9.1	6.4	6.1	5.5	9.2	33.9	69.1	303.1
14	Lighting level I improvements	63.3	39.2	28.4	16.4	11.8	9.1	6.4	6.1	5.5	9.2	33.6	67.1	296.2
15	Improved oven	63.4	39.3	28.5	16.5	11.9	9.2	6.5	6.2	5.6	9.4	33.7	67.2	297.3
16	Added DHW Tank Insulation	63.9	39.8	29.0	16.9	12.3	9.5	6.8	6.4	5.8	9.7	34.2	67.7	302.1
17	Cooling Elimination Subpackage	69.5	43.6	30.8	18.1	12.3	9.5	6.8	6.4	5.8	9.8	35.8	73.5	321.7
18	Refrigerator water heater	68.4	43.1	30.7	18.3	13.4	11.2	8.7	8.0	7.0	11.7	36.3	72.6	329.5
19	Dishwasher	68.8	43.5	31.1	18.5	13.7	11.4	8.9	8.0	7.1	11.9	36.6	73.0	332.5

5.3 Supply Curves

Figure 7 and Figure 8 show the supply curves for electricity and gas savings. The curves show the increasing cost of conserved energy (CCE) by individual EEM as a function of energy savings. The dashed line on each graph represents PG&E's marginal cost at the beginning of the ACT^2 project: $0.43/therm and $0.064/kWh. Measures that rise above the dashed line are not cost effective according to ACT^2 criteria. Each measure appears on one curve or the other; those that save mostly electricity are on the electricity savings supply curve and those that save more gas are plotted on the gas curve.

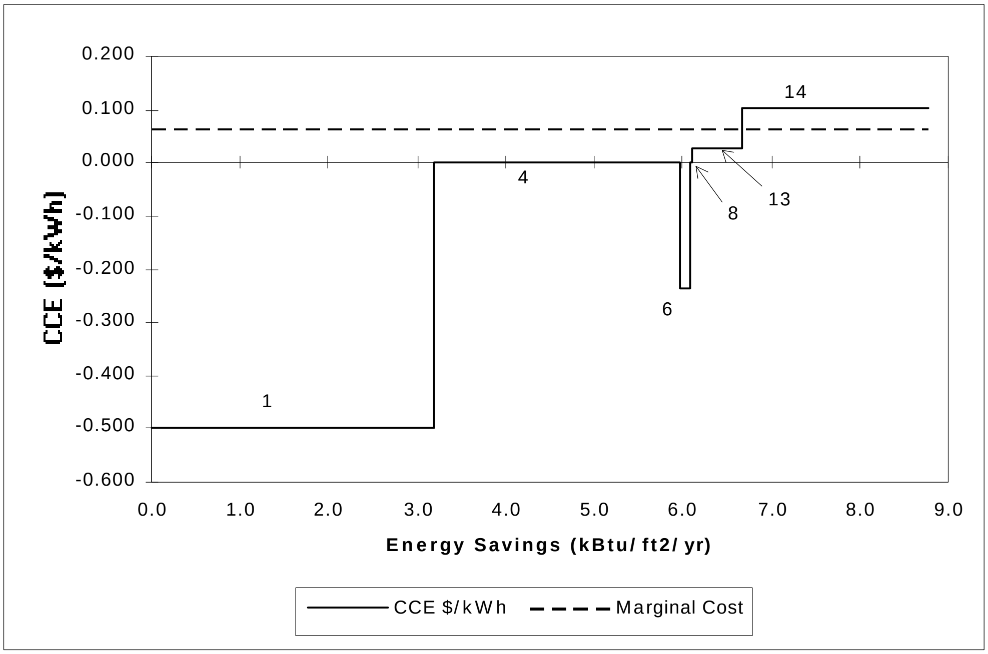

Figure 7
Electricity Savings Supply Curve, Measured Results from Table 6

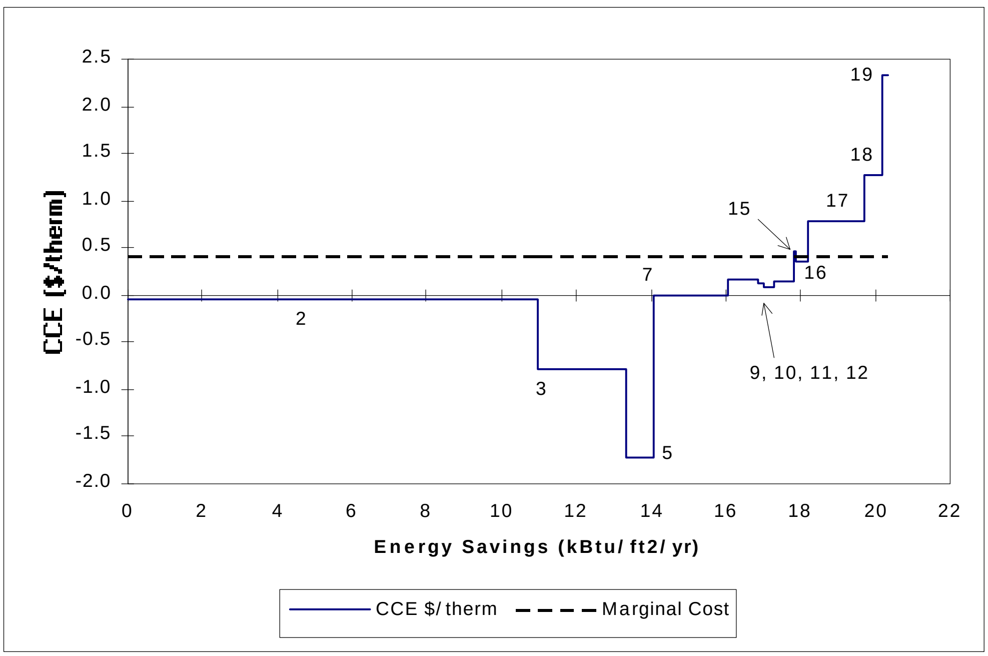

Figure 8
Gas Savings Supply Curve, Measured Results from Table 6

5.4 Figures of Merit

Table 16
Figures of Merit

	BASE CASE		EEM PACKAGE	
	Predicted	**Measured**	**Predicted**	**Measured**
General Characteristics				
Front Orientation	North		North	
Floor Area				
Conditioned	1656		1656	
Unconditioned	380		380	
Projected Energy Use				
kBtu/ft2-yr	61.5	55.8	24.0	27.1
kWh/ft2-yr	3.6	2.9	1.8	1.8
Peak kW	3.8	3.6	1.1	1.9
therms/ft2-yr	0.33	0.33	0.10	0.12
Building Envelope				
Glazing				
Total (ft2 & % of CFA)	260 ft2 / 15.7%		199.5 ft2 / 12.0%	
North (ft2 & % of CFA)	78 ft2 / 4.7%		41 ft2 / 2.5%	
South (ft2 & % of CFA)	99 ft2 / 6.0%		126 ft2 / 7.6%	
East (ft2 & % of CFA)	78 ft2 / 4.7%		23.5 ft2 / 1.4%	
West (ft2 & % of CFA)	78 ft2 / 4.7%		9 ft2 / 0.5%	
Visible Transmittance	0.81		0.71	
Shading Coefficient	0.88		0.64	
Overall U-value	0.65		0.28	
Wall Overall U-value	0.085		0.039	
Roof Overall U-value	0.025		0.022	
Door Overall U-value	0.33		0.091	
Heating, Cooling & DHW Equipment				
Space Cooling				
Projected Energy Use (kWh/ft2-yr)	0.48	0.46	0.04	0.11
Cooling Capacity (tons)	3.5		n/a	
Efficiency (SEER)	10.0		n/a	
Supply Air Flow (cfm)	1,600		n/a	
Space Heating				
Projected Energy Use (therms/ft2-yr)	0.17	0.15	0.03	0.05
Heating Capacity (Btu/hr input)	75,000		100,000 (water heater input)	
Efficiency	78% AFUE		94% recovery eff.	
Supply Air Flow (cfm)	1,000		n/a	
DHW				
Projected Energy Usage (therms/ft2-yr)	0.11	0.14	0.02	0.04
Heating Capacity (Btu/hr input)	33,000		(see heating)	
Efficiency	76%		(see heating)	
Miscellaneous				
Lighting				
Projected Energy Use (kWh/ft2-yr)	0.96	0.35	0.33	0.12
Installed W/ft2	1.85	1.33	0.75	0.57
Refrigerator (kWh/ft2-yr)	0.88	0.93	0.18	0.51
Cooking (kBtu/ft2-yr)	2.5	1.02	2.4	0.97

5.5 Differences Between Predicted and Measured Results

For several EEMs, the measured results differ significantly from the savings predicted in the Final Design Report [3]. Most of the difference in total savings is due to three EEMs: Schematic Design, High Efficiency Refrigerator, and Built-in Lighting Improvements. The source of change for these EEMs is discussed below. Table 17 lists the change for each EEM, illustrating the relative magnitude of changes, and briefly describes reasons for the differences, which typically fall into one of the following categories.

- Design has changed since predicted savings were calculated (the refrigerator is the most significant example),
- Measured usage patterns are different from design assumptions (interior lighting hours are affected the most),
- Model parameters have been adjusted during calibration (slab floor modeling change is most signficant),
- Sequential order of EEMs is changed.

A rough analysis of the relative impacts of the types of changes shows that the first three listed above each account for roughly one-third of the total difference, with the fourth responsible for only about one percent.

5.5.1 Reasons for Schematic Design EEM Differences

Heating savings for this measure drop by 76 therms/yr, while electricity savings increase by 113 kWh/yr. The differences are attributable to modeling changes and use of measured data in the analysis. The design is not changed. Due to the complexity of interaction between these changes, the relative magnitude of their impacts has not been determined.

Some of the difference is due to a revised slab heat loss model. The new model was developed by J. Huang of Lawrence Berkeley National Laboratory and specifies heat loss rates that vary throughout the year. The previous model assumed that heat flowed to outdoor air through the uninsulated slab perimeter. The new model was developed for the actual building configuration and was not available for the base case building form. Therefore, the measured savings do not account for the impact of the reduced slab perimeter (changed wall area is accounted for, however, and is likely a more significant impact). The magnitude of this impact is not known.

One of the changes in modeling that affects this and many other EEMs is the use of measured lighting, plug load and occupancy data in the model, which results in different internal heat gain profiles. The predicted savings were based on assumptions of lighting hours and miscellaneous equipment energy. Therefore, measured heating and cooling energy are different from predicted values.

Thermostat schedules are changed compared to those used to predict savings. The new schedules are closer to occupants actual usage, providing heating at 70°F and cooling at 80°F seven days per week. The original schedules assumed that heating and cooling were used only three days per week.

Several changes were made to modeling parameters during the calibration process to match measured usage [9]. The window shading algorithm was changed so that curtains are assumed to close when outdoor temperatures exceed 85° rather than the previously assumed 94°F. The distribution of heating supply between the sleeping and living zones was changed from 60%/40% to 45%/55%. The natural ventilation schedule was changed to allow natural ventilation in the morning and evening rather than at all hours for four days per week.

Each of these modeling changes affects both the base case and EEM package results (see Table 5). The savings for each EEM are affected at least indirectly by these changes.

5.5.2 Reason for High Efficiency Refrigerator EEM Differences

Savings for the refrigerator EEM drop by 578 kWh/yr, the result of a design change. The original design called for a high efficiency Sunfrost unit, while the occupants requested a change to a less efficient model (see Section 6.4). The base case refrigerator consumption does not change compared to predicted usage, but the EEM consumption increases.

5.5.3 Reason for Built-in Lighting Improvements EEM Differences

Savings for this measure drop from a predicted 1062 kWh/yr to 523 kWh/yr. Measured data show that the actual operating hours for the lighting system are roughly half of the predicted schedule. Both the base case and EEM case consumption are decreased by this change. The fraction of lighting power saved is the same as predicted, but the magnitude is lower. This modeling change is responsible for 839 kWh of the 1,086 kWh difference between the predicted and measured base case electricity consumption (see Section 6.14).

Table 17
Difference Between Predicted and Measured Energy Savings
(negative value indicates measured savings are lower than predicted)

No.	EEM Description	therms	kWh	MBtu	% of Total Change	Reasons for Differences
1	Schematic Design (perimeter & glazing)	-76	113	-6.6	44%	Revised slab loss model, different loads & occupancy (measured), window shade modeling, t-stat change.
2	Radiant Sub-Package	15	-256	-0.5	3%	Revised slab loss model, different loads & occupancy (measured), actual hot water consumption, revise water heater kW (from .130 to .166), t-stat control, sequential order changed (used to follow wall, roof and window measures)
3	Engineered Wall Framing	-1	22	0.1	-1%	Different loads & occupancy (measured), new sequential order (was #4, but before radiant subpackage).
4	High efficiency refrigerator	4	-578	-4.2	28%	Design change (lower efficiency unit installed at owner request).
5	High R Window Frames	-4	14	-0.3	2%	Different loads & occupancy (measured), new sequential order (was #2, but before radiant subpackage).
6	Roof Surface Characteristics	2	-37	0.0	0%	Absorptivity increased from 0.25 to 0.40 due to change from white to light brown tile, different loads & occupancy (measured), new sequential order (was #3, but before radiant subpackage).
7	Low flow showerheads	23	0	2.3	-15%	Measured HW consumption, calibrated water heating model
8	High efficiency exhaust fans	0	-4	0.0	0%	Measured usage pattern. Design change to less efficient fan.
9	Horizontal axis clothes washer	-3	-3	-0.4	2%	Measured kWh/load higher than rated, calibrated HW model used.
10	Parallel piping	0	0	0.0	0%	Measured HW consumption, calibrated water heating model
11	PTV improvements	2	0	0.2	-1%	Measured HW consumption, calibrated water heating model
12	High efficiency lavatory faucets (faucet flippers)	2	0	0.1	-1%	Measured HW consumption, calibrated water heating model
13	Owner lamp retrofit	-1	20	0.0	0%	Measured usage profiles used. Actual lamp replacements used instead of predicted replacements.
14	Built-in Lighting Improvements	-2	-539	-4.5	30%	Measured operating hours lower than original assumption.
15	Improved oven	-1	2	-0.1	0%	Cooling impact added to analysis
16	Added DHW tank insulation	0	0	0.1	0%	Construction change - second layer not installed, measured HW consumption
17	Cooling elimination subpackage	12	-90	0.5	-4%	Construction change increases ceiling fan kW, whole house fan and ceiling fan usage higher than assumed, less natural vent due to outdoor noise, infiltration leakage area calibrated, sequential order changed (used to follow refr WH), meas loads & occ.
18	Refrigerator water heater	-10	-23	-1.2	8%	Measured heat recovery data used. Design changed due to refrigerator substitution. Seq order changed to put measure after cooling elimination subpackage.
19	Energy efficient dishwasher	-3	-42	-0.6	4%	Measured kWh/cycle higher than rated performance, measured # cycles and HW consumption used.
	Total	**-39**	**-1400**	**-15.1**	**100%**	

6. Discussion of Individual EEMs

This section includes more information on each EEM, including analysis method, savings results and costs. Table 7 through Table 15 in Section 5.2 list the savings for each EEM by end-use and by month.

6.1 Schematic Design

6.1.1 EEM Description

The original house design was modified with reduced perimeter area and with reduced and re-arranged window areas. The perimeter length was reduced from 211 feet to 188 feet, reducing potential losses and gains from the slab and wall area. The window areas were re-arranged to reduce north, east and west glazing and increase south-facing window area.

6.1.2 Analysis Method

The as-built building form is used as the base case for all other measures. Therefore, the schematic design is modeled by adding extra wall and window area to the DOE2 model. Window orientation is also rearranged. Floor area is the same in both cases. The slab model is not changed although the reduced perimeter length may have some impact. Slab loss was precalculated by Lawrence Berkeley National Lab using a finite element model for the actual slab configuration (but not for the base case slab configuration). The added accuracy achieved by developing another model for the base case was not considered to be worth the extra cost. The impact of this assumption is probably a slight underestimation of savings.

6.1.3 Savings Results

The schematic design EEM reduces heating energy by 25 therms (10%) and cooling by 333 kWh (48%). The significant cooling savings are largely due to the reduced and rearranged window area.

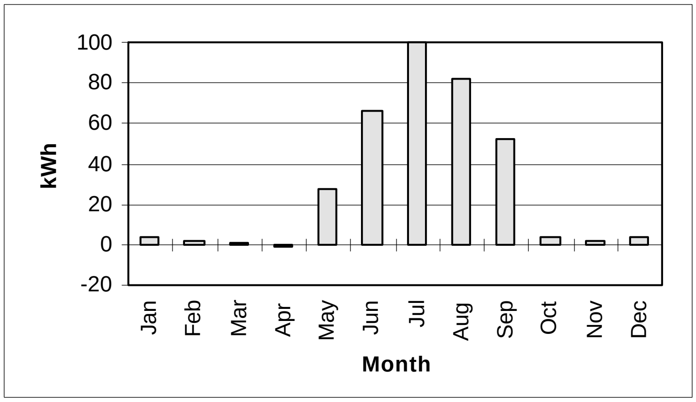

Figure 9
Monthly Electricity Savings

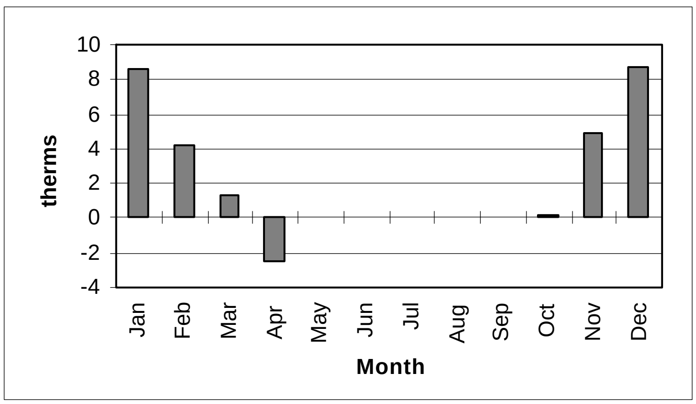

Figure 10
Monthly Gas Savings

6.1.4 Measure Cost Review

Final design cost estimates are used in the impact analysis. This measure is reported to reduce initial construction cost by $4,089. Lower costs are due to reduced window area, reduced perimeter length, and a one-ton reduction in air conditioner size ($600). Combined with the energy savings, the net present value of this measure is $5,332, close to a predicted value of $5,198.

As-built cost data are not readily available in a form to confirm the cost savings estimate. The installed cost assumption of $24/ft^2 for the base case windows is high compared to production housing costs. However, it is reasonable to assume a significant negative cost for this EEM, even if the exact magnitude is uncertain.

6.2 Radiant Subpackage

6.2.1 EEM Description

The radiant subpackage utilizes a high efficiency water heater to provide both domestic hot water and radiant floor heating. The system is also designed to provide some cooling by drawing cold supply water through the pipes in the slab during the cooling season. This measure includes the following components which are analyzed as a package.

- Polaris Water Heater (high efficiency condensing heater, energy factor of 0.86, recovery efficiency of 0.94)[1]
- Radiant Floor Tubing and Manifold
- Radiant Floor Controls
- Radiant Floor Pump
- Floor Cooling Valve
- Underfloor Insulation (1 inch extruded polystyrene, R-5)
- Slab Edge Insulation (2 inch polystyrene, R-10, 12 inch depth)

The base case heating system is a 75,000 Btu/hr gas furnace with an AFUE of 78%, the cooling system is a 2.5 ton split system air conditioner with an SEER of 10.0, and the gas water heater has an energy factor of 0.54 and recovery efficiency of 76%. The heating duct efficiency is 80% and the cooling distribution efficiency is 85% (per preconditions model).

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[1] Recovery efficiency of a water heater is the ratio of thermal energy transferred to the water to the energy input to the heater. Energy factor is a measure of overall efficiency; therefore, it is always lower than recovery efficiency. The energy factor accounts for standby losses and pilot light energy, and is typically reported on a water heater energy label.

6.2.2 Analysis Method

The radiant-floor heating system is approximated in the model as a gas furnace. The final design model assumed a 94% efficiency, 130 watts of draft fan and pump power, and a heating temperature setpoint of 68°F (reduced from 70°F in the base case). The heating distribution efficiency was improved to 92% from the base case of 68%. The reason that the distribution efficiency was not set to 100% was reportedly to account for slab heat losses. The part-load efficiency penalty was eliminated for slab heating.

The same modeling method is used for this analysis. The only parameter to be changed is the combustion blower fan and radiant floor pump power, which is increased from 130 watts to 166 watts in order to match measured data. The original model underestimated the water heater's fan power.

The cooling impact of the floor cooling valve was estimated to be 1,000 Btu/hr in the Final Design Model. (1000 gal/day, 1000 Btu/hr [3]; 900 gal/day, 880 Btu living zone, 550 Btu/hr sleeping zone, May 1 - Oct 26 [7]). For this analysis, the impact is modeled using an external hourly schedule produced from monitored data. The heat extraction (or addition) from the slab is determined from the cold water flow and the temperature differential between inlet and outlet (calculated data point QFLOOR). The heat extraction is assumed to occur only during the cooling season, in this case from March 26 to October 31. During the heating season this schedule is set to zero because the valves are changed so that cold water is no longer drawn through the slab coils.

Measured data listed in Table 18 show that the cold water supply temperature was higher than expected, reaching 80°F in July, and that no cooling was available during the peak summer months.

Table 18
Slab Floor Measured Inlet Temperature and Heat Input
(negative value indicates heat extracted from slab)

Month	Cold Water Supply Temperature (°F)	Slab Floor Heat Input (Btu)
April	65°	-65,749
May	69°	-20,286
June	76°	22,652
July	80°	135,354
August	79°	56,415
September	77°	1,604
October	71°	-53,659

Water heating savings are calculated using a monthly energy consumption model developed during calibration. The model uses measured water consumption as an input, together with estimates of recovery efficiency and standby loss for the alternate systems. See the calibration report for more information on the water heating model.

6.2.3 Savings Results

This measure results in a slight net increase of 9 kWh in electricity consumption. Electricity is saved by eliminating the heating supply air fan, but the savings are offset by the water heater combustion blower and the radiant floor pump. Gas savings are large: 100 therms for space heating (45%) and 82 therms for domestic hot water (36%).

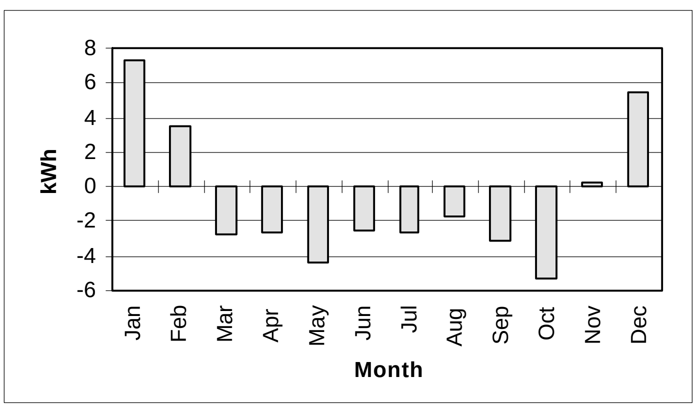

Figure 11
Monthly Electricity Savings

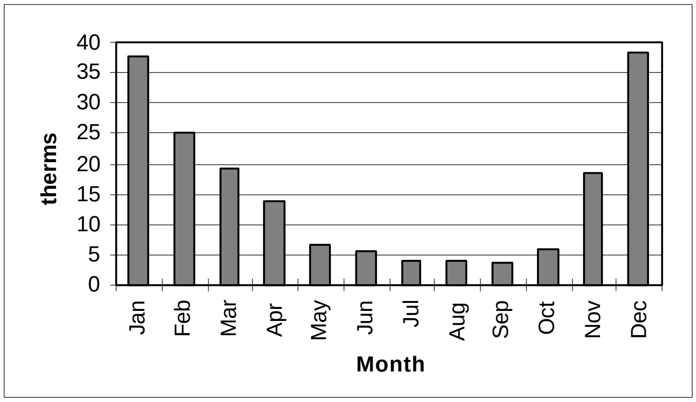

Figure 12
Monthly Gas Savings

6.2.4 Measure Cost Review

The final design estimate is used for this analysis. However, the mature market price for the Polaris water heater seems low. The current market price is listed as $1,320 and the mature market is $417. It seems unlikely that the price could drop so far even at high production levels. However, the net present value for this measure is estimated to be $1,275. Therefore, the system cost could be higher and the measure would still be cost effective.

6.3 Engineered Wall Framing

6.3.1 EEM Description

The base case R-13 wall (2x4 framing, R-13 batt insulation, stucco exterior) is replaced with an R-25.9 wall construction. The engineered wall features timberstrand studs on 24 inch centers with 3.5 inches of polyisocyanurate foam between the studs. The framing area fraction is 10% in the engineered wall compared to an estimated 36% in the base case wall. The wall construction is described in detail in the Final Design Report.

6.3.2 Analysis Method

In DOE2.1E the base case wall construction is replaced by the engineered wall construction, dropping the U-value from 0.085 to 0.039.

Analysis of measured data shows an R-value of 31 (hr-ft2-°F/Btu) for the portion of wall between framing members. Wall conductance was calculated based on the heat flux and the corresponding temperature difference between indoors and outdoors. A U-value of 0.0325 (Btu/hr-ft2-°F) resulted from a regression analysis on temperature and heat flux data from the period between midnight and 4:00 AM for the month of January 1995. Nighttime data were used to avoid the impact of solar gain heating the outside surface of the wall. The measured R-value agrees well with the design/build team's engineering estimate of 31.35 (hr-ft2-°F/Btu).

The assumed surface absorptivity of the wall is 0.4, and it is not varied for any EEMs. The actual absorptivity was not measured.

6.3.3 Savings Results

The engineered wall saves 38 therms and 11 kWh. It reduces space heating by 31%. Cooling electricity consumption increases by only 6 kWh, which is more than offset by a reduction in heating electricity consumption of 17 kWh.

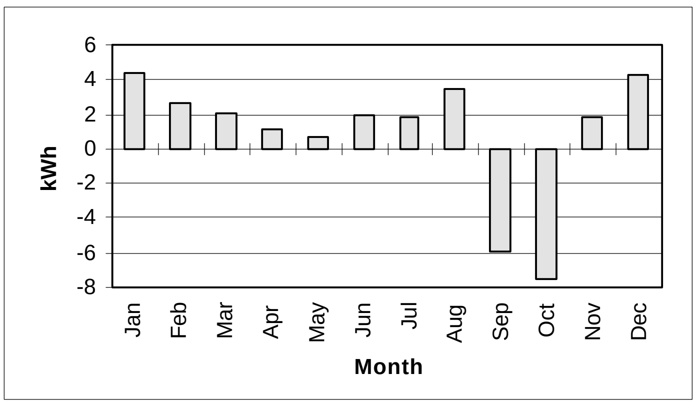

Figure 13
Monthly Electricity Savings

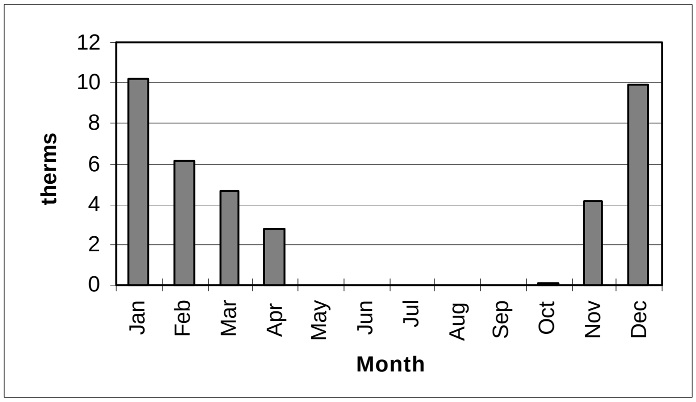

Figure 14
Monthly Gas Savings

6.3.4 Measure Cost Review

In the final design report, the mature market cost for the engineered wall is estimated to be $433 less than the base case wall, at $\$4.92/ft^2$ vs. $\$5.19/ft^2$. In the current cost estimate, the engineered wall costs $\$6.14/ft^2$, which is $1,500 more than the base case. The main difference between current market and mature market estimates is the labor cost, which was expected to drop by 30% in the mature market.

The builder estimated this measure to add $4,165 to the base cost, including $1,406 for insulation. It is not clear how much of the $4,165 is due to ACT^2-specific costs. Therefore, the costs are not adjusted for this analysis.

6.4 High Efficiency Refrigerator

6.4.1 EEM Description

The high-efficiency refrigerator is a new Amana BZ20R. (A higher efficiency Sunfrost refrigerator was specified in the Final Design Report, but the Amana was substituted at the request of the occupants). The Amana was estimated to use 612 kWh per year, vs. 296 kWh for the Sunfrost.

The base case refrigerator was assumed to be a typical California unit consuming 1,462 kWh per year [3]. It was assumed that the occupants would bring a refrigerator from their previous residence. The savings are expected to be 58%.

Reasons given for rejection of the Sunfrost refrigerator include its large size, lack of usable space and lack of user friendly controls. The homeowners talked with people who had previously used and rejected the Sunfrost and used that conversation in making their decision.

6.4.2 Analysis Method

To estimate the heating and cooling impact of the efficient refrigerator, the base case consumption is assumed to be 1,462 kWh/yr, and the actual usage of 852 kWh/yr is assumed for the EEM usage. Measured hourly consumption is used in the model to simulate the heating and cooling load impact of the refrigerator.

In reality, the savings for the efficient refrigerator will be somewhat higher than is reported here because the measured values used for this estimate include the impact of the Refrigerator Water Heater measure. The refrigerator's condenser coil is rejecting heat into a warm water tank instead of the kitchen air, and the efficiency is lower than if the refrigerator were installed on its own. Therefore, the savings for this measure are underestimated by an unknown amount, and the savings for the Refrigerator Water Heater are overestimated by the same amount. The total package savings are correct.

6.4.3 Savings Results

Net savings are 688 kWh/yr, including 78 kWh/yr of cooling energy savings due to reduced loads. Heating energy increases by 9 therms/yr because the heat produced by the refrigerator drops.

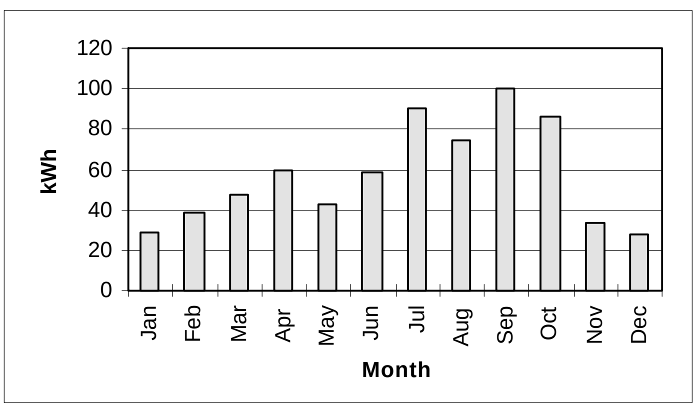

Figure 15
Monthly Electricity Savings

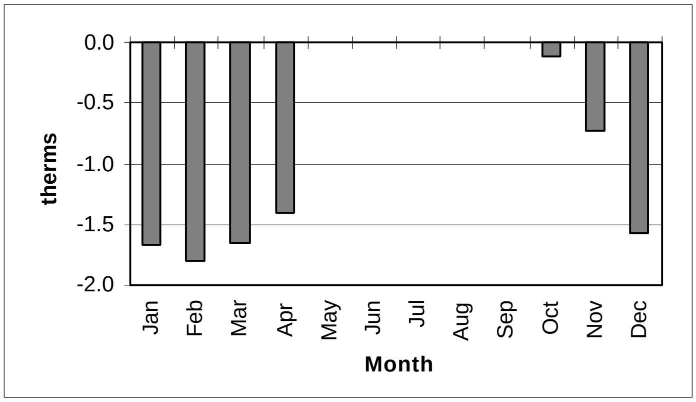

Figure 16
Monthly Gas Savings

6.4.4 Measure Cost Review

The final design cost estimate was based on the originally specified Sunfrost refrigerator, with a current market cost of $2,500 and mature market estimate of $1,000. The base case refrigerator cost was $548, including $400 for the refrigerator and $148 for the avoided air conditioning cost (the avoided air conditioning cost is added to the base case equipment cost to take credit for air conditioning equipment size reductions from measures that reduce cooling loads).

The actual cost for the Amana refrigerator is approximately $900.

The sequential analysis report uses a zero cost increment, which assumes that the extra refrigerator cost is offset by the avoided air conditioning cost. The zero cost assumption is maintained for this analysis.

6.5 High R Window Frames

6.5.1 EEM Description

Thermally broken aluminum frames in the base case (Title 24 minimum) are replaced with vinyl frames. The frames are manufactured by Certainteed. With double-pane, low-e, argon filled glazing the overall performance is reported to be a U-value of 0.24 and shading coefficient of 0.56.

6.5.2 Analysis Method

The savings are modeled in DOE2.1E by reducing the frame conductance from a base case of 1.245 to 0.319 Btu/hr-ft2-°F. These conductances are the recommended typical values in

DOE2.1E documentation. (Note: 0.30 was used in final design model instead of 0.319, which is the conductance excluding air film resistances.)

No monitored data are available for specific calibration of window frame R-value. Therefore, the default values are used.

6.5.3 Savings Results

The improved window frames provide both heating and cooling savings. Heating drops by 10 therms/yr and cooling by 27 kWh/yr.

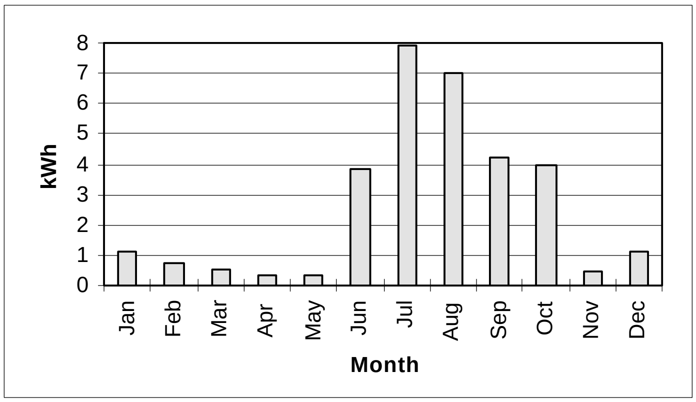

Figure 17
Monthly Electricity Savings

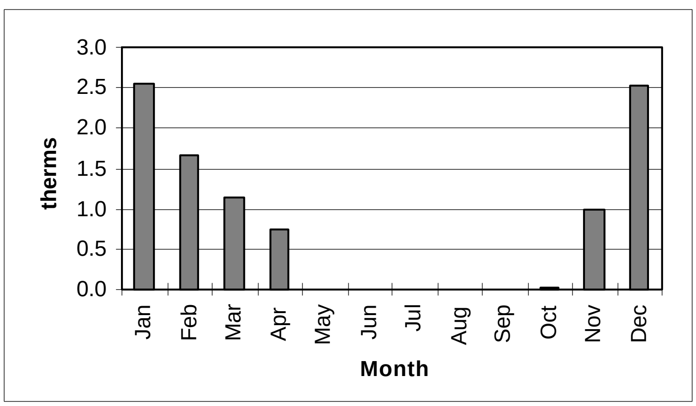

Figure 18
Monthly Gas Savings

6.5.4 Measure Cost Review

In the final design report the vinyl frames were reported to cost $275 less than the base case frames, for an average of $1.40/ft^2 for the 199 ft^2 of window area. It is reasonable to assume that the vinyl is cheaper because thermally broken aluminum frames are uncommon in California and are likely to be more costly to manufacture than vinyl frames. Savings for air-conditioner downsizing of 0.06 tons is assumed.

The builder estimate of -$295 supports the final design cost.

6.6 Roof Surface Characteristics

6.6.1 EEM Description

The base case brown concrete roof tiles are replaced with "light-brown" concrete roof tiles. The lighter colored roof has a lower solar absorptivity, resulting in lower cooling loads.

6.6.2 Analysis Method

The roof absorptivity in DOE2.1E is reduced from 0.8 in the base case to 0.4 for the light colored tiles. (Note: in the sequential analysis a 0.25 absorptivity was used because white tile was assumed in the final design but was later rejected by the builder in favor of the light brown tile). For both cases, the same surface emissivity is used; the DOE2.1E default value is 0.9.

6.6.3 Savings Results

The lighter roof color results in 50 kWh/yr of cooling savings. Heating consumption rises slightly from 84 to 86 therms/yr.

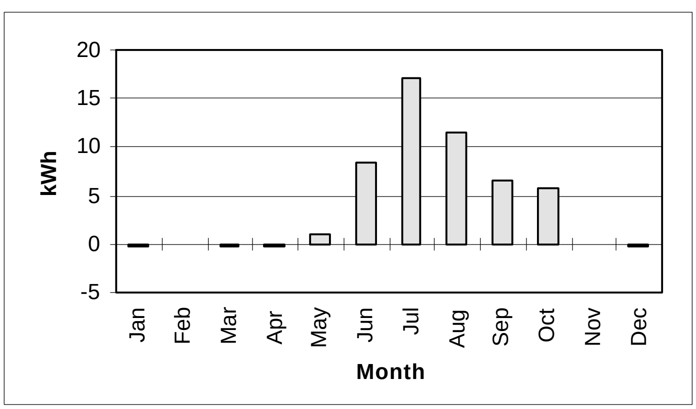

Figure 19
Monthly Electricity Savings

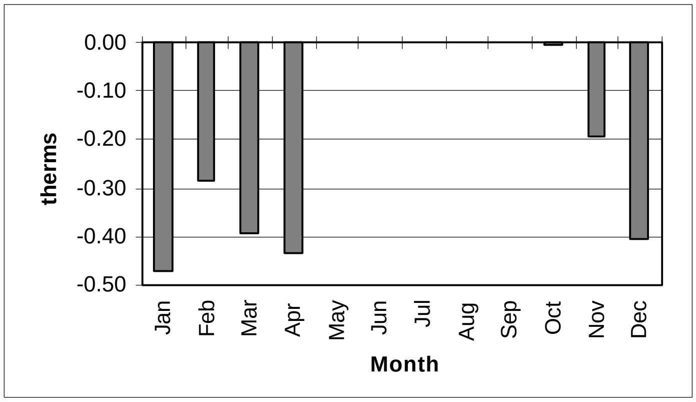

Figure 20
Monthly Gas Savings

6.6.4 Measure Cost Review

There is no additional cost for this measure. Savings for air-conditioner downsizing of 0.09 tons is assumed.

6.7 High Efficiency Showerheads

6.7.1 EEM Description

High efficiency shower heads measured to use 1.21 and 1.32 gpm replace base case shower heads assumed to use 2.5 gpm, for average savings of 49%. [4]

6.7.2 Analysis Method

The exact impact of the shower heads is unknown because the hot water flow through these fixtures is not measured directly. As a rough estimate, measured data for the hot water consumption for clothes- and dish-washing (which are measured independently) are subtracted from the total hot water consumption. The remainder consists of shower and lavatory water use along with kitchen and garage faucet consumption. Estimate that 80% of the remainder is shower and 20% is bathroom faucet.

The energy impact of reduced hot water flow is calculated using the water heating model discussed earlier for the radiant subpackage measure.

6.7.3 Savings Results

The savings estimate of 33 therms/yr assumes that the high-efficiency water heater has already been installed as part of the radiant subpackage.

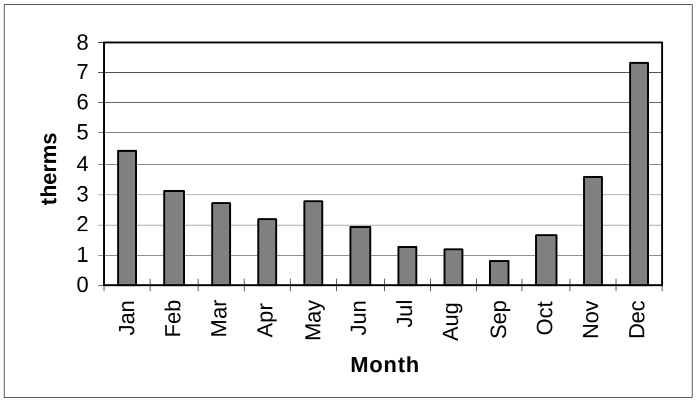

Figure 21
Monthly Gas Savings

6.7.4 Measure Cost Review

In the final design report, high efficiency shower heads are assumed to have zero incremental cost, which is reasonable as a mature market cost. The builder estimated an increment of $35 to install the shower heads.

6.8 High Efficiency Exhaust Fans

6.8.1 EEM Description

For this measure, standard exhaust fans are replaced with high efficiency units. Three fans are installed, one in each bathroom and a third in the laundry closet. The Panasonic fans were measured during commissioning to draw 13 to 14 watts [4], vs. 13 watts predicted. Air flow was measured at 40 to 50 cfm, vs 50 cfm predicted.

The baseline fan power is assumed to be 36 W (Dayton Bathroom Ventilator, 50 cfm, Grainger Catalog). Therefore, the Panasonic fans save 64% of exhaust fan energy and power.

6.8.2 Analysis Method

Use monitored data to determine total power consumption of the exhaust fans, and calculate the savings based on the power that would have been consumed by the base case fans. The base case fans use 2.8 times more electricity.

6.8.3 Savings Results

Monitored data show the actual electricity consumption to be 4.4 kWh/year. Base case consumption is 12.2 kWh/yr, so the savings is 7.8 kWh/yr. The maximum power measurement over a 15 minute period is 31 watts. The corresponding peak for the base case is 87 watts, for a savings of 56 watts. Figure 22 profiles exhaust fan energy consumption for each hour of the day.

The Final Design Report savings were based on a more efficient fan than was actually installed. The predicted values were 15 kWh/yr base case and 3 kWh/yr for the measure, for a savings of 12 kWh. Therefore, actual savings are slightly lower than predicted.

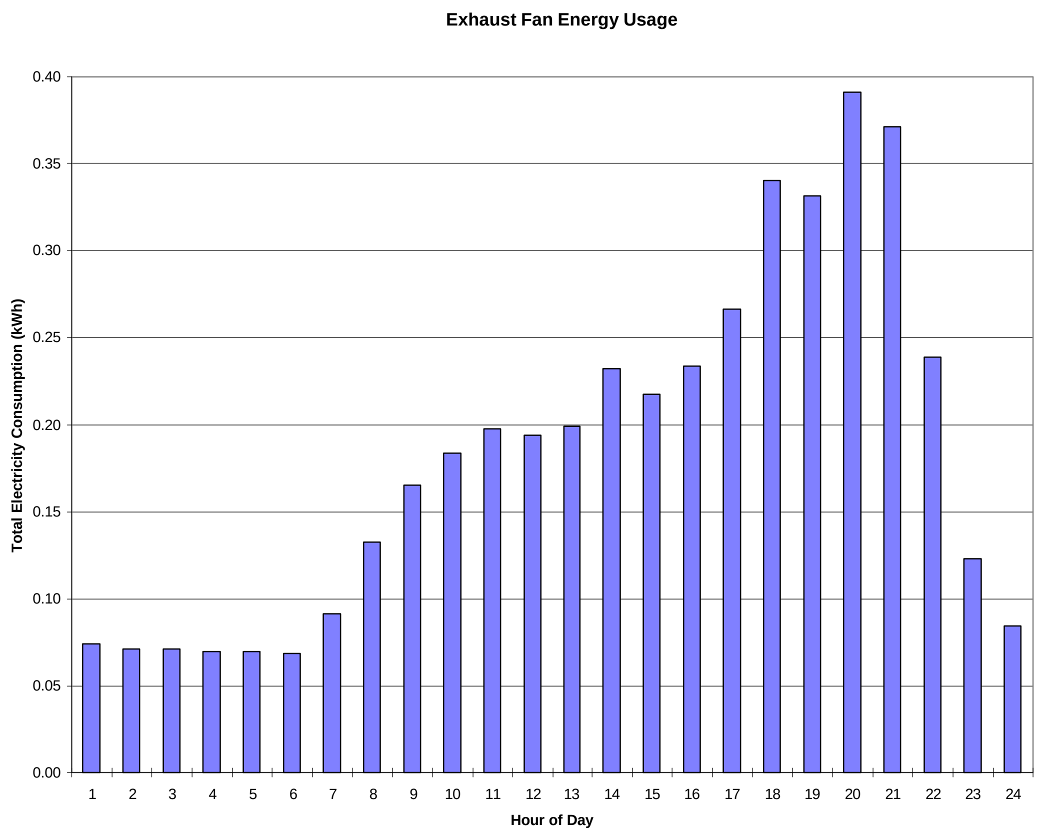

Figure 22
Exhaust Fan Energy Usage

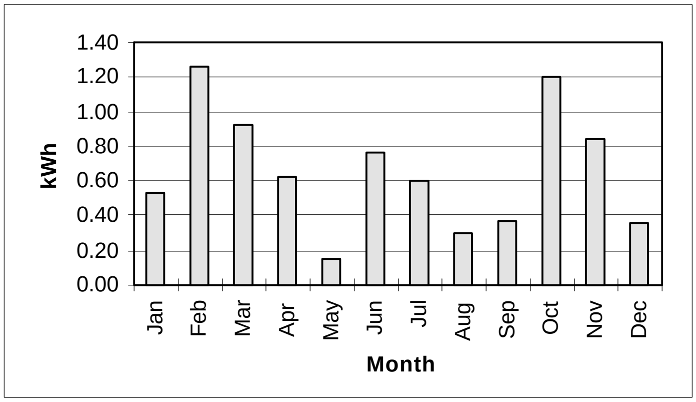

Figure 23
Monthly Electricity Savings

6.8.4 Measure Cost Review

The final design estimate of zero incremental cost in the mature market is retained for this analysis. However, the builder's estimated incremental cost was $289 for the Panasonic fans in the current market.

6.9 High Efficiency (Horizontal Axis) Clothes Washer

6.9.1 EEM Description

The high efficiency washing machine is a Staber Industries horizontal-axis, 3-cycle machine. Wash water usage is 7.0 gallons per wash, and the average hot water usage is estimated to be 4.0 gallons per wash. Each wash is expected to use 0.15 kWh.

The base case vertical-axis washing machine is assumed to use 12.6 gallons of hot water and 0.27 kWh per cycle. Assumed usage is 267 cycles per year.

6.9.2 Analysis Method

Electricity savings are determined from measured data and the reported base case consumption. Energy savings due to reduced hot water consumption are calculated using a monthly water heating model developed during calibration.

6.9.3 Savings Results

Measured data show that approximately 400 loads were washed during the year. The total hot water consumption was 1,515 gallons. Therefore, the average hot water use per load was 3.8

gallons. Inspection of the data shows that the majority of the loads, about 75 percent, consumed between 2.5 and 3.0 gallons. The other loads used between 5.0 and 6.0 gallons. Water heating gas savings are 11 therms/yr.

The measured electricity use of 0.195 kWh/load (commissioning report) matches monitored data (77 kWh / 400 loads = 0.193 kWh/load). Electricity savings of 29 kWh/yr are 28% compared to the base case.

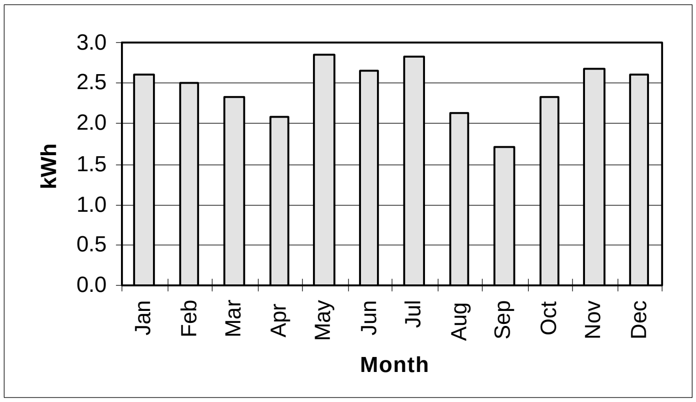

Figure 24
Monthly Electricity Savings

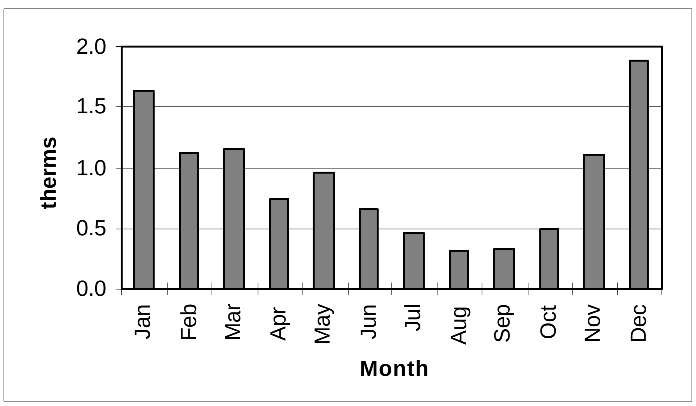

Figure 25
Monthly Gas Savings

6.9.4 Measure Cost Review

The final design report lists a $700 current market cost, compared to a base case of $400, for an incremental cost of $300. The mature market increment is $160. The builder's cost estimate at $621 is lower than the final design cost. Therefore, it appears that the mature market cost from the final design report is reasonable. Detergent savings of $16 per year are included in the economic analysis.

6.10 Parallel Piping

6.10.1 EEM Description

The base case of a branched hot water supply is replaced with smaller diameter pipes that run directly to each fixture. Heat loss is reduced because the pipes hold less water.

6.10.2 Analysis Method

The design/build team savings estimate was used.

6.10.3 Savings Results

Savings are estimated to be 3 therms/yr.

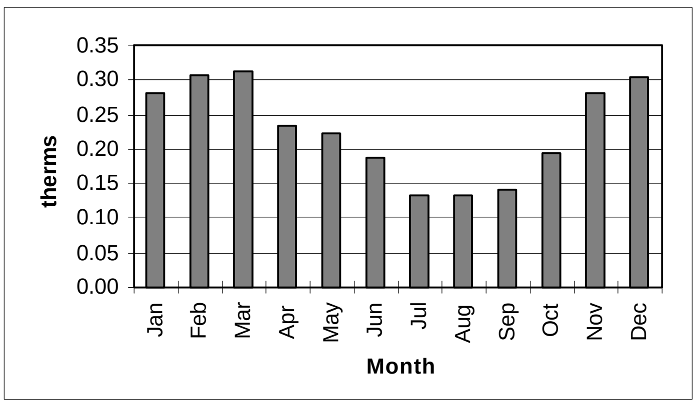

Figure 26
Monthly Gas Savings

6.10.4 Measure Cost Review

The mature market costs in the final design report are for polybutylene hot water supply piping, while copper was eventually installed because it was required by the building department. The actual cost increment estimated by the builder for the copper piping is $178, but the original design estimate of $7 is retained for this analysis.

6.11 PTV Improvements

6.11.1 EEM Description

An insulated cover was added to the hot water pressure-temperature relief valve. This measure saves energy by reducing the standby heat loss.

6.11.2 Analysis Method

The exact savings for this measure cannot be determined from monitored data. However, the overall standby loss was estimated during calibration, and a rough estimate of the savings is possible using the estimate of standby loss made during commissioning, before this measure was installed. As a rough estimate, the resulting savings are divided equally between this measure, PTV improvements, and the water heater tank wrap.

6.11.3 Savings Results

Savings are estimated to be 5 therms/yr.

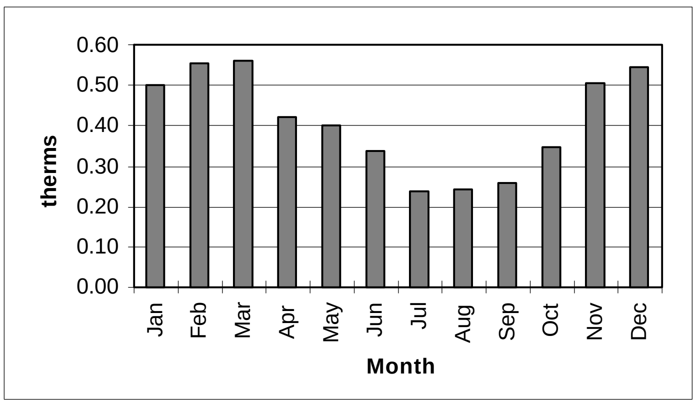

Figure 27
Monthly Gas Savings

6.11.4 Measure Cost Review

The final design report lists the incremental cost as $5, and the builder estimates the same (with the addition of a $40 supervision cost).

6.12 High Efficiency Lavatory Faucets

6.12.1 EEM Description

High efficiency faucets are installed to reduce hot water consumption. The two bathroom faucets are reported to use 1.68 and 1.76 gpm [4]. "Faucet flippers" were also provided to the occupants for these faucets, but they reportedly were not acceptable. A faucet flipper is a valve at the outlet of the faucet that allows the flow to be reduced to a trickle without having to close the normal faucet valves. It allows users to start and stop the flow and not have to readjust the water temperature. Together with the faucet flippers this measure was expected to reduce usage by 51% over the base case faucets with 2.5 gpm flow. The measure has not been reanalyzed without the faucet flippers.

The homeowners rejected the faucet flippers because they were told by a friend in the plumbing supply business that the faucet flippers put too much pressure on the fixture when the valve is closed and can damage the faucet.

6.12.2 Analysis Method

See the high efficiency shower heads measure for details. The savings were analyzed assuming that the faucet flippers were installed. Therefore, actual savings will be somewhat lower than listed here.

6.12.3 Savings Results

Water heating gas consumption drops by 8 therms/yr as a result of these measures.

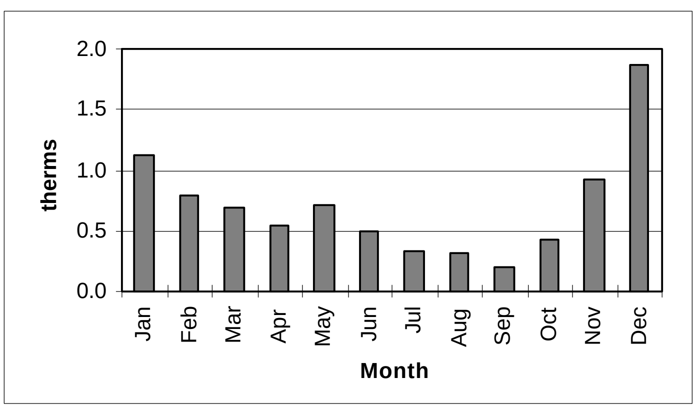

Figure 28
Monthly Gas Savings

6.12.4 Measure Cost Review

In the final design report, incremental costs are reported as $15 for the faucet flippers and zero cost for the efficient faucets, a reasonable mature market incremental cost. The builder estimated an increment of $56 to install these measures.

6.13 Level II Lighting improvements

6.13.1 EEM Description

This measure consists of retrofitting occupant supplied lighting with compact fluorescent bulbs. The commissioning report states that two 160 watt lamps were retrofit to 22 watt, and one 150 watt , 3-way lamp was retrofit to 39 watt. Assuming an average power of 100 watts for the 3-way lamp, the total reduction is from 420 watts to 83 watts, for a maximum savings of 337 watts (276 assumed to be in the sleeping zone and 61 in the living zone).

6.13.2 Analysis Method

The occupant supplied lighting is not measured directly; it is part of the plug loads. Therefore, savings must be estimated indirectly. The measured data were used as the EEM package energy consumption, and the base case was created by increasing the measured loads by a factor of 1.42 in the sleeping zone and 1.03 in the living zone. These multipliers assume that the lights are on one hour per day, for a direct lighting savings of 101 kWh/yr in the sleeping zone and 22 kWh/yr in the living zone. The multipliers increase the actual consumption by the amount of the estimated savings in order to determine the impact on heating and cooling loads.

6.13.3 Savings Results

Total savings are 127 kWh/yr, including 3 kWh/yr for cooling. Measured receptacle energy usage is 241 kWh for the sleeping zone, 704 kWh in the living area, and 37 kWh for the kitchen. Heating energy consumption increases by 1 therm/yr.

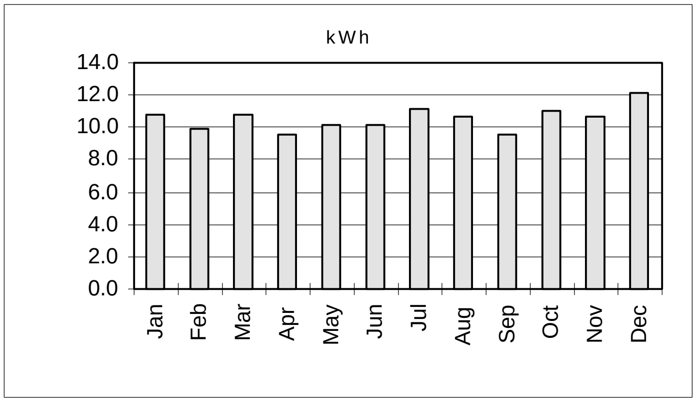

Figure 29
Monthly Electricity Savings

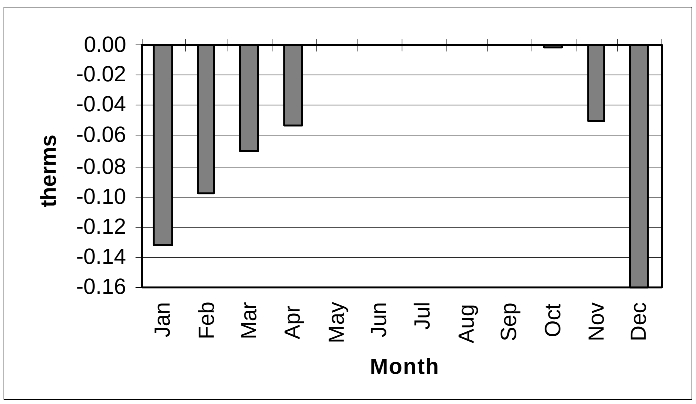

Figure 30
Monthly Gas Savings

6.13.4 Measure Cost Review

The final design incremental costs are $54 current market and $39 mature market. There are no recorded as-built costs. The mature market cost is reasonable for the three bulbs.

6.14 Level I Lighting improvements

6.14.1 EEM Description

High efficiency hard-wired fluorescent lighting (with minimal use of halogen incandescent) replaces the base case of standard fluorescent fixtures in the kitchen and bath and incandescent elsewhere. The design is described in detail in the Final Design Report [3].

Final Design Report lists installed lighting power of 709 W interior and 45 W exterior. Commissioning report lists measured values of 860 W and 58 W (with unreported quantity of "standard" bulbs instead of halogen bulbs in the track lighting). The design may have been changed after the Final Design Report. Measured data confirms the power listed in the Commissioning Report.

6.14.2 Analysis Method

Directly measured lighting power is used as an hourly input to the simulation model. To create the base case consumption, the actual consumption is increased by a factor of 2.08 for interior lighting and 4.6 for exterior lighting. The model provides both direct lighting and indirect cooling impact.

6.14.3 Savings Results

Actual lighting energy consumption is 199 kWh/yr for interior lighting and 39 kWh/yr for exterior lighting. The peak power during the monitored period is 658 W interior (940 W non-coincident peak for the sum of the two interior zones) and 59 W exterior. Savings are 375 kWh/yr for interior lighting and 140 kWh/yr for exterior lighting.

This measure saves significantly less than the original design estimates because the operating hours for lights are less than anticipated. The hypothetical base case consumption was estimated to be 1,591 kWh/yr and the savings were predicted at 1,042 kWh/yr [3]. The measured usage leads to a base case consumption estimate for interior and exterior lighting of 752 kWh/yr, with savings of 515 kWh/yr. The actual usage is about one-half of the predicted consumption. Therefore, the savings also drop by 50%.

This lighting measure also reduces cooling energy consumption by 12 kWh/yr while raising heating by 7 therms/yr.

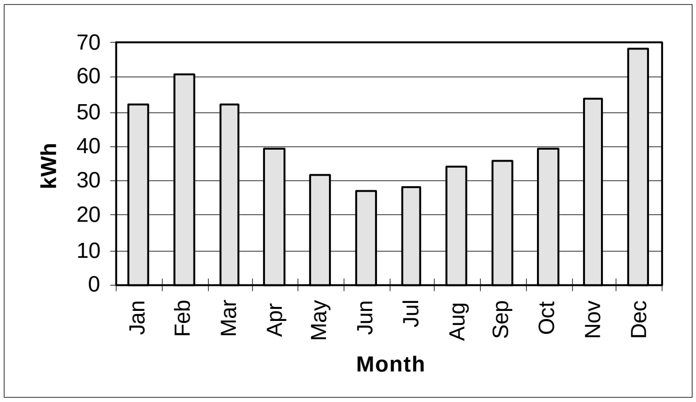

Figure 31
Monthly Electricity Savings

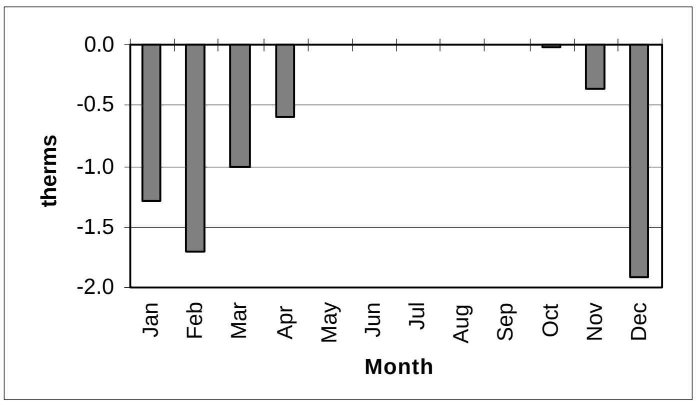

Figure 32
Monthly Gas Savings

6.14.4 Measure Cost Review

There is a significant difference between the final design estimates and the builder's estimates for this measure. The final design increment is $1,537 in the current market and $724 in the mature market. The builder's original estimate was $6,504, which was augmented by a change order for $1,502, for a total of $8,006. The reason for the difference is not clear from the information available. Some of the difference may due to the fact that the specified fixtures had to be customized with electronic ballasts. Others may have had large cost premiums due to their newness on the market and the small quantities purchased. Though there is uncertainty about the cost for this measure, there is not enough information to change the final design estimate.

Due to the reduction in energy savings, the benefit cost ratio for this measure drops to 0.69 from the predicted value of 1.50.

6.15 Improved Oven

6.15.1 EEM Description

One inch of rigid insulation was installed in the oven cabinet before the oven was put in place. The specified oven had no window in the door for reduced heat loss, but a non-window door was not available in the desired model. The EEM saves energy by reducing heat loss.

The base case oven was assumed to use 21 therms/yr. This measure was estimated to save 1.7 therms/yr.

6.15.2 Analysis Method

Gas consumption for the oven is measured together with the range, providing a total consumption for cooking. Therefore, not enough information is available to determine savings directly. The original design estimate is used in this analysis.

6.15.3 Savings Results

Total gas consumption for cooking is 17.3 therms/yr. Net savings is 1 therm, with 2 therms saved for cooking and a 1 therm increase in heating energy. Cooling energy drops by 3 kWh.

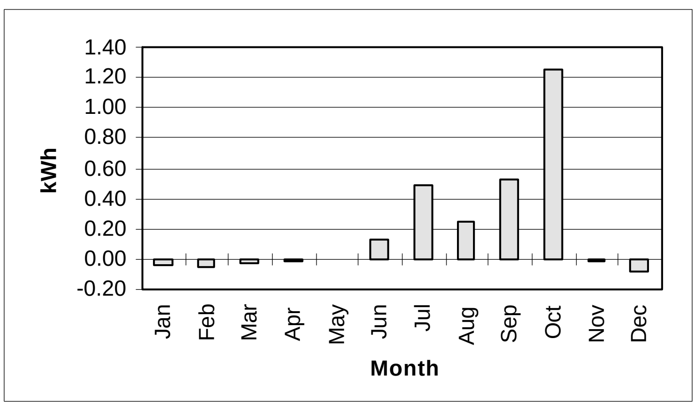

Figure 33
Monthly Electricity Savings

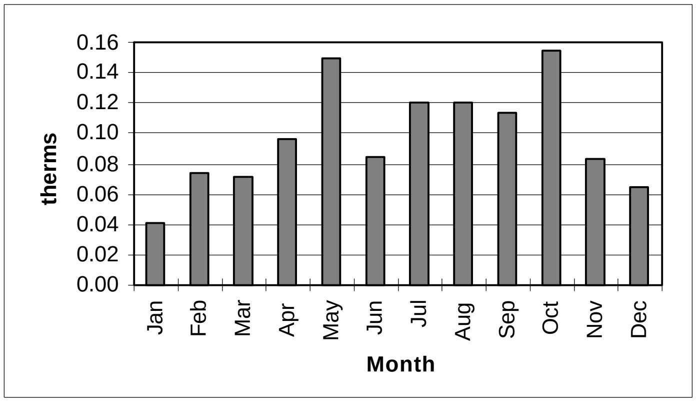

Figure 34
Monthly Gas Savings

6.15.4 Measure Cost Review

The final report lists an incremental cost of $7 for the extra insulation. The builder estimate was $184. The final design estimate may be reasonable if it is assumed that in the mature market the insulation is added to oven during manufacturing. In the actual installation, foam board insulation was installed in the oven cabinet. The material cost alone for the actual installation would be more than $7.

6.16 Extra DHW Tank Insulation

6.16.1 EEM Description

This measure consists of one layer of "Reflectix" reflective insulation wrapped around the water heater to reduce standby loss. The tank is internally insulated to R-16.6. [3] Two layers were planned, but only one layer could be applied due to limited space. [4]

6.16.2 Analysis Method

Same as for the PTV improvement measure.

6.16.3 Savings Results

This measure saves 5 therms/yr of water heating energy.

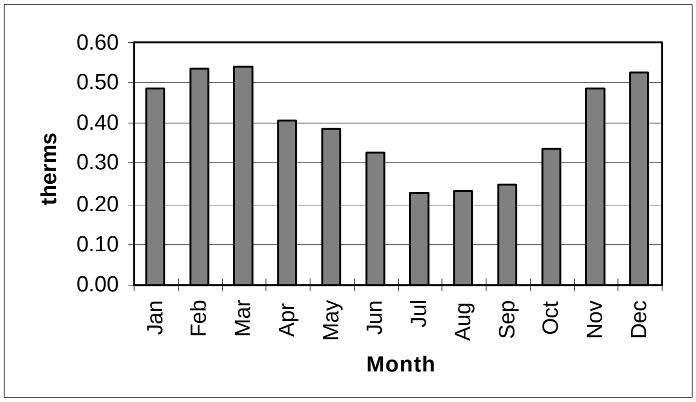

Figure 35
Monthly Gas Savings

6.16.4 Measure Cost Review

The final design report estimated $20 for the water heater jacket. The builder's cost is $69. The measure was revised during installation, and the actual cost is not recorded. The $20 estimate is close to the advertised retail price ($25) of a "Reflectix" insulation kit. Therefore, the final design cost is used in this analysis.

6.17 Cooling Elimination Subpackage

6.17.1 EEM Description

The cooling elimination subpackage includes the following measures that were not cost effective on their own, but were found to be cost-effective when combined because they allowed elimination of the last bit of air conditioning load.

- Ceiling and Oscillating Fans
- Insulated Doors
- Attic Radiant Barrier
- Increased Tile Floor Area
- Whole House Fan
- Double Drywall in Living Area
- Low-e Gas Filled Glazing

6.17.2 Analysis Method

A number of the measures are modeled explicitly in DOE2.1E. Some, however, must be approximated in the model.

Savings for the ceiling fans are approximated by raising the cooling temperature setpoint by 3°F, from 80°F to 83°F. Actual hourly electricity consumption is used as an input to the model.

The cooling impact of the whole house fan is modeled with DOE2.1E's natural ventilation algorithm. During the morning and evening, the fan is thermostatically controlled to cool the house down to 68° when the air is cooler outdoors than indoors. The fan is assumed to provide 22.5 air changes per hour, which is equal to 5,000 cfm (actual flow was not measurable during commissioning [4]).

The measured electricity consumption is used as an input to the model. Monitored data show that the whole house fan consumed 99.6 kWh, with a peak demand of 336 watts, vs. predicted consumption of only 12 kWh/yr. The fan operated from May to October, with consumption peaking in August. The fan came on during the early morning hours as well as in the evening between 6:00 PM and 10:00 PM. The fan ran for an equivalent of 300 full load hours during the year. In previous analyses, the electricity consumption of the fan motor was determined outside of DOE2, based on typical Davis operation. The measured usage is so much higher than predicted because the windows could not be left open at night due to noise from crop dusters. The intent of the design was to take advantage of natural ventilation as much as possible.

The impact of the radiant barrier is approximated by decreasing the absorptivity of the roof surface in the DOE2.1E model. During calibration, the 0.05 estimate was increased to 0.20 based on observations of attic temperature. The measured average attic temperature peaks at 84°F in July and drops to 51°F in the winter.

6.17.3 Savings Results

The cooling elimination subpackage saves less than predicted, but it does succeed in eliminating cooling energy from the modeled home. Much of the discrepancy is due to the whole house fan, which was not operated during the night as intended due to outdoor noise problems. The fan consumed 99 kWh while it was predicted to need only 12 kWh. Similarly, the ceiling fans were substituted at the occupants' request with slightly less efficient models, and actual consumption was 89 kWh, compared to an assumption of 50 kWh.

The net savings for this package of measures is 71 kWh and 20 therms. Cooling savings of 251 kWh are partly offset by 189 kWh of whole house fan and ceiling fan energy consumption. Figure 36 shows that in July there is a net savings because cooling savings are greater than the added fan energy. However, in the months of May, June and September, this measure increases net electricity consumption because the fan energy exceeds the cooling savings. The electricity savings in the winter months are due to reduced heating fan operation and to elimination of the air conditioner's crankcase heater energy.

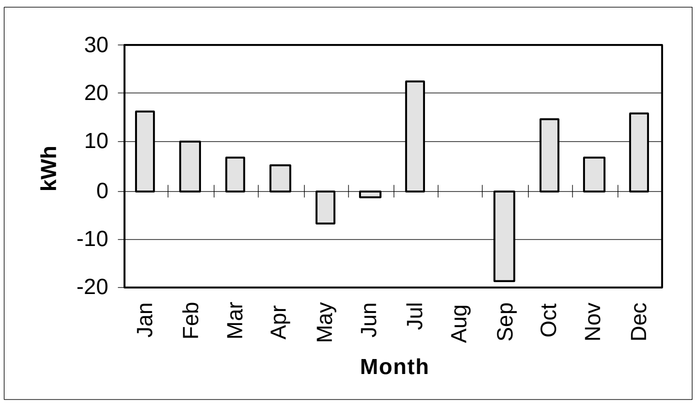

Figure 36
Monthly Electricity Savings

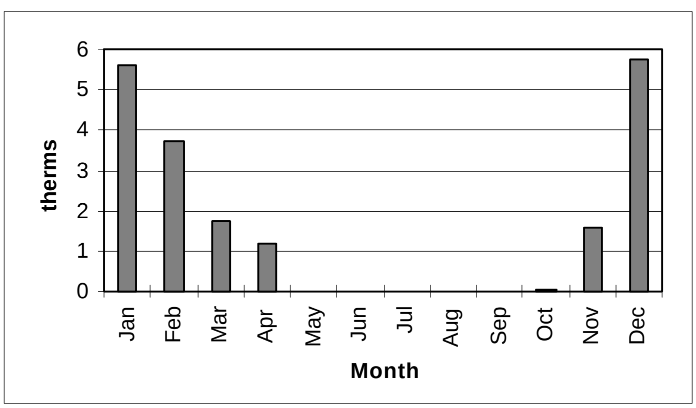

Figure 37
Monthly Gas Savings

6.17.4 Measure Cost Review

The incremental cost for this package of measures was estimated to be $1,630 in the final design report (current market). The builder's incremental cost estimate was $7,460. The difference appears to be due largely to "sheet metal" costs, probably for the whole house fan plenum and ducting. It is not clear if the builder cost includes a credit for the 1.8 tons avoided air conditioning that is considered in the final design estimate. The final design costs are retained for this analysis.

The benefit-cost ratio for the cooling elimination subpackage is 0.65, close to the predicted value of 0.70.

6.18 Refrigerator Water Heater

6.18.1 EEM Description

Heat rejected by the refrigerator is recovered in a small water tank on top of the refrigerator. The supply to the water heater passes through a heat exchanger in this tank, pre-heating the hot water. The measure reduces water heating energy and decreases the amount of refrigerator heat rejected to the space. Therefore, cooling energy use should decrease and heating energy consumption should increase. The water heating savings are partially offset by the decreased refrigerator efficiency due to rejection of heat to a warm tank.

6.18.2 Analysis Method

Energy recovered from the refrigerator heat exchanger is measured directly; therefore, the avoided gas consumption may be calculated. The recovered heat may also be subtracted from the internal heat gain for DOE2 modeling.

The water heating impact is estimated using the monthly water heating model, where the hot water load is reduced by the amount of the recovered heat. Due to errors in the measured hot water flow, savings for the summer months are approximate. See the Calibration Report for more details.

6.18.3 Savings Results

Recovered heat is estimated to be 1.74 MBtu/yr based on measured data. This estimate is approximate because water flow data for July and one-half of August are not available. The savings are equivalent to 23 therms of gas with the base case water heater and 19 therms with the high efficiency water heater.

The increase in space heating energy partially offsets the water heating savings. The measure provides no cooling savings because no cooling load remains following installation of the cooling elimination subpackage. The measure saves 8 therms and increases electricity consumption by 5 kWh (due to space heating increase).

In reality, this measure increases the electricity usage of the refrigerator because the condenser coil rejects heat to a tank of warm water rather than to indoor air. However, this impact is not included in the savings for this measure. The reduced refrigerator efficiency shows up in the savings for the High Efficiency Refrigerator measure, which is based on directly measured consumption.

The savings are lower than the predicted values of 18 therms/yr and 18 kWh/yr for several reasons. The heat exchanger design had to be changed due to the occupants' rejection of the Sunfrost refrigerator. In addition, in the original sequential order this EEM was installed before the cooling elimination subpackage, allowing some cooling savings. Savings might improve with further engineering development.

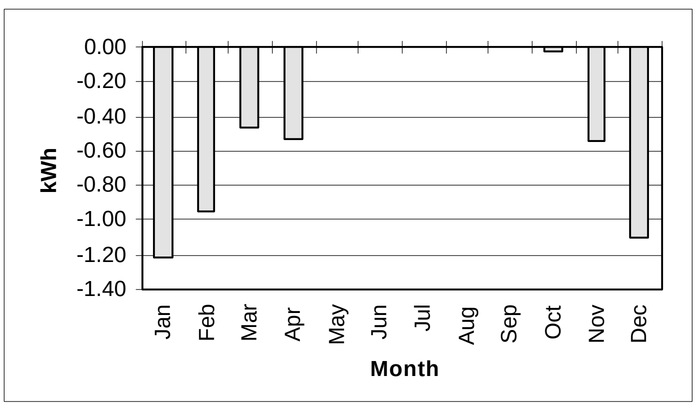

Figure 38
Monthly Electricity Savings

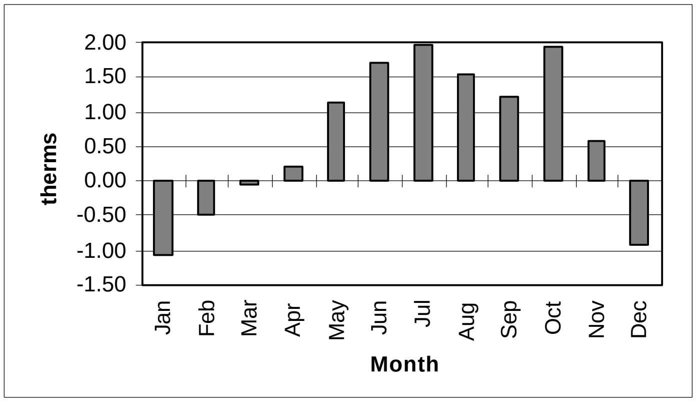

Figure 39
Monthly Gas Savings

6.18.4 Measure Cost Review

No current cost estimate is included in the final design report. The mature market cost was estimated to be $160. The builder's cost estimate for this custom unit is significantly higher at $2,116. The $160 estimate may be low when considering the extra plumbing and hardware required. However, it is conceivable that volume production of a refrigerator water heater could result in a $160 increment. The benefit-cost ratio for this measure drops from a predicted value of 1.0 to 0.32.

6.19 Efficient Dishwasher

6.19.1 EEM Description

An efficient Bosch dishwasher replaces a standard efficiency unit. The efficient dishwasher was rated at 0.5 kWh per cycle, while the measured data show 0.9 kWh/cycle.

The base case dishwasher consumes 11 gal/cycle of hot water and 0.7 kWh/cycle.

6.19.2 Analysis Method

Measured data are used to determine the actual hot water and electricity consumption. An estimate of detergent savings developed by the Design/Build Team is included in the economic analysis. This measure was assumed to reduce the detergent costs from $48 to $26 per year.

6.19.3 Savings Results

The total hot water consumption was 1253 gallons, and the electricity consumption was 209 kWh.

The approximate number of dishwasher runs was 203. Therefore, the average consumption is 6.2 gal/cycle and 1.03 kWh/cycle. The gas savings are 3 therms/yr.

There are no electricity savings over the base case.

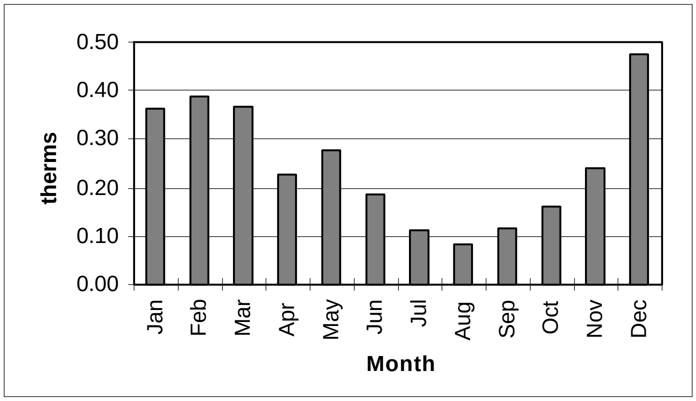

Figure 40
Monthly Gas Savings

6.19.4 Measure Cost Review

This measure was not included in the final design report, as it was added later. The builder estimate is an incremental cost of $450.

Because the electricity consumption is higher than predicted, the BCR drops from 1.1 to 0.18 and the EEM does not appear to be cost-effective.

6.20 Anti-Convection Valves

This measure was eliminated from consideration because the high efficiency water heater includes an anti-convection valve.

6.21 High-Efficiency Dryer Motor

This EEM was eliminated because an appropriate motor was not available. Dryer energy consumption is 131 kWh/yr and 42.3 therms/yr. Peak electricity demand is 0.29 kW.

7. Conclusions and Observations

1. The cooling system elimination strategy appears to be successful. Measured indoor temperatures did not exceed 82°F during the summer, while the maximum outdoor temperatures exceeded 104°F. The average daily maximum indoor temperature was 78°F in July and August.

2. The elimination of cooling provides significant peak electricity demand savings, but peak savings are not a factor in the ACT^2 economic analysis. Therefore, the measures that reduce cooling load would be more cost-effective if electric demand savings were considered directly in the analysis.

3. Slab cooling was not as effective as anticipated. Cold supply water routed through the radiant floor coils during the cooling season was much warmer than the Design/Build Team estimated, peaking at an average of 80°F in July. Measured data show that this EEM actually heated the slab somewhat during mid summer. Following the first year of operation, the circulation of city water through the slab has been disabled.

4. The whole-house fan used for night ventilation was not operated as planned, but it was still effective in reducing indoor temperatures. The occupants turned on the fan for only a few hours in the evening and in the morning. The intent of the design was that the windows be left open at night to allow natural ventilation, assisted by the thermostatically controlled whole-house fan. However, noise from early morning crop dusting forced the occupants to close the windows at night, and the fan could not be used when occupants were sleeping. It is likely that fan energy would be lower if the crop dusting noise were not a problem.

5. Overall electricity savings are only 38% partly because roughly one-quarter of base case electricity consumption (about 1,110 kWh) is due to miscellaneous plug loads that are not addressed by EEMs. These end-uses include occupant-supplied appliances and entertainment equipment. The plug loads comprise 37% of electricity consumption in the EEM package case.

6. Savings for efficient hard-wired lighting are 523 kWh/yr, roughly one-half of the predicted savings. The drop is not due to problems with the design or equipment; the operating hours are

less than one-half of expected operation. The expected annual consumption was 549 kWh, while measured data show only 199 kWh. Due to the drop in energy savings, the BCR for this measure drops from 1.50 to 0.69.

7. The thermal performance of the engineered wall framing system appears to meet expectations of an R-26 insulation value. The present value of energy savings is estimated to be $248. Therefore, the incremental construction cost could be that high and the measure would still be cost effective. The design/build team estimates that the mature market cost is lower than conventional construction costs.

8. The measured savings are lower than predicted by 39 therms and 1,400 kWh. Overall source energy savings drop from 62% to 52%. Most of the difference is due to three types of changes: 1) design changes, 2) use of measured usage patterns in the simulations, and 3) changed model parameters resulting from the calibration process. Each of these accounts for roughly one-third of the total difference. Three EEMs account for most of the difference: 1) high efficiency refrigerator, 2) built-in lighting, and 3) the schematic design (see Section 5.5 for more details).

8. References

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3. ACT[2] Davis Site Final Design Report, DEG, April 13, 1993.

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