Measurement & Verification Load Impact Study for NCPA SB5X Residential Air Conditioning and Commercial and Industrial Load Control (Emergency Based) Programs

Study ID: NCP0001.11

FINAL REPORT

Prepared for
John Berlin, Project Manager
Northern California Power Agency
Roseville, California

Prepared by
Principal Investigators: Robert Mowris and Kathleen Carlson
Robert Mowris & Associates
Olympic Valley, California

June 25, 2005

Funded with California Senate Bill 5X Funds

TABLE OF CONTENTS

Acknowledgements ii
1. Executive Summary 1
  2.1 M&V Findings for MID AC Load Control 3
  2.2 M&V Findings for TID AC Load Control 6
  2.3 M&V Findings for Palo Alto C&I Load Curtailment 7
3. Participant Survey Results 10
4. M&V Methodology 10
  4.1 Sample Design and Statistical Analysis 10
  4.2 Database 14
  4.3 Baseline 14
  4.4 Program Evaluation Savings Estimates 14

Acknowledgements

This measurement and verification load impact study was funded by Senate Bill 5X and administered by Northern California Power Agency under the auspices of the California Energy Commission. System-wide electrical power field measurements of load controllers using real-time Supervisory Control and Data Acquisition (SCADA) were made possible with the cooperation of the following individuals, utilities, and companies: Peter Govea, Steve Carlson, and Henry Azevedo, Modesto Irrigation District; Kate Schulenburg, Turlock Irrigation District; and Virginia Waik, City of Palo Alto Utilities. Robert Mowris, P.E., and Kathleen Carlson, Esq., managed the study and designed the EM&V plan and database. Peter Pressley, Ph.D., developed the NCPA M&V tracking database and Rachel Noack, B.S., managed and revised the database. Robert Mowris, performed the on-site inspections, engineering and statistical analyses, and wrote the report with assistance from Anne Blankenship, B.S., Ean Jones, B.S., and Rachel Noack. John Berlin was the project manager for Northern California Power Agency. Rick Ridge, Ph.D., Ridge Associates, provided review comments and suggestions regarding the statistical analysis and sample design.

1. Executive Summary

This study was conducted at the request of Northern California Power Agency (NCPA) and the California Energy Commission (CEC). The study was managed by NCPA. It was funded by Senate Bill 5X (SB5X) and is available online at www.calmac.org. This report provides Measurement and Verification (M&V) load impact study results for the NCPA SB5X Residential Air Conditioning (AC) Load Control (emergency based) Programs implemented by Modesto Irrigation District (MID) and Turlock Irrigation District (TID) and Commercial and Industrial (C&I) Load Control Programs 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.[1] City of Palo Alto realized peak kW savings by implementing load curtailment at the City Hall, Main Library, and Water Quality Control Plant (WQCP). The programs are in effect for the May through September cooling season with $1,600,740 of SB5X funds administered by NCPA.

The M&V results are summarized in **Table 1.1**. Total ex ante program savings are 4,615 kW. The net to gross ratio is not applicable since these programs would not have been implemented without SB5X funding. Therefore, the gross and net program savings are 4,640 kW ± 58.9 kW at the 90 percent confidence level. The net realization rate for kW savings is 1.01. 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) before, during, and after turning off LCR 5000 load controllers. For MID, the LCR 5000 units were turned off during periods of high outdoor temperatures (i.e., greater than 100 degrees Fahrenheit, F). The M&V savings for TID are extrapolated from M&V savings for MID based on the number of units installed since the TID program was not completed until after the cooling season was over. The M&V savings for City of Palo Alto are based on SCADA measurements of affected equipment or similar equipment. The effective useful lifetime of the load controllers is assumed to be 15 years.

Table 1.1 Summary of M&V Results for NCPA SB5X Load Control

NCPA Utility	Sites	Ex Ante Program Savings kWh/yr	Ex Ante Program Savings kW	M&V Gross Program Savings kWh/yr	M&V Gross Program Savings kW	Net-to-Gross Ratio	M&V Net Program Savings kWh/yr	M&V Net Program Savings kW	Net Realization Rate Relative to Planning kWh/yr	Net Realization Rate Relative to Planning 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**

Section 2 presents detailed M&V analyses for the three programs and M&V savings. **Section 3**

[1] The MID program installed LCR 5000 AC controllers that use 900 MHz paging technology installed on the outdoor condensing unit of split-system air conditioners. The TID program installed AC load control programmable thermostat that use 152.8 MHz paging technology and replace existing air conditioner thermostats. Participating MID and TID controllers are cycled off for an average of 10 minutes per 30 minute period, and are pre-programmed into different load groups and are normally stagger-cycled. Both controllers are used to 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.

presents participant survey results (not applicable). **Section 4** presents the M&V methodology used for the sample design, database, baseline, and program evaluation savings estimates.

2. M&V Approach and Results for Load Control

The measurement and verification approach for the study is based on the *International Performance Measurement & Verification Protocols* (IPMVP) defined in **Table 2.1**.[2] The M&V approach for the load impact evaluation involved performing on-site measurement and verification activities for a statistically significant random sample of participating customers. Ex post energy savings were determined using the following IPMVP Options.

- MID air conditioner load controllers were evaluated using IPMVP Option C (i.e., whole facility power use) for all sites (a census) with on-site verification at random sites.
- TID air conditioner load controllers were evaluated by extrapolating savings from MID using IPMVP Option A (i.e., stipulated or deemed values).
- Palo Alto commercial and industrial load controllers were evaluated using IPMVP Options A and B (i.e., retrofit isolation).

Table 2.1 IPMVP M&V Options

M&V Option	How Savings Are Calculated	Typical Applications
Option A. Partially Measured Retrofit Isolation Savings are determined by partial field measurement of energy use of system(s) to which a measure was applied, separate from facility energy use. Measurements may be either short-term or continuous. Partial measurement means that some but not all parameters may be stipulated, if total impact of possible stipulation errors is not significant to resultant savings. Careful review of measure design and installation will ensure that stipulated values fairly represent the probable actual value.	Engineering calculations using short term or continuous post-retrofit measurements or stipulations.	Pre- and post-retrofit values are measured with a kW meter and operating hours are based on interviews with occupants or stipulated values.
Option B. Retrofit Isolation Savings are determined by field measurement of the energy use of the systems to which the measure was applied, separate from the energy use of the rest of the facility. Short-term or continuous measurements are taken throughout the post-retrofit period.	Engineering calculations using short term or continuous measurements	Lighting system electricity use is measured with a kW meter. Hours of operation are measured with light loggers.
Option C. Whole Facility Savings are determined by measuring energy use (and production) at the whole facility level. Short-term or continuous measurements are taken throughout the post-retrofit period. Continuous measurements are based on whole-facility billing data.	Analysis of whole facility utility meter or sub-meter data using techniques from simple comparison to regression analysis or conditional demand analysis.	Energy management program affecting many systems in a building. Utility meters measure energy use for 12-month base year and throughout post-retrofit period.
Option D. Calibrated Simulation Savings are determined through simulation of the energy use of components or the whole facility. Simulation routines must be demonstrated to adequately model actual energy performance measured in the facility. This option usually requires considerable skill in calibrated simulation.	Energy use simulation, calibrated with hourly or monthly utility billing data and/or end-use metering.	Project affecting many systems in a building but where base year data are unavailable. Utility meters measure post-retrofit energy use. Base year energy use is determined by simulation using a model calibrated with post-retrofit utility data.

The M&V findings for MID are discussed in **Section 2.1**, M&V findings for TID are discussed in **Section 2.2**, and M&V findings for Palo Alto are discussed in **Section 2.3**. The M&V savings

[2] See *International Performance Measurement & Verification Protocols*, DOE/GO-102000-1132, October 2000.

are discussed in **Section 2.4**, the database is discussed in **Section 2.5**, and the program baselines are discussed in **Section 2.6**.

2.1 M&V Findings for MID AC Load Control

MID provided an ex ante peak load reduction estimate of 3,000 kW for 3,000 LCR 5000 AC Load Controllers. MID actually installed 3,234 controllers, and customers agreed to have their air conditioners turned off for ten minutes over a 30 minute time period. Therefore, MID can turn off 33 percent of the installed LCR 5000 units on a continuous basis. MID kW savings are based on average savings of 3 kW per LCR 5000 controller (see **Equation 1**). MID assumed no kWh savings for the LCR 5000 AC Load Controllers.

Eq. 1 $$\text{MID Ex Ante Savings} = 3{,}000\ \text{LCR5000} \times \left[\frac{3\ \text{kW}}{\text{LCR5000}}\right] \times 33\% = 3{,}000\ \text{kW}$$

The M&V savings are based on system-wide electrical power field measurements of AC load controllers before, during, and after turning off units during periods of high outdoor temperatures (i.e., greater than 100 degrees Fahrenheit, F). 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. The average measured load reduction is 3,095 kW for both days based on 33 percent of the units turned off continuously (see following equation and **Tables 2.2** and **2.3**). The total measured load reduction was 9,118 kW on July 10, 2002 at approximately 3PM (see **Figure 2.1)** and 9,450 kW on July 11, 2002 at approximately 5PM (see **Figure 2.2**). The load reduction is greater at 5 PM due to more AC systems being on. Savings are calculated using **Equation 2**.

Eq. 2 $$\breve{Y}_{\text{MID}} = \frac{\left(\overline{\text{KW}}_{\text{Normal}} - \overline{\text{KW}}_{\text{LCR5000}}\right)_{7-10-02} + \left(\overline{\text{KW}}_{\text{Normal}} - \overline{\text{KW}}_{\text{LCR5000}}\right)_{7-11-02}}{2} \times 33\%$$
$$= \frac{(590{,}375 - 581{,}257)_{7-10-02} + (587{,}405 - 577{,}955)_{7-11-02}}{2} \times 33\% = 3{,}095\ \text{kW}$$

Mean savings per AC Load controller are calculated using **Equation 3**.

Eq. 3 $$\bar{y} = \text{Mean savings} = \frac{1}{n}\sum_{j=1}^{n} y_j = \frac{1}{3{,}234\ \text{Units}} \times 3{,}095\ \text{kW} = 0.957\ \text{kW}$$

The standard deviation, s, of the mean is calculated using **Equation 4**.

Eq. 4 $$s = \text{Standard Deviation} = \sqrt{\frac{\sum_{j=1}^{n}\left(y_j - \bar{y}\right)^2}{n-1}} = 0.305\ \text{kW/Unit}$$

The confidence interval for the mean savings is calculated using **Equation 5**.

Eq. 5 $$\text{Confidence Interval} = \bar{y} \pm t\,\frac{s}{\sqrt{n}} = 0.957\ \text{kW} \pm 0.010\ \text{kW}$$

Where,

t = The value of the normal deviate corresponding to the desired confidence probability of 1.645 at the 90 percent confidence level.

The MID program savings are 3,095 kW ± 39 kW at the 90 percent confidence level. The expected lifetime for the LCR 5000 units is 15 years.

Table 2.2 Measured kW Savings for the LCR 5000 Load Controllers on 7-10-02

Date/Time	System Load (kW)	Outdoor Temp. (F)	Notes
7/10/2002 14:57	586,650	104.07	Normal Operation
7/10/2002 14:58	586,430	104.42	Normal Operation
7/10/2002 14:59	585,528	104.51	Normal Operation
7/10/2002 15:00	586,057	104.51	Paging Signal Sent to Turn off 3,234 LCR 5000 Units
7/10/2002 15:01	582,964	104.60	Processing Signal
7/10/2002 15:02	581,341	104.51	Processing Signal
7/10/2002 15:03	581,801	104.51	LCR 5000 Units Turned Off
7/10/2002 15:04	579,735	104.51	LCR 5000 Units Turned Off
7/10/2002 15:05	580,134	104.51	LCR 5000 Units Turned Off
7/10/2002 15:06	581,124	104.77	LCR 5000 Units Turned Off
7/10/2002 15:07	581,212	104.95	LCR 5000 Units Turned Off
7/10/2002 15:08	581,595	104.95	LCR 5000 Units Turned Off
7/10/2002 15:09	581,793	104.95	LCR 5000 Units Turned Off
7/10/2002 15:10	582,330	104.42	LCR 5000 Units Turned Off
7/10/2002 15:11	581,501	104.42	LCR 5000 Units Turned Off
7/10/2002 15:12	582,930	104.42	LCR 5000 Units Turned Off
7/10/2002 15:13	586,421	104.42	Transition to Normal Operation
7/10/2002 15:14	590,779	104.69	Transition to Normal Operation
7/10/2002 15:15	592,633	104.69	Transition to Normal Operation
7/10/2002 15:16	591,095	104.69	Normal Operation
7/10/2002 15:17	592,973	104.69	Normal Operation
7/10/2002 15:18	593,673	104.69	Normal Operation
7/10/2002 15:19	593,783	104.86	Normal Operation
7/10/2002 15:20	581,498	104.69	Normal Operation

Figure 2.1 MID LCR 5000 AC Load Control versus Temperature (7-10-2002)

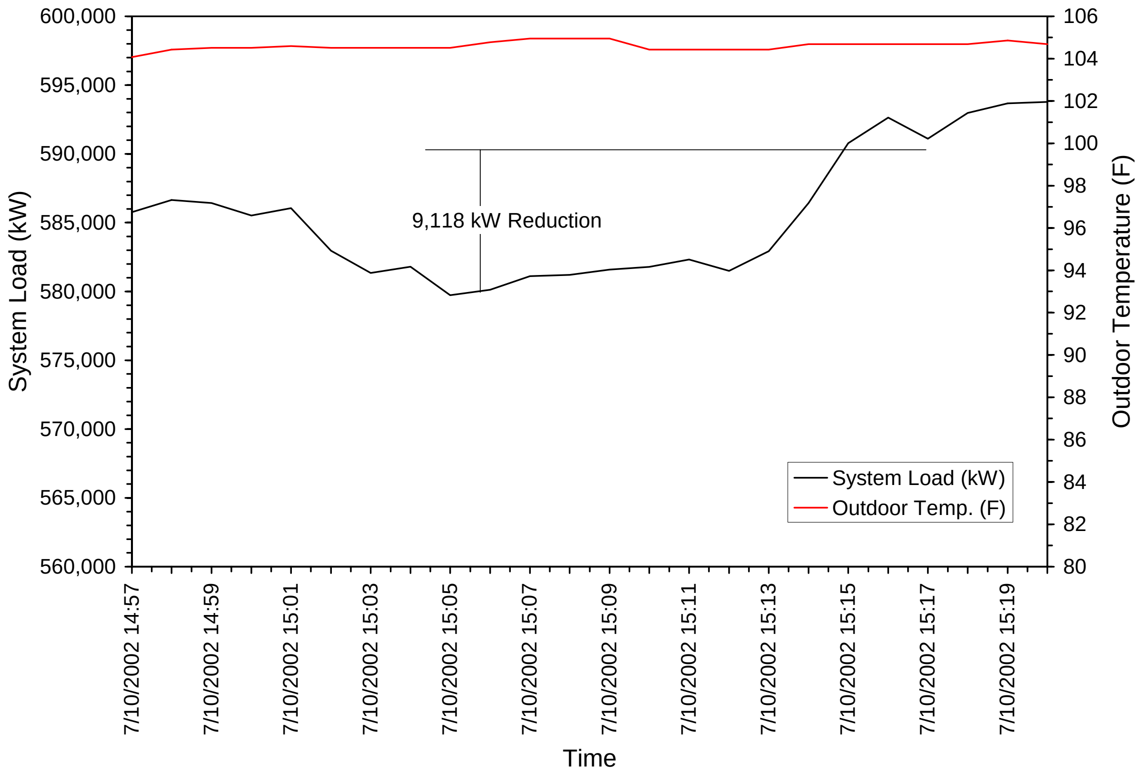
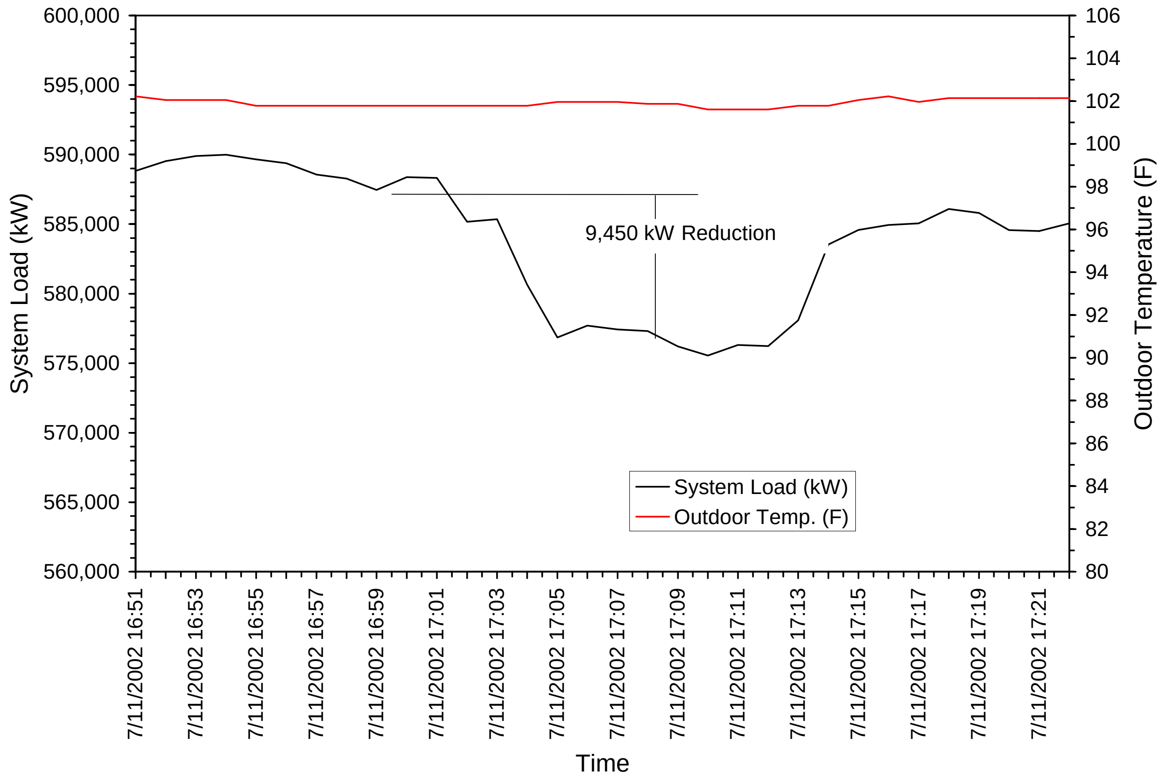


Table 2.3 Measured kW Savings for the LCR 5000 Load Controllers on 7-11-02

Date/Time	System Load (kW)	Outdoor Temp. (F)	Notes
7/11/2002 16:51	588,835	102.22	Normal Operation
7/11/2002 16:52	589,518	102.05	Normal Operation
7/11/2002 16:53	589,906	102.05	Normal Operation
7/11/2002 16:54	589,996	102.05	Normal Operation
7/11/2002 16:55	589,659	101.79	Normal Operation
7/11/2002 16:56	589,373	101.79	Normal Operation
7/11/2002 16:57	588,557	101.79	Normal Operation
7/11/2002 16:58	588,267	101.79	Normal Operation
7/11/2002 16:59	587,452	101.79	Normal Operation
7/11/2002 17:00	588,372	101.79	Paging Signal Sent to Turn off 3,234 LCR 5000 Units
7/11/2002 17:01	588,316	101.79	Processing Signal
7/11/2002 17:02	585,166	101.79	Processing Signal
7/11/2002 17:03	585,355	101.79	LCR 5000 Units Turned Off
7/11/2002 17:04	580,639	101.79	LCR 5000 Units Turned Off
7/11/2002 17:05	576,843	101.96	LCR 5000 Units Turned Off
7/11/2002 17:06	577,705	101.96	LCR 5000 Units Turned Off
7/11/2002 17:07	577,425	101.96	LCR 5000 Units Turned Off
7/11/2002 17:08	577,319	101.87	LCR 5000 Units Turned Off
7/11/2002 17:09	576,193	101.87	LCR 5000 Units Turned Off
7/11/2002 17:10	575,545	101.61	LCR 5000 Units Turned Off
7/11/2002 17:11	576,299	101.61	LCR 5000 Units Turned Off
7/11/2002 17:12	576,234	101.61	LCR 5000 Units Turned Off
7/11/2002 17:13	578,076	101.79	Transition to Normal Operation
7/11/2002 17:14	583,523	101.79	Transition to Normal Operation
7/11/2002 17:15	584,587	102.05	Transition to Normal Operation
7/11/2002 17:16	584,926	102.22	Transition to Normal Operation
7/11/2002 17:17	585,047	101.96	Normal Operation
7/11/2002 17:18	586,083	102.14	Normal Operation
7/11/2002 17:19	585,802	102.14	Normal Operation
7/11/2002 17:20	584,566	102.14	Normal Operation
7/11/2002 17:21	584,487	102.14	Normal Operation
7/11/2002 17:22	585,048	102.14	Normal Operation

Figure 2.2 MID LCR 5000 AC Load Control versus Temperature (7-11-2002)



2.2 M&V Findings for TID AC Load Control

TID provided an ex ante peak load reduction estimate of 1,500 kW for 1,500 units. It was not possible to perform field measurements for TID since the TID program installation was not completed until after the cooling season was over. TID M&V savings are extrapolated from MID M&V savings of 0.957 kW/unit times the number of units installed according to **Equation 6**.[3]

Eq. 6 $$\hat{Y}_{TID} = 1{,}502 \text{ Units}_{TID} \times 0.957 \text{ kW/Unit} = 1{,}437 \text{ kW}$$

The TID program savings are 1,437 kW ± 13 kW at the 90 percent confidence level. TID assumed no kWh or therm savings for the AC load control programmable thermostats even though TID chose these controllers to provide energy savings in addition to load control. The M&V study takes no credit for additional savings since this is beyond the scope of the study.

[3] The assumed MID savings of 0.957 kW/unit is close to the M&V savings of 0.94 kW/unit found by KEMA-XENERGY in an M&V study of AC load control programmable thermostats installed in the San Diego Gas and Electric Company (SDG&E) service area. The KEMA-XENERGY study found savings of 0.94 kW/unit for an 8F reset temperature for hour 16 with an outdoor temperature of 95F (see Table A-8, page A-8, *2002 Smart Thermostat Program Evaluation*, prepared for San Diego Gas and Electric Company, prepared by KEMA-XENERGY, February 2003). The MID savings are for an average outdoor temperature of 103.5F. Using the MID savings as a proxy for TID is reasonable, given that TID and MID have similar weather conditions and each program uses similar control strategies (i.e., unit cycled off as opposed to an 8F reset).

2.3 M&V Findings for Palo Alto C&I Load Curtailment

City of Palo Alto provided an ex ante peak load reduction estimate of 115 kW for the following three C&I sites.

1. City Hall load curtailment of 4 kW from 97 2-lamp T8F32 fluorescent fixtures with electronic ballasts.
2. Main Library load curtailment of 15 kW from a 30-ton roof-top air conditioner.
3. Water Quality Control Plant load curtailment of 96 kW from three sets of recirculation and discharge pumps. Two sets run at any time with one set in standby. Each recirculation pump motor is rated at 100 horsepower and each discharge pump motor is rated at 30 horsepower.

The M&V kW savings for the City Hall load curtailment are calculated using **Equation 7**.

Eq. 7 $$\text{kW Savings}_k = \sum_{k=1}^{n} \text{Quantity}_k \times \left[\text{kW}_{pre} - \text{kW}_{post}\right]_k$$

Where,

kW Savings_k = kW savings for site "k."

Quantity = Quantity of fixtures.

kW_{pre} = Pre-installation kW use per fixture.

kW_{post} = Post-installation kW use per fixture.

The lighting fixture kW use per fixture was verified with field measurements at the site (see NCPA C&I Lighting M&V Final Report). The M&V estimate from the City Hall load curtailment project is 5.044 ± 0.5 kW as shown in **Table 2.4**.

Table 2.4 Palo Alto City Hall Load Curtailment

Pre-Retrofit	Qty	W/fix	kW	Post-Retrofit	Qty	W/fix	kW	kW Savings
T8F32-2 Lamp Fixtures No Curtailment	97	52.0	5.044	T8F32-2 Lamp Fixture Load Curtailment	97	0	0	5.044

The Palo Alto Main Library 30-ton RTU air conditioner load curtailment project was completed after the cooling season. Therefore, M&V savings are extrapolated from field measurements of a 25-ton roof top unit (RTU) air conditioner measured in Modesto during the summer of 2002 as shown in **Figure 2.3**.[4] Extrapolated kW values for the 30-ton RTU are based on **Equation 8**.

[4] Field measurements of the 25-ton RTU were made in Modesto on days when maximum outdoor temperatures ranged from 86°F to 96°F. These outdoor temperatures are similar to the 93°F cooling design condition for San Jose (nearest site to Palo Alto) from the *2001 ASHRAE Fundamentals Handbook*, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1791 Tullie Circle N.E., Atlanta, GA 30329.

Eq. 8 $$kW_{30-ton} = kW_{25-ton} \times \frac{30}{25}$$

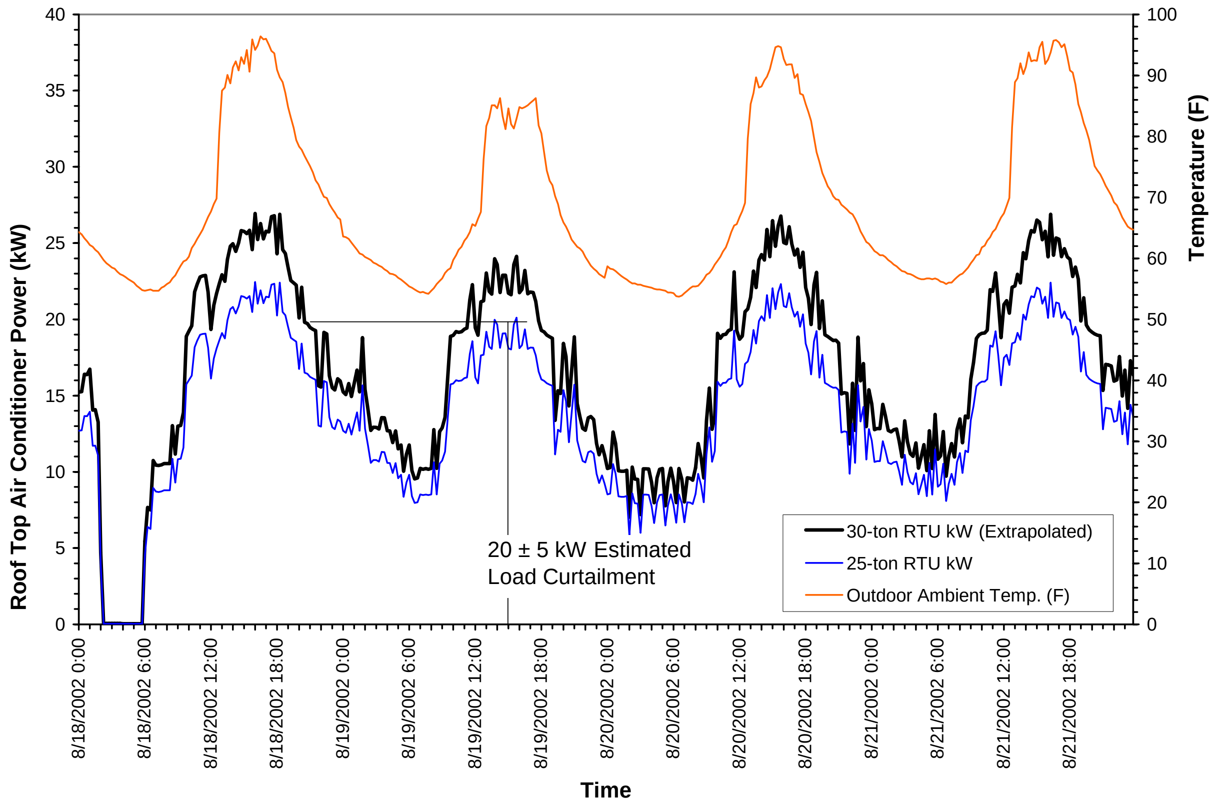
Where,

kW_{25-ton} = kW measurement for the 25-ton unit.

kW_{30-ton} = Extrapolated kW for the 30-ton unit.

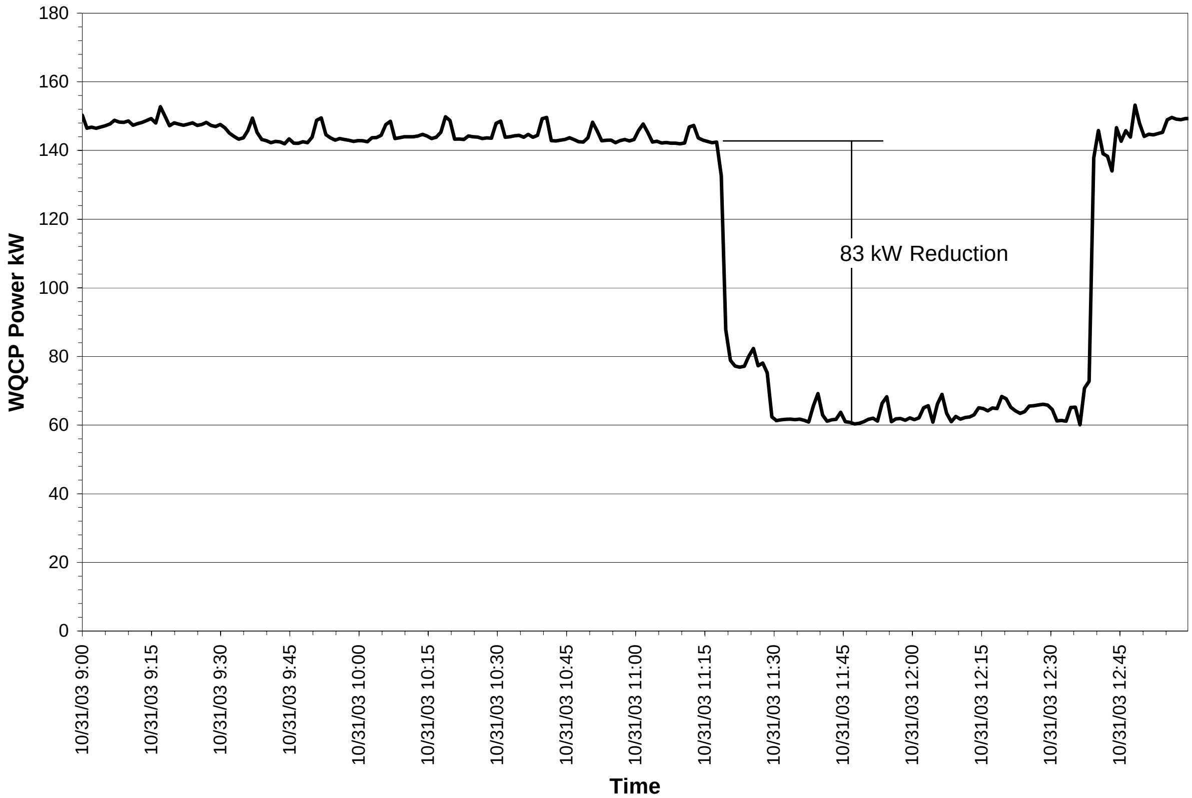
Based on the extrapolated curve, the M&V estimate for the 30-ton RTU load curtailment project is 20 ± 5 kW as shown in **Figure 2.3**.

Figure 2.3 Roof Top Air Conditioner Load Curtailment



The M&V kW savings for the Palo Alto Water Quality Control Plant load curtailment are based on SCADA field measurements from the site made in October 2003 as shown in **Figure 2.4**. The M&V estimate for the WQCP load curtailment project is 83 ± 1.4 kW as shown in **Figure 2.4**.

Figure 2.4 City of Palo Alto Water Quality Control Plant Load Curtailment



Palo Alto implemented load curtailment measures at three sites controlling a quantity of 97 lighting fixtures, 1 roof-top air conditioner, and 3 pumps. The Palo Alto load curtailment program ex ante savings are 115 kW and the ex post savings are 108 ± 6.9 kW as shown in **Table 2.5**.

Table 2.5 Summary of M&V Results for Palo Alto Load Curtailment Program

NCPA Utility	Qty	Ex Ante Program Savings kWh/yr	Ex Ante Program Savings kW	M&V Gross Program Savings kWh/yr	M&V Gross Program Savings kW	Net-to-Gross Ratio	M&V Net Program Savings kWh/yr	M&V Net Program Savings kW	Net Realization Rate Relative to Planning kWh/yr	Net Realization Rate Relative to Planning kW
City Hall	97	n/a	4	n/a	5	n/a	n/a	5	n/a	1.25
Library	1	n/a	15	n/a	20	n/a	n/a	20	n/a	1.33
WQCP	3	n/a	96	n/a	83	n/a	n/a	83	n/a	0.86
Total	**101**	n/a	**115**	n/a	**108**	n/a	n/a	**108**	n/a	**0.94**

3. Participant Survey Results

Participant surveys were not conducted for load control programs since customers are not able to participate without a controller installed on their air conditioner or C&I equipment.

4. M&V Methodology

The M&V methodology for the field metering tasks are discussed above in **Section 2**. The M&V methodology for sample design, database tracking, and baseline are discussed below.

4.1 Sample Design and Statistical Analysis

Statistical survey sampling methods were used to select a sample of customers or projects from each program population in order to evaluate load impacts.[5] Selecting participants for the sample was guided by the statistical sampling plan as well as input from NCPA utilities. Statistical analysis methods were used to analyze the data and extrapolate mean savings estimates from the sample sites to the population of all program participants and to evaluate the statistical precision of the results. Considering each NCPA utility program within a program category as a stratum, the sample mean within a program was calculated using **Equation 9**.

Eq. 9 Mean Savings $= \bar{y}_h = \frac{1}{N_h} \sum_{k=1}^{n} y_k$

Where,

$\bar{y}_h =$ M&V mean kW or kWh savings for stratum "h."

$N_h =$ Number of measures or sites in stratum "h."

$y_k =$ M&V kW or kWh savings estimate for measure "k."

The mean savings for each program category is based on the sample mean savings estimate across NCPA utility programs strata in the program category. The program category sample mean savings were calculated using **Equation 10**.

Eq. 10 Program Category Sample Mean $= \bar{y}_p = \sum_{h=1}^{L} W_h \bar{y}_h$

Where,

$\bar{y}_p =$ Program category sample mean savings estimate.

$W_h = \frac{N_h}{N_p} =$ Weighting factor across all strata.

$N_p =$ Total number of measures across all strata in program category.

[5] Cochran, William G. *Sampling Techniques*. New York: John Wiley & Sons, 1977, Kish, Leslie. *Survey Sampling*. New York: John Wiley & Sons, 1965. Thompson, Steven K. *Sampling*. New York: John Wiley & Sons, 1992.

The variance, s_h^2, of the sample mean for a utility program stratum within a program category was calculated using **Equation 11**.

Eq. 11
$$s_h^2 = \frac{\sum_{k=1}^{n}\left(y_k - \bar{y}_h\right)^2}{N_h - 1}$$

The coefficient of variation (Cv) provides a relative measure of the sample size required to satisfy the 90/10 criteria (or 80/20 criteria) for estimating the mean of the population. The sample Cv for the utility program stratum was calculated using **Equation 12**.

Eq. 12
$$\text{Sample Coefficient of Variation} = Cv_h = \frac{s_h}{\bar{y}_h}$$

Where,

$s_h = \sqrt{s_h^2}$ = Standard deviation of the sample mean savings in stratum h.

The sample size necessary to obtain a desired level of relative precision for the utility program stratum mean savings estimate was calculated using **Equation 13**.

Eq. 13
$$\text{Utility Program Stratum Sample Size} = n_h = \frac{t_o Cv_h^2}{r_h^2}$$

Where,

n_h = Sample size of the utility program stratum.

r_h = Desired relative precision for the utility program stratum.

For small populations, the sample size was corrected using the finite population correction (FPC) equation as follows.[6]

Eq. 14
$$\text{FPC Sample Size} = n_{FPC\,h} = \frac{n_h}{1 + \left(n_h - 1\right)/N_h}$$

Where,

$n_{FPC\,h}$ = Sample size for stratum with finite population correction.

The utility program stratum error bound of $\bar{y}_h$ as an estimator of the mean value at the 90% level of confidence was calculated using **Equation 15**.

Eq. 15
$$\text{Stratum Error Bound} = Eb\left(\bar{y}_h\right) = t_o \frac{s_h}{\sqrt{n_h}}$$

Where,

t_o = 1.645 at 90 percent level of confidence (1.28 at 80 percent confidence).

[6] Cochran, William G. *Sampling Techniques*. New York: John Wiley & Sons, 1977, Kish, Leslie. *Survey Sampling*. New York: John Wiley & Sons, 1965. Thompson, Steven K. *Sampling*. New York: John Wiley & Sons, 1992.

n_h = Number of units in sample in stratum "h."

An unbiased estimate of the program category variance was calculated using **Equation 16**.

Eq. 16 $$s_p^2 = \sum_{h=1}^{L} \frac{W_h^2 s_h^2}{n_h} - \sum_{h=1}^{L} \frac{W_h s_h^2}{N_p}$$

Where,

s_p^2 = Variance of the program category mean savings estimate, $\bar{y}_p$.

The Cv for the program category was calculated using **Equation 17**.

Eq. 17 $$\text{Program Category Coefficient of Variation} = Cv_p = \frac{s_p}{\bar{y}_p}$$

Where,

s_p = $\sqrt{s_p^2}$ = Standard deviation of the mean savings in the program category.

Statistical analysis was used to extrapolate M&V ex post kW and kWh savings at the sample level for a utility program (stratum) to the program category level and finally for the NCPA SB5X portfolio. This step included an assessment of the error bounds and relative precision of program-level kW and kWh savings as discussed above. The program category savings estimate was calculated as the sum of the number of measures for the utility program stratum times the M&V ex post sample mean savings estimate as shown in **Equation 18**.

Eq. 18 $$\hat{Y}_p = \text{M\&V Gross Ex Post Program Category Savings} = \sum_{h=1}^{L} \left[N_h \times \bar{y}_h \right]$$

Where,

$\hat{Y}_p$ = M&V gross ex post program category savings (kW or kWh).

The M&V Average Gross Realization Rates (AGRR) for kW and kWh savings were calculated using **Equation 19**.

Eq. 19 $$AGRR_h = \frac{\hat{Y}_h}{\hat{X}_h}$$

Where,

$AGRR_h$ = Average Gross Realization Rate for kW or kWh savings defined as the sum of M&V kW savings for measures in program stratum "h" divided by the ex ante kW savings.

$\hat{Y}_h$ = Ex post program stratum "h" savings (kW or kWh).

$\hat{X}_h$ = Ex ante program stratum "h" savings (kW or kWh).

The error bound for the program category is the square root of the sum of the squared error bounds for each of the utility program stratums and was calculated using **Equation 20**.[7]

Eq. 20 $$\hat{E}b(\bar{y}_p) = \sqrt{\sum_{i=1}^{m}\left[Eb(\bar{y}_h)\right]^2}$$

The AGRR is combined with the Net-to-Gross Ratio (NTGR) to develop the Net Realization Rate (NRR) relative to planning using **Equation 21**.

Eq. 21 $$NRR_h = NTGR_h \times AGRR_h$$

Where,

NRR_h = Net Realization Rate for kW or kWh savings in program stratum "h."

$NTGR_h$ = Net to Gross Ratio defined as the number of units that would not have been installed without the program divided by the total number of units installed through the program (kW or kWh).

Some statistics were calculated using other equations.[8]

A census was performed for the MID AC load controllers and the Palo Alto load curtailment programs. The M&V results for MID AC load controllers were extrapolated to TID AC load controllers since both utilities deployed similar strategies and measures in the same geographic climate zone. 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. For Palo Alto, the load impact measurements for the Water Quality Control Plant were made by curtailing two out of three sets of recirculation and discharge pumps. Two sets run at any time with one set in standby. The other Palo Alto load curtailment projects were evaluated using detailed engineering estimates or extrapolated from field measurements of similar equipment. The weighted sample coefficient of variation for kW savings is 0.32. The Cv value is relatively small because 68.9 percent of program savings are based on direct field measurements of load controllers during actual operation. The M&V on-site survey sample of 3,237 participants provided relative precision of ±1.3% for MW for the program category.

---

[7] This result is a consequence of (a) the fact that the standard deviation of the difference between two statistically independent random variables (e.g., the standard savings of each program) is the square root of the sum of the squares of the standard deviations of each of the random variables, and (b) the error bound at the 90 percent level of confidence is 1.645 times the standard deviation. See Hall, N., Barata, S., Chernick, P., Jacobs, P., Keating, K., Kushler, M., Migdal, L., Nadel, S., Prahl, R., Reed, J., Vine, E., Waterbury, S., Wright, R. 2004. *The California Evaluation Framework*, Chapter 12: Uncertainty, pp. 280-306. San Francisco, Calif.: California Public Utilities Commission.

[8] Hall, N., Barata, S., Chernick, P., Jacobs, P., Keating, K., Kushler, M., Migdal, L., Nadel, S., Prahl, R., Reed, J., Vine, E., Waterbury, S., Wright, R. 2004. *The California Evaluation Framework*, San Francisco, Calif.: California Public Utilities Commission. Cochran, William G. *Sampling Techniques*. New York: John Wiley & Sons, 1977, Kish, Leslie. *Survey Sampling*. New York: John Wiley & Sons, 1965. Thompson, Steven K. *Sampling*. New York: John Wiley & Sons, 1992.

4.2 Database

Data for the Load Control programs are tracked and archived in the NCPA Tracking Database. The database includes customer name, customer address, city, ZIP code, account number, phone number, serial number, installation date, make/model, age, capacity (tons), compressor amperage, and fan amperage. The data was delivered electronically by utility program staff and entered into the database after the programs were completed.

4.3 Baseline

The baseline is the same as the measure savings since the AC units or C&I loads are either on or off. Total system baseline measurements were made before, during, and after turning off the units. For MID, the LCR 5000 units were measured during periods of high outdoor temperatures (i.e., greater than 100 degrees Fahrenheit, F). Baseline measurements were made on July 10, 2002, when outdoor temperatures were approximately 105 F and on July 11, 2002, when outdoor temperatures were approximately 102 F. The average baseline AC usage was 0.957 kW/unit. This measured value includes the diversity factor (i.e., probability of units being on). The baseline for the City of Palo Alto C&I load curtailment program was based on field measurements of the affected equipment or similar equipment (i.e., the 30-ton RTU).

4.4 Program Evaluation Savings Estimates

Gross and net program evaluation savings (i.e., kW) are based on sample mean measurements of 3,234 LCR 5000 AC load controllers and three C&I load curtailment projects. The gross and net savings estimates obtained at the participant level are extrapolated to the population of program participants using the methods described above. The M&V results are summarized in **Table 4.1**.

Table 4.1 Summary of M&V Results for NCPA SB5X Load Control

NCPA Utility	Sites	Ex Ante Program Savings kWh/yr	Ex Ante Program Savings kW	M&V Gross Program Savings kWh/yr	M&V Gross Program Savings kW	Net-to-Gross Ratio	M&V Net Program Savings kWh/yr	M&V Net Program Savings kW	Net Realization Rate Relative to Planning kWh/yr	Net Realization Rate Relative to Planning 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**

The total ex ante savings for the MID and TID AC load control programs and Palo Alto load curtailment program are 4,615 kW. The net to gross ratio is not applicable since these programs would not have been implemented without SB5X funding. Therefore, the gross and net program savings are 4,640 kW ± 58.9 kW at the 90 percent confidence level. The net realization rate for kW savings is 1.01. The M&V savings are based on SCADA field measurements of the total system load before, during, and after turning off units. For MID, the LCR 5000 units were turned off during periods of high outdoor temperatures (i.e., greater than 100 degrees Fahrenheit, F). The M&V savings for TID are extrapolated from M&V savings for MID based on the number of units installed since the TID program installation was not completed until after the cooling season was over. The M&V savings for City of Palo Alto were based on SCADA field measurements of affected equipment or similar equipment. The net-to-gross ratio doesn't apply to load control programs.