

Portfolio Evaluation of Sixty-Three Public Utility Energy Efficiency Resource Programs

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ABSTRACT

Measurement and verification (M&V) study results are provided for a portfolio of sixty-three energy efficiency peak demand reduction and load control programs. The programs were implemented by seventeen public utilities with funding from Senate Bill 5X administered by Northern California Power Agency under the auspices of the California Energy Commission. The study adhered to the International Performance Measurement and Verification Protocols (IPMVP). Programs were grouped into ten end-use categories. The portfolio provided incentives for 281,390 measures with a budget of \$8,700,000. The net ex post savings are 37,346,290 ± 546,362 kWh/year and 15,886 ± 204 kW. Net lifecycle savings are 541,241,505 ± 6,822,445 kWh and 14.5 year life. The net realization rates are 0.860 ± 0.013 for kWh and 0.842 ± 0.011 for kW. The Total Resource Cost test is 3.4 ± 0.05 or 0.060 ± 0.001 \$/kWh. The cost effectiveness is 547.7 ± 7.0 \$/kW. Several programs had low realization rates due to unrealistic ex ante savings. Realization rates can be improved by developing ex ante savings from M&V studies available from the California Measurement Advisory Council. The utilities haven't previously conducted M&V studies and were unfamiliar with tracking accomplishments and measuring results. Future programs should budget 5 to 10% for M&V studies to improve reliability and reduce uncertainty. Future evaluations should include the following requirements: 1) tracking database, 2) net savings including precision and error bounds, 3) process evaluation, 5) independent study management, 6) adequate time, and 7) M&V contractors must have experience with IPMVP field measurement procedures.

Introduction

This report provides measurement and verification (M&V) results for a portfolio of sixty-three energy efficiency and renewable energy peak demand reduction and load control programs (Mowris et al. 2005). The programs were implemented by seventeen public utilities with funding from Senate Bill 5X and administered by Northern California Power Agency (NCPA) under the auspices of the California Energy Commission (CEC). The evaluation study adhered to the International Performance Measurement & Verification Protocols (IPMVP) and options defined in **Table 1** (USDOE 2002). On-site energy and peak demand measurements, engineering analyses, billing regression analyses, and calibrated building energy simulations were used to evaluate load impacts consistent with the IPMVP. Gross energy savings were evaluated by comparing measured base year energy use to post-retrofit energy use according to **Equation 1**.

Eq. 1 Gross Energy Savings = Base Year Energy Use - Post-Retrofit Energy Use ± Adjustments

Equation 1 adjusts energy use in the two time periods to the same set of conditions. Conditions commonly affecting energy use are weather, occupancy, production, and equipment

operations. Adjustments were used to normalize for weather variations, or shifts in occupancy or for abnormal increased or decreased electrical usage. Savings are estimated for a statistically representative sample, and extrapolated to the program population using statistical methods.

Table 1. IPMVP Options

M&V Option	Savings Calculation	Typical Applications
Option A. Partial Measured Retrofit Isolation Savings are determined by short-term or continuous field measurements of energy use, separate from facility energy use. Partial measurement means some parameters may be stipulated.	Engineering calculations using short term or continuous post-retrofit measurements and stipulations.	Lighting retrofit where power draw is measured periodically. Operating hours of the lights are measured with light loggers or based on interviews with building personnel.
Option B. Retrofit Isolation Savings are determined by short-term or continuous measurements of energy use of ECM, separate from the energy use of the rest of the facility.	Engineering calculations using short term or continuous measurements	Variable speed drive used on a constant speed fan. Fan motor electricity use is measured with and without the variable speed drive.
Option C. Whole Facility Savings are determined by measuring energy use at the whole facility level. Short-term or continuous measurements are taken during post-retrofit period.	Analysis of whole facility utility meter or sub-meter data using comparison or regression analyses.	Energy management program affecting many systems in a building. Pre- and post-retrofit energy use is measured with utility meters.
Option D. Calibrated Simulation Savings are determined through simulation of components or whole facility. Simulation models actual energy performance measured in the facility.	Energy use simulation, calibrated with hourly or monthly utility billing data and/or end-use metering.	Weather-sensitive measures in a building. Savings based on simulations calibrated with pre- or post-retrofit utility data.

Source: USDOE 2002

Programs were organized into ten end-use categories: 1) commercial and industrial (C&I) lighting, 2) C&I HVAC, 3) C&I refrigeration, 4) C&I custom, 5) LED traffic signals, 6) residential HVAC, 7) residential CFL, 8) refrigerator recycling, 9) load control, and 10) miscellaneous (**Table 2**).

Table 2. NCPA SB5X Program Categories, Budget, and Savings

#	NCPA Program Category	Budget \$	Ex Ante MWh/yr	Ex Ante MW	Ex Ante Lifecycle GWh	Net Ex Post MWh/yr	Net Ex Post MW	Net Ex Post Lifecycle GWh
1	C&I Lighting	\$2,100,482	21,024	4.94	336.38	20,302	4.41	324.82
2	C&I HVAC	\$988,748	5,645	2.48	83.72	3,945	2.14	58.50
3	C&I Refrigeration	\$380,000	1,194	0.77	23.88	822	0.89	16.43
4	C&I Custom	\$370,550	4,898	1.16	73.86	3,754	0.82	56.61
5	LED Traffic Signals	\$450,697	2,700	0.31	43.21	2,126	0.24	34.02
6	Residential HVAC	\$1,344,803	2,712	1.89	40.68	801	1.05	12.02
7	Residential CFL	\$250,096	1,883	1.95	12.66	3,486	1.06	23.42
8	Refrigerator Recycling	\$344,647	2,431	0.33	14.59	1,724	0.44	10.34
9	Miscellaneous Programs	\$246,519	922	0.43	12.06	387	0.18	5.06
10	Load Control	\$1,600,740	0	4.62	0.00	0	4.64	0.00
	Total	\$8,077,282	43,410	18.88	641.03	37,346	15.89	541.24

Source: Mowris et al. 2005

Statistical methods were used to select samples of customers or projects from each program category (Cochran 1977). Samples were selected to obtain precision at the 90 percent confidence level. Samples for similar measures were selected across utility service areas. More effort was focused on sites and program categories with the largest savings. **Table 3** provides units, M&V samples, coefficient of variation (Cv), relative precision, and error bounds at the 90

percent confidence interval for each of the ten program categories.¹ The overall relative precision for total MW and GWh savings is the square root of the sum of the squared error bounds for each program divided by total savings. Estimated demand savings were measured with an error bound of ± 0.20 MW and total relative precision of $\pm 1.3\%$ (Table 3). Energy savings were measured with an error bound of ± 0.55 GWh and relative precision of $\pm 1.5\%$.

Table 3. M&V Net Savings, Sample Sizes and Relative Precision for Load Impacts

#	NCPA Program Category	Total Units	M&V Sample	Cv MW	Cv GWh	Relative Precision MW	Relative Precision GWh	Error Bound MW	Error Bound GWh
1	C&I Lighting	125,966	23,875	0.40	0.55	1.0%	1.1%	0.05	0.21
2	C&I HVAC	12,489	9,620	0.42	0.47	7.3%	5.7%	0.16	0.23
3	C&I Refrigeration	560	560	0.04	0.39	4.4%	14.2%	0.04	0.12
4	C&I Custom	239	10	0.52	0.59	4.1%	4.7%	0.03	0.18
5	LED Traffic Signals	4,924	890	0.04	0.21	1.2%	0.9%	0.00	0.02
6	Residential HVAC	1,892	60	0.24	0.11	6.7%	18.2%	0.07	0.15
7	Residential CFL	72,627	60	0.26	0.47	5.7%	10.3%	0.06	0.36
8	Refrigerator Recycling	1,609	107	0.40	0.46	3.8%	4.3%	0.02	0.07
9	Misc. Programs	68,698	50	0.07	0.03	11.2%	5.0%	0.02	0.02
10	Load Control	4,837	3,237	0.32	n/a	1.3%	n/a	0.06	0.00
	Total	293,841	38,469			1.3%	1.5%	0.20	0.55

Source: Mowris et al. 2005

Decision-maker surveys (DMS) were used to assess net-to-gross ratios (i.e., to account for free riders). Surveys were completed using telephone and on-site participant interviews. The DMS sample size, Cv, and relative precision for each program category are provided in Table 4.

Table 4. M&V Savings, Samples, and Relative Precision for Decision-Maker Surveys

#	NCPA Program Category	M&V Net Ex Post Savings GWh	M&V Net Ex Post Savings MW	Participants or Units	M&V DMS Sample	M&V DMS Cv	DMS Relative Precision
1	C&I Lighting	20.30	4.41	626	75	0.18	3.4%
2	C&I HVAC	3.94	2.14	526	41	0.09	2.3%
3	C&I Refrigeration	0.82	0.89	1	1	0.00	0.0%
4	C&I Custom	3.75	0.82	64	12	0.17	8.1%
5	LED Traffic Signals	2.13	0.24	165	3	0.00	0.0%
6	Residential HVAC	0.80	1.05	1,871	60	0.14	3.0%
7	Residential CFL	3.49	1.06	34,984	62	0.29	6.1%
8	Refrigerator Recycling	1.72	0.44	1,568	110	0.46	7.2%
9	Miscellaneous Programs	0.39	0.18	1,726	24	0.22	7.4%
10	Load Control	0.00	4.64	4,739	n/a	n/a	n/a
	Total	37.35	15.89	46,270	388		

Source: Mowris et al. 2005

The total decision maker sample was 388 with Cv values ranging from zero to 0.46 and relative precision ranging from ± 0 to 8.1 percent.

¹ The coefficient of variation is a measure of dispersion of a probability distribution and defined as the ratio of the standard deviation to the mean. The error bound is the ratio of the standard deviation of the sample mean divided by the square root of the number of units in the sample times the normal deviate corresponding to the desired confidence probability. Relative precision is the ratio of the error bound divided by the program savings.

The program tracking database provided a framework for the M&V study including the following information: customers, programs, incentives, and pre/post-retrofit measures (i.e., make, model, efficiency, operational hours, installed cost, energy use, and energy savings). The tracking database includes a “Master” database that stores records from all utilities and separate “satellite” databases including pre-formatted up- and down-loadable spreadsheets used by each utility to enter program tracking data.

On-site M&V and engineering analyses were used to gather information regarding pre- and post-retrofit equipment in order to evaluate kW and kWh savings. Sites with significant savings received more effort in terms of spot, short-term, or continuous measurements to monitor hours of use with light loggers or electrical use with data loggers. For sites with HVAC, EMS, or process measures the M&V efforts included gathering information to develop simulations or spreadsheets to assess kW and kWh savings. Sites with large HVAC savings were evaluated using DOE-2.2 or eQuest simulations calibrated to utility billing data (Hirsch 2002).

Statistical methods were used to analyze data and extrapolate kW and kWh savings estimates from the sample to the population and to evaluate statistical precision (Cochran 1977). This step included an assessment of the relative precision and error bounds of program-level kW and kWh. For C&I lighting, C&I HVAC, C&I refrigeration, and C&I custom programs the savings per site were normalized on a per unit basis in the statistical analyses (e.g., kW/fixture, kW/ton, kW/bin, and kW/hp).² For LED traffic signals residential HVAC, residential CFLs, residential refrigerator recycling, miscellaneous, and load control programs with discrete measures, the program category savings were calculated as the sum of the number of measures for the utility program stratum times the M&V sample mean savings estimate. Some statistics were calculated using other equations (Hall 2004).

Commercial & Industrial Lighting Programs

Commercial and industrial lighting programs were implemented by Alameda, Gridley, Healdsburg, Lassen MUD, Lodi, Lompoc, Modesto Irrigation District, Palo Alto, Roseville, Santa Clara, and Truckee Donner Public Utility District. The programs realized energy and peak demand savings by paying incentives for high efficiency lighting systems, lamp removal (i.e., delamping), or controls. Approximately 626 projects and 125,966 lighting fixtures were installed from 2001 through 2003 under programs sponsored by 11 utilities with \$2,100,482 of SB5X funds. The ex ante and ex post load impacts for C&I lighting are summarized in **Table 5**.

² For C&I lighting the units are fixtures, for C&I HVAC the units are cooling tons (i.e., ton = 12,000 Btu/hr), for C&I refrigeration the units are bins of fruit per degree Fahrenheit (i.e., 835 pounds of apricots or 1,010 pounds of peaches), and for C&I custom the units are horsepower (i.e., 745.7 watts or 33,000 foot-pounds per minute).

Table 5. Ex Ante and Ex Post Load Impacts for NCPA SB5X C&I Lighting Programs

NCPA Utility	Qty.	Ex Ante Savings kWh/yr	Ex Ante Savings kW	Gross Ex Post Savings kWh/yr	Gross Ex Post Savings kW	Net-to-Gross Ratio	Net Ex Post Savings MWh/yr	Net Ex Post Savings kW	Net Realization Rate kWh/yr	Net Realization Rate kW
Alameda	6,091	1,127,255	368.00	1,123,456	337.27	0.85	954,938	286.68	0.85	0.78
Gridley	74	38,468	16.99	37,940	16.74	0.84	31,870	14.06	0.83	0.83
Healdsburg	110	20,434	4.90	20,365	4.49	0.85	17,310	3.81	0.85	0.78
LMUD	994	183,964	80.44	183,344	73.72	0.85	155,842	62.67	0.85	0.78
Lodi	24	4,500	1.01	4,485	0.92	0.85	3,812	0.78	0.85	0.78
Lompoc	50	15,768	1.81	15,768	1.81	1.00	15,768	1.81	1.00	1.00
MID	11,230	847,226	207.20	844,371	189.89	0.84	709,272	159.51	0.84	0.77
Palo Alto	8,822	1,128,674	285.71	1,031,308	258.72	0.98	1,010,682	253.55	0.90	0.89
Roseville	6,718	1,651,041	384.96	1,294,766	423.13	0.88	1,139,394	372.36	0.69	0.97
Santa Clara	87,913	15,612,124	3,436.29	19,089,720	3,742.14	0.83	15,844,468	3,105.98	1.01	0.90
TDPUD	3,940	394,545	156.40	422,386	154.40	0.99	418,162	152.86	1.06	0.98
Total	125,966	21,023,999	4,943.70	24,067,909	5,203.25	0.85	20,301,517	4,414.07	0.97	0.89

Note: Net-to-Gross Ratios for Alameda, Healdsburg, LMUD, and Lodi are weighted averages

The ex ante savings are 21,023,999 kWh/yr and 4,944 kW. The M&V gross ex post program savings are 24,067,909 kWh/yr \pm 255,650 kWh/yr and 5,203 kW \pm 54 kW at the 90 percent confidence level. The M&V net ex post program savings are 20,301,517 kWh/yr \pm 213,512 kWh/yr and 4,414 kW \pm 46 kW at the 90 percent confidence level. The M&V net ex post lifecycle savings are 324,824,278 \pm 3,416,193 kWh based on a 16-year effective useful life. The net realization rates are 0.97 for kWh and 0.89 for kW savings. The ex post savings are based on engineering analyses, pre- and post-retrofit lighting power measurements, light logger measurements, and on-site audits for a random sample of 44 sites consistent with the IPMVP. The net-to-gross ratios are calculated based on decision maker surveys completed for 75 participants. The weighted average net-to-gross ratio is 85 percent meaning that roughly 15 percent of customers would have made the lighting improvements without the program.³ The M&V on-site audit sample size included 23,875 fixtures at 44 participant sites. The M&V sample Cv is 0.55 for kWh/fixture and 0.40 for kW/fixture based on the gross realization rates from the M&V results. The participant survey Cv was 0.18. The M&V on-site survey sample of 44 participants provided relative precision of \pm 1% for MW and GWh. The DMS sample of 75 participants yielded relative precision of \pm 3.4%.

Commercial & Industrial HVAC Programs

Commercial and industrial heating, ventilating, and air conditioning (HVAC) programs were implemented by Gridley, Lodi, Modesto Irrigation District, Palo Alto, Port of Oakland, Plumas Sierra Electric Cooperative, Redding, Roseville Electric, Truckee Donner PUD, Turlock Irrigation District, and Ukiah. The programs realized energy and peak demand savings by paying incentives for the following energy efficiency measures: high efficiency packaged HVAC units, chillers, cooling towers, thermal storage, energy management systems, controls, evaporative pre-coolers, and HVAC tune-ups. The programs provided incentives for 590 measures with \$988,748 of SB5X funds. The ex ante and ex post load impacts are summarized in **Table 6**. The ex ante program savings are 5,645,055 kWh/yr and 2,482 kW. The gross ex post savings are 4,095,475 \pm 231,669 kWh/yr and 2,236 \pm 159 kW. The net ex post savings for the program are 3,944,622 \pm

³ The net-to-gross ratio is the weighted average based on savings per program divided by savings for all programs.

225,177 kWh/yr and 2,142 ± 156 kW. The net ex post lifecycle savings are 58,498,564 ± 3,370,974 kWh. The gross ex post savings are based on engineering analyses, measured data, billing regression analyses, and calibrated DOE-2.2 simulations consistent with the IPMVP.

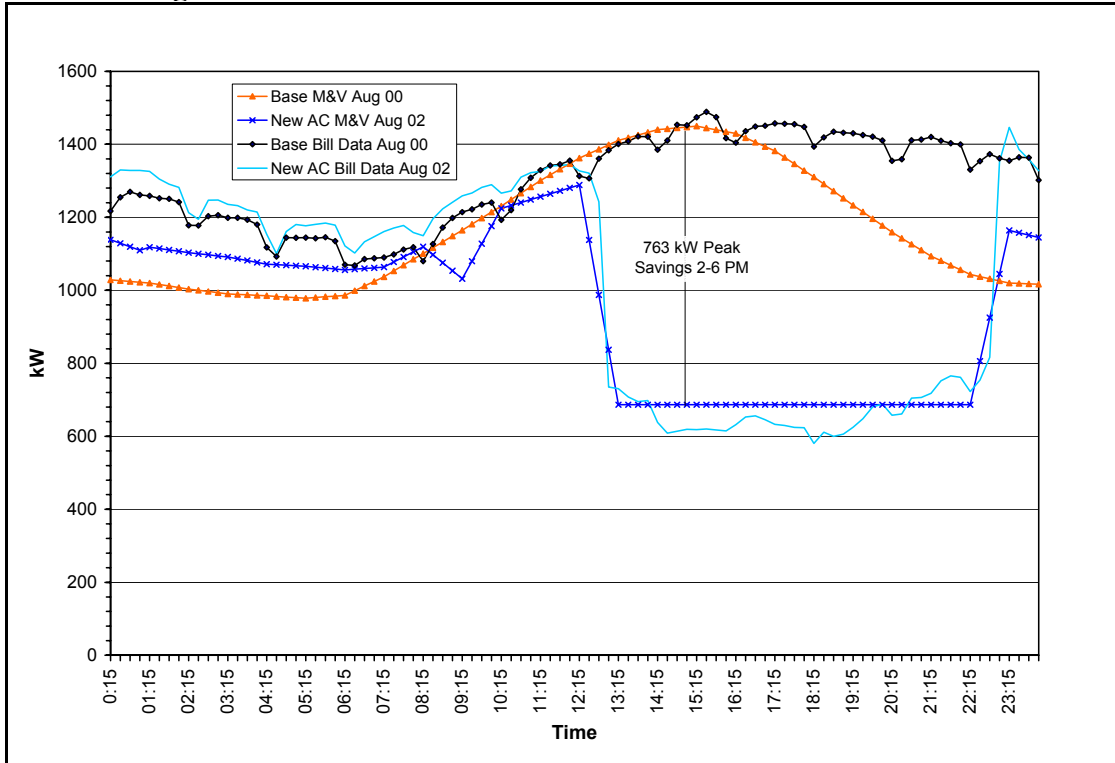
Table 6. Ex Ante and Ex Post Load Impacts for NCPA SB5X C&I HVAC Programs

NCPA Utility	Qty.	Ex Ante Savings kWh/yr	Ex Ante Savings kW	Gross Ex Post Savings kWh/y	Gross Ex Post Savings kW	Net-to-Gross Ratio	Net Ex Post Savings kWh/y	Net Ex Post Savings kW	Net Realization Rate kWh/y	Net Realization Rate kW
Gridley	2	3,995	4.4	1,005	1.2	0.97	972	1.1	0.24	0.25
Lodi	6	1,200	1.3	4,021	4.6	0.96	3,860	4.4	3.22	3.41
MID	79	46,479	52.8	50,542	57.8	0.77	38,918	44.5	0.84	0.84
MID-Custom	4	1,582,858	789.0	1,673,760	961.0	0.96	1,603,623	920.7	1.01	1.17
Palo Alto-Custom	1	2,776,800	960.0	1,473,327	815.0	0.99	1,456,957	805.9	0.52	0.84
Oakland-Custom	1	250,000	60.0	250,000	60.0	1.00	250,000	60.0	1.00	1.00
PSREC-GSHP	16	256,016	63.4	91,881	24.6	0.88	80,396	21.5	0.31	0.34
Redding	33	38,101	42.5	19,939	22.9	0.96	19,141	21.9	0.50	0.52
Roseville	93	203,288	205.3	95,731	80.5	0.83	79,681	67.0	0.39	0.33
Roseville AC Tune-up <5 ton	250	130,000	130.0	73,828	44.7	0.96	70,875	42.9	0.55	0.33
Roseville AC Tune-up >5 ton	43	44,720	44.7	25,988	14.0	0.96	24,949	13.5	0.56	0.30
TDPUD-Custom	1	229,166	87.0	305,628	116.0	0.95	290,347	110.2	1.27	1.27
TID	50	29,177	29.8	23,457	26.9	0.79	18,538	21.3	0.64	0.71
Ukiah	11	53,255	12.2	6,367	7.3	1.00	6,367	7.3	0.12	0.60
Total	590	5,645,055	2,482.4	4,095,475	2,236.46	0.96	3,944,622	2,142.35	0.70	0.86

Source: Mowris et al. 2005

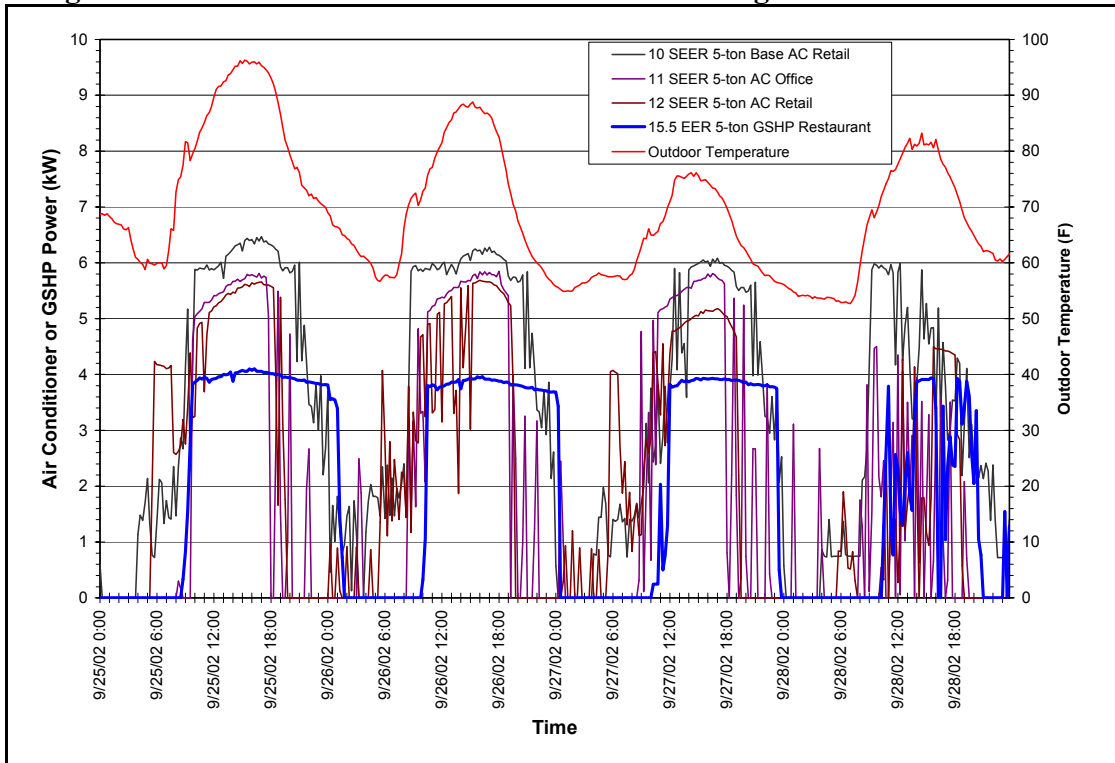
Ex post load impacts were evaluated with a random sample of 76 packaged air conditioners and 6 custom sites accounting for 84 percent of total kWh savings and 71% of the total kW savings. The average net-to-gross ratio is 96% indicating approximately 4% of the measures would have been purchased without the program. The realization rates are 0.70 for kWh and 0.86 for kW savings. The weighted sample Cv for kWh savings is 0.47, the weighted Cv for kW savings is 0.42, and the weighted participant survey Cv is 0.09. The M&V on-site survey sample of 82 participants provided relative precision of ±7.3% for MW and ±5.7% for GWh. The survey sample of 41 participants yielded relative precision of ±2.3%. Peak kW savings for custom sites are based on pre- and post-retrofit measurements. Examples are provided in **Figure 1** for a custom thermal storage project and **Figure 2** for packaged units.

Figure 1. Field Measurements of Peak kW for Custom Site #2



Source: Mowris et al. 2005

Figure 2. Field Measurements of Peak kW for Packaged AC and GSHP Units



Source: Mowris et al. 2005

Commercial & Industrial Refrigeration Program

The commercial and industrial refrigeration program was implemented by City of Lodi. The program realized energy and peak demand savings by paying incentives of \$380,000 with SB5X funds for high efficiency refrigeration systems. The ex ante program and ex post load impacts are summarized in **Table 7**. The ex ante program savings are 1,194,000 kWh/yr and 765 kW. The gross ex post program savings are 838,477 ± 118,943 kWh/yr and 907 ± 40 kW. The net ex post program savings are 821,708 ± 116,564 kWh/yr and 889 ± 39.2 kW. The net ex post lifecycle savings are 16,434,160 ± 2,331,275 kWh based on a 20-year lifetime.

Table 7. Ex Ante and Ex Post Load Impacts for NCPA SB5X C&I Refrigeration Program

NCPA Utility	Qty.	Ex Ante Savings kWh/yr	Ex Ante Savings kW	Gross Ex Post Savings kWh/y	Gross Ex Post Savings kW	Net-to-Gross Ratio	Net Ex Post Savings kWh/y	Net Ex Post Savings kW	Net Realization Rate kWh/y	Net Realization Rate kW
Lodi	1	1,194,000	765	838,477	907	0.98	821,708	889	0.69	1.16

Source: Mowris et al. 2005

Ex post savings are based on field measurements, monthly billing data, production data, and engineering analyses for 2000 and 2001 consistent with the IPMVP. The realization rates are 0.69 for kWh and 1.16 for kW. The old hydro-cooling refrigeration system poured chilled water over the top of bins of fruit that traveled slowly down a conveyor. The bins were then taken inside the cold storage building until processing. The new internal air-cooling system saves 56% on peak electric demand and 67% on electrical usage with computer control, variable-frequency and 2-speed drives, and air versus water cooling.

Commercial & Industrial Custom Programs

Commercial and industrial custom incentive programs were implemented by Turlock Irrigation District, Ukiah, Lompoc, and Truckee Donner Public Utility District. The programs realized peak kW and kWh savings by paying incentives to C&I customers for installing custom high efficiency measures such as air compressors, variable speed controllers, computer monitors, vacuum pumps, motors, solar sunscreens, and photovoltaic systems. The programs provided incentives for 64 projects from 2001 through 2003 with \$370,550 of SB5X funds. The ex ante and ex post load impacts are summarized in **Table 8**.

Table 8. Ex Ante and Ex Post Load Impacts for NCPA SB5X C&I Custom Programs

NCPA Utility	Qty.	Ex Ante Savings kWh/yr	Ex Ante Savings kW	Gross Ex Post Savings kWh/y	Gross Ex Post Savings kW	Net-to-Gross Ratio	Net Ex Post Savings kWh/y	Net Ex Post Savings kW	Net Realization Rate kWh/y	Net Realization Rate kW
TID	60	4,877,817	1148.3	4,445,082	969.0	0.84	3,733,869	814.0	0.77	0.71
Ukiah	1	15,160	5.0	15,160	5.0	1.00	15,160	5.0	1.00	1.00
Lompoc	2	4,680	2.6	4,680	2.6	1.00	4,680	2.6	1.00	1.00
TDPUD	1	329	0.1	329	0.1	1.00	329	0.1	0.07	0.03
Total	64	4,897,986	1,156	4,465,251	976.7	0.84	3,754,038	821.7	0.77	0.71

Source: Mowris et al. 2005

The ex ante program savings are 4,897,986 kWh/yr and 1,156 kW. The M&V gross ex post savings are 4,465,251 ± 210,158 kWh/yr and 977 ± 41 kW. The M&V net ex post savings are 3,754,038 ± 176,534 kWh/yr and 821.7 ± 34 kW. The net ex post lifecycle savings are 56,613,105 ± 2,648,085 kWh. Gross ex post kWh savings are based on electric power measurements, billing data, and engineering analyses of 10 custom sites accounting for 31% of the total kWh savings and 25 percent of total kW savings consistent with the IPMVP. The M&V sample included high efficiency air compressors, variable frequency drives, vacuum pumps, and motors affecting 419 horsepower out of a total of 2,808 horsepower in the program. The average net-to-gross ratio is 84% indicating 16% of measures would have been purchased without the program. The net realization rates are 0.77 for kWh savings and 0.71 for kW savings. The weighted sample Cv for kWh savings was 0.52, the weighted Cv for kW savings was 0.59, and the weighted participant survey Cv was 0.17. The M&V on-site survey sample of 10 participants provided relative precision of ±4.1% for MW and ±4.7% for GWh. The DMS sample of 12 participants yielded relative precision of ±8.1%.

LED Traffic Signals Programs

Light emitting diode (LED) traffic signals programs were implemented by Lompoc, Modesto Irrigation District, and Santa Clara. The programs realized peak kW and kWh savings by paying incentives to local city or county jurisdictions for the installation of high efficiency LED traffic signals. The three programs provided incentives totaling \$450,697 for 4,924 LED traffic signals installed from 2001 through 2003 with SB5X funds. The ex ante and ex post load impact results are summarized in **Table 9**. The ex ante program savings are 2,700,354 kWh/yr and 308 kW. The M&V gross ex post savings are 2,419,003 ± 22,919 kWh/yr and 276 ± 3.3 kW. The M&V net ex post savings are 2,126,207 ± 20,102 kWh/yr and 242.8 kW ± 3 kW at the 90% confidence level. The net ex post lifecycle savings are 34,019,304 ± 321,629 kWh based on an effective useful lifetime of 16 years. The net realization rates are 0.79.

Table 9. Ex Ante and Ex Post Load Impacts for NCPA SB5X LED Traffic Signals

NCPA Utility	Qty.	Ex Ante Savings kWh/yr	Ex Ante Savings kW	Gross Ex Post Savings kWh/yr	Gross Ex Post Savings kW	Net-to-Gross Ratio	Net Ex Post Savings kWh/yr	Net Ex Post Savings kW	Net Realization kWh/yr	Net Realization kW
Lompoc	1,074	546,568	62.4	496,976	56.7	0.87	432,369	49.4	0.79	0.79
MID	2,109	923,114	105.4	838,345	95.7	0.87	729,360	83.3	0.79	0.79
Santa Clara	1,741	1,230,672	140.5	1,083,682	123.7	0.89	964,477	110.1	0.78	0.78
Total	4,924	2,700,354	308.3	2,419,003	276	0.88	2,126,207	243	0.79	0.79

Source: Mowris et al. 2005

The M&V savings are based on the verified quantity of installed measures, pre- and post-retrofit power measurements for a random sample of 18 intersections and 1,074 signals, billing data for 17 intersections and 890 signals, and hours of operation from Caltrans consistent with the IPMVP.⁴ The weighted sample Cv for kWh savings is 0.21 and the weighted Cv for kW

⁴ CalTrans traffic signal operational hours are based on intersection metering data by Electra-test, Inc. (ETI) and verified by Schiller Associates for the PG&E Power Saving Partners. ETI monitored 160 signals over 29 intersections. Review of CalTrans-Traffic Signal Duty Cycle Monitoring Results, Schiller Associates, prepared for PG&E Power Saving Partners Program, ID#95PSP 105 CalTrans - Traffic Signal Retrofit, November 1999.

savings is 0.04. The M&V on-site survey sample of 890 traffic signals provided relative precision of $\pm 1.2\%$ for MW and $\pm 0.9\%$ for GWh. A DMS census found zero free riders.

Residential HVAC Rebate Programs

Residential heating, ventilating, and air conditioning rebate programs were implemented by Modesto Irrigation District, Plumas Sierra Electric Cooperative, Redding Electric Utility, Roseville Electric, and Turlock Irrigation District. The programs realized peak kW and kWh savings by paying rebates for high efficiency air conditioners. The programs provided 1,892 air conditioner rebates from 2001 through 2003 with \$1,344,803 of SB5X funds. Ex ante and ex post load impacts are summarized in **Table 10**.

Table 10. Ex Ante and Ex Post Load Impacts for NCPA SB5X Residential HVAC Rebates

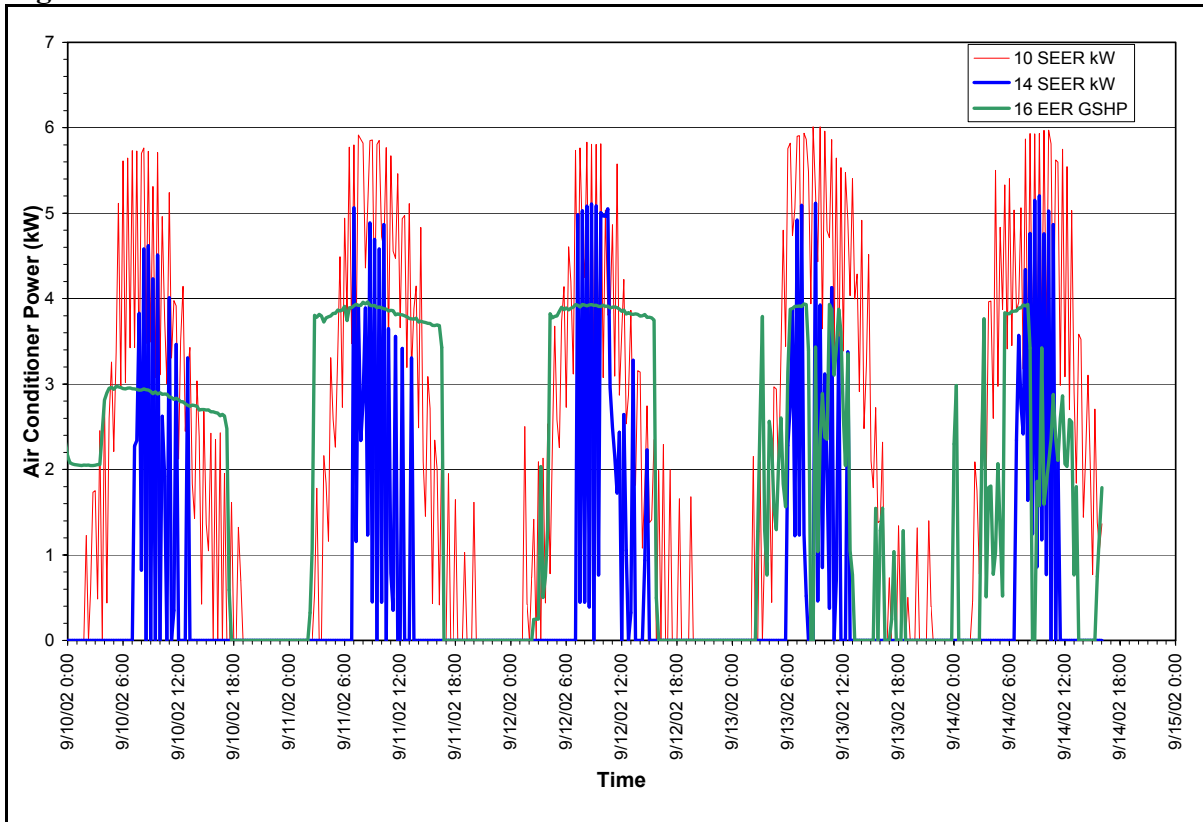
NCPA Utility	Qty.	Ex Ante Savings kWh/yr	Ex Ante Savings kW	Gross Ex Post Savings kWh/y	Gross Ex Post Savings kW	Net-to-Gross Ratio	Net Ex Post Savings kWh/y	Net Ex Post Savings kW	Net Realization Rate kWh/y	Net Realization Rate kW
MID	316	350	0.64	446	0.52	0.82	115,513	135.8	1.04	0.67
PSREC-GSHP	82	16,001	3.96	913	2.10	0.84	62,864	144.6	0.05	0.45
Redding	704	666	0.76	561	0.71	0.83	327,658	413.2	0.70	0.77
Roseville	134	2,594	2.59	581	0.79	0.86	67,011	91.2	0.19	0.26
TID	656	721	0.74	430	0.51	0.81	228,313	268.4	0.48	0.56
Total or Ave.	1,892	1,433.56	1.00	513	0.67	0.82	801,358	1,053.3	0.30	0.56

Note: PSREC includes cooling kW savings and cooling plus heating kWh savings for GSHP

The ex ante program savings are 2,712,291 kWh/yr and 1,892 kW. The net ex post program savings are $801,358 \pm 145,753$ kWh/yr and $1,053 \pm 71$ kW. The net ex post lifecycle savings are $12,020,370 \pm 2,186,295$ kWh based on a 15-year lifetime. Net realization rates are 0.30 for kWh and 0.56 for kW savings. The gross ex post energy savings are based on billing regression analyses for 60 sites. Peak demand savings are based on field measurements of kW for 21 units consistent with IPMVP. Each unit included in the random sample was measured for several weeks to obtain 15-minute average kW measurements from 2 PM to 6 PM (**Figure 3**). Measured savings for conventional AC units ranged from 0.59 kW for 2.5-ton 14 SEER units to 0.80 kW for a 5-ton 14 SEER units. The maximum savings are 2.1 kW for ground source heat pumps (GSHP).⁵ Participant telephone surveys were used to evaluate net-to-gross ratios. The average net-to-gross ratio is 83 percent indicating 17 percent would have been purchased without the program. The weighted sample Cv for kWh savings is 0.11 the Cv for kW savings was 0.24, and the participant survey Cv is 0.15. The M&V on-site survey sample of 61 participants provided relative precision of $\pm 6.7\%$ for MW and $\pm 18.2\%$ for GWh. The DMS sample of 60 participants yielded relative precision of $\pm 3\%$.

⁵ SEER is an adjusted rating based on steady-state EER measured at standard conditions of 82°F outdoor and 80°F drybulb/67°F wetbulb indoor temperature multiplied by the Part Load Factor with a default of 0.875 (ARI 2003).

Figure 3. Field Measurements of 10 and 14 SEER Air Conditioners and 16 SEER GSHP



Source: Mowris et al. 2005

Residential CFL Programs

Residential compact fluorescent lamp (CFL) programs were implemented by Biggs, Gridley, Healdsburg, Plumas-Sierra Rural Electric Cooperative, and Redding. The programs realized peak kW and kWh savings by providing free CFLs to consumers.⁶ The five utility CFL programs gave away 72,627 CFLs during 2001 through 2003 that were purchased with \$250,096 of SB5X. The ex-ante and ex post load impacts for the programs are summarized in **Table 11**.

Table 11. Ex Ante and Ex Post Load Impacts for NCPA SB5X Residential CFL Programs

NCPA Utility	Qty.	Ex Ante Savings kWh/yr	Ex Ante Savings kW	Gross Ex Post Savings kWh/yr	Gross Ex Post Savings kW	Net-to-Gross Ratio	Net Ex Post Savings kWh/yr	Net Ex Post Savings kW	Net Realization Rate kWh/yr	Net Realization Rate kW
Biggs	1,407	94,329	38.7	94,371	32.3	0.60	56,315	19.3	0.60	0.50
Gridley	1,117	126,126	52.0	66,993	28.2	0.71	47,433	20.0	0.38	0.38
Healdsburg	3,024	190,512	136.1	154,968	36.3	0.72	111,133	26.0	0.58	0.19
PSREC	1,469	104,299	83.7	128,363	33.5	0.80	102,469	26.7	0.98	0.32
Redding	65,610	1,367,968	1640.2	4,377,930	1,332.7	0.72	3,168,498	964.5	2.32	0.59
Average	72,627	1,883,234	1950.8	4,822,625	1,463	0.72	3,485,846	1,057	1.85	0.54

Source: Mowris et al. 2005

⁶ City of Biggs provided incentives to customer for CFLs purchased at local hardware stores.

The ex ante program savings are 1,883,234 kWh/yr and 1,951 kW. The M&V gross ex post program savings are 4,822,625 ± 498,651 kWh/yr and 1,463 ± 83 kW at the 90 percent confidence level. The M&V net program savings are 3,485,846 ± 360,430 kWh/yr 1,057 ± 60 kW. The net ex post lifecycle savings are 23,424,885 ± 2,422,090 kWh based on the EUL for screw-in CFLs of 6.72 years. The net realization rates are 1.85 for annual kWh savings and 0.54 for kW savings. The M&V savings are based on pre- and post-retrofit power measurements and analyses of telephone survey data for a random sample of 62 participants consistent with the IPMVP. The net-to-gross ratios are also calculated based on decision maker surveys completed for 62 participants. The average net-to-gross ratio is 72 percent meaning that roughly 28 percent of customers would have purchased and used CFLs without the program. The weighted sample Cv is 0.47 for kWh and 0.26 for kW based on the gross realization rates from the M&V results. The DMS survey Cv is 0.29. The M&V survey sample of 62 participants provided relative precision of ±5.7% for MW and ±10.3% for GWh. The DMS sample yielded precision of ±6.1%.

Residential Refrigerator Recycling Programs

Refrigerator recycling programs were implemented by Biggs, Gridley, Lodi, Lompoc, Plumas-Sierra Rural Electric Cooperative, and Santa Clara. The old appliances were taken to a recycling center where the refrigerant was removed and the unit was permanently disposed. Third-party contractors operated the programs in Lodi and Santa Clara respectively. In addition to recycling refrigerant, these contractors also recycled foam, plastic, metals, and other components. Biggs, Gridley, Lompoc, and Plumas-Sierra had an arrangement with their local solid waste management companies to recycle the appliances. Approximately 1,609 refrigerators and freezers were recycled during 2001 and 2002 with \$344,647 of SB5X funds. The ex ante and ex post load impacts are summarized in **Table 12**.

Table 12. Ex Ante and Ex post Load Impacts for NCPA SB5X Refrigerator Recycling

NCPA Utility	Qty.	Ex Ante Savings kWh/yr	Ex Ante Savings kW	Gross Ex Post Savings kWh/yr	Gross Ex Post Savings kW	Net-to-Gross Ratio kWh/yr	Net-to-Gross Ratio kW	Net Ex Post Savings kWh/yr	Net Ex Post Savings kW	Realization Rate kWh/yr	Realization Rate kW
Biggs	2	1,053	0.22	1,682	0.362	0.91	1	3,061	0.7	1.45	1.68
Gridley	42	1,540	0.30	1,682	0.362	0.55	0.67	38,854	10.2	0.60	0.82
Lodi	541	1,593	0.18	1,682	0.362	0.69	0.76	627,874	148.8	0.73	1.53
Lompoc	77	1,593	0.18	1,682	0.362	0.61	0.79	79,004	22.0	0.65	1.59
PSREC	200	958	0.38	1,682	0.362	0.62	0.79	208,568	57.2	1.09	0.76
Santa Clara	747	1,593	0.18	1,682	0.362	0.61	0.76	766,437	205.5	0.64	1.51
Total	1,609					0.64	0.76	1,723,798	444.5	0.71	1.33

Source: Mowris et al. 2005

The ex ante program savings are 2,431,274 kWh/yr and 335 kW. The gross ex post program savings are 2,706,338 kWh/yr ± 198,127 kWh/yr and 582.5 ± 37.5 kW. The net ex post program savings are 1,723,798 ± 126,197 kWh/yr and 445 ± 29 kW. The net ex post lifecycle savings are 10,342,788 ± 757,182 kWh based on a 6-year effective useful lifetime. The ex post savings are based on short-term power measurements of 107 units consistent with the IPMVP. The average M&V full-year unit energy consumption for refrigerators and freezers is 1,682 kWh/yr and 0.36 kW.⁷ The net-to-gross ratio is calculated based on part use and attribution

⁷ The refrigerator M&V gross savings estimate is 1,625 kWh/yr ± 135 kWh/yr and 0.365 ± 0.03 kW. The freezer

regarding whether or not the unit would have been disposed of without the program. The average attribution factor was 76 percent meaning that roughly 24 percent of units would have been taken out of service without the program. The weighted sample Cv for the metering sample was 0.46 and the participant survey Cv was 0.45. The M&V on-site survey sample of 107 participants provided relative precision of $\pm 6.48\%$ for MW and $\pm 7.3\%$ for GWh. The DMS sample of 110 participants yielded relative precision of $\pm 7.2\%$.

Miscellaneous Programs

Miscellaneous rebate programs were implemented by Lodi, Lompoc, Modesto Irrigation District), Roseville Electric, Turlock Irrigation District, and Santa Clara. The programs realized peak kW and kWh savings by paying incentives to customers for installing high efficiency miscellaneous measures. The programs provided 1,726 incentives for 68,468 measures from 2001 through 2003 with \$246,519 SB5X funds. Ex ante savings and ex post load impacts are summarized in **Table 13**.

Table 13. Ex Ante and Ex Post Load Impacts for NCPA SB5X Miscellaneous Programs

NCPA Utility	Qty.	Ex Ante Savings kWh/yr	Ex Ante Savings kW	Gross Ex Post Savings kWh/y	Gross Ex Post Savings kW	Net-to-Gross Ratio	Net Ex Post Savings kWh/y	Net Ex Post Savings kW	Net Realization Rate kWh/y	Net Realization Rate kW
Roseville-Vender Misers	115	212,900	19.3	178,710	11.5	0.96	171,562	11.0	0.81	0.57
MID - Res ESW	44872	98,718	179.5	98,718	134.6	0.65	64,167	87.5	0.65	0.49
MID - Comm. Sun Screens	16243	51,978	65.0	43,856	24.4	0.96	42,102	23.4	0.81	0.36
MID - Res SS	5881	12,938	23.5	9,410	4.1	0.48	4,517	2.0	0.35	0.08
MID - Res WHF	24	6,600	12.0	4,872	4.8	0.66	3,216	3.2	0.49	0.26
MID - Refrig.	704	371,893	80.4	46,464	9.9	0.80	37,171	7.9	0.10	0.10
Lompoc- Kits	500	36,850	13.0	33,500	11.5	0.80	26,800	9.2	0.73	0.71
Lompoc - WB	1	900	0.3	270	0.1	0.80	216	0.1	0.24	0.24
Lodi - Win. Film	9	900	0.6	635	0.2	0.96	610	0.2	0.68	0.36
TID - Win. Film	34	5,376	5.6	4,516	2.1	0.96	4,335	2.0	0.81	0.36
Santa Clara - Plug Sensor	85	122,850	28.05	33,856	36.6	0.96	32,501	35.1	0.26	1.25
Total	68,468	921,903	427	454,806	239.8	0.76	387,196	181.6	0.42	0.42

Source: Mowris et al. 2005

The ex ante program savings are 921,903 kWh/yr and 427 kW. The M&V gross ex post program savings are 454,806 \pm 24,239 kWh/yr and 240 \pm 29 kW. The net ex post program savings are 387,196 \pm 19,339 kWh per year and 182 \pm 20 kW at the 90 percent confidence level. The net ex post lifecycle savings are 5,064,053 \pm 290,760 kWh. Ex post kWh savings are based on billing data analyses, sub-metered data, engineering analyses, and previously published M&V studies consistent with the IPMVP. The net-to-gross ratio is calculated based on decision maker surveys regarding whether or not the unit would have been installed without rebates from the programs. The average net-to-gross ratio is 85 percent indicating approximately 15 percent of measures would have been purchased anyway without the program. The net realization rates are 0.42 for kWh and kW savings. The weighted sample Cv for kWh savings was 0.03, the weighted

M&V gross savings estimate is 2,009 kWh/yr \pm 241 kWh/yr and 0.348 kW \pm 0.06 kW.

Cv for kW savings was 0.07, and the weighted participant survey Cv was 0.19. The M&V sample of 50 participants provided relative precision of $\pm 11.2\%$ for MW and $\pm 5\%$ for GWh. The DMS sample of 24 participants yielded relative precision of $\pm 7.4\%$.

Load Control Programs

Residential air conditioner emergency-based load control programs were implemented by Modesto Irrigation District and Turlock Irrigation District. Commercial and industrial emergency-based load control programs were implemented by the City of Palo Alto. MID and TID realized peak kW savings by providing monthly bill credits to customers in exchange for the installation of residential AC load controllers. The MID program installed 3,234 Load Control Receivers and the TID program installed 1,502 AC load control programmable thermostats.⁸ City of Palo Alto realized peak kW savings by implementing load curtailment at the City Hall, Main Library, and Water Quality Control Plant. The programs are in effect for the May through September cooling season with \$1,600,740 of SB5X funds. The ex ante and ex post load impacts are summarized in **Table 14**.

Table 14. Ex Ante and Ex Post Load Impacts for NCPA SB5X Load Control

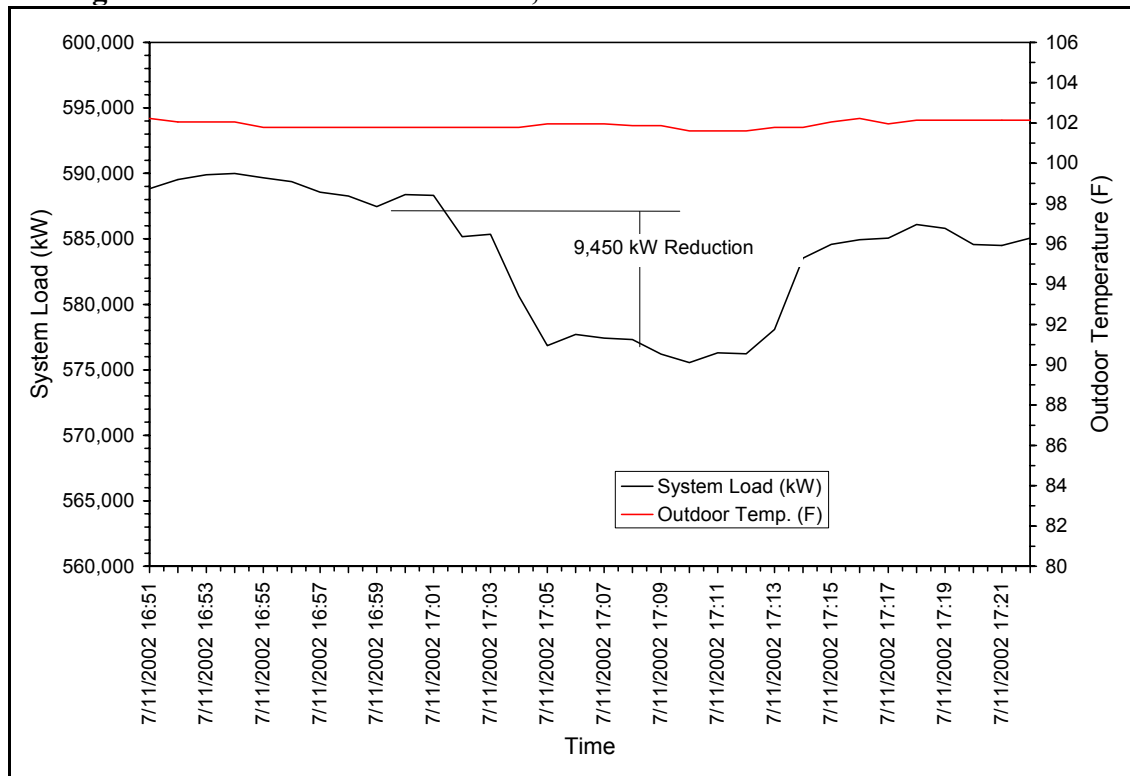
NCPA Utility	Sites	Ex Ante Savings kWh/yr	Ex Ante Savings kW	Gross Ex Post Savings kWh/yr	Gross Ex Post Savings kW	Net-to-Gross Ratio	Net Ex Post Savings MWh/yr	Net Ex Post Savings kW	Net Realization Rate kWh/yr	Net Realization Rate kW
MID	3,234	n/a	3,000	n/a	3,095	n/a	n/a	3,095	n/a	1.03
TID	1,502	n/a	1,500	n/a	1,437	n/a	n/a	1,437	n/a	0.96
Palo Alto	3	n/a	115	n/a	108	n/a	n/a	108	n/a	0.94
Total	4,739	n/a	4,615	n/a	4,640	n/a	n/a	4,640	n/a	1.01

Source: Mowris et al. 2005

Total ex ante program savings are 4,615 kW. The gross and net program savings are 4,640 kW \pm 58.9 kW. The M&V savings are based on system-wide electric power measurements of AC load controllers using real-time Supervisory Control and Data Acquisition (SCADA) consistent with IPMVP. The M&V savings for City of Palo Alto are based on SCADA measurements of affected equipment or similar equipment consistent with IPMVP. For MID, the load impact measurements were made during a ten-minute deployment of 3,234 LCR 5000 AC Load Controllers on July 10, 2002, when outdoor temperatures were approximately 105 F and on July 11, 2002, when outdoor temperatures were approximately 102 F (see **Figure 4**). The weighted sample Cv is 0.32 for kW savings. The Cv is relatively small because 68.9 percent of program savings are based on field measurements of load controllers during operation. The M&V on-site survey sample of 3,237 participants provided relative precision of $\pm 1.3\%$ for MW.

⁸ MID installed LCR 5000 AC controllers using 900 MHz paging technology installed on air conditioner outdoor condensing units. TID installed AC load control programmable thermostats using 152.8 MHz paging technology. MID and TID controllers cycle off for an average of 10 minutes per 30 minute period, in pre-programmed stagger-cycled load groups. Both controllers shut off the air conditioner compressor. In emergency situations, participating AC load controllers can be cycled off to reduce electricity demand in the MID or TID service areas.

Figure 4. Field Measurements of 3,234 LCR 5000 Load Controllers in MID



Source: Mowris et al. 2005

Conclusion

Measurement and verification (M&V) study results are provided for a portfolio of sixty-three energy efficiency peak demand reduction and load control programs. The programs were implemented by seventeen public utilities with funding from Senate Bill 5X administered by Northern California Power Agency under the auspices of the California Energy Commission. The study adhered to the International Performance Measurement and Verification Protocols (IPMVP) and protocols adopted by the California Public Utilities Commission. Each program was grouped into one of ten end-use categories. The programs provided incentives for 281,390 measures with a budget of \$8,700,000. The net ex post savings are 37,346,290 ± 546,362 kWh/year and 15,886 ± 204 kW. Net lifecycle savings are 541,241,505 ± 6,822,445 kWh with an average lifetime of 14.5 years. The net realization rates are 0.860 ± 0.013 for kWh and 0.842 ± 0.011 for kW. The net TRC is 3.4 ± 0.05 or 0.060 ± 0.001 \$/kWh. The cost effectiveness is 547.66 ± 7.03 dollars per kW. The realization rates have confidence intervals ranging from 13 to 15 percent. This indicates the level of uncertainty associated with the load impact analysis due to variability in the participants' energy consumption.

Several programs had low realization rates due to unrealistic ex ante savings. Realization rates can be improved by developing ex ante savings from M&V studies available from the California Measurement Advisory Council (www.calmac.org). Studies worthy of consideration include this study, the 2004 California Statewide Residential Appliance Saturation Survey (KEMA 2004), and the Database for Energy Efficiency Resources (Itron 2005). The utilities haven't previously conducted independent M&V studies and are unfamiliar with tracking

accomplishments and measuring results. Future programs should budget 5 to 10 percent for load impact and process evaluation studies to improve reliability and reduce uncertainty.

Future programs should include M&V studies that adhere to the IPMVP and evaluation protocols adopted by the California Public Utilities Commission (Hall 2005b). Future M&V studies should include the following minimum requirements included in this study: 1) tracking database, 2) net first-year and lifecycle kWh, kW, and therm impacts including precision and error bounds (net should be adjusted for free-riders and persistence), 3) actual program expenditures, 4) process evaluation and participant satisfaction assessments including recommendations for improvements, 5) independent study management from program management, 6) adequate time for planning and implementing studies in step with program implementation, and 7) M&V contractors must be experienced with IPMVP options requiring technology-based on-site field measurements.

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