Measurement & Verification Load Impact Study for NCPA SB5X LED Traffic Signals

Study ID: NCP0001.06

FINAL REPORT

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June 25, 2005

Funded with California Senate Bill 5X Funds

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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. Traffic signal field measurements and traffic signal billing data analysis were made possible with cooperation from the following individuals and utilities: Peter Govea, Modesto Irrigation District; Joyce Kinnear, Silicon Valley Power; Mary Kammer, City of Lompoc; and Virginia Waik, City of Palo Alto Utilities. Robert Mowris, P.E., and Kathleen Carlson, Esq., managed the study. Robert Mowris developed the EM&V plans, database, and survey instruments. Anne Blankenship, B.S., performed the participant surveys. Robert Mowris performed the field measurements, engineering and statistical analyses, and wrote the report with assistance from Ean Jones, B.S., Rachel Noack, B.S., and Anne Blankenship. Peter Pressley, Ph.D., developed the NCPA M&V tracking database and Rachel Noack managed and revised the database. 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 Light Emitting Diode (LED) Traffic Signals Programs implemented by Lompoc, Modesto Irrigation District (MID), 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 administered by NCPA.

The M&V results are summarized in **Table 1.1**. The ex ante program savings are 2,700,355 kWh/yr and 308 kW. Total gross M&V program savings are 2,419,003 ± 22,919 kWh/yr and 276 ± 3.3 kW. Total M&V net program savings are 2,126,207 ± 20,102 kWh/yr and 242.8 kW ± 3 kW at the 90 percent confidence level. The effective useful life for LED traffic signals is 16 years.[1] Therefore, the net ex post lifecycle savings are 34,019,304 ± 321,629 kWh. The net realization rates are 0.79 for kWh and kW savings. The M&V savings are based on detailed on-site engineering analyses for a random sample of 18 traffic signal intersections encompassing roughly 1,074 traffic signal measurements. Pre- and post-retrofit billing data was available for 17 intersections and 890 signals and this data along with the on-site measurements were used to develop M&V savings. The on-site audits included verification of all installed measures that received incentives as well as true RMS power measurements of pre- and post-installation fixtures. Respective traffic engineering departments provided operational hour data from their traffic signal controllers and this data was verified with power measurements. The net-to-gross ratios are based on decision maker surveys (see **Section 3**).

Table 1.1 Summary of M&V Results for NCPA SB5X LED Traffic Signals

NCPA Utility	Qty.	Ex Ante Savings kWh/yr	Ex Ante Savings kW	M&V Gross Ex Post Savings kWh/yr	M&V Gross Ex Post Savings kW	Net-to-Gross Ratio	M&V Net Ex Post Savings kWh/yr	M&V Net Ex Post Savings kW	Net Realization Rate Relative to Planning kWh/yr	Net Realization Rate Relative to Planning 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

Section 2 presents the M&V approach and results for the site visits and billing data for 42 signals. **Section 3** presents participant survey results and the methodology used to develop net-to-gross ratios. **Section 4** presents the M&V methodology used for the sample design, database, baseline, impact analysis, and program evaluation savings estimates. **Appendix A** provides the LED Traffic Signal Decision-Maker Survey.

[1] See *Energy Efficiency Policy Manual*, Chapter 4, pages 21-22, prepared by the California Public Utilities Commission, 2001.

2. M&V Approach and Results for Miscellaneous

The measurement and verification approach for the study was based on the *International Performance Measurement & Verification Protocols* (IPMVP) defined in **Table 2.1**.[2] Ex post energy and peak demand savings were determined using IPMVP Option A (i.e., partially measured retrofit isolation), Option B (i.e., retrofit isolation), and IPMVP Option C (whole site billing regression analysis). Billing data, sub-metered data, engineering analyses, and previously published M&V studies were used to develop baseline energy use and gross energy and peak demand savings. A random sample of 42 signals where selected from the program tracking database for metering. True RMS electric power measurements were performed for a representative sample of incandescent and LED traffic signal lamps. Respective traffic engineering departments provided operational hour data from their traffic signal controllers. The overall M&V methodology is discussed in **Section 2.1**, M&V equations are discussed in **Section 2.2**, and findings of the M&V results are discussed in **Section 2.3**.

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	Electricity use is measured with kW meters. Hours of operation are measured with motor 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.	Program affecting many systems at sites or buildings. 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 systems at a site where pre or post year data are unavailable. Utility billing meters measure pre- or post-retrofit energy use. Savings are determined by simulation using a model calibrated with utility billing data.

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

2.1 M&V Methodology

The following M&V methodology was used to determine savings for each LED Traffic Signals Program.

1. Randomly select M&V sites from the utility program tracking database.
2. Review rebate applications for selected sites to determine M&V plan for each site.
3. Perform site visits.
   - Verify pre-retrofit incandescent traffic signal power and hours of operation to develop the M&V baseline of energy and peak demand (i.e., kWh/yr and kW).
   - Verify post-retrofit equipment including proper installation of all LED traffic signals, and controls that received rebates including make, model, fixture counts, and power use.
   - Collect data for representative traffic signals using billing data, RMS digital power meters, data loggers, and interviews with the traffic engineering representatives. Groups of like fixtures were measured at the signal control box or individually to determine true RMS watts per fixture. Measured values were compared to reference values to ensure accurate engineering analysis of energy and peak demand savings.
4. Perform decision maker surveys to evaluate net-to-gross ratios.
5. Perform the M&V engineering analyses based on information collected during the on-site surveys in order to evaluate energy and peak demand program savings.

M&V site work was performed from February 2002 through May 2003 at sites in the Lompoc and Santa Clara utility service areas. The M&V savings for MID were calculated based on measurements obtained from site visits in Lompoc and Santa Clara.

2.2 M&V Algorithms for Estimating kW and kWh Savings

M&V algorithms for estimating kW and kWh savings for each site in the random sample are based on the verified quantity of installed measures, pre- and post-installation fixture wattages and hours of operation (obtained from Caltrans or traffic engineering personnel). Traffic signal hours of operation from CalTrans are shown in **Table 2.2**.[3] Power measurements of incandescent and LED traffic signals are shown in **Table 2.3**.

Table 2.2 CalTrans Traffic Signal Estimated Operational Hours

Signal Type	Hours/yr
12" LED Red	4746
8" LED Red	4746
12" LED Red Arrow	7771
12" LED Green	3751
8" LED Green	3751
12" LED Green Arrow	726
12" LED Yellow	263
8" LED Yellow	263
12" LED Yellow Arrow	263
Pedestrian Hand/Walking Person Combo	8642

[3] 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. ET1 monitored 160 signals over 29 intersections. *Review of CalTrans-Traflic Signal Duty Cycle Monitoring Results*, Schiller Associates, prepared for PG&E Power Saving Partners Program, lD#95PSP 105 CalTrans - Traffic Signal Retrofit, November 1999.

Table 2.3 Power Measurements of Incandescent and LED Traffic Signals

#	Incandescent Baseline Description	Rated Power (Watts)	Measured Power (Watts)	LED Measure	Rated Power (Watts)	Measured Power (Watts)
1	12" Ball Incandescent Rated 169W	169	149	12" LED Red	11	11
		169	149	12" LED Green	12	12
		169	149	12" LED Yellow	10	10
2a	8" Ball Incandescent Rated 116W	116	107	8" LED Red	8	8
		116	107	8" LED Green	10	10
		116	107	8" LED Yellow	13	13
2b	8" Ball Incandescent Rated 69W	69	64	8" LED Red	8	8
		69	64	8" LED Green	10	10
		69	64	8" LED Yellow	13	13
3a	12" Arrow Incandescent Rated 169W	169	149	12" LED Red Arrow	7.5	7.5
		169	149	12" LED Green Anrow	10	10
		169	149	12" LED Yellow Arrow	10	10
3b	12" Arrow Incandescent Rated 116W	116	107	12" LED Red Arrow	7.5	7.5
		116	107	12" LED Green Arrow	10	10
		116	107	12" LED Yellow Arrow	10	10
4	Pedestrian Incandescent 169W	167	149	LED Ped/Combo	9	9
4	Pedestrian Incandescent 116W	116	107	LED Ped/Combo	9	9

The M&V kW and kWh savings for each site are calculated using **Equations 1** and **2**.

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

Where,

kW Savings_k = kW savings for site "k" in the random sample.

Quantity = Quantity of fixtures.

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

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

Eq. 2 $$\text{kWh Savings}_k = \sum_{j=1}^{m} \text{Quantity} \times \left[\text{kW}_{pre} - \text{kW}_{post}\right] \times \text{hours/year}$$

Where,

kWh Savings_k = kWh savings for site "k" in the random sample.

hours/year = Hours of operation per year per fixture based on traffic engineering or CalTrans traffic signal operational hours (see **Table 2.3**).

The measured power of incandescent traffic signal lamps is 7 to 11 percent less than the rated power (see **Table 2.2** and **Figure 2.1**). The measured power of LED signals is equivalent to the rated power as shown in **Figure 2.2** for an LED signal intersection in Lompoc where 32 signals are on at any given time (i.e., 315W / 32 = 9.84 W/LED signal).[4]

[4] For the Lompoc intersection with all LED signals there are eight 12" red signals (8 x 11W = 88W) plus eight 12" red arrow signals (8 x 7.5 = 60W) plus eight 12" Green signals (8 x 12W = 96W) plus eight pedestrian/combo signals (8 x 9W = 72W) for a total of 316W and this is within 0.4% of the average measured power of 315W.

Figure 2.1 Incandescent Traffic Signal Power Measurements

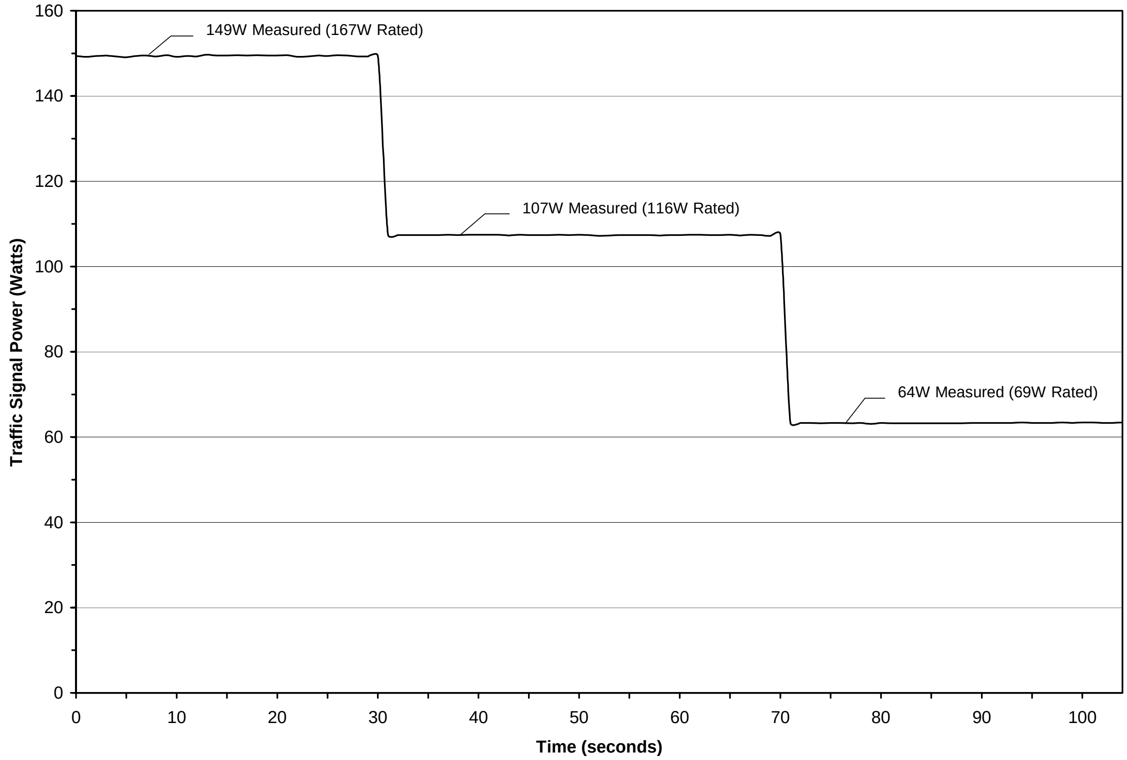
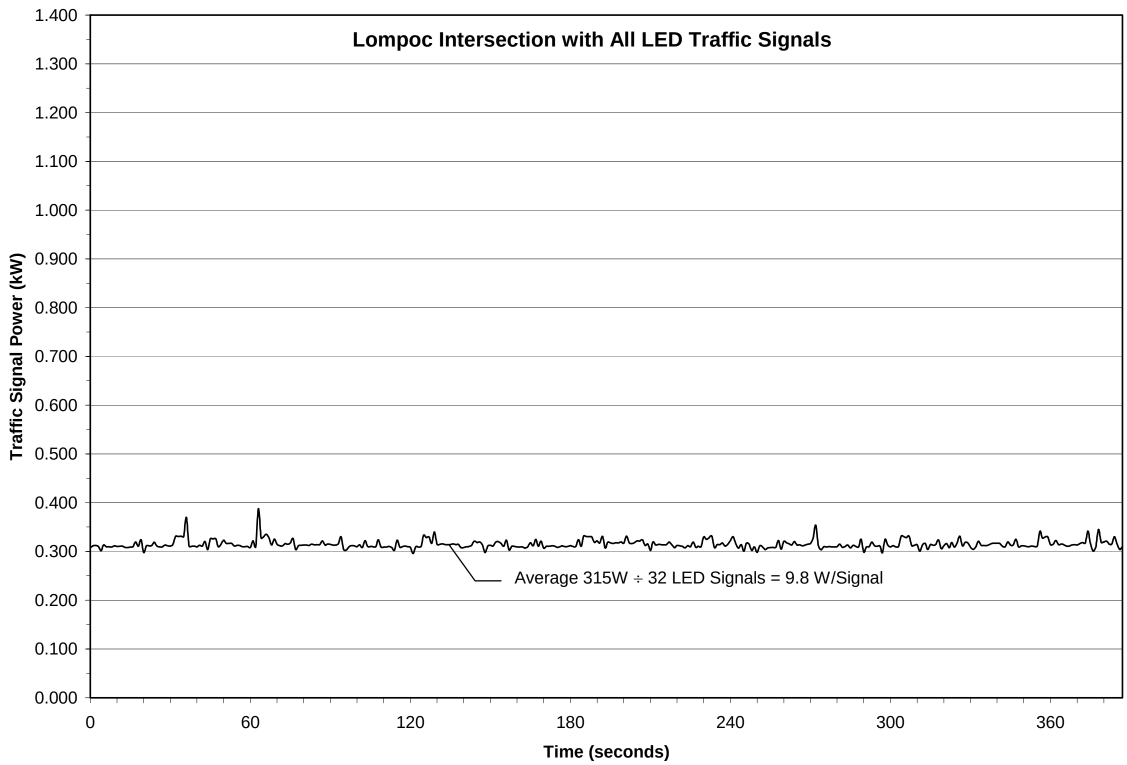
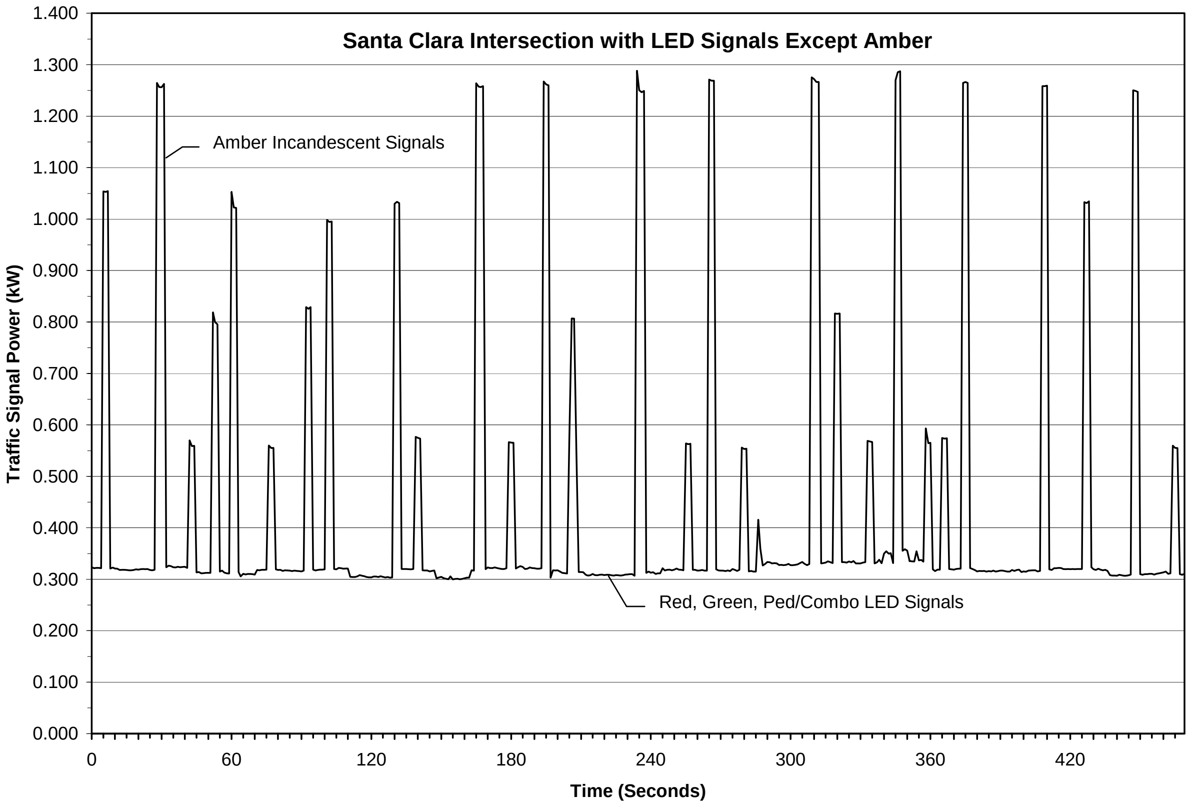


Figure 2.2 Lompoc Intersection with All LED Traffic Signals



Measurements of a Santa Clara intersection with all LED signals except incandescent amber signals shows roughly the same power usage (i.e., 315W) when the red, green, and pedestrian LED signals are operating without the amber signals (see **Figure 2.3**). The power use is two to four times greater for this intersection, when the incandescent amber signals are operating.

Figure 2.3 Santa Clara Intersection with LED Traffic Signals Except Amber



Savings for the M&V sites were summed and compared to ex ante savings to develop Average Gross Realization Rates (AGRR) for kW and kWh savings. The AGRR for kW and kWh savings were calculated using **Equation 3**.

Eq. 3

$$AGRR_h = \frac{\sum_{k=1}^{n} \text{M \& V Sample Savings}_k}{\sum_{k=1}^{n} \text{Ex Ante Sample Savings}_k}$$

Where,

$AGRR_h$ = Average gross realization rate for program stratum "h." Defined as the sum of M&V savings for measures or sites in the random sample divided by ex ante savings for measures or sites in the random sample (kW or kWh).

The AGRR is combined with the Net-to-Gross Ratio (NTGR) to develop the Net Realization Rate (NRR) relative to planning. The net realization rates for kW and kWh savings were calculated using **Equation 4**.

Eq. 4 $NRR_h = NTGR_h \times AGRR_h$

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).

The effective useful lifetime of LED traffic signals is 16 years.[5]

2.3 Findings of the M&V On-Site Audits

Findings of the M&V on-site audits are provided in **Tables 2.4** through **2.7** for the Lompoc, MID, and Santa Clara service areas.

Table 2.4 shows M&V savings versus billing data savings for 17 intersections and 890 LED traffic signals in Lompoc. M&V savings are within 1.2 percent of billing data savings indicating that the M&V calculation methodology is accurate regarding pre- and post-retrofit lamp Wattages and annual operational hours. M&V savings are based on Caltrans operational hours. The Caltrans operational hours provided M&V savings results that were closer to the billing data savings than the hours provided by Lompoc electric utility.

Table 2.5 shows that the M&V gross realization rates for Lompoc are 91 percent. This is due to using CalTrans operational hours and measured incandescent lamp baseline Wattages in the M&V calculations (i.e., 8 to 11 percent lower).

Table 2.6 shows that the M&V gross realization rates for MID are 91 percent. This is due to using CalTrans operation hours in the M&V calculations which are lower than the assumed ex-ante operational hours.[6]

Table 2.7 shows that the M&V gross realization rates for Santa Clara are 88 percent. This is due to using measured incandescent and LED lamp baseline Wattages in the M&V calculations. City of Santa Clara operational hours were verified with traffic engineering as well as measured data.

[5] See *Energy Efficiency Policy Manual*, Chapter 4, pages 21-22, prepared by the California Public Utilities Commission, 2001.

[6] A representative of the City of Modesto Traffic Engineering Division Engineering and Transportation Department verified that the CalTrans operational hours are reasonable and appropriate for Modesto.

Table 2.4 M&V Savings versus Billing Data Savings for 17 Intersections and 890 LED Signals in Lompoc

Signal Inter-section	Meter Number	Major Street	Cross Street	Red LEDs	Amber LEDs	Green LEDs	Red Arrows	Amber Arrow	Green Arrow	Ped-Head Combo	Total LEDs	Billing Data Savings	M&V Savings
1	17052910	Ocean	G	12	12	10	2	2	4	8	50	19,873	20,147
2	17043760	Central	Walmart	8	8	8	4	4	4	8	44	26,338	18,499
3	17161200	H	Longs Ent	10	10	10	4	4	4	8	50	13,252	20,560
4	17161160	Central	O	12	12	12	8	8	8	8	68	23,994	26,099
5	17172170	Central	H	8	8	8	8	8	8	8	56	22,902	21,975
6	17018610	Ocean	South A	10	10	8	2	2	8	8	48	19,191	18,367
7	17144980	Ocean	7th	11	11	11	4	4	4	8	53	19,654	21,591
8	17000930	College	H	10	9	9	5	6	7	8	54	28,243	21,128
9	17084270	Ocean	I	12	12	12	2	2	4	8	52	27,015	21,025
10	17161210	Central	L	12	12	12	8	8	8	8	68	24,055	26,099
11	17118860	H	Barton	10	10	10	4	4	4	6	48	16,467	18,867
12	17081540	H	Mission	10	10	10	4	4	4	6	48	16,929	18,867
13	17155190	Hwy 1	246	11	11	11	6	7	8	6	60	21,115	21,802
14	17172160	H	Pine	11	11	9	2	2	6	6	47	15,417	17,563
15	17019510	Ocean	O	12	12	10	2	2	4	8	50	24,337	20,147
16	17083800	H	Walnut	12	12	10	2	2	4	8	50	18,643	20,147
17	17011720	H	North	8	8	8	4	4	6	6	44	16,868	16,946
Subtotal				179	178	168	71	73	95	126	890	354,292	349,828

Table 2.5 M&V Summary for Lompoc LED Traffic Signals Program

#	Measure Description	Ex-Ante Qty.	Ex-Ante Pre W/fix	Ex-Ante Post W/fix	Ex-Ante Hrs/yr	Ex-Ante kW Savings	Ex-Ante kWh/y Savings	M&V Qty.	M&V Pre W/fix	M&V Post W/fix	M&V Hrs/yr	M&V kW Savings	M&V kWh/y Savings	M&V Gross Realization Rate kW	M&V Gross Realization Rate kWh/y
1	12" LED Red	113	167	10	5168.4	10.467	91,693	113	149	11	4746	8.449	74,009	0.81	0.81
2	8" LED Red	93	116	7	5168.4	5.981	52,392	93	107	8	4746	4.988	43,696	0.83	0.83
3	12" LED Red Arrow	77	167	8	7095.6	9.917	86,871	77	149	7.5	7771	9.665	84,669	0.97	0.97
4	12" LED Green	126	167	10	3328.8	7.517	65,850	126	149	12	3751	7.392	64,750	0.98	0.98
5	8" LED Green	93	116	7	3328.8	3.852	33,744	93	107	10	3751	3.863	33,838	1.00	1.00
6	12" LED Green Arrow	117	167	8	1401.6	2.976	26,074	117	149	10	726	1.348	11,807	0.45	0.45
7	12" LED Yellow	135	167	10	262.8	0.636	5,570	135	149	18	263	0.531	4,651	0.84	0.84
8	8" LED Yellow	93	116	7	262.8	0.304	2,664	93	107	13	263	0.262	2,299	0.86	0.86
9	12" LED Yellow Arrow	83	167	8	262.8	0.396	3,468	83	149	10	263	0.346	3,034	0.87	0.87
10	LED Ped/Combo	144	167	10	7884	20.347	178,241	144	149	9	8642	19.888	174,223	0.98	0.98
Total		1074				62.4	546,568	1074				56.7	496,976	0.91	0.91

Table 2.6 M&V Summary for Modesto Irrigation District LED Traffic Signals Program

#	Measure Description	Ex-Ante Qty.	Ex-Ante Pre W/fix	Ex-Ante Post W/fix	Ex-Ante Hrs/yr	Ex-Ante kW Savings	Ex-Ante kWh/y Savings	M&V Qty.	M&V Pre W/fix	M&V Post W/fix	M&V Hrs/yr	M&V kW Savings	M&V kWh/y Savings	M&V Gross Realization Rate kW	M&V Gross Realization Rate kWh/y
1	12" LED Green	1389	150	12	4,197.5	91.848	804,585	1389	149	12	3,850	83.633	732,628	0.91	0.91
2	8" LED Green	309	69	10	4,197.5	8.736	76,525	309	64	10	3,850	7.333	64,241	0.84	0.84
3	12" LED Green Arrow	411	150	10	730.0	4.795	42,004	411	149	10	726	4.735	41,476	0.99	0.99
Total		2109				105.4	923,114	2109				95.7	838,345	0.91	0.91

Table 2.7 M&V Summary for Santa Clara LED Traffic Signals Program

#	Measure Description	Ex-Ante Qty.	Ex-Ante Pre W/fix	Ex-Ante Post W/fix	Ex-Ante Hrs/yr	Ex-Ante kW Savings	Ex-Ante kWh/y Savings	M&V Qty.	M&V Pre W/fix	M&V Post W/fix	M&V Hrs/yr	M&V kW Savings	M&V kWh/y Savings	M&V Gross Realization Rate kW	M&V Gross Realization Rate kWh/y
1	12" LED Red	489	167	10	5168.4	45.296	396,794	489	149	11	5168.4	39.814	348,774	0.88	0.88
2	8" LED Red	77	116	7	5168.4	4.952	43,378	77	107	8	5168.4	4.498	39,399	0.91	0.91
3	12" LED Red Arrow	108	167	8	7095.6	13.909	121,846	108	149	7.5	7095.6	12.378	108,435	0.89	0.89
4	12" LED Red Flasher	6	167	10	4380	0.471	4,126	6	149	11	4380	0.414	3,627	0.88	0.88
5	12" LED Green	555	167	10	3328.8	33.111	290,055	555	149	12	3328.8	28.893	253,105	0.87	0.87
6	8" LED Green	74	116	7	3328.8	3.065	26,850	74	107	10	3328.8	2.728	23,894	0.89	0.89
7	12" LED Green Arrow	173	167	8	1401.6	4.401	38,554	173	149	10	1401.6	3.848	33,704	0.87	0.87
8	12" LED Yellow Flasher	17	167	10	4380	1.335	11,690	17	149	16	4380	1.131	9,903	0.85	0.85
9	12" LED Yellow Arrow	4	167	8	4380	0.318	2,786	4	149	10	263	0.017	146	0.05	0.05
10	LED Ped/Combo	238	167	10	7884	33.629	294,594	238	149	9	7884	29.988	262,695	n/a	n/a
Total		1741				140.5	1,230,673	1741				123.7	1,083,682	0.88	0.88

3. Participant Survey Results

This study uses participant surveys to estimate the net-to-gross ratios for kWh and peak kW savings. Participant surveys were completed for 3 participants in three NCPA utility service areas, representing a census of all three decision makers.

3.1 Participant Survey Methodology

Participant surveys were used to develop net-to-gross ratios (NTGRs) for calculating net kW and kWh savings. The net-to-gross ratio is used to estimate the fraction of free riders who would have otherwise implemented lighting improvements in the absence of the program. Ten participant survey questions are used to assess net-to-gross ratios as shown in **Table 3.1**. The NTGR score for each completed participant survey is the average score based on answers to questions 2 through 10. No score is assigned to responses of “don’t know”, “refused to answer,” or “other.”

Table 3.1 Net-to-Gross Ratio Participant Survey Questions and Scoring

#	Question	Answer	Score
2	Did you understand the value of the program BEFORE or AFTER you installed the efficiency upgrades?	Before	1
		After	0
3	Did you install the upgrade (i.e., LED signals) BEFORE or AFTER you heard about the incentive program?	Before	0
		After	1
4	On a scale from 0 to 10, with 0 being no influence at all and 10 being very influential, how much influence did the Utility or Rebate have on your decision to install the efficiency upgrades?	0 to 10	0=0, 10=1
5	If the rebates had not been available, how likely is it you would have done exactly the *same* thing. Please use a scale from 0 to 10, with 0 being not at all likely and 10 being very likely.	0 to 10	0=1, 10=0
6	What role did the Utility Program play in your decision to install the upgrades?	1 = Reminded	0.25
		2 = Speeded Up (i.e., early replacement)	0.5
		3 = Showed Benefits Didn’t Know Before	1
		4 = Clarified Benefits	0.75
		5 = No role	0
7	The Utility Program was nice but it was unnecessary to get the efficiency upgrades installed.	0 to 10	0=1, 10=0
8	The Utility Program was a critical factor in installing the efficiency upgrades.	0 to 10	0=0, 10=1
9	We would not have installed the efficiency upgrades without the Utility Program.	0 to 10	0=0, 10=1
10	If you had not received the [rebate or service] from the Utility, would you have installed upgrades?	Within 6 months	0
		< 1 year	0.125
		1 to 2 years	0.25
		2 to 3 years	0.5
		3 to 4 years	0.75
		4 or more years	1
		Never	1

3.2 Findings of the Participant Surveys

Findings of the participant surveys for each program are presented in **Table 3.2**. The weighted average net-to-gross (NTG) ratio is 0.88 based on average participant survey results multiplied times savings for each program divided by total savings for all programs.[7] For comparison, a

[7] Participant survey results represent a census of the decision-makers who participated in the three programs.

similar M&V LED Traffic Signals study conducted in 2000 found 0.828 for the ex-post NTG ratio.[8]

Table 3.2 Findings of Participant Surveys

NCPA Utility	Projects	Completed Surveys	Ex Post Program Savings kWh/yr	Ex Post Program Savings kW	Weighting Factor kWh/yr	Weighting Factor kW	Net-to-Gross Ratio	Weighted Net-to-Gross Ratio
Lompoc	1	1	546,568	62.4	0.218	0.218	0.87	0.189760
MID	1	1	923,114	105.4	0.428	0.428	0.87	0.372630
Santa Clara	1	1	1,230,673	140.5	0.354	0.354	0.89	0.314681
Total	3	3	2,700,355	308	1.000	1.000	0.88	0.88

4. M&V Methodology

The M&V methodology for the on-site audit tasks are discussed above in **Sections 2**. The M&V methodology for sample design, database tracking, baseline, and program evaluation savings estimates 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.[9] 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 5**.

Eq. 5

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

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 6**.

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[8] *Evaluation of Pacific Gas & Electric Company's Pre-1998 Commercial Energy Efficiency Incentives Program Carry-Over for Traffic Signal Technologies*, PG&E Study ID number 404D, prepared by Quantum Consulting, Inc., March 2000. The PG&E study NTG ratio is the sum of (1-FR) plus spillover, where FR is the free-ridership ratio. For this study we did not evaluate spillover, but our NTG ratio is reasonably close to the PG&E study.

[9] 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.

Eq. 6 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.

The variance, s_h^2, of the sample mean for a utility program stratum within a program category was calculated using **Equation 7**.

Eq. 7 $$s_h^2 = \frac{\sum_{k=1}^{n}(y_k - \bar{y}_h)^2}{N_h - 1}$$

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 8**.

Eq. 8 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 9**.

Eq. 9 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.[10]

Eq. 10 FPC Sample Size = $n_{FPC\,h} = \frac{n_h}{1 + (n_h - 1)/N_h}$

Where,

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

[10] 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 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 11**.

Eq. 11 $$\text{Stratum Error Bound} = Eb(\bar{y}_h) = t_o \frac{s_h}{\sqrt{n_h}}$$

Where,

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

n_h = Number of units in sample in stratum h.

An unbiased estimate of the program category variance was calculated using **Equation 12**.

Eq. 12 $$s_p^2 = \sum_{h=1}^{L} \frac{W_h^2 s_h^2}{n_h} - \sum_{h=1}^{L} \frac{W_h s_h^2}{N_p}$$

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 13**.

Eq. 13 $$\text{Program Category Coefficient of Variation} = Cv_p = \frac{s_p}{\bar{y}_p}$$

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 gross M&V ex post program category savings were calculated as the sum of the ex ante program stratum savings times the respective M&V average gross realization rate (AGRR) as shown in **Equation 14**.

Eq. 14 $$\hat{Y}_p = \text{M\&V Ex Post Program Category Savings} = \sum_{h=1}^{L} \left[\hat{X}_h \times AGRR_h\right]$$

Where,

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

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

$AGRR_h$ = M&V average gross realization rate for program stratum "h." Defined as the sum of M&V savings for measures or sites in the random sample divided by ex ante savings for measures or sites in the random sample (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 15**.[11]

Eq. 15 $$\hat{E}b(\bar{y}_p) = \sqrt{\sum_{h=1}^{L} \left[Eb(\bar{y}_h)\right]^2}$$

Some statistics were calculated using other equations.[12]

The weighted sample coefficient of variation (Cv) is 0.21 for kWh savings, the weighted Cv is 0.04 for kW savings. Pre- and post-retrofit lamp power consumption, traffic signal intersection power use, and billing data were used to develop M&V savings. This data was used to develop accurate hours of operation verified from the traffic signal computer controls and CalTrans data. Therefore, the minimum 90/10 sample size for the M&V site visits was less than 12 (based on Equation 7). The M&V on-site audit sample size included 18 signal intersections encompassing roughly 1,074 traffic signal measurements. Pre- and post-retrofit billing data was available for 17 intersections and 890 signals and this data along with the on-site measurements were used to develop M&V savings. The participant survey sample size was a census of 3.[13] These sample sizes exceed the 90/10 confidence level.

4.2 Database

Data for the commercial and industrial lighting programs was tracked and archived in the NCPA Tracking Database. Data for all programs of this type are summarized within the database for M&V sampling and reporting purposes. The source of the tracking system data is based on reports provided by the respective utilities. The database includes general customer information, quantity and type of lighting fixtures, make and model number, and NCPA account number (if available). Tracking data was delivered electronically by utility program staff and entered into the database after the programs were completed.

[11] 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.

[12] 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.

[13] M&V audit sites of traffic signal intersections were randomly selected in the utility service areas of Lompoc and Santa Clara. MID signal intersections were verified and power measurements were made of pre-retrofit lamps. MID post retrofit LED lamp power measurements were based on M&V measurements of the same products from LED manufacturers for the other programs.

4.3 Baseline

The baseline kWh and kW values are based on measured fixture Wattages or reference fixture Wattages. Measurements were made to verify pre-retrofit equipment power and hours of operation to develop the M&V baseline of energy and peak demand (i.e., kWh/yr and kW). Data were collected for representative lighting fixtures using true RMS digital power meters, data loggers, light loggers, interviews, and telephone surveys (i.e., decision maker survey). Groups of like fixtures were measured at the light switch or electrical panel to determine true RMS wattage per fixture. Measured values were compared to reference values to ensure accurate engineering analysis of energy and peak demand savings.

4.4 Program Evaluation Savings Estimates

Gross M&V program evaluation savings (i.e., kWh/yr and kW) are based on the average gross realization rates from the metered data and billing data. Gross M&V savings for each site in the audit are based on the difference between pre- and post-retrofit equipment power and billing data. Gross savings for the sampled sites were used to develop gross realization rates for kW and kWh/yr, and these values were multiplied by the ex ante program savings to develop gross M&V program savings. Net program evaluation savings are based on the participant decision-maker survey results that were analyzed to develop net-to-gross ratios for kWh and kW savings. Methods used to develop net-to-gross ratios are described above in **Section 3**. The gross and net savings estimates obtained at the participant level are extrapolated to the population of program participants using the methods described above in **Section 4**. Gross M&V savings and realization rates for the LED traffic signal programs are provided in **Table 4.1**.

Table 4.1 Gross M&V Savings and Realization Rates LED Traffic Signal Programs

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	AGRR kWh/yr	AGRR kW
Lompoc	1,074	546,568	62.4	496,976	56.7	0.909	0.909
MID	2,109	923,114	105.4	838,345	95.7	0.908	0.908
Santa Clara	1,741	1,230,672	140.5	1,083,682	123.7	0.881	0.881
M&V Total	4,924	2,700,354	308.3	2,419,003	276.1	0.896	0.896

The M&V results are summarized in **Table 4.2**. The ex ante program savings are 2,700,354 kWh/yr and 308 kW. Total gross M&V program savings are 2,419,003 ± 22,919 kWh/yr and 276 ± 3.3 kW. Total M&V net program savings are 2,126,207 ± 20,102 kWh/yr and 242.8 kW ± 3 kW at the 90 percent confidence level. The effective useful life for LED traffic signals is 16 years.[14] Therefore, the net ex post lifecycle savings are 34,019,304 ± 321,629 kWh. The relatively small confidence interval is due to the accuracy of measured pre/post traffic signal lamp power and operational hours. The net realization rates are 0.79 for kWh and kW savings. The M&V savings are based on detailed on-site engineering analyses for a random sample of 18 traffic signal intersections encompassing approximately 1,074 traffic signal measurements. Pre- and post-retrofit billing data was available for 17 intersections and 890 signals and this data

[14] See *Energy Efficiency Policy Manual,* Chapter 4, pages 21-22, prepared by the California Public Utilities Commission, 2001.

along with the on-site measurements were used to develop M&V savings. The on-site audits included verification of all installed measures that received incentives as well as true RMS power measurements of pre- and post-installation fixtures. Respective traffic engineering departments provided operational hour data from their traffic signal controllers and this data was verified with power measurements. The net-to-gross ratios are based on decision maker surveys (**Section 3**).

Table 4.2 Summary of M&V Results for NCPA SB5X LED Traffic Signals

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 MWh/yr	M&V Net Program Savings kW	Net Realization Rate Relative to Planning kWh/yr	Net Realization Rate Relative to Planning 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

Appendix A: NCPA LED Traffic Signals Decision-Maker Survey

Interview Instructions for Decision-Maker Survey

1. Purpose

The purpose of the Decision-Maker Survey is to obtain sufficient information to estimate the Net-to-Gross Ratio (NTGR).

2. Selection of Respondent

The **decision-maker** must be the person who decided to install or implement rebated measures.

3. Two Types of Sites

This survey will be used for two types of sites:

1. **On-Site M&V Only**. Sites that receive an on-site inspection for the M&V evaluation.
2. **Telephone Only**. Sites that only receive a telephone survey.

4. How to Start the Survey

Complete the following steps to start one of these surveys:

1. Review file information for the site (if available).
2. Make sure you understand what was installed prior to initiating the call or visit.
3. Contact the person and explain the purpose of the Survey. Tell them that the data provided by them will be kept strictly confidential and will not be shared with anyone.

LED TRAFFIC SIGNALS DECISION-MAKER SURVEY

Customer Name: ______________________________ Date: ____

Business Name: ______________________________ Contact: ____________________________________

Phone Number: ______________________________ City: ____

Start Call Time: ______________________________ End Call time: ______________________________

Surveyor Initials: ____________________________ Survey Completed: Y NA R WB BN

Y = yes, NA = no answer, R = refused, WB = wrong business, BN = bad number

The purpose of the decision-maker survey is to obtain information necessary to calculate a net-to-gross ratio. You will need to interview the customer who was responsible for the decision to implement measures at the site. If this person is not available attempt to locate someone who is at least familiar with how that decision was made.

Introduction

Say: "Hello. My name is [**Anne**] and I am conducting a survey regarding the your participating in the energy efficiency programs funded with SB5X funds. Would you mind spending 5 minutes to answer a few questions."

Begin Survey

1. When and how did you first learn about the Utility Program? [**Only ask this question once, for the first recommendation for each site.**]

   ____

   1 Didn't know there was a program (**Go to Q.3**)

2. Keeping that in mind, did you understand the value of the Utility Program Rebate BEFORE or AFTER you installed the efficiency upgrades? (**Circle One**)

   1 Before **2** After (**Go to Q.4**) **98** Don't Know **99** Refused to Answer

3. Did you decide to install the efficiency upgrade(s) BEFORE or AFTER you learned about the Utility Program Rebate? (**Circle One**)

   1 Before **2** After **98** Don't Know **99** Refused to Answer

4. On a scale from 0 to 10, with 0 being no influence at all and 10 being very influential, how much influence did the Utility or Rebate have on your decision to install the efficiency upgrades?

   ___ Response (**0-10**) **98** Don't Know **99** Refused to Answer

5. If the rebates had not been available, how likely is it you would have done exactly the *same* thing. Please use a scale from 0 to 10, with 0 being not at all likely and 10 being very likely.

   ___ Response (**0-10**) **98** Don't Know **99** Refused to Answer

   Notes: ____

LED TRAFFIC SIGNALS DECISION-MAKER SURVEY (Continued)

Special Instruction for Contradictory Responses: If [**Q.4 is 0,1,2** *and* **Q.5 is 0,1,2**] *or* [**Q.4 is 8,9,10** *and* **Q.5 is 8,9,10**]. Probe for the reason. However, it is important not to communicate a challenging attitude when posing the question. For example, say,

> When you answered "8" for the question about the influence of the rebate or service, I interpreted that to mean that the Utility Program was important to your decision. Then, when you answered "8" for how likely you would be to take the same action *without* the rebate or service, it sounds like the Utility was *not* very important. I want to check to see if I understand your answers or if the questions may have been unclear.
>
> If they volunteer a helpful answer at this point, respond by changing the appropriate answer. If not, follow up with something like: "Would you explain in your own words, the role the Utility Program played in your decision to take this action?

If possible translate their answer into responses for **Questions 4** and **5** and check these responses with the respondent for accuracy. If the answer doesn't allow you to decide what answer should be changed, write the answer down and continue the interview.

Answer: ____

6. What role did the Utility Program play in your decision to install the upgrades [**describe implemented recommendation**]? [Prompt by reading list if the respondent has trouble answering.]

   1 Reminded us of something we already knew

   2 Speeded up process of what we would have done anyway (i.e., early replacement)

   3 Showed us the benefits of this action that we didn't know before

   4 Clarified benefits that we were *somewhat* aware of before

   5 Recommendation had no role

   6 Other ____

   98 Don't Know

   99 Refused to Answer

Say: Here are some statements that may be more or less applicable for your home or business about the Utility Program [**or recommendation**]. Please assign a number between 0 and 10 to register how applicable it is. A 10 indicates that you fully agree, and 0 indicates that you completely disagree.

7. The Utility Program rebate was nice but it was unnecessary to get the efficiency upgrades installed.

   ___ Response (**0-10**) **98** Don't Know **99** Refused to Answer

8. The Utility Program rebate was a critical factor in installing the efficiency upgrades.

   ___ Response (**0-10**) **98** Don't Know **99** Refused to Answer

LED TRAFFIC SIGNALS DECISION-MAKER SURVEY (Continued)

9. We would not have installed the efficiency upgrades without the Utility Program.

   ___ Response (**0-10**) **98** Don't Know **99** Refused to Answer

10. If you had not received the [rebate or service] from the Utility, would you have installed upgrades [**or other measures**]...

    1 ..within 6 months?

    2 ..6 months to 1 year?

    3 ..one to two years later?

    4 ..two to three years later?

    5 ..three to four years later?

    6 ..four or more years later?

    7 ..Never

    98 ..Don't Know - **Try less precise response, if still "don't know" use 98**

      8 ...less than one year?

      9 ...one year or more?

    99 ...Refused to Answer

    Time relative to the installation date. For customers with more than one measure ask if their response is the same. If not, obtain a response for each measure. Write answers in margins and enter answers on a new line in the Excel spreadsheet.

Repeat **Questions 2** through **10** for each installed measure or service.