Evaluation Measurement and Verification of the California Public Utilities Commission HVAC High Impact Measures and Specialized Commercial Contract Group Programs

2006-2008 Program Year

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2. Abstract

High-Impact Measures (HIM)

The California Public Utilities Commission Energy Division (CPUC) created a grouping of programs and measure evaluations consisting of three heating, ventilation and air conditioning high-impact measures (HVAC HIMs), including residential and small commercial applications. The HIMs are defined as those efficiency measures that contribute 1% or more to the entire IOU savings portfolio for reductions in electrical energy consumption (kWh), electrical demand (kW), or natural gas (therm) consumption. The IOUs filed gross energy and demand savings estimates with the CPUC based on the Database for Energy Efficiency Resources (DEER) and workpaper estimates of unit energy savings (UES) for multiple categories of measures, building types, building vintages, and locations.

This evaluation estimated the unit energy savings (UES), installation rate, and net-to-gross ratio (NTGR), an estimate of the percentage of measures that would not be installed without the incentive programs, for each program and measure combination using a CPUC approved consistent methodology. HIMs addressed by this evaluation include refrigerant charge and airflow (RCA), AC replacement, and duct sealing. The final HVAC HIM evaluated savings yielded lower gross savings than the ex-ante estimates for most program-HIM combinations.

Specialized Commercial Contract Group

The California Public Utilities Commission Energy Division (CPUC) selected the consulting firm KEMA to lead an impact evaluation to estimate the actual achieved energy and demand savings resulting from several energy efficiency measures and programs implemented by the four California investor owned utilities (IOUs), Pacific Gas and Electric (PG&E), San Diego Gas and Electric (SDG&E), Southern California Electric (SCE), and Southern California Gas (SCG), from 2006 to 2008. The CPUC created a grouping of programs and measures called the Specialized Commercial Contract Group (CG) consisting of and two non-HIM programs with M&V for measures with future potential, and a diverse array of relatively new, energy-efficiency programs directed at the non-residential sector.

Non-HIM programs were included under this evaluation and subjected to site M&V: Management Affiliates Partnership Program, Energy-Efficiency Program for Entertainment Centers, Upstream HVAC/PTAC, and Upstream HVAC/Motors Program. The other programs were not subject to site M&V to assess program-level savings, due to program closure or expected minor impact. Overall non-HIM evaluated savings are shown in the table below.

Table of Contents

List of Figures:

List of Tables:

3. Executive Summary

The California Public Utilities Commission Energy Division (CPUC) selected KEMA to lead an impact evaluation to estimate energy and demand savings resulting from several energy-efficiency measures and programs implemented from 2006 to 2008 by California's four investor-owned utilities (IOUs). These IOUs include Pacific Gas and Electric Company (PG&E), San Diego Gas and Electric Company (SDG&E), Southern California Edison Company (SCE), and Southern California Gas Company (SCG). The CPUC created a grouping of programs and measures called the Specialized Commercial Contract Group (CG) consisting of three heating, ventilation, and air-conditioning high-impact measures (HVAC HIMs): Refrigerant charge and airflow (RCA), Air Conditioner (AC) replacement, and Duct Sealing; as well as measurement and verification (M&V) for two programs offering non-HIM measures with future potential and a diverse array of relatively new energy-efficiency programs directed at the non-residential segment.

The HVAC HIM evaluation measures looked at refrigerant charge and airflow (RCA), air-conditioner replacement, and duct-sealing to calculate the following values for all measures:

- Installation rate of measures
- Unit energy savings (UES)
- Net-to-gross ratios (NTGRs)
- Efficiency and cooling output improvement as a charge adjustment function

3.1 Refrigerant Charge and Airflow

The measurement and verification (M&V) for RCA revealed that if done properly the measure results in energy savings, but a number of issues contributed to the evaluated impacts being lower than expected. The efficiency of an AC system can be substantially reduced due to improper refrigerant charge and airflow. The residential and commercial RCA measure entailed RCA testing and AC monitoring based on the assumption that proper refrigerant charging can increase system efficiency significantly, providing valuable energy savings.

The evaluation used data collected through field engineering measurements performed on a sample of AC units, user surveys, and market-actor surveys to estimate both the savings and cost-effectiveness of IOU programs. As an intermediate step to calculating the UES for RCA measures, pre- and post- RCA measure AC efficiency was calculated for RCA measures then applied to the same DOE-2 energy simulation models used for estimating UES for DEER RCA measures. As part of this evaluation effort, appropriate site-level contextual data—including duct location, return air strategy, airflow, and AC-system was also collected to inform building energy models for the DEER process. A complete list of parameters collected for all residential and commercial HVAC sites is provided in the appendix of the report.

The results for RCA are shown in Table 3-1 and Table 3-2, for energy and demand savings respectively. RCA ex-ante and ex-post gross therm savings were zero. The installation rate was determined by comparing onsite diagnostic results of randomly selected program units to the final AC contractor-collected diagnostic parameters, known as subcooling and superheat[1]. Because there was an incentive for a contractor to find a problem to be fixed (since their payment was much greater in that case), there was the possibility of biased reporting of the refrigerant charge correction. The ex-post results estimated the UES and measure load shape for RCA by both building type and climate zone. The estimated ex-post NTGR for each program and measure combination was developed using the NTGR algorithm described in the report and described in further detail in the appendix.

Residential RCA efforts were centered on logging systems' efficiency data pre- and post-maintenance. The large mass-market programs were comprised of more multifamily than single family units. Pre- and post-metering samples were evaluated in terms of improvements in systems' energy-efficiency rating (EER), capacity, sensible capacity (ability to reduce the dry-bulb temperature), as well as demand reduction. Then, these values were converted into degradation factors (estimated impairment in pre-RCA capacity and efficiency) against a standard set of eQuest® models, which are software simulation models that calculate energy savings for the DEER database. These simulations, or runs, resulted in total estimated kWh savings by climate zone. Primary savings were evaluated for units that received a refrigerant charge adjustment. Overall, for each program containing RCA, ex-post savings were not as high as claimed by the utility. RCA program installation rates ranged from 45% to 89%, NTGR ranged from a low of 0.54 to 0.97. These results are further discussed in the report. Recommendations for the RCA programs are explained in further detail in the report; the following is a summary of the recommendations:

- The C&I RCA results were lower on average and highly variable, which suggests the specific application of charge adjustments to small commercial units should be subject to additional M&V early on in future, programs to establish best and sustainable practices.

[1] See Appendix D for more detail regarding the procedure for calculating actual subcooling and superheat and additional definitions of diagnostic calculations using RCA data.

- The HVAC team recommends establishing an independent service tool list and protocol used for residential and C&I RCA verification testing and standard tables and data quality procedures to validate program-collected and evaluator-collected data.

- For the C&I RCA measures, the low results for final net savings suggest that an approach not based on deemed unit savings may be appropriate such as a measured-performance approach. Programs should consider measurements of the operating performance before and after servicing to better establish savings claims given the variability in observed measure performance. If larger future samples for the C&I measure are achieved that show similar results as this study, then the measured-performance approach would be strongly recommended.

- The rates of free-ridership for future programs should be based on early M&V that is coupled with process evaluation to develop the most appropriate methods to mitigate and further evaluate mid-market incentives.

- The programs should have strong links of rebates and savings data to program units and contractor measurement data. Recommendations include a statewide unit identification standard and sticker, standard program measurement data table definitions, and development of common data definitions for key parameters. Program implementers need to notify and inform customers when they sign up to participate in programs. Implementers also need to attempt to get participants to agree to terms and conditions that allow measurement and verification work upon request.

Table 3-1: Summary of Savings for Refrigerant Charge and Airflow Measure (kWh)

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	HIM Ex-ante Gross kWh Savings	HIM Ex-post Gross kWh Savings	HIM Gross kWh Realization Rate [Column B/Column A]	HIM Install Rate	HIM Installed Ex-post Gross kWh Savings [Column B * Column D]	HIM NTGR	HIM Ex-post Net kWh Savings [Column E * Column F]
Res RCA	PGE2000	28,966,327	7,990,218	28%	52%	4,114,962	0.63	2,592,426
	PGE2078	1,191,979	457,739	38%	89%	406,930	0.78	317,405
	SCE2502	3,760,920	1,684,228	45%	89%	1,497,279	0.78	1,167,878
	SCE2507	56,440,821	25,260,503	45%	55%	13,893,277	0.97	13,476,479
	SDGE3035	1,373,476	452,317	33%	89%	402,109	0.78	313,645
C&I RCA	PGE2068	4,818,552	2,172,294	45%	68%	1,485,849	0.54	802,358
	PGE2080	9,161,619	1,814,383	20%	45%	824,720	0.55	453,596
	SCE2507	9,758,899	7,020,259	72%	67%	4,731,655	0.94	4,447,755
	SDGE3043	2,944,930	619,598	21%	67%	413,272	0.7	289,290

Table 3-2: Summary of Savings for Refrigerant Charge and Airflow Measure (kW)

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	Peak Ex-ante Gross kW Savings	Peak Ex-post Gross kW Savings	HIM Gross kW Realization Rate [Column B/Column A]	Install Rate	Peak Installed Ex-post Gross kW Savings	NTGR	Peak Ex-post Net kW Savings
Res RCA	PGE2000	30,508	10,434	34%	52%	5,373	0.63	3,385
Res RCA	PGE2078	2,489	663	27%	89%	589	0.78	460
Res RCA	SCE2502	4,996	1,922	38%	89%	1,708	0.78	1,332
Res RCA	SCE2507	41,546	29,790	72%	55%	16,384	0.97	15,893
Res RCA	SDGE3035	1,745	592	34%	89%	526	0.78	410
C&I RCA	PGE2068	1,923	2,108	110%	68%	1,442	0.54	779
C&I RCA	PGE2080	13,339	1,685	13%	45%	766	0.55	421
C&I RCA	SCE2507	17,261	5,923	34%	67%	3,992	0.94	3,752
C&I RCA	SDGE3043	2,183	514	24%	67%	343	0.7	240

3.2 AC Replacement

The rooftop or split-system AC-replacement measure provided incentives for both residential and commercial buildings to replace burnt-out AC units (Replacement on Burnout) and those being replaced early with some remaining useful life in the unit (Early Replacement or ER). The replacement systems were high-efficiency AC systems that provided either energy and demand savings over standard-efficiency air conditioners (for replacement on burnout) or the prior unit (for early replacements). The evaluation's M&V entailed monitoring units with claimed savings from AC replacements and comparing those units' performance to a theoretical code minimum-efficient unit. In addition, the evaluation monitored the performance of recently replaced non-high-efficient units (minimally code-compliant) to estimate actual field operating efficiency and the usage of standard-efficiency replacements.

The evaluation used data collected through field engineering measurements performed on a sample of AC units, participant surveys, and market-actor surveys to determine savings and other parameters required by the CPUC to estimate the cost effectiveness of IOU programs. The lack of data availability was a serious issue. To assess the direct impact of these HVAC replacement measures, the evaluation team tried to determine what would have occurred in the absence of a program. To accomplish this, matched samples of non-treated installations were recruited and evaluated to generate realistic baseline system performance and compared to the sample of treated installations. Replacement savings equal the difference in baseline and monitored-data energy use. All programs saw an installation rate of 100%, meaning that all air conditioning units were actually replaced, which led to high ex-post kWh savings, as shown in Table 3-3 through Table 3-4. Gross kWh realization rates range from 25% to 93%. NTG ratios range from 0.53 to 0.96. A few selected recommendations are below. Results and recommendations are further discussed in detail in the report.

- For both the residential and commercial sector, correcting field installation issues would improve overall performance. Currently, average performance for the code compliant unit is considerably less than the manufacturers' rated performance of the unit.

- We recommend the IOU estimates use the most recent ALJ definition for consistency. Presently, evaluated grid-level peak demand estimates differ from the IOU estimates because the evaluated grid-level peak demand estimates used the most recent ALJ definition of system grid peak.

Table 3-3: Summary of Savings for Air Conditioner Replacement Measure (kWh)

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	HIM Ex-ante Gross kWh Savings	HIM Ex-post Gross kWh Savings	HIM Gross kWh Realization Rate [Column B/Column A]	HIM Install Rate	HIM Installed Ex-post Gross kWh Savings [Column B * Column D]	HIM NTGR	HIM Ex-post Net kWh Savings [Column E * Column F]
Res AC Replacement	SCE2507	2,463,896	1,140,969	46%	100%	1,140,969	0.56	638,942
Res AC Replacement	SDGE3029	2,802,029	699,369	25%	100%	699,369	0.53	370,665
C/I AC Replacement	SCE2507	7,669,393	7,137,578	93%	100%	7,137,578	0.96	6,852,075
C/I AC Replacement	SDGE3029	3,226,695	2,222,766	69%	100%	2,222,766	0.94	2,089,400
C/I AC Replacement	PGE2080	36,969,145	17,258,976	47%	100%	17,258,976	0.94	16,223,438

Table 3-4: Summary of Savings for Air Conditioner Replacement Measure (kW)

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	Peak Ex-ante Gross kW Savings	Peak Ex-post Gross kW Savings	Gross kW Realization Rate [Column B/Column A]	Install Rate	Peak Installed Ex-post Gross kW Savings [Column B * Column D]	NTGR	Peak Ex-post Net kW Savings [Column E * Column F]
Res AC Replacement	SCE2507	2,901	1,636	56%	100%	923	0.56	517
Res AC Replacement	SDGE3029	3,790	967	26%	100%	247	0.54	133
C/I AC Replacement	SCE2507	5,841	6,514	112%	100%	7,265	0.96	6,974
C/I AC Replacement	SDGE3029	2,185	2,061	94%	100%	1,944	0.94	1,827
C/I AC Replacement	PGE2080	27,521	22,445	82%	100%	22,445	0.94	21,098

3.3 Duct Sealing

Duct leakage in homes can result in conditioned (cooled or heated) air being lost to unconditioned space and/or unconditioned (cool or warm) air slipping in. Sealing duct leaks increases a system's efficiency and results in saved energy and demand for all-electric systems as well as gas space-heating savings for electric-gas systems.

This evaluation portion was centered on producing actual system-leakage estimates and then comparing them to standardized measurements gathered from duct-sealing contractors. A Minneapolis Duct Blaster® and a Minneapolis Blower Door™ were used to test total system duct leakage and duct leakage to the outside, respectively. The evaluation team also measured duct-system leakage for post-diagnostic performance and compared the results to the pre- and post-measurements of duct leakage collected by the program implementers. The HVAC duct-sealing HIM evaluation calculated the measure's installation rate, as claimed by the programs, through field measurements and developed NTGRs from telephone surveys. The evaluation used the ex-ante UES estimates for duct-sealing measures given the limitations in the ability to accurately and precisely measure parameters to calculate actual energy savings from field M&V.

Duct-sealing measure savings results are shown in Table 3-5 through Table 3-7 below. Each program achieved relatively low installation rates, ranging from 37.7% to 54.0%. Program savings and savings by climate zone are discussed in detail in the report. The following recommendations are also discussed in more detail in the report:

- We recommend exploring advanced testing methodologies for use in M&V studies including a further developed DeltaQ test. Existing and current research support the current UES estimates from duct sealing being used until advanced methods can be applied to large samples to establish program-HIM level estimates.

- The time required to do a good job of duct sealing is likely much greater than the time it takes to do a less rigorous job. With a standard financial incentive for all sealing jobs, there may be disincentive to do good sealing jobs. Direct field oversight and risk-reward mechanisms should be explored to ensure rebates are provided for quality sealing jobs.

Table 3-5: Summary of Savings for Duct-Sealing Measure (kWh)

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	HIM Ex-ante Gross kWh Savings	HIM Ex-post Gross kWh Savings	HIM Gross kWh Realization Rate [Column B/Column A]	HIM Install Rate	HIM Installed Ex-post Gross kWh Savings [Column B * Column D]	HIM NTGR	HIM Ex-post Net kWh Savings [Column E * Column F]
Res Duct Seal	PGE2000	6,148,183	6,148,183	100%	49%	3,012,610	0.54	1,626,809
Res Duct Seal	PGE2078	414,452	414,452	100%	41%	170,657	0.85	145,058
Res Duct Seal	SCE2502	2,245,083	2,245,083	100%	41%	924,446	0.79	730,312
Res Duct Seal	SCE2507	508,596	508,596	100%	51%	259,384	0.96	249,009
Res Duct Seal	SDGE3035	900,668	900,668	100%	41%	370,863	0.80	296,691

Table 3-6: Summary of Savings for Duct-Sealing Measure (kW)

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	HIM Ex-ante Gross kW Savings	HIM Ex-post Gross kW Savings	HIM Gross kW Realization Rate [Column B/Column A]	HIM Install Rate	HIM Installed Ex-post Gross kW Savings [Column B * Column D]	HIM NTGR	HIM Ex-post Net kW Savings [Column E * Column F]
Res Duct Seal	PGE2000	8,387	8,387	100%	49%	4,110	0.54	2,219
Res Duct Seal	PGE2078	1,127	1,127	100%	41%	464	0.85	394
Res Duct Seal	SCE2502	n/a	n/a	n/a	41%	n/a	0.79	n/a
Res Duct Seal	SCE2507	558	558	100%	51%	285	0.96	273
Res Duct Seal	SDGE3035	100	100	100%	41%	41	0.80	33

Table 3-7: Summary of Savings for Duct-Sealing Measure (therms)

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	Measure Ex-ante Gross therms Savings	Measure Ex-post Gross therms Savings	Measure Gross therms Realization Rate [Column B/Column A]	Measure Install Rate	Measure Installed Ex-post Gross therms Savings [Column B * Column D]	Measure NTGR	Measure Ex-post Net therm Savings [Column E * Column F]
Res Duct Seal	PGE2000	886,905	886,905	100%	49%	434,583	0.54	234,675
Res Duct Seal	PGE2078	70,615	70,615	100%	41%	29,077	0.85	24,715
Res Duct Seal	SCE2502/ SCG3539	84,490	84,490	100%	41%	34,790	0.79	27,484
Res Duct Seal	SCE2507	-	-	100%	51%	-	0.96	-
Res Duct Seal	SDGE3035	195,696	195,696	100%	41%	80,581	0.80	64,464

3.4 Non-HIM Programs

The following non-HIM programs were included under this evaluation and subjected to site M&V:

- Management Affiliates Partnership Program (selected measures)
- Energy-Efficiency Program for Entertainment Centers
- Upstream HVAC/PTAC-PTHP
- Upstream HVAC/High Efficiency Motors Program

Each non-HIM program description, methodology, and savings are described in detail in the report. Overall non-HIM evaluated savings are shown in Table 3-8 through Table 3-11 below. Note that the non-HIM programs did not claim therms savings and gas savings were not evaluated for programs with site M&V.

Table 3-8: Overall Non-HIM Evaluated Savings-Programs with Site M&V (kWh)

		A	B	C	D	E	F	G
Non-High Impact Measure	Program with Measure	HIM Ex-ante Gross kWh Savings	HIM Ex-post Gross kWh Savings	HIM Gross kWh Realization Rate [Column B/Column A]	HIM Install Rate	HIM Installed Ex-post Gross kWh Savings [Column B * Column D]	HIM NTGR	HIM Ex-post Net kWh Savings [Column E * Column F]
MAP: CO Sensor	SCE2537	5,787,836	4,688,147	81%	100%	4,688,147.00	1.000	4,688,147
MAP: Turbocor	SCE2537	7,019,603	7,019,603	100%	100%	7,019,603.00	0.800	5,615,682
Entertainment Centers: CO2 Demand Control Ventilation	SCE2561	978,667	569,437	58%	100%	569,437.00	0.938	534,132
Upstream HVAC: PTAC/PTHC	SDGE3029	592,399	592,399	100%	95%	562,779.00	0.800	450,223
Upstream HVAC: High Efficiency Motors	SDGE3029	132,430	131,756	99%	79%	104,087.00	0.975	101,485

Table 3-9: Overall Non-HIM Evaluated Savings-Programs with Site M&V (kW)

		A	B	C	D	E	F	G
Non-High Impact Measure with Site M&V	Program with Measure	Measure Ex-ante Gross kW Savings	Measure Ex-post Gross kW Savings	Measure Gross kW Realization Rate [Column B/Column A]	Measure Install Rate	Measure Installed Ex-post Gross kW Savings [Column B * Column D]	Measure NTGR	Measure Ex-post Net kW Savings [Column E * Column F]
MAP: CO Sensor	SCE2537	820.00	906.00	110%	100%	906.00	0.840	761.04
MAP: Turbocor	SCE2537	2,369.00	2,369.00	100%	100%	2,369.00	0.800	1,895.20
Entertainment Centers: CO2 Demand Control Ventilation	SCE2561	496.00	497.00	100%	100%	497.00	0.946	470.16
Upstream HVAC: PTAC/PTHC	SDGE3029	250.00	250.00	100%	95%	237.50	0.800	190.00
Upstream HVAC: High Efficiency Motors	SDGE3029	49.72	49.53	100%	79%	39.12	0.974	38.10

The following programs were not subject to site M&V, due to program closure or expected minor impact:

- Management Affiliates Partnership Program (selected measures)
- Integrated Schools
- 80 PLUS Program
- Energy Efficiency/Demand Response Flex
- Lighting Energy Efficiency/Demand Response Flex
- Escalator PowerGenius Program
- DHW Control Program
- Constant Volume Retrofit

- HVAC Training, Installation, and Maintenance
- Enhanced Automation Initiative
- PGE Air Care Plus

Table 3-10: Non-HIM Evaluated Savings-Programs without Site M&V (kWh)

		A	B	C	D	E	F	G
Non-High Impact Measure without Site M&V	Program with Measure	Measure Ex-ante Gross kWh Savings	Measure Ex-post Gross kWh Savings	Measure Gross kWh Realization Rate [Column B/Column A]	Measure Install Rate	Measure Installed Ex-post Gross kWh Savings [Column B * Column D]	Measure NTGR	Measure Ex-post Net kWh Savings [Column E * Column F]
MAP: CO2 Demand Control Ventilation	SCE2537	446,173	446,173	100%	100%	446,173	0.800	356,938
MAP: Daylight Harvesting Lighting	SCE2537	656,780	656,780	100%	100%	656,780	0.800	525,424
MAP: Hotel Keycard Energy System	SCE2537	822,670	822,670	100%	100%	822,670	0.800	658,136
MAP: HVAC Cycle Manager	SCE2537	765,993	765,993	100%	100%	765,993	0.800	612,794
MAP: Lighting Power Regulator	SCE2537	614,695	614,695	100%	100%	614,695	0.800	491,756
MAP: Lighting Project	SCE2537	456,309	456,309	100%	100%	456,309	0.800	365,047
MAP: Lighting Retrofit	SCE2537	4,412,188	4,412,188	100%	100%	4,412,188	0.800	3,529,750
MAP: VFD	SCE2537	1,182,089	1,182,089	100%	100%	1,182,089	0.800	945,671
MAP: Window Film	SCE2537	1,291,573	1,291,573	100%	100%	1,291,573	0.800	1,033,259
Integrated Schools: Green Campus	SCE2504	401,580	401,580	100%	68%	274,681	0.800	219,745
Integrated Schools: Green Schools	SCE2504	1,227,925	1,227,925	100%	77%	939,363	0.800	751,490
Integrated Schools: LivingWise Screw-in CFL 14 Watt	SCE2504	1,156,847	1,639,069	142%	67%	1,098,176	0.800	878,541
Integrated Schools: LivingWise Screw-in CFL 23 Watt	SCE2504	1,901,940	1,708,985	90%	68%	1,162,110	0.800	929,688
Integrated Schools: LivingWise Showerhead	SCE2504	101,542	14,047,778	13834%	45%	6,321,500	0.800	5,057,200
Integrated Schools: LivingWise Faucet Aerators, Kitchen	SCE2504	76,157	4,760,256	6251%	39%	1,856,500	0.800	1,485,200
Integrated Schools: LivingWise Faucet Aerators, Bathroom	SCE2504	76,157	3,834,211	5035%	38%	1,457,000	0.800	1,165,600
Integrated Schools: LivingWise Air Filter Alarm	SCE2504	574,045	2,191,650	382%	30%	657,495	0.800	525,996
Integrated Schools: LivingWise LED Night Light	SCE2504	977,033	1,062,224	109%	42%	446,134	0.800	356,907
Enhanced Automation Initiative	PGE2061	2,155,154	2,155,154	100%	100%	2,155,154	0.800	1,724,123
Escalator PowerGenius	SCE2565	199,425	279,918	140%	100%	279,918	0.800	223,934
80 PLUS	SCE2535	4,218	4,218	100%	100%	4,218	0.900	3,796

Table 3-11: Non-HIM Evaluated Savings-Programs without Site M&V (kW)

		A	B	C	D	E	F	G
Non-High Impact Measure without Site M&V	Program with Measure	Measure Ex-ante Gross kW Savings	Measure Ex-post Gross kW Savings	Measure Gross kW Realization Rate [Column B/Column A]	Measure Install Rate	Measure Installed Ex-post Gross kW Savings [Column B * Column D]	Measure NTGR	Measure Ex-post Net kW Savings [Column E * Column F]
MAP: CO2 Demand Control Ventilation	SCE2537	262	262	100%	100%	262	0.800	210
MAP: Daylight Harvesting Lighting	SCE2537	192	192	100%	100%	192	0.800	154
MAP: Hotel Keycard Energy System	SCE2537	287	287	100%	100%	287	0.800	229
MAP: HVAC Cycle Manager	SCE2537	0	0	0%	0%	0	0.000	0
MAP: Lighting Power Regulator	SCE2537	139	139	100%	100%	139	0.800	111
MAP: Lighting Project	SCE2537	90	90	100%	100%	90	0.800	72
MAP: Lighting Retrofit	SCE2537	941	941	100%	100%	941	0.800	753
MAP: VFD	SCE2537	173	173	100%	100%	173	0.800	139
MAP: Window Film	SCE2537	533	533	100%	100%	533	0.800	426
Integrated Schools: Green Campus	SCE2504	42	42	100%	68%	29	0.800	23
Integrated Schools: Green Schools	SCE2504	108	108	100%	77%	82	0.800	66
Integrated Schools: LivingWise Screw-in CFL 14 Watt	SCE2504	102	102	100%	67%	68	0.800	54
Integrated Schools: LivingWise Screw-in CFL 23 Watt	SCE2504	167	167	100%	68%	114	0.800	91
Integrated Schools: LivingWise Showerhead	SCE2504	22	604	2706%	45%	272	0.800	218
Integrated Schools: LivingWise Faucet Aerators, Kitchen	SCE2504	17	453	2706%	39%	177	0.800	141
Integrated Schools: LivingWise Faucet Aerators, Bathroom	SCE2504	17	453	2706%	38%	172	0.800	138
Integrated Schools: LivingWise Air Filter Alarm	SCE2504	196	196	100%	30%	59	0.800	47
Integrated Schools: LivingWise LED Night Light	SCE2504	0	0		42%		0.800	
Enhanced Automation Initiative	PGE2061	61	61	100%	100%	61	0.800	49
Escalator PowerGenius	SCE2565	45	54	119%	100%	54	0.800	43
80 PLUS	SCE2535	1	1	100%	100%	1	0.900	1

4. Introduction and Purpose of Study

This report contains the combined HVAC evaluation results of two evaluation contract groups (CGs) assessing the impact of the energy efficiency programs and measures implemented by the four California investor owned utilities[2] (IOUs) from 2006 to 2008. The California Public Utilities Commission Energy Division (CPUC) selected the consulting firm KEMA to lead the impact evaluation of the Specialized Commercial group of programs, while the consulting firm Cadmus, was chosen to perform the impact evaluation of the Residential Retrofit programs. For the purpose of this report, the combined efforts of both contract groups will be referred to as the Evaluation Team or the HVAC Evaluation Team. The goal of the CPUC impact evaluation is to estimate the actual achieved energy and demand savings resulting from the IOU funded program activities.

4.1 Purpose of High Impact Measure (HIM) Evaluations

The CPUC directed that both the Residential Retrofit and Specialized Commercial contract groups focus primarily on the evaluation of HIMs. The HIMs are defined as those efficiency measures that contribute 1% or more to the entire IOU savings portfolio for reductions in electrical energy consumption (kWh), electrical demand (kW), or natural gas (therm) consumption. The CPUC assigned three high-impact HVAC measures to the Specialized Commercial and Residential Retrofit CGs, all addressing potential savings from commercial and residential HVAC efficiency measures. Specifically, the HIMs were residential and commercial refrigerant charge and airflow (RCA), rooftop or split air conditioning (AC) system replacement, and residential duct sealing which are briefly described below.

RCA. The efficiency of an AC system can be substantially reduced by improper refrigerant charge and airflow. The residential and commercial RCA measure entailed RCA testing and AC monitoring based on the assumption that proper refrigerant charging can increase system efficiency significantly, providing valuable energy savings.

AC Replacement. The AC-replacement measure provided incentives to AC distributors and contractors which were passed on to IOU customers for replacement of both burned-out failed AC units and those with remaining useful life. Replacement systems were high-efficiency AC systems that provided both energy and demand savings over the standard efficiency air

[2] The four California IOUs include Pacific Gas and Electric (PG&E), San Diego Gas and Electric (SDG&E), Southern California Electric (SCE), and Southern California Gas (SCG).

conditioner for replacement on burnout or the prior unit for early replacements. Units replaced on burnout were required to be replaced with above-code units, better than SEER 13. Units retired before the end of their useful life could be replaced with SEER 13 code-compliant units.

Duct Leakage Sealing. Duct leakage can result in conditioned, cooled or heated, air being lost to unconditioned space. Sealing duct leaks increases the efficiency of a system and results in saved energy and demand for all-electric systems, as well as gas space heating savings for electric-gas systems.

The IOUs report gross energy and demand savings estimates to the CPUC for the HVAC HIMs offered in the 2006-2008 program cycle. The majority of the savings estimates were based on the Database for Energy Efficiency Resources (DEER) estimate of unit energy savings (UES) for multiple categories of measures, building types, building vintages, and climate zones. These estimates were used directly for each measure or weighted together by vintage and measure type in workpapers to produce average measure savings. Finally, some estimates were based on past evaluations of previous implementation of the same third party program.

This evaluation study estimated the UES and measure savings annual load shape for RCA, AC replacement, and Duct Sealing. The UES estimate used a CPUC-approved M&V approach developed by the evaluation team and vetted through experts hired by the CPUC to advise the Energy Division. The net-to-gross ratio (NTGR), an estimate of the percentage of measures that would not be installed without the incentive programs, was estimated for each program and measure combination using a CPUC approved consistent methodology developed by the CPUC net-to-gross working group comprised of Energy Division staff and its technical consultants. Table 4-1 summarizes the evaluation approaches used for the HVAC HIMs.

Table 4-1: High Impact Measure Evaluations

HIM	*Verification*	*Gross Savings*		*Net Savings*	
Report Section	*On-site Audits (Inspections and post-field tests)*	*End-Use Metering Analysis*	*Field Performance Measurement*	*Participant Self-Report Surveys*	*Vendor / Contractor Surveys*
6 - RCA	Installation Rate	UES	Pre-Post AC Efficiency	NTGR	N/A
7 - Rooftop or split system	Installation Rate	UES	New AC Efficiency	NTGR	NTGR
8 - Duct Sealing	Installation Rate	UES	Pre-Post Duct Efficiency	NTGR	N/A

4.2 HIM-Program Descriptions

This section describes the IOU programs containing the HVAC HIMs. The HVAC HIM measures are grouped by HIM, HIM sub-category denoted as EM&V activity, and applicable IOU program ID, as shown in Table 4-2. The table disaggregates commercial and industrial (C&I) and residential (Res) measures and separates AC replacements into replace on burnout and early replacement measures as these HIM subcategories have different savings estimates and require different evaluation approaches.

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4.2.1 Programs with Multiple HIMs

Several mass market IOU programs all contained more than one of the three HIMs: RCA, rooftop or split system AC replacement, and duct sealing:

- PGE2000 and PGE 2080 Mass Market – Commercial & Residential
- SCE 2507 Comprehensive HVAC – Commercial & Residential
- Manufactured-Mobile Homes: PGE 2078 CMMHP, SDG&E 3035 Mobile Home, SCE 2502 Multifamily, SCG 3539 Mobile Homes

Table 4-2: Evaluation Plan Grouping

HIM	EM&V Activity	Program ID
RCA	C&I RCA	PG&E2080
RCA	C&I RCA	SCE2507
RCA	C&I RCA	SDG&E3043
RCA	C&I RCA	PG&E2068
RCA	Res RCA	PG&E2000R
RCA	Res RCA	SCE2507
RCA	Res RCA	SDG&E3043
RCA	Res RCA	SCE2502
RCA	Res RCA	SDG&E3035
RCA	Res RCA	PG&E2078
Rooftop or Split System	C/I Upstream A/C	PG&E2080
Rooftop or Split System	C/I Upstream A/C	SCE2507
Rooftop or Split System	Res Upstream A/C	SCE2507
Rooftop or Split System	Res Upstream A/C	PG&E2000R
Rooftop or Split System	ER - C/I Downstream A/C	SCE2507
Rooftop or Split System	ER - Res Downstream A/C	SCE2507
Rooftop or Split System	ER - Res Upstream A/C	SDG&E3029
Rooftop or Split System	ER - C/I Upstream A/C	SDG&E3029
Duct Sealing	Res Duct Sealing	PG&E2000R
Duct Sealing	Res Duct Sealing	SCE2507
Duct Sealing	Res Duct Sealing	SDG&E3043
Duct Sealing	Res Duct Sealing	SCE2502
Duct Sealing	Res Duct Sealing	SDG&E3035
Duct Sealing	Res Duct Sealing	PG&E2078
Duct Sealing	Res Duct Sealing	SCG3539

A diverse group of implementation vendors and contractors each using their own marketing and measure implementation delivery strategies administered the HVAC HIMs within these commercial and residential programs. One implementation contractor administered all of the manufactured and mobile home programs. These programs also included other HIMs and non-HIMs being evaluated under the Residential Retrofit Specialized Commercial and Small Commercial Contract Groups. Some of these programs have undergone process evaluations and field M&V activities conducted by the IOUs, and the results, lessons learned, and program modifications that resulted from these activities were leveraged to the extent possible by the Specialized Commercial CG Evaluation Team.

4.2.1.1 PGE2000R and PGE 2080 Mass Market – Commercial & Residential

PG&E's Residential and Commercial Mass Market Programs were the largest of the commercial and residential programs of all the IOU programs in 2006 through 2008 and included all three HVAC HIMs among a large number of other common measures. The programs were offered through a variety of delivery channels and contracted with a variety of market actors to deliver upstream (manufacturers and some distributors), midstream (retailers, contractors and other distributors), and downstream incentives to customers. The upstream and midstream delivery channels were used primarily for the HVAC HIMs within the programs and the program was managed directly by PG&E.

4.2.1.2 SCE 2507 Comprehensive HVAC – Commercial & Residential

Southern California Edison's HVAC Program targeted residential and non-residential customers with air-cooled AC. It provided training and incentives to contractors and/or end users for the implementation of qualifying HVAC energy-efficiency measures including all three HVAC HIMs. The program offered comprehensive services covering both the midstream and downstream, HVAC service and replacement markets and was managed by a third-party energy services firm.

4.2.1.3 Manufactured-Mobile Homes: PGE 2078 CMMHP, SCG&E 3035 Mobile Home, SCE 2502 Multifamily, SCG 3539 Mobile Homes

The comprehensive manufactured-mobile home program (CMMHP) installed the following measures, or performed the following activities, in as many existing manufactured homes as possible: duct tests and sealing and RCA, compact fluorescent lamps, aerators and low-flow showerheads, CFL hardwire fixtures, and efficiency upgrades to common area lighting (CFL bulbs and fixtures) in manufactured home parks. To stimulate participation, the CMMHP measures were installed free of charge to the residents and owners of the manufactured homes. The program implementer, a third-party energy services firm, delivered this program in all of the IOU service territories. SCE and SCG sponsored and operated the program jointly in their shared service territory.

4.2.2 Individual RCA and AC Replacement Programs by Utility

The HVAC HIMs were also identified in other IOU programs each of which included incentives for multiple other non-HIM HVAC measures. Each program was implemented by a third-party energy services firm focusing on the AC market. The methods used to implement the high impact measures were consistent within each program.

4.2.2.1 SDG&E 3043 HVAC Training, Installation, and Maintenance – Commercial RCA

The HVAC Training, Maintenance and Installation Program was designed to promote energy efficiency through comprehensive training for HVAC technicians and the creation of customer awareness and demand for quality HVAC installation and maintenance services for residential and commercial markets. The third-party energy services implementer provided services for the previous program cycle, and continued to work with HVAC contractors to support the use of advanced diagnostic methods in system maintenance. The program targeted both the organizational decision-makers at these facilities and the contractors who serve them. Directly, this program provided incentives for a number of HVAC measures with commercial RCA measures being the only HIM from this program for SDG&E.

4.2.2.2 PGE2068 Air Care Plus – Commercial RCA

AirCare Plus (ACP) provided incentives to maintenance service contractors for rooftop HVAC units for refrigerant charge and airflow modifications in addition to non-HIM measures. ACP targeted light commercial customers, including high tech and restaurant businesses, and others for whom HVAC loads are high. In particular, AirCare Plus provided service contractors' technicians with on-site energy efficiency training and ongoing technical support, including use of a hand-held software device that used proprietary AirCare Plus software. The handheld device allowed the technicians to upload their activity information through a wireless connection to the implementer's web site to identify savings and additional tune-up opportunities.

4.2.2.3 SDG&E 3029 Upstream HVAC/Motors Program– Residential AC Replacement

The Upstream HVAC/Motors Program began with residential retrofit contractors as the primary target market and later evolved into a more traditional energy efficiency program marketing directly to the customers, that is, those who purchase and have the equipment installed. During the course of the program, it became obvious to the implementer that the upstream/midstream marketing was not pushing the market as fast as program planners originally thought it would, and that the push needed to be downstream at the customer level. In addition, there were commercial market segments that were not traditionally part of the contractors' customer base. As a result, the implementer also marketed the program to commercial customers directly using a more traditional program model.

4.3 Non-HIM Programs

The following non-HIM programs were included in this contract group and subjected to site M&V:

- Management Affiliates Partnership Program. (SCE2537, select measures)
- Energy Efficiency Program for Entertainment Centers (SCE2561)
- Upstream HVAC/PTAC-PTHP (SDG&E3029)

- Upstream HVAC/Motors Program (SDG&E3029)

The following programs were not subject to site M&V, due to program closure or expected minor impact. These programs received limited impact evaluations which are discussed in the Appendix.

- Management Affiliates Partnership Program (SCE2537, select measures)
- Integrated Schools (SCE2504)
- 80 PLUS Program (SCE2535)
- Energy Efficiency/Demand Response Flex (SCE2536)
- Lighting Energy Efficiency/Demand Response Flex (SCE2538)
- Escalator PowerGenius Program (SCE2565)
- DHW Control Program (SDG&E3034)
- Constant Volume Retrofit (SCG3536)
- Enhanced Automation Initiative (PGE2061)

5. Refrigerant Charge and Airflow

Improper refrigerant charge and airflow (RCA) can reduce the efficiency of small commercial and residential direct-expansion AC systems. The HVAC team, comprised of evaluators under the specialized commercial and residential retrofit contract groups, conducted M&V activities to assess the energy and demand savings of RCA measures implemented by 2006-2008 IOU programs. The evaluation sought to isolate the savings due to adding or removing refrigerant charge and did not assess savings for additional measures administered to the AC systems by the programs. The team developed procedures and a methodology meeting the requirements for enhanced rigor for the necessary samples consistent with the CPUC *Evaluation Protocols* to estimate the parameters necessary to calculate energy and demand savings for the RCA measures. The evaluation study by the HVAC team calculated energy and demand savings through a measurement and verification study of the efficiency improvements over a range of operating conditions for 240 monitored units. In addition to the final evaluation parameters, the primary data results are sought to inform revisions or updates to future DEER estimates by producing detailed data to establish pre- and post-maintenance air conditioner efficiency.

The majority of the utility reported ex-ante savings estimates were based on the Database for Energy Efficiency Resources (DEER) estimates of unit energy savings (UES) for multiple categories of measures, building types, building vintages, and locations. These estimates were used directly for each measure or weighted together by vintage and measure type in workpapers to produce average measure savings. Some workpaper estimates included savings of non-DEER measures being combined with DEER measures, such as condenser coil cleaning combined with RCA. Finally, some estimates were based on past evaluations of previous implementations of the same third-party program. The current RCA savings estimates in the 2005 and 2008 DEER were based on the average, instantaneous efficiency change calculated from the addition or removal of refrigerant for 65 units, with each unit at a unique operating condition.[3] These data and analyses are part of the DEER 2005 Report.[4]

5.1 Evaluation Objectives

Programs offering RCA measures test pre-existing conditions, remedy the revealed deficiencies, and retest equipment implementation to ensure proper system performance. The programs paid a smaller incentive for, and claimed no savings from, systems not requiring

[3] Mowris, R. 2004. "Refrigerant Charge and Airflow Verification Program". ACEEE Summer Study on Energy Efficiency in Buildings.

[4] http://www.deeresources.com/

remediation. Many of the IOUs' programs did not claim airflow adjustment savings from the RCA measures, and in many observed cases, airflows were not significantly improved. Additional air-conditioner maintenance may have been a part of the RCA measure, but the HVAC team focused on the savings due to refrigerant charge adjustments, which were a component in all the high-impact measures implemented in all the IOU programs. This evaluation's M&V entailed verification testing of units with claimed savings from RCA and monitoring of pre- and post-performance, based on the assumption that proper refrigerant charging can increase a system's efficiency, significantly providing valuable energy savings.

5.1.1 Estimated Parameters

The evaluation used data collected through field engineering measurements on a sample of AC units, user surveys, and market-actor surveys to estimate the savings and other parameters required by the CPUC to estimate the cost effectiveness of the IOU programs. The HVAC HIM evaluation for RCA calculated the:

- Installation rate
- Unit energy savings (UES)
- Net-to-gross ratios (NTGRs)
- Energy efficiency ratio (EER) and cooling output improvement as a function of the amount of charge adjustment

These post-evaluation estimates (ex-post) of the parameters were also compared to those estimates filed by the IOUs with the CPUC (ex-ante). The ex-ante gross energy and demand-savings estimate for RCA measures were DEER or workpaper-based estimates of the UES, based on multiple categories of refrigerant charge adjustments, building type and vintage, and location[5]. The ex-post results estimated the UES and measure load shape for RCA, as administered by the various IOU programs, by building type and climate zone. The ex-post estimated NTGR for each program and measure combination was developed using a consistent method described in Section 5.2.4.

[5] The standard unit for RCA measures is a ton of installed cooling.

5.1.2 Challenges to Achieving HIM Objectives

The RCA programs were designed to collect system performance and/or performance parameter data prior to applying measures. The diagnostic measurements taken by the contractor that determine whether or not the unit needs refrigerant added or removed must be recorded since these pre-maintenance data cannot be replicated after adjustments are made to refrigerant levels. The recorded pre-adjustment measurements of system diagnostics were the only opportunity to determine baseline system performance and performance improvement for the entire population of measures. Therefore, the quality of these data was paramount to evaluating savings for units sampled in this evaluation. In addition to recording the measurements, units serviced must be clearly marked in the field with stickers or have HVAC serial numbers recorded to clearly distinguish serviced units. This is particularly important at multifamily complexes and commercial building rooftops where there are multiple units.

One of the main issues identified by the evaluation team was the lack of pre-maintenance, “baseline”, performance data on refrigerant charge tests and the uncertainty and potential bias of using contractor pre-measurements. Because there was an incentive for a contractor to find a problem to be fixed (since their payment was much greater in that case), there was the possibility of biased reporting of the refrigerant charge. The CPUC-approved program implementation plans for the programs containing the RCA measures evaluated in this study indicated pre- and post-measurement data would be collected by contractors and verified by the implementers or verification service providers (VSPs). Furthermore, some programs did not report data on charge adjustments, some only reported adjustments without measurements, and the contractor measurement data that was submitted did not include enough parameters to estimate the efficiency of the system before and after adjustment

As a solution to the issue of establishing whether there was an efficiency improvement as a result of the RCA measures, the Evaluation Team conducted two evaluation visits per site. The first visit consisted of initial RCA tests and the installation of monitoring equipment that was left behind to record parameters used to estimate system efficiency and refrigerant charge values. Two to three weeks later, implementation contractors visited these same sites, and tested the units to determine if the coolant charge needed remediation. If the tests determined this was the case, the implementer recharged the coolant, and the evaluation team returned to the site 2-3 weeks later to retest the units and collect the monitoring equipment. This evaluation approach has potential for bias, however, since the servicing contractor could see which units were being monitored since the evaluation equipment was clearly visible. This potential bias was predicted to be upward toward additional efficiency gains because even if technicians had no knowledge of metering equipment, the contracting companies had agreed to the metering. Although a bias may exist in the results it was not quantified. The Evaluation Team determined this method superior to the alternative of one time before and after service system performance measurement since the tests were sensitive to temperature. Installation of monitoring equipment allowed for the collection of continuous temperature and system efficiency data. The equipment left in place only eliminated all doubt that the unit in question was being sampled to the technician. The coordination required to get to the unit prior to treatment was sufficient to notify the implementation contractor that this site would have been sampled.

The evaluation defined a measure as verified if it was "installed and working properly", which is the CA Protocols definition of verification. Visual inspections were insufficient for installation verification of measures, like RCA. Checking to see whether this sticker is present, however, only proves the contractor was present, there is no assurance the unit was charged. Some program implementers did not require contractors to mark units. Units that were not clearly identifiable using serial number data and did not also have service stickers made it difficult to perform RCA verification measurements. In addition, the RCA tests are weather dependent.[6] This limited the evaluation of these measures to data collected during the summers of 2008 and 2009 when weather conditions were similar to when implementer tests were made.

5.1.3 Overview of Other Evaluation Objectives

The data collected through the RCA HIM evaluation was intended to inform future DEER estimates in addition to the primary parameters described in the section above. As an intermediate step to calculating the UES for RCA measures, pre- and post-measure AC efficiency were calculated for RCA measures and applied to the same DOE-2 energy simulation models used for estimating UES for the DEER RCA measures. As part of the evaluation effort, appropriate site-level contextual data were also collected to inform building energy models for the DEER process. The contextual data included duct location, return air strategy, airflow, AC system capacity, conditioned square footage, building vintage, and building construction characteristics. A complete list of parameters collected for all residential and commercial HVAC sites is listed in Appendix D.

[6] In the HVAC industry, it is accepted that the minimum ambient temperature for testing and adjusting refrigerant charge is 55° Fahrenheit with no industry standard maximum. However, most AC manufacturer performance curves do not allow extrapolation of performance below 75° or above 115° outside temperature. When ambient temperatures are low, the system does not perform under typical operating and loading conditions. AC contractor-collected test data can confirm proper charge, but the data are not useful in an engineering assessment of system performance since data are collected under conditions within the manufacturer's performance curves (and lack of all required data points eliminated the use of contractor data already).

5.2 Methodology

The HVAC team developed a methodology, consistent with the CPUC Evaluation Protocols, to estimate the parameters necessary to calculate energy and demand savings for the RCA measures. The evaluation study is centered on producing pre- and post-refrigerant adjustment AC cooling efficiency as a function of operating conditions, primarily air temperature entering the condenser from the outside. This effort required development of standard field procedures using a robust and cost-effective set of data loggers. The team specified the tools and sensor arrays capable of measuring all parameters required to calculate system efficiency and verify if a system was charged correctly, according to diagnostic measurements. The team also measured an equally sized sample of AC units, chosen to best represent the claimed program savings. The post-diagnostic performance verification test results were compared to the programs' collected pre- and post-measurements of AC diagnostic-performance parameters and industry standard diagnostic targets to determine if service was performed properly.

The team used engineering algorithms to combine the data collected to produce efficiency estimates and developed relationships of the efficiency and cooling output to a range of operating conditions. Measured efficiency and cooling performance improvements were applied as input parameters to standard representative building models and run for all building types and climate zones of interest to calculate realized UES. A significant M&V effort was required to develop the change in system operating efficiency from the application of the RCA. A large amount of coordination with program implementers and contractors, technical challenges of large-scale monitoring deployment, and anticipated site-to-site system configuration variability were a few issues that had to be addressed in the project. The issues were described in section 5.1.2 and the details of the sampling, onsite data collection, net-to-gross surveys, and analysis methods are described in the following sections, 5.2.1 through 5.2.4.

The following sections address sample sizes, on-site data collection, and NTGR. The references and background for the methods applied for the RCA HIM savings analysis is presented in Appendix C.

5.2.1 Sample Sizes for RCA EM&V

In addition to the RCA evaluation sample of AC units that received two visits and had monitoring equipment installed for an extended period of time, the Evaluation Team drew a separate sample from program tracking records for each program and HIM combination to receive a single evaluation visit after the implementer's work was completed. This approach was chosen to establish changes in efficiency from servicing units and to perform post-maintenance verifications on a representative, randomly selected sample for maintenance measures performed on existing HVAC units. When estimating the expected variability of measured savings relative to the claim (error ratio), the cooling systems' operating efficiencies were used rather than unit energy savings. The system efficiencies were subject to less variation than total usage or total savings leading to smaller required sample sizes and thus more rigorous M&V and innovative field approaches were justified. The team assumed an error ratio value of 0.5 for planning purposes. Verification samples were used to independently describe the quality of contractor work. The post-only, single site visit verification samples were used to independently describe the quality of contractor work since they were randomly selected and implementers did not know which sites were being tested. Table 5-1 below shows the planned RCA sample sizes by program type and ID. The final achieved samples for these efforts varied for each HIM within the programs listed, and the details are presented in Section 5.6.

Table 5-1: Planned RCA Sample Sizes

HIM	Program ID	Surveys	Verific. Units	Pre-Post Units
C&I RCA	PG&E2080	200	50	50
C&I RCA	SCE2507	250	50	50
C&I RCA	SDG&E3043	200	20	20
C&I RCA	PG&E2068	250	60	60
Res RCA	PG&E2000R	350	150	90
Res RCA	SCE2507	300	90	90
Res RCA	SDG&E3043	25	-	-
Res RCA	SCE2502	100	6	10
Res RCA	SDG&E3035	100	6	10
Res RCA	PG&E2078	100	6	10

The survey and verification samples were designed to represent program units based on the program tracking data. The survey and verification samples were stratified by climate zone, since location is a primary driver of the typical UES used in the program savings estimates. In some cases, the format of the program tracking data allowed stratification based on additional parameters, such as cooling capacity in tons, AC replacement type, and measure program year. This information was used to improve sampling efficiency whenever possible. The sample designs for verifications and surveys followed the typical climate zone stratification along with additional stratification as shown in Table 5-2.

Table 5-2: Sample Design for PGE2000 Residential RCA

	Sample Size (Units)	
Climate Zone	**Survey**	**Verificaton**
CZ2	2	1
CZ3	1	0
CZ4	1	0
CZ11	22	10
CZ12	64	27
CZ13	260	112
Total	350	150

Table 5-3: Sample Design for SCE2507 Residential RCA

	2006-Q2_2008		Q3&4_2008	
Climate Zone	Survey	Verificaton	Survey	Verificaton
CZ6	3	1	0	0
CZ8	13	4	13	4
CZ9	17	5	13	4
CZ10	60	18	27	8
CZ13	10	3	23	7
CZ14	13	4	10	3
CZ15	34	10	64	19
Total	150	45	150	45

Table 5-4: Sample Design for PG&E 2078 Residential RCA

	Sample Size (Units)	
Climate Zone	**Survey**	**Verification**
CZ02	1	1
CZ03	5	1
CZ04	17	1
CZ05	0	
CZ11	6	1
CZ12	40	1
CZ13	31	1
CZ16	0	
Total	100	6

Table 5-5: Sample Design for SCE 2502 Residential RCA

	Sample Size (Units)	
Climate Zone	**Survey**	**Verification**
CZ06	5	1
CZ08	14	1
CZ09	11	1
CZ10	55	1
CZ14	4	1
CZ15	12	1
Total	100	6

SDG&E 3035 Residential RCA was not divided by climate zone. Like PG&E 2078 and SCE 2502, SDG&E 3035 Residential RCA had a sample size total of 100 Survey Units and 6 Verification Units.

Table 5-6: Sample Design for PGE2068 Commercial RCA

	Sample Size (Units)	
Climate Zone	Survey	Verificaton
CZ2	21	5
CZ3	38	9
CZ4	96	23
CZ5	4	1
CZ11	8	2
CZ12	50	12
CZ13	33	8
Total	250	60

Table 5-7: Sample design for SDGE3043 Commercial RCA

	Sample Size (Units)	
Climate Zone	**Survey**	**Verification**
CZ07	129	13
CZ10	71	7
Total	200	20

Table 5-8: Sample Design for SCE2507 Commercial RCA

Climate Zone	2006-Q2_2008		Q3&4_2008	
	Survey	Verificaton	Survey	Verificaton
CZ6	17	4	4	1
CZ8	54	13	8	2
CZ9	33	8	9	2
CZ10	67	16	9	2
CZ13	21	5	4	1
CZ14	8	2	4	1
CZ15	8	2	4	1

The pre-post samples were coordinated to represent program activity, but were not sampled from a population. The climate zones with the highest participation levels and UES were targeted for the coordinated pre-post monitoring. A series of meetings were held beginning in July and continuing through October, involving CPUC contractors, PG&E project managers, CPUC staff and Verification Service Providers (VSPs). The meetings served as a method to facilitate coordination and establish project goals within the time and resource constraints. A cutoff date was established by the CPUC and consultants, the date was based on weather conditions and reporting deadlines. Achieving the planned samples was a challenge, since program contractors were busy during the same periods of hot weather when monitoring needed to be completed. Sites for pre-post monitoring in the summer of 2009 were taken from programs operating under bridge funding. The bridge-funding activity levels were much lower than those experienced near the end of the 2006 to 2008 program cycle.

The planned survey, verification, and metering sample designs were implemented to some extent for all programs with the exception of PGE 2080 and PGE2000R RCA measures. The PGE 2080 RCA participants were generally unwilling to cooperate with the verification activities; where we were able to conduct onsite verifications, the treated units were difficult-to-impossible to identify since they had no identifying stickers and serial numbers were not tracked in program records. The metered sites for pre- and post-measurements required a high level of coordination with IOU program managers, implementers, and AC contracting firms. For the most part, the metering was installed in time to obtain sample points within the planned sample designs with the exception of PG&E 2000R and 2080. A small number (10% of target sample) of PG&E 2000R residential units were sampled for pre- and post-RCA metering at the end of the study, while no PG&E 2080 commercial contacts were identified in time to inform this evaluation. A loss of precision was the result of the lack of sample points, but a bias was not likely introduced for the RCA metering since results across programs and contractors were ultimately pooled into residential and commercial results that were then applied to the programs based on their individual characteristics.

5.2.2 Onsite Data Collection

The evaluation study was centered on producing detailed AC efficiency curves[7] representing pre- and post-refrigerant adjustment. The following parameters were logged for a minimum of two weeks pre-adjustment and two weeks post-adjustment: return and supply air temperatures and relative humidity, indoor and outdoor temperature, refrigerant liquid/suction line temperatures and pressures, compressor discharge temperature (where possible), and AC power consumption. Instantaneous measurements of supply air-flow rate, electric power input, supply and return temperature, supply and return relative humidity, suction and liquid-line pressure and temperature, and condenser air temperature were made during equipment installation and during equipment removal. For all monitored AC units, nameplate information was taken during the initial site visit, including AC manufacturer, model and serial number, supply fan horsepower (HP)/Amperes (Amp), condenser-fan HP/full-load amps, compressor-motor HP and rated-load amps, outside air position, and control type. To account for changes after charging, thermostat set points were recorded pre- and post-charging. Schematics showing measurement locations of key parameters are presented below in Figure 5-1 for typical residential configurations and in Figure 5-2 and Figure 5-3 for typical commercial measurements.

[7] Equipment efficiency curves express efficiency as a function of outdoor and indoor temperature and humidity.

Figure 5-1: Residential RCA Measurement Locations

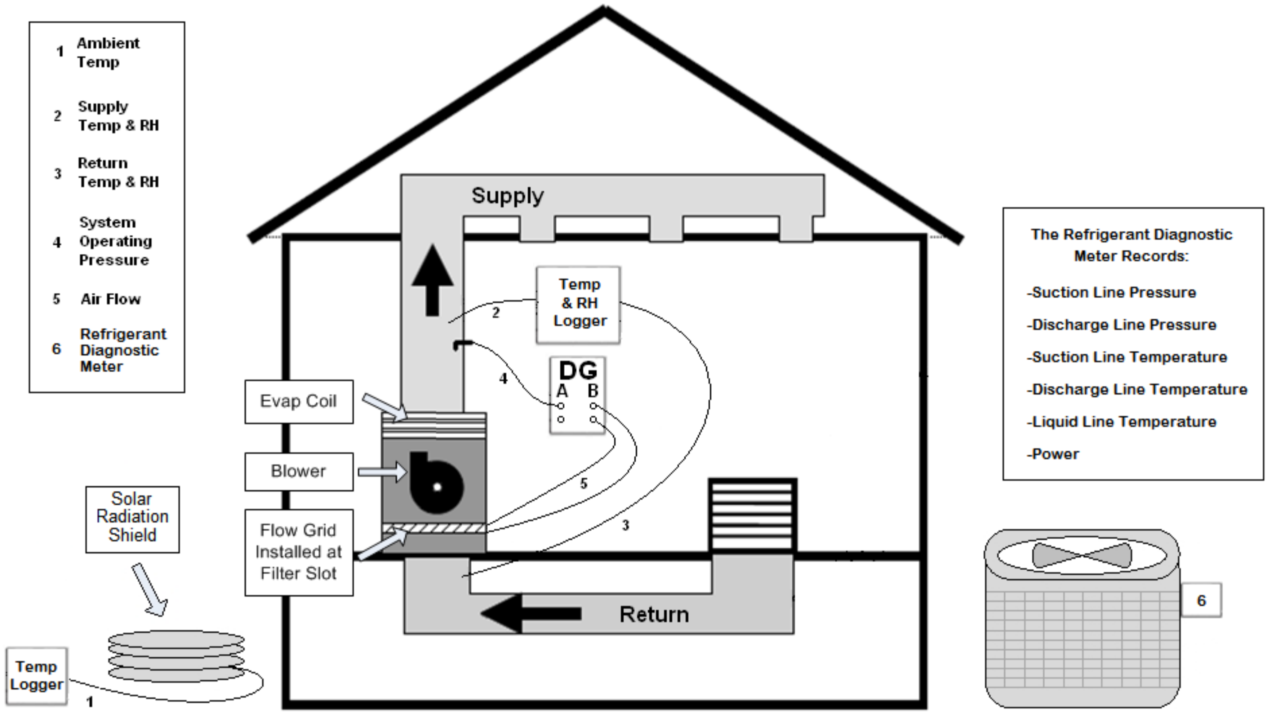


Figure 5-2: Small Commercial RCA Measurement Locations, Airside Parameters

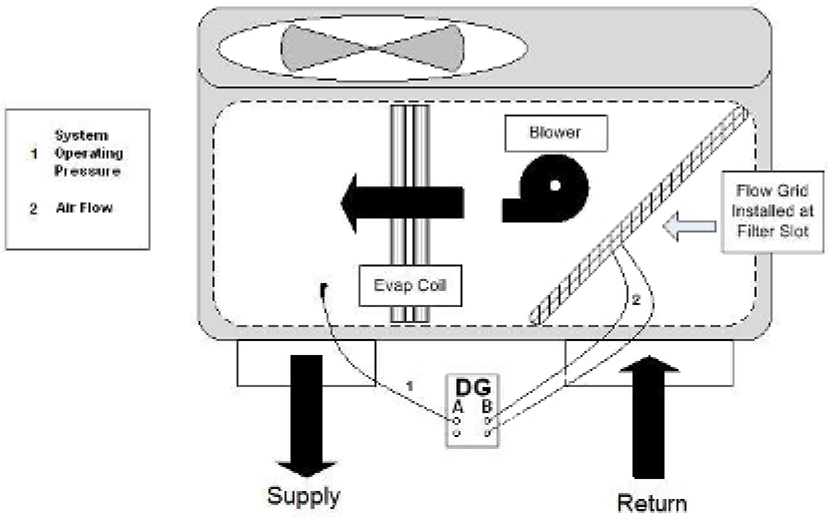
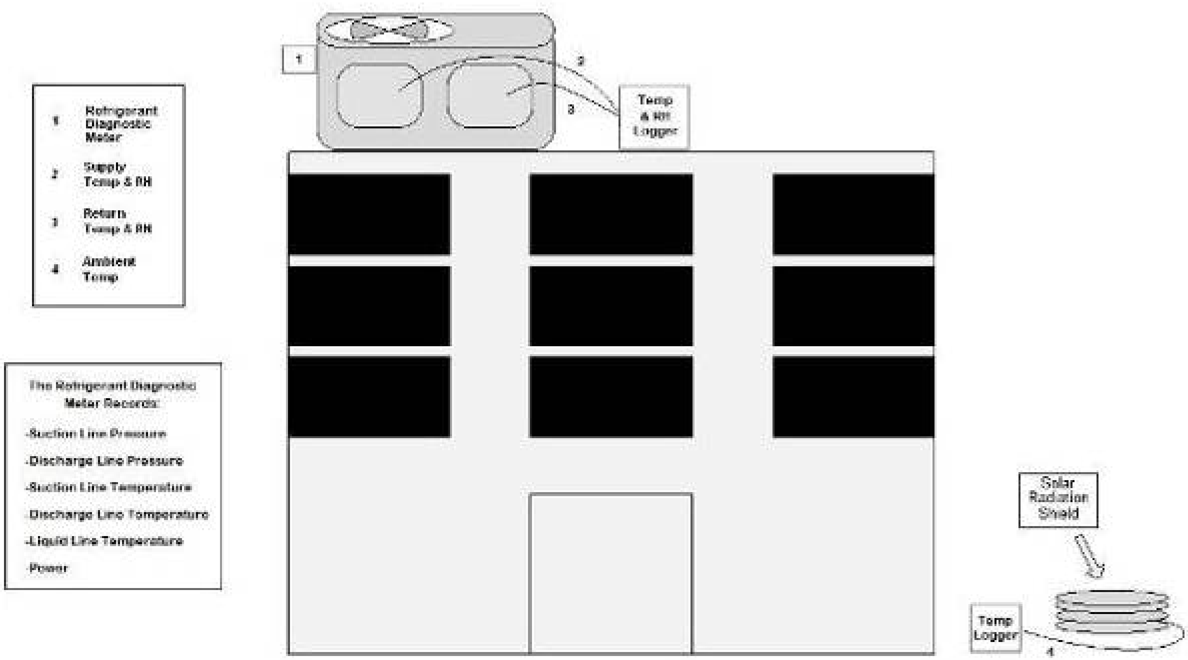


Figure 5-3: Small Commercial RCA Measurement Locations, Refrigerant Parameters



Field data collection was performed in teams of two engineers or technicians. All staff members were required to pass EPA refrigerant handling certification and all had experience testing systems for past research and evaluation projects. The engineers and technicians all underwent a project specific training with an industry expert field technician trainer and the project included an ongoing QA/QC component.

The field measurement techniques for air-conditioner efficiency do not have an industry standard. This lack of a standard primarily presents an issue when comparing the results of the field study, which have greater uncertainty, to measurements made under tightly-controlled conditions in a laboratory or case-study setting. Since the relative change in EER due to RCA was investigated using the same measurement equipment and techniques pre- and post-RCA, the evaluation standard that was used should not bias the relative impacts. The explicit intent of this project was not to establish field standards for air conditioner efficiency data collection; however the protocols developed provide a foundation for the evaluation community and HVAC industry to build upon. Various methods were available and wherever possible particular evaluation measurement techniques followed established American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and Air-Conditioning, Heating and Refrigeration Institute (AHRI) Standards for laboratory testing of AC-unit efficiency, as well as Air Conditioning Contractors of America (ACCA) guidelines for unit testing during installation and maintenance.

The primary issues recognized were the uncertainty in relative humidity (RH) monitoring particularly in the supply plenum where RH values were greatest, response time for temperature and RH measurements in the moving airstream, and the measurement of system airflow. The instrumentation specifications and primary data collected in pilots for the above issues were used in uncertainty analyses presented in section 5.4.3.

Table 5-9 outlines the instruments used in pre-/post-installation logging and metering, while Table 5-10 shows the instrumentation used for the instantaneous (one-time) measurements. The instantaneous measurements were used to verify proper RCA in the post-only verification study and were also used to validate the time-series measurements taken during the pre/post study.

Table 5-9: Measurement Points and Instrumentation

Function /Data Point to Measure	Equipment Brand/Model	Qty Req'd	Rated Full Scale Accuracy	Accuracy of Expected Measurement	Planned Metering Duration	Planned Metering Interval
Power	Wattnode/WNB-3Y-480-P	1	± 0.05%	± 0.45%	4-6 weeks	1 min
Power	Onset/ Hobo Energy Logger Pro H22-001 with pulse adapter S-UCC-M006	1	±0.3	±0.4	4-6 weeks	1 min
Supply Temperature/RH	Onset/ Hobo Temp/ RH 12-Bit data logger S-THB-M002	1	±2.5-3.5 RH	±3.5	4-6 weeks	1 min
Return temperature/RH	Onset/ Hobo Temp/ RH 12-Bit data logger S-THB-M002	1	±2.5-3.5 RH	±2.5	4-6 weeks	1 min
Line temperature	BetaTherm/Thermistor 10K3D630-1 (NTC or RTD)	3	± 1.0%	± 2.0%	4-6 weeks	1 min
Air flow	The Energy Conservatory/True flow meter & DG700 pressure gauge	1	± 7% CFM ± 1% Pa	+5%-15%CFM	Instant	5 minute average
Air flow	Testo/Anemometer 0560 4052	1	± 2.0%	D/K	Instant	5 minute average
Pressure transducer	Transducer Direct/TDA09 model	2	± 0.5-2%	± 2.0%	4-6 weeks	1 min

Table 5-10: Measurement Points and Instrumentation Detail for RCA Verification

Function/ Data Point to Measure	Equipment Brand/Model	Qty Req'd	Rated Full Scale Accuracy	Accuracy of Expected Measurement	Planned Metering Duration	Planned Metering Interval
Suction and discharge pressure	Crystal Engineering/XP2i, 1000psi model	1	± 0.1% of reading	± 0.3% of reading	15 min	5 min
Suction and liquid line temp	Omega/RTD surface probes Class B or better SA2C-RTD-3-100-B-40	2	1°F @ 150°F	1°F @ 150°F	15 min	5 min
Ambient temp	Omega/RTD ambient probe class B or better HSRTD-3-100-B-40-E	1	1°F @ 150°F	1°F @ 150°F	15 min	5 min
<Spare>	Omega/RTD ambient probe class B or better HSRTD-3-100-B-40-E	1	1°F @ 150°F	1°F @ 150°F	15 min	5 min
Temperature	Omega/Digital RTD thermometers HH804U	2	N/A	N/A	N/A	N/A
Wet/dry bulb temp	Vaisala/H41 Model	1	1 °F, 2% RH	1 °F, 2% RH	15 min	5 min
RMS Power	Fluke/49 Model Amprobe/Exetech Eq.	1	± 2.0%	± 2.0%	10 min	5 min
Refrigerant leaks	Bacharach/ Refrigerant leak detector, must detect R-410a Tru Pointe 19-7112	1	N/A	N/A	N/A	N/A
RMS Power	WattsUp Pro/Plug load meter	1	± 2.0%	± 2.0%	10 min	5 min
Air handler pressure/CFM	The Energy Conservatory/TrueFlow Air Handler Flow Meter Kit	1	± 7% CFM ± 1% Pa	+5%-15%CFM	Instant	5 minute average
Pressure	The Energy Conservatory/DG700 digital pressure gauge	1	± 1.0%	± 2.0%	15 min	5 min

5.2.3 Reference and Background for the Methods Applied

The RCA HIM savings analysis methodology was developed to be consistent with the California Public Utilities Commission (CPUC) Evaluation Protocols and Evaluation Framework. The HVAC team used refrigerant charge and airflow (RCA) test data to determine the change in EER, cooling total, and sensible capacity as a result of the RCA service. Pre-RCA performance is expressed in terms of a series of degradation factors that quantify the loss in efficiency and cooling capacity of the unit due to improper RCA. The performance degradation factors were used within the DEER modeling framework to produce unit energy savings for RCA adjustments across climate zones. For the verification tests, the instantaneous test data were compared to target values to establish whether a unit was properly charged. These data were also compared to contractor reported data to identify problems with contractor procedures and/or instrumentation. The team compared the estimates of post-maintenance performance to pre-maintenance performance of the same unit. A similar comparison was made to the in-situ performance of a new standard efficiency unit where possible.

Unit Energy Savings

Using the direct measurement of energy input, the operating efficiency was estimated by determining the system output or cooling delivered. The objective was to calculate the energy efficiency ratio (EER), as shown in Equation 1, a standard definition of the system efficiency of direct-expansion air conditioning.

Equation 1: General EER Equation

$$EER = \frac{CoolingDelivered(Btu/h)}{EnergyInput(W)}$$

The cooling delivered was derived from the measured properties of the air being cooled by the air-conditioning system and the measured airflow during cooling operation. Using the psychometric properties of air, as defined by ASHRAE, the team calculated the specific enthalpy of the return and supply air. The enthalpy is the amount of energy content of one pound of air and was determined by measurements of air temperature and moisture content. The density or specific volume can also be determined from the same measured properties and is used to relate the volumetric air measurements to the mass flow rate used in the delivered cooling calculation. The enthalpy and specific volumes were defined as the following:

$$h_{spec} = Enthalpy\_moist\_air(T_{db}, \%RH) \qquad v_{spec} = specVolMoistAir(T_{db}, \%RH)$$

We determined the rate of energy transfer from the air—the cooling delivered—by calculating the difference in specific enthalpies of the return and supply air together and multiplying that by the measured airflow. Equation 2 was developed to report cooling in the standard terms of British thermal unit per hour (Btuh).

Equation 2: Cooling Delivered Equation

$$\dot{Q} = \left(\frac{CFM}{v_{spec-return}} \right) * 60 * (h_{spec-return} - h_{spec-supply})$$

where:

$\dot{Q}$ = Cooling Delivered. The rate of energy transfer from the air [kBtuh]

CFM = True flow test flow rate [CFM]

$v_{spec-return}$ = Specific volume of the return air [lbm/cf]

$h_{vol-supply}$ = Specific enthalpy of the supply air [kBtu/lbm]

$h_{vol-return}$ = Specific enthalpy of the return air [kBtu/lbm] for residential units or mixed air for commercial units

Finally, the evaluation determined EER as follows in Equation 3. This equation assumes constant fan-power consumption, as it was the predominant fan type for the existing AC units subject to maintenance by the programs. No variable speed fans were encountered in the field monitoring for RCA measures.

Equation 3: Evaluation EER Equation

$$EER = \frac{\dot{Q}}{kW_{cond} + kW_{AHU}}$$

where:

kW_{cond} = Condensing unit power (determined from the watt transducer)

kW_{AHU} = Air handler power (from spot watt measurement)

It should be noted that the Watt transducer measured the compressor, condenser fan, and supply fan power at commercial and residential rooftop package units. The relationship of efficiency to operating conditions was developed in the bi-quadratic form, specified by ASHRAE for use in building energy modeling software such as DOE-2. The standard curve-fits to measured data had outdoor temperature (ODB) and return air wet-bulb temperature (EWB) as dependent variables for unit efficiency and capacity. The cooling delivered by the air conditioner and the efficiency of cooling operation are driven by the embedded energy in the air at the two heat exchangers. The hotter and more humid the conditions forced onto the condenser (ODB) and evaporator (EWB) will result in lower delivered cooling and efficiency. In general, the monitored data revealed little variation in the evaporator entering wet-bulb temperature. Where insufficient return air data points were available for pre- and post-maintenance periods, the function was simply based on outside temperature with the other coefficients set to zero.

The differences in pre- and post-performance were incorporated into the DEER modeling tools. The model inputs were degradation factors that represented the diminished cooling output and efficiency of under- and over-charged units. The three primary inputs were degradation factors for total cooling capacity, sensible capacity, and efficiency. The inputs were developed for two commercial and four residential charge-adjustment categories using the performance changes from M&V data collected in this study. These data were supplemented with RCA test data from the 2008 DEER study, where appropriate, to represent particular charge-change categories and building types. The charge categories and final combination of M&V results with DEER inputs are shown in Table 5-11. The capacity and energy input ratio (EIR)[8] factors were used to establish the unit's pre-measure performance. Post-measure performance was simulated with all factors set to one. Similar to the data used for the DEER analysis, the field average degradation factors show greater variability and somewhat different trends than laboratory results. An important distinction is that actual monitored results were often at much drier conditions than laboratory rating conditions and units responded differently to charge adjustments.

Table 5-11: Final Residential RCA Inputs

Charge Change Category	N	Cap Frac	Sens Cap Frac	EIR Frac (comp and cond fan)
dCharge >= -20%	21	0.822	0.905	1.359
dCharge -5 to -20%	28	0.931	0.964	1.133
dCharge +5 to +20%	27	0.897	0.926	1.099
dCharge >=+20%	17	0.843	0.884	1.104

Installation Rate

Generally, the installation rate is the proportion of measures "installed and working properly" and for RCA measures was defined by the HVAC team as units which pass a set of diagnostic tests. The installation rate was determined by comparing on-site diagnostic results of randomly selected program units to the final AC contractor-collected diagnostic parameters, known as

[8] Energy input ratio (EIR) is the inverse of efficiency and thus higher numbers are less efficient.

subcooling and superheat.[9] The refrigerant superheat and subcooling were calculated according to American Heating and Refrigeration Institute (AHRI) definitions. Some programs did not report data on charge adjustments; some only reported adjustments without measurements. Where contractor measurement data were available, the data did not include enough parameters to estimate the efficiency of the system before and after adjustment.

Units that were not clearly identifiable using serial number data and/or did not have service stickers made it difficult to conduct the RCA verification activities. The HVAC team worked with program managers and contractors to mitigate the issue, but in some cases the sample sizes were impacted by the inability to identify treated air conditioners during site visits to customers where not all units were treated.

Correct refrigerant charge was verified by measuring the amount of subcooling in the condenser for air-conditioning units with a thermostatic expansion valve (TXV) or the amount of superheat in the evaporator for those with fixed-orifice metering. These measured values were then compared to targets, as determined by the manufacturer, as a function of the unit operating conditions. Typically, manufacturers publish subcooling targets for TXV units manufactured after 1992. The majority of units manufactured before this date were not equipped with TXVs; for those that were, the manufacturer target as stamped on the nameplate or presented in manufacturer literature was used, otherwise a standard target of 10˚F[10] was used whenever a specific manufacturer target was unavailable. Superheat targets were calculated from Table RT-2 (in the 2005 CEC Residential Compliance Manual[11]) using measured return-air wet-bulb and condenser-entering-air dry-bulb temperatures.

The IOU programs, CEC Title 24, and industry standard procedures for meeting superheat targets are consistent for units with fixed-orifice metering devices. For systems with TXVs, some RCA measures within IOU programs during particular program years declared units properly charged that tested within plus or minus five degrees of the subcooling target. The verification team followed industry standards and Title 24 requirements by tightening the standard to plus or minus three degrees of the subcooling target.

Target superheat or subcooling values were obtained from manufacturer's data or calculated from the *2005 Residential ACM Approval Manual* and compared to actual values. The units

[9] See Appendix D for more detail regarding the procedure for calculating actual subcooling and superheat and additional definitions of diagnostic calculations using RCA data.

[10] The default target was based on the default used by some, but not all programs and providers. The 10˚F subcooling target had a high frequency in programs records available and is near the average of units with known targets. The newest Title 24 does have a default target and AHRI does not track targets in their database.

[11] 2005 Residential Compliance Manual, California Energy Commission (CEC). Publication # CEC-400-2005-005-CMF. Fourth Quarter Revisions posted May 26, 2006.

were also further analyzed using all data available, including the measured cooling output using the airflow, power, and temperature and humidity measurements. The secondary and tertiary criteria were applied due to the fact that some units may have received maintenance and the diagnostic values improved, but were not within fixed criteria after all adjustments. Units that were adjusted by the program and generally operating at optimal efficiency were considered passing, which was defined as the EER Screen. All units were assigned a passing or failing status based on the first criterion of unit diagnostics and all failing units were then subject to the EER Screen. The criteria used to determine the installation rates of RCA measures were:

- Superheat / Subcooling Screen: Tests where the superheat or subcooling (TXV) values were within five or three degrees respectively of the target passed
- EER Screen: There were two possible ways a unit could pass the EER screen. If the unit in question passed one of these screens it was considered to be a passing unit.

1. The first method used nominal airflow and actual measured enthalpy to calculate output, which was then divided by the capacity. The tonnage was multiplied by 12,000 to convert it to Btuh. If the ratio of cooling output was 90% or higher of the capacity the unit was considered passing:

$$\frac{\left(h_{Return} - h_{Supply}\right) \times \left(NomAirflow\right)}{Tonnage \times 12{,}000}$$

2. The second method used actual measured airflow and enthalpy to calculate output, which was divided by the nominal capacity Again, the tonnage needed to be converted to Btuh. If the ratio of output to capacity was 80% or higher the unit was considered passing:

$$\frac{\left(h_{Return} - h_{Supply}\right) \times \left(MeasuredAirflow\right)}{Tonnage \times 12{,}000}$$

The team determined the diagnostics could be compared to the air-side measurement of efficiency, but independent efficiency assessments from refrigerant measurements were subject to much greater uncertainties than expected. Three methods of estimating efficiency, based on refrigerant-side measurements, were piloted for the installation rate of M&V and pre- and post-RCA metering. Ultimately, the approaches were not used as analysis, using field collected data, showed them to have large uncertainties, as described in Appendix C.

A primary issue revealed in the measurements was the fact that superheat was rarely measured near the evaporator for residential systems. Poorly insulated, long suction lines can pick up superheat between the compressor and evaporator. The superheat data on TXV systems will be analyzed further to inform adjustments to the measured superheat for non-TXV systems and estimate systematic adjustment factors for units where suction-line length and insulation quality were an issue.

In addition, under conditions when the superheat target was near zero the system was operating with a dry coil—a somewhat common situation. For these units, the team also looked at the subcooling of the unit with a target of 8°F. Units that had a reasonable value for measured superheat and a measured dry coil situation that passed the subcooling test were treated as passing.

5.2.4 Net-to-Gross Ratio

One objective of the California energy-efficiency program evaluations is to identify the portion of savings directly attributable to the program effort and to properly account for those effects that would have occurred in the absence of the program. California reporting protocols for the 2006-2008 program require the discounting of savings by a "free-ridership factor" in the estimation of net program savings by applying the NTGR. The 2006 Evaluation Protocols allow for the use of a participant self-report approach (SRA) to estimate the net-to-gross ratio for the Basic level of rigor and with additional participant-specific documentation for the Standard level of rigor.

The CPUC Energy Division convened a committee of evaluators to develop a standard framework for the measurement of NTGRs[12] for residential and small commercial programs in a systematic and consistent manner using the SRA approach. The approach was designed to fully comply with the CPUC's *Evaluation Protocols.*[13] The Energy Division developed the *Guidelines for Estimating Net-To-Gross Ratios Using the Self-Report Approaches (Guidelines)* in October 2007 as more detailed guidance than was available in the California *Evaluation Protocols* guidelines.

Participants who were involved in the decision-making process at each participating household or small commercial site were interviewed to measure the program's influence on respondents' decision-making. The survey obtained highly structured responses concerning the probability that the household or firm would have installed the same measure(s) during the same time period in the absence of the program. The survey also included open-ended and closed-ended

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[12] Currently, California net impacts are specified as net of free-riders and do not include either participant or non-participant spillover.

[13] TecMarket Works, Megdal & Associates, Architectural Energy Corporation, RLW Analytics, Resource Insight, B & B Resources, Ken Keating and Associates, Ed Vine and Associates, American Council for an Energy Efficient Economy, Ralph Prahl and Associates, and Innovologie. (2004). *The California Evaluation Framework.* Prepared for the California Public Utilities Commission and the Project Advisory Group.

questions that focused on the household's or firm's motivation for installing the efficiency measure. These questions covered all the requirements provided in the *Guidelines*, such as multiple questions; efficiency level; likelihood of adoption; timing and quantity; and consistency checks.

The NTGR algorithm derived four separate measurements of free-ridership from different inquiry routes. The first measurement consisted of responses to a series of yes/no questions that measured the impact of the program on the quantity, efficiency, and timing of the purchase. The second measurement consisted of a 0-10 scale that asked the likelihood that the respondent would have purchased the same exact high-efficiency measure in the absence of the program. The third measurement combined responses to the quantity and timing questions with questions set to a 0-10 scale that asked the respondents' agreement with the statement that, in the absence of the program, they would have paid the additional rebate amount to buy the high-efficiency equipment on their own. The final measurement combined responses to the quantity and timing questions with questions set to a 0-10 scale that asked respondents' agreement with the statement that the program was a critical factor in their decision to purchase the high-efficiency equipment. In cases where responses were inconsistent among the four measurements, an analyst reviewed responses to open-ended questions that asked for clarification of the inconsistency, and recoded the four measurements as needed.

These four measurements were averaged to derive the final free-ridership estimate at the measure level. Prior to finalizing the NTGR algorithm, the committee conducted iterative testing with a partial dataset. This testing contributed to the reliability of the algorithm and its computer coding.

Measures included in the HVAC program cluster utilized a modified version of the NTG Method to provide consistent questions to end-use customers where applicable. The HVAC program's deliveries allowed flexibility to the contractor in terms of the marketing and incentive, especially for RCA and duct-sealing measures. This variable program design element required a method that supplemented the participant self-report surveys with contractor surveys. The plan utilized participant and non-participant contractor interviews to determine if the end-use customers were aware of the incentive and if the service was available outside the program. The simple NTG questionnaire included questions necessary to analyze the effect of the acceleration on the lifetime savings stream and partial increase in efficiency levels or quantities of efficient equipment.

A vendor survey was completed for non-residential sites that indicated a high level of vendor influence in the decision to implement the energy-efficient measure. For those sites that indicated the vendor was very influential in decision making, the vendor survey results entered directly into the NTG scoring. Vendors were queried on the program's significance in their decision to recommend the energy-efficient measures and on their likelihood to have recommended the same measure in the absence of the program. The vendors contacted as part of this study were generally contractors, design engineers, distributors, and installers.

Appendix P contains the *Guidelines for Estimating Net-To-Gross Ratios Using the Self-Report Approaches* and self-report free-ridership algorithm and self-report free-ridership stability indicators.

5.3 Confidence and Precision of Key Findings

5.3.1 Planned Confidence and Precision

Survey sample sizes described in section 5.2.1, as prescribed by the California *Evaluation Protocols*, were at least 300 per program for NTG analysis. Where program delivery methods varied within a program, sample sizes were changed to address the differing nature of contractor-based and traditional residential and small commercial rebates. In some cases, the actual survey sample size was different than the minimum required by the protocols based on the program delivery method. The sample size of 300 will meet the precision target for a free-ridership or verification-type statistic to be captured that is pass- fail or 0 to 100%. Essentially, this size would achieve 10% relative precision or better where there is a Coefficient of Variation (CV) of 1 or less. This is true of all samples of large populations where the sample size was less than 1% of the population.

The overall verification and net savings sampling strategy was to achieve 10% precision at the 90% confidence level for each measure by utility. For cooling measures, the participation in each utility service territory was focused on the hotter, cooling-intense climates and very focused on particular California Energy Commission (CEC) climate zones. As expected for weather-dependent HVAC measures, the primary driver of expected savings (on a per-unit basis) is CEC climate zone, as defined by DEER and Title 24. For example, because over 90% of RCA measures in the PG&E residential program fall into climate zones 12 and 13, the verification sampling plan was to achieve 10% precision at the 90% confidence level for these two climate zones. This goal was relaxed for the other climate zones with the smallest impacts, such as the coastal zones with low participation. The sample stratification for verifications applies to the other IOUs, both residential and commercial and was the general strategy for verification and metered samples. Pre- and post RCA sample sizes for metered units described here were developed using a statistical model with an error ratio (ER) of 0.5 and a z-value of 1.645.[14] The metered samples and verification samples were intended to be of matched size and the metered sample considered in estimates of planned and achieved precision. Table 5-12 and Table 5-13 show the planned precision using our estimate of error ratio and the resulting sampling error bound on electric energy savings. The variation in relative changes in EER were assumed to have lower variations than the assumed ER used in the sampling assumptions, but the ultimate assumption was limited by the fact that the uncertainty of the modeling process used for ex-ante and ex-post results did not have a quantified error estimate nor was it feasible to determine the error for this study. The ultimate realized precision levels focused on the degradation factors developed and do not project error bounds on energy and demand savings.

Table 5-12: Residential RCA Samples and Savings

HIM	Program ID	Pre-Post Units	Error Ratio (er)	Sample RP at 90%CI	2006-08 kWh Savings	kWh Error Bound
Res RCA	PG&E2000R	90	0.5	9%	28,966,327	2,509,574
Res RCA	SCE2507	90	0.5	9%	56,440,821	4,881,425
Res RCA	SCE2502	10	0.5	26%	3,760,920	977,767
Res RCA	SDG&E3035	10	0.5	26%	1,373,476	356,885
Res RCA	PG&E2078	10	0.5	26%	1,191,979	309,547

Table 5-13: C&I Samples and Savings

HIM	Program ID	Pre-Post Units	Error Ratio (er)	Sample RP at 90%CI	2006-08 kWh Savings	kWh Error Bound
C&I RCA	PG&E2080	50	0.5	12%	9,161,619	1,064,462
C&I RCA	SCE2507	50	0.5	12%	9,758,899	1,128,921
C&I RCA	SDG&E3043	20	0.5	18%	2,944,930	538,907
C&I RCA	PG&E2068	60	0.5	11%	4,818,552	507,803

5.3.2 Achieved Confidence and Precision

The programs in 2009 were operating under bridge funding, which made it particularly difficult to perform pre- and post-monitoring of units at large multifamily complexes since some programs stopped serving this market segment. The pre- and post-RCA metering samples and achieved

[14] The error ratio measures the variability of measured energy savings relative to the program tracking estimate of energy savings and the z-value is a statistical value that defines the 90% confidence interval. The California Evaluation Framework, Chapter 13 further describes these terms with examples of their application.

results for measures within the mass-market and Comprehensive Manufactured-Mobile Home Program (CMMHP) programs are indicated in Table 5-14, Table 5-15, and Table 5-16 below. Recall that the samples were developed at the air conditioner unit level (metered units) and there were multiple units per site for multifamily sites and at some single family homes. The metered units were those where site measurements were completed according to the protocols described previously. The data quality-control protocols were applied to the raw collected data, which yielded the final number of air conditioner level tests (Units Passing Data Quality Check (QC)), which were available to the UES analysis. Additionally some units did not receive charge adjustments or the adjustment was not accurately recorded by the contractor and these units were also not included in the modeling runs. Recall that contractor cooperation under bridge funded programs was required to achieve the pre- and post-metering samples for RCA. The pre-post samples were coordinated to represent program activity, but were not sampled from a population. The climate zones with the highest participation levels and UES were targeted for the coordinated pre-post monitoring.

Table 5-14: SCE 2507 Pre-Post Metering Sample Achieved

RCA Status	Pre & Post Metering	
	MF	SF
Metering Sampling Target	70	20
Metered Sites	3	7
Metered Units	78	12
Units Passing Data QC	30	7

Table 5-15: PGE2000 Pre-Post Metering Sample Achieved

RCA Status	Pre & Post Metering	
	MF	SF
Metering Sampling Target	65	25
Metered Sites	1	3
Metered Units	11	5
Units Passing Data QC	3	4

Table 5-16: CMMHP Pre-Post Metering Sample Achieved

RCA Status	Pre & Post Metering	
Program	**SCE2502**	**SDGE3035**
Metering Sampling Target	10	10
Metered Sites	8	7
Metered Units	8	5
Units Passing Data QC	4	2

The pre- and post-RCA measurements of changes in efficiency and cooling output were grouped into residential and commercial. The relative change in parameters were fed through an energy simulation modeling process to determine savings for combinations of building types, climate zones, which were then applied to the population characteristics of the HIMs within each program. The variation in degradation factors was analyzed to produce initial estimates of the relative precision at the 90% confidence level of those parameters produced from M&V data. Producing a final error ratio was not possible at a program HIM-combination level since all data for residential and commercial RCA were combined to produce modeled measure savings. The precision estimates for the residential RCA degradation factors are shown in Table 5-17.

Table 5-17: Residential RCA M&V Achieved Precision

Final M&V Results		RELATIVE PRECISION		
Charge Change Category	N	Cap Frac	Sens Cap Frac	EIR Frac (comp and cond fan)
dCharge >= -20%:	4	13%	13%	14%
dCharge 0 to -20%:	6	10%	12%	9%
dCharge 0 to +20%:	10	7%	8%	7%
dCharge >= +20%:	12	12%	14%	13%
dCharge < +/- 5	4	9%	4%	12%
dCharge = 0, N/A	6	7%	8%	9%

The lack of precision for the particular measure groups required to extrapolate the gross unit energy savings led the HVAC team to combine the results with those of previous field studies in California. Both the M&V and previous data collected could be expressed in terms of degradation factors and the precisions below represent those for the final residential RCA inputs.

Table 5-18: Residential RCA Relative Precision of Final Inputs

Final Residential Inputs		RELATIVE PRECISION		
Charge Change Category	N	Cap Frac	Sens Cap Frac	EIR Frac (comp and cond fan)
dCharge >= -20%:	21	4%	3%	4%
dCharge -5 to -20%:	28	4%	3%	3%
dCharge 5 to +20%:	27	3%	4%	3%
dCharge >= +20%:	17	9%	10%	9%

The pre- and post-RCA metering samples and achieved results for measures within the commercial programs are indicated in Table 5-19, Table 5-20, and Table 5-21. The details of all units metered are summarized in Appendix E and details of challenges to achieving the metered samples are described in Section 5.7.

Table 5-19: SCE 2507 Pre-Post Metering Sample Achieved

RCA Status	Pre & Post Metering			
Climate Zone	8	10	13	Other
Metering Sampling Target	13	16	5	15
Metered Sites	4	6	1	0
Metered Units	13	27	2	0
Units Passing Data QC	7	21	2	0

Table 5-20: PGE2068 Pre-Post Metering Sample Achieved

RCA Status	Pre & Post Metering
Metering Sampling Target	60
Metered Sites	9
Metered Units	53
Units Passing Data QC	37

Table 5-21: SDG&E 3043 Pre-Post Metering Sample Achieved

RCA Status	Pre & Post	
Climate Zone	7	10
Metering Sampling Target	13	7
Metered Sites	4	2
Metered Units	9	6
Units Passing Data QC	6	4

The relative change in parameters were fed through an energy simulation modeling process to determine savings for combinations of building types, climate zones, which were then applied to the population characteristics of the HIMs within each program. The variation in degradation factors was analyzed to produce initial estimates of the relative precision at the 90% confidence level of those parameters produced from M&V data. Producing a final error ratio was not possible at a program HIM-combination level since all data for commercial RCA were combined to produce modeled measure savings. The precision estimates for the degradation factors are shown in Table 5-22.

Table 5-22: C&I RCA M&V Achieved Precision

Final Commercial RCA Inputs		Relative Precision		
Charge Change Category	Sample Size (n)	Cap Frac	Sens Cap Frac	EIR Frac (comp and cond fan)
Charge Increase	19.000	2%	4%	2%
Charge Decrease	4.000	2%	2%	3%

5.4 Validity and Reliability

5.4.1 Measurement and Calculated Uncertainty of System Efficiency

Uncertainty analysis was conducted to increase the reliability of the results by reducing random measurement error and identifying and mitigating potential sources of systematic bias. The evaluators explored the uncertainties in the estimate of instantaneous system efficiency using the current instrumentation suite. The HVAC Team also developed a monitoring plan to record required parameters and estimate system performance over varying operating conditions. The team worked with the program management and their contractors to pursue pre-post monitoring of sites receiving charge and airflow adjustments through the programs. As outlined in previous sections, the goal was to record data for up to 390 units, although the actual number was less given the constraints of favorable weather for these tests in the remainder of the program cycle and the ability to coordinate pre implementation visits with participant sites and complete metering before the end of favorable weather conditions in 2009. The initial step was a pilot phase to further explore the measurement techniques, instrumentation, and analysis options. Prior to the pilots, the evaluators looked in greater detail at the setups and instrumentation for past RCA research, which are predominately lab studies or field studies by 2006-2008 VSPs.

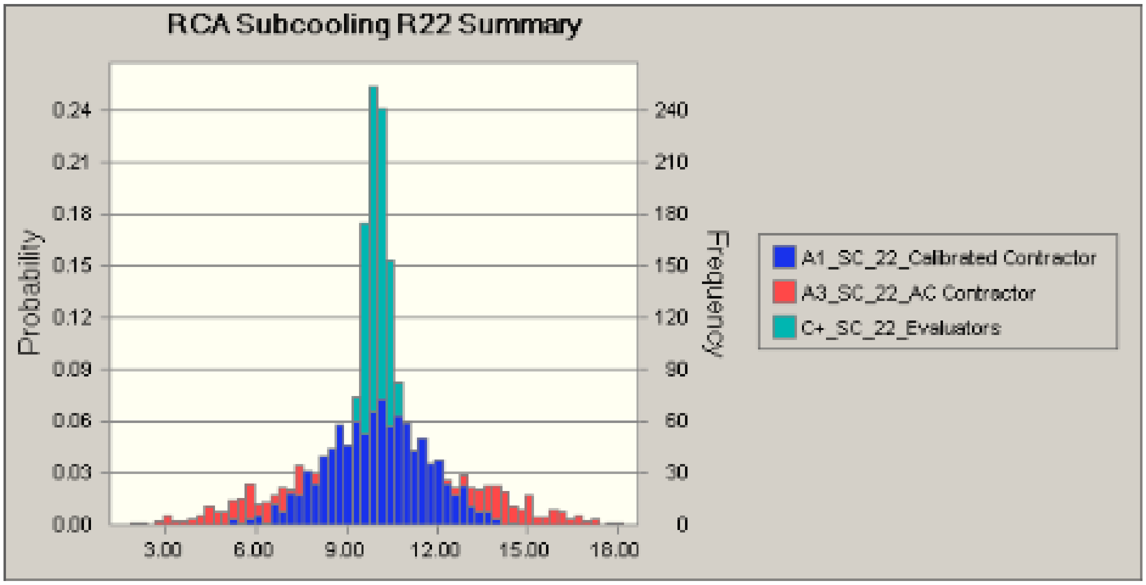
For the airside measurement based efficiency estimate, it is known through experience and other research that the instantaneous measurement of airflow was a major source of uncertainty. Flow grids, flow hoods, and anemometers all offer accuracies in the range of five to fifteen percent under close to ideal and controlled conditions. In existing construction it is likely that any particular method may have even greater uncertainties. Additional error can be introduced by sharp elbows in return ducts, coil bypass, the influence of downstream or upstream duct leakage on temperatures and flow, and stratification. In order to explore alternative energy balance methodologies not subject to airflow uncertainties, indirect methods used to determine refrigerant mass flow rate were evaluated by the HVAC team. Details of the methods are presented in Appendix C.

5.4.2 Uncertainty Analysis of RCA Diagnostics

The current procedure for CPUC RCA verification includes measurements of operating conditions collected by contractors and also includes instantaneous direct airflow and power measurements. The verification assessment also used a refrigerant leak detector to check if there were refrigerant leaks which would rapidly degrade measure savings. The instrumentation suites for verification are manufactured and calibrated to tighter tolerances than those being used by contractors in the field. This reduction in instrumentation uncertainty should produce an independent and more accurate assessment of the appropriateness of refrigerant charge modifications made by the contractors. The program evaluators ran Monte Carlo simulations to explore engineering propagation of error of the various instrumentation components required to assess superheat and subcooling which was used to inform the need and selection of improved instrumentation suites.

Essential to this study was the accuracy of the instruments used for typical refrigerant charge and airflow testing including superheat and subcooling tests. To that effect both the accuracy levels and instrument costs of several models were subject to comparison. The models of the instruments tested included calibrated instruments used by the contractors and those eventually chosen for use in the study (the evaluator). In each case it was determined that the accuracy of the instruments used by the evaluator for this study far exceeded that of the contractors. An example of these analyses is shown in Figure 5-4 for a system with R-22 refrigerant and a thermal expansion valve (TXV) metering device. The figure shows that the HVAC Team's instrumentation suite is more likely to achieve the target of 10 degrees subcooling than instrumentation that is typically used by AC contractors and VSPs.

Figure 5-4: Monte Carlo Simulation Results for Various Instrumentation Precisions: Air Conditioner with TXV and R-22 Refrigerant



5.4.3 Uncertainty Analysis of Cooling Measurements

The HVAC team recognized that the accuracy of EER measurements were dependent primarily on the airflow and supply enthalpy measurements. The power measurements were accurate to within 2% and the return enthalpy measurements were generally steady during cooling operation under conditions where most sensors have optimal accuracy. The uncertainty in airflow and supply enthalpy measurements used in the RCA study are described in detail followed by Monte Carlo Simulation results.

Uncertainties of Airflow Measurements.

Any flow measurements can be inaccurate in certain air flow geometries, but, in general, the flow grid used in this study and fan-assisted flow meter methods perform well. The true reference method is an inline flow meter which is only practical in laboratory settings. The flow grid method takes about 20 minutes to perform. In laboratory settings, the fan-assisted flow meter method, which takes significantly longer at around 1 hour to perform, has a mean difference of only 7% from the flow plate method. In the Palmiter and Francisco (2000)[15] study of 74 houses, preliminary comparisons of the fan-assisted flow meter to airflows using the flow plate and grid found measurements with a mean difference of 17% with less than 5% flow

[15] Palmiter, Larry and Francisco, Paul. 2000. "Development of a Simple Device for Field Air Flow Measurement of Residential Air Handling Equipment."

difference in 54% of the houses. The flow grid has a manufacturer stated measurement accuracy of plus or minus 7% under ideal installation conditions, which is supported by the literature.

Airflow measurements using the flow plate and grid showed a negative bias of 9% to 14% relative to fan-assisted flow meter measurements, according to a more recent study of measurement techniques by Lawrence Berkeley National Laboratory (LBNL). It is unlikely that the bias is due to flow bypass because the rigid plate was taped to the air handler in each test; still the reason for the bias is unknown. Although the bias was within measurement deviations reported by Palmiter and Francisco (2000), the LBNL study did not expect to find such a consistent bias.

Based on the evaluator's field experience using the orifice plate flow grid, all biases tend to be low. The openings on the flow grid pipes are all normal to the flow in a filter slot, but filtered returns and flow turbulence would likely account for many non-normal flow components which may be partially measured or "unseen" by the flow grid. As a result, there is an understanding that the "flow grid flow" is likely lower than actual system airflow and the difference needs to be quantified by future study. The uncertainty analyses show a consistent downward bias has negligible impact on the relative performance since the pre and post measurements used the same biased measurement.

Uncertainties of Supply Enthalpy Measurements

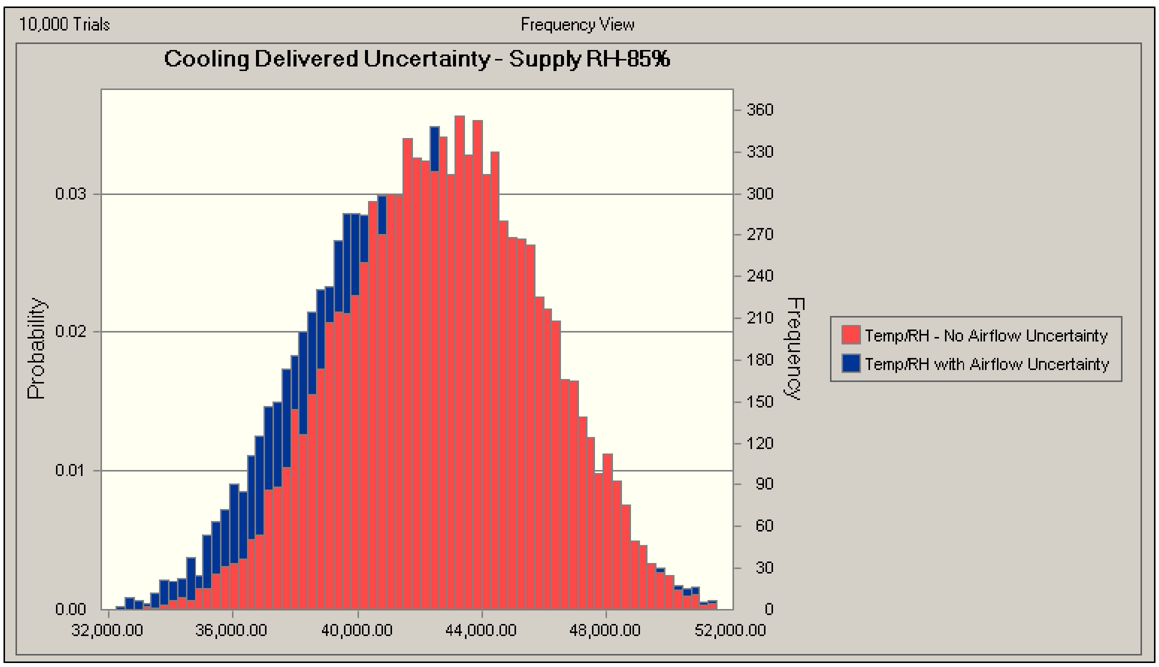
The tables for the monitoring points included a combination RH /Temperature sensor in the supply plenum. The analysis did use the dry bulb temperature recorded by this sensor but it did not always use the recorded RH. The analysis anticipated the problems associated with measuring the RH of the supply airstream, where common RH sensors perform poorly (and often fail) at RH above 90%, a very common condition for the supply air. Yet the supply RH, or equivalent, is absolutely necessary in-order to calculate the supply air enthalpy, and ultimately the thermal output of the unit. RH measurements below 90% relative humidity had an accuracy of plus or minus 2.5% and accuracy above 90% can be 3.5% to 5%. Prolonged exposure to the high humidity such as the supply plenum also decreases the performance of the measurements below 90% RH to plus or minus 3.5%. Therefore, this analysis used a process to estimate the supply air enthalpy from sensor data.

The HVAC team assumed a saturated supply air stream if measurements of RH were above 90% because of the poor accuracy, especially after prolonged exposure. If the relative humidity measurements were below 90% the values were used in the calculations of supply enthalpy.

The enthalpy calculation was checked using the saturation temperature based on the return air absolute humidity and supply air dry bulb temperature to confirm dehumidification.

Trial simulations of these differences between the ideal and the actual supply air humidity did not lead to a significant error in the enthalpy or the final estimate of delivered cooling. The airflow uncertainties were combined with the uncertainties in humidity measurements to produce Monte Carlo simulations of delivered cooling. Figure 5-5 below shows the biasing effect of airflow on the cooling calculation. The results show the maximum relative precision at the 90% confidence interval of a random cooling delivered measurement to be 11.9% without introducing the airflow uncertainty and 13.5% with the airflow uncertainty added.

Figure 5-5: Uncertainty in Individual Cooling Measurements

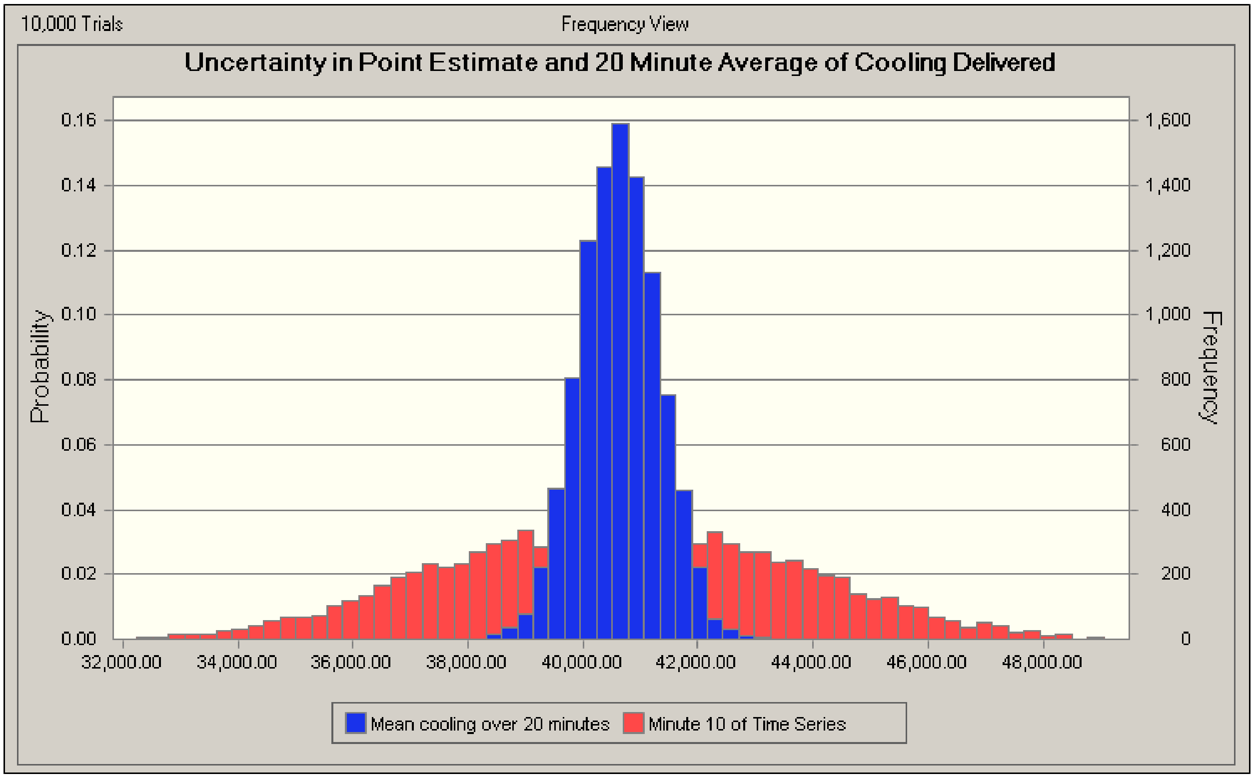


For any particular cooling cycle of 20 one-minute measurements, the uncertainties on the average cooling delivered for that cycle are on the order 3.0% without introducing airflow and 7% with airflow uncertainties. This is true if all measurements in the time-series are unbiased and are not statistically significant from one another[16]. Figure 5-6 below illustrates the Monte Carlo simulation of the average delivered cooling along with the simulation of one-measurement point within the series. This shows the primary justification for taking time-series measurements

[16] California Evaluation Framework: Chapter 12 Uncertainty: Page 302, Pooling Two Statistically Independent Estimators of the Same Parameter

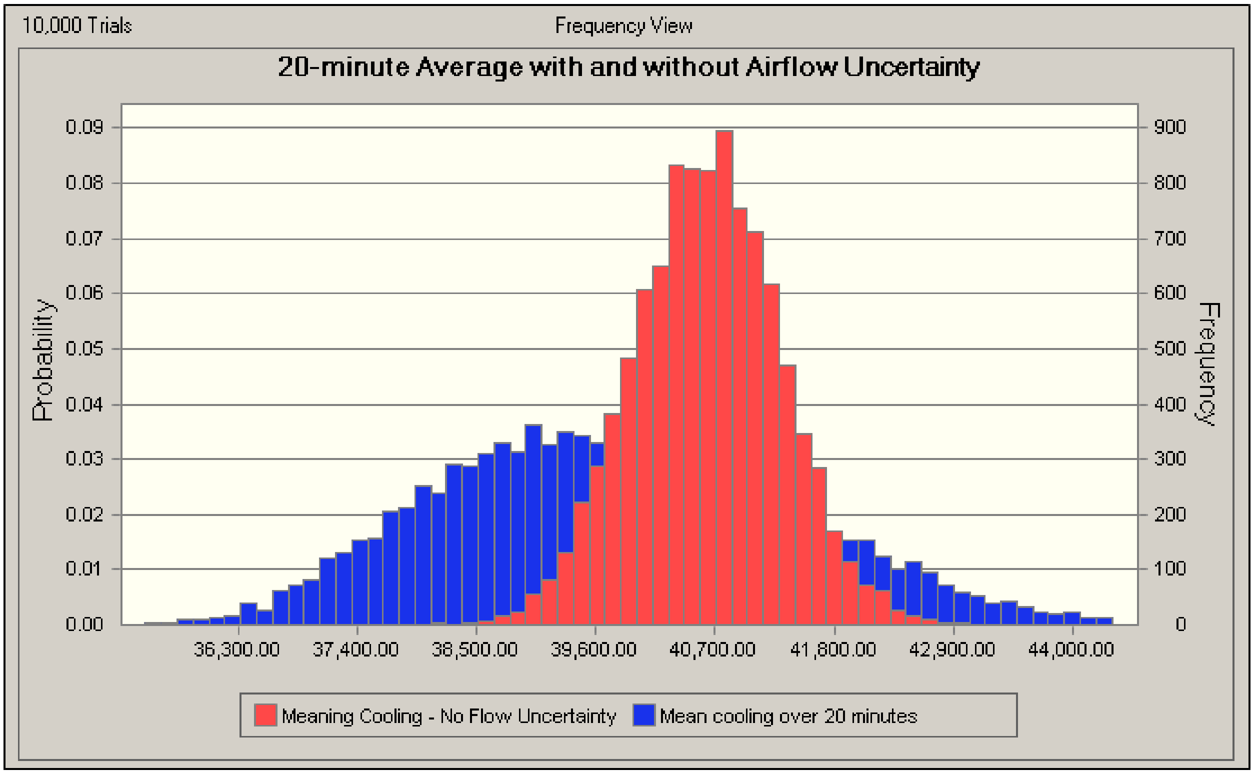
as opposed to instantaneous measurements of efficiency; averaging measurements over sufficiently long cooling cycles produces a more precise estimate.

Figure 5-6: Uncertainty in Average Cooling Compared to Individual Measurement Uncertainty – No airflow Uncertainty



The apparent bias in the airflow measurements and sensor placement and calibration could lead to an inaccurate measurement of efficiency despite the estimate being reasonably precise. Figure 5-7 shows the increased uncertainty of adding the airflow measurement bias which also biases the mean cooling estimate low by 2% in addition to roughly doubling the uncertainty of the mean cooling estimate. So long as both the pre- and post-measurements were equally precise and had the same amount and direction of bias, inaccuracy, there was a negligible effect on the relative performance. Sensors that went out of calibration or changed location from pre- to post-measurement were excluded from analysis as it was not reasonable to assume consistent inaccuracy.

Figure 5-7: Uncertainty in Average Cooling with and without Airflow Uncertainties



The primary issue for measurements was the response time of the sensors which were on the order of five minutes in moving air. Additional simulations using real data from the sensors at different logging intervals showed that the one minute sampling rate chosen was the only acceptable option as five minute or greater intervals do not allow for response time compensation and lead to errors 50% or larger for five-minute intervals. The actual collected data showed good stability when cooling cycle of five minutes or longer are used in efficiency calculations. Ultimately only cooling runs greater than fifteen minutes were used in efficiency calculations for RCA to allow for "steady-state" comparisons across units.

5.4.4 Procedures to Minimize Non-response Bias

Non-response bias could occur when the HVAC team was unable to conduct data collection on a unit selected for the sample. This non-response bias could affect telephone surveys, site visit recruiting, and on-site data collection efforts.

The HVAC team took rigorous approaches to minimize non-response bias for each data collection mode. For example, for telephone surveys, our team used several approaches including:

- Extensively training and monitoring interviewers to ensure that they used effective introductions, followed professional survey research techniques, and used rapport building techniques to keep respondents on the phone.
- Using computer-aided telephone interviewing software that managed call queues so that numbers were called back at different times of the day and days of the week, at regular intervals, and at times that respondents requested.
- When possible, sent advance postcards or letters to respondents to both inform them of the purpose of the call and give them contact information to call in at their convenience.
- Using veteran interviewers to convert soft refusals.
- Using bilingual interviewers to reach Spanish households.
- When possible, traced bad or disconnected phone numbers to reach the desired respondent.

For all site visits (including verification and metering), our team also used several techniques to minimize non-response including:

- Training on-site technicians to ensure that they were effectively introducing themselves to homeowners and provided a letter of verification from the CPUC in both Spanish and English.
- Including customer interaction etiquette in training and provided staff with CPUC complaint forms to mitigate issues the customer had with the utility, program, or program vendors.
- Sending post cards in advance of the homeowners being called to schedule a site visit.
- Calling recruits up to five times – including weekends and evenings – recording date, time, and disposition of the contact.
- If recruits were not reachable, the schedulers left a brief message citing the program contact's name and a brief outline of the project, including the incentive offered and the scheduler's contact information to call back if interested in participating in the study.
- Providing site visit times throughout the day, evening, and weekends.

- When a contact was skeptical or wary of the study described, a CPUC "evaluation validation" letter was sent and the technical lead for the project called the contact to review the study in an effort to reduce the customer's concerns.
- Technical leads and project managers provided email follow-ups for commercial and multifamily recruitment, which included study descriptions, technical specifications of equipment, and proof of insurance.
- Using Spanish-speaking technicians when available.

When a participant was not home for their appointment, attempts were made to reschedule those missed appointments. If the contact canceled or the HVAC Team was unable to reschedule, effort was placed on rescheduling with the next contact, in terms of sample priority from the same climate zone.

Regarding data collected at the site, technicians used a data-collection form. Data items not collected during installation were flagged for collection at meter pick-up.

In addition, the research efforts for all HIMs employed stratified random-sample approaches. Random sampling ensured that there was no systematic bias in terms of how participants were selected for the telephone or on-site portions of the study. The stratification varied by HIM, but, in general, research efforts were stratified based on year of participation (to ensure that all program years are represented in the study) and utility. A number of HIMs, where savings are likely weather dependent, were also stratified based on climate zone (e.g., AC replacement, RCA, duct sealing, and furnaces) to ensure that a representative mix of participants by climate zone were included in the study.

In some cases, on-site sampling for verification of multiple units was employed, using accepted randomization techniques. For the pre-post metering efforts, the units selected were not based on randomization but rather pre-measurements of the evaluators or contractors and, in some cases, all available units at the site. Technical leads placed limits on the maximum number of units to be sampled per site, similar to verifications, to avoid "convenience sampling" by technicians and engineers where feasible. However, in the case of pre-post monitoring, coordination of sites was changed to allow as many units to be monitored per site as feasible given the difficulties in coordination. Program contractor data for randomly sampled residential and commercial units show a great deal of variation in the performance and performed maintenance of other units at the same site. Issues were called in to project managers to determine if there were technical feasibility issues with units selected through the randomization process, to ensure that only units not capable of following the M&V plan or out of scope would be "skipped" by field workers.

5.5 Detailed Findings

The UES estimates were intended to represent potential in-field savings from the RCA measure when properly applied. The differences between the ex-ante and ex-post estimates of performance increases due to application of RCA were reflected in the realization rate. Random samples of program participating units were used in a separate effort to determine the rate of proper installations. Since contractors had knowledge of which units were being monitored it was assumed that only proper installations would be applied to the pre-post units. Units in the pre-post study that would not have passed the post verification were not included in the modeling inputs, thus the UES estimated are representative of passing units which the installation rate is applied to. The field monitored results of residential and small-commercial air conditioners, before and after maintenance, were used to develop building energy simulation inputs in the form of performance degradation factors. This section describes the unit-level results of monitoring efforts used to develop the UES for each measure and the post verifications of randomly sampled program units.

5.5.1 Residential RCA Field Findings

The residential RCA efforts were centered on pre- and post-maintenance data logging of system efficiency. The large mass-market programs (PGE2000 and SCE 2507) were comprised more of multifamily than single-family units as shown in Table 5-23 and Table 5-24. The overall effort also included monitoring of manufactured homes. The final results across all residential units were used to develop the degradation factors. The pre- and post-coordination with contractors during their busiest time of year was the most challenging issue, as various degrees of cooperation were experienced by the HVAC team.

5.5.1.1 Program Demographics and Charge Distribution

The resulting energy savings from residential RCA were dependent on the building type and amount of refrigerant charge correction for the program populations. The building-types and climate-zone distributions of the programs guided the pre- and post-monitoring sampling and the resulting extrapolation of energy-savings results. The multifamily and single-family homes in the SCE 2507 residential RCA program population were distributed with seventy-eight percent multifamily units, as displayed below in Table 5-23.

Table 5-23: SCE 2507 Residential Building Types

Housing Type	% of Population
Multifamily	78%
Single Family	22%
Total	100%

The distribution for the populations of single-family and multifamily homes was similar in total and is presented in Table 5-24 per climate zone for PGE2000 residential RCA measures.

Table 5-24: PGE2000 Residential Building Types and Climate Zones

Climate Zone	% MF	% SF	Units
CZ02	84.6	15.4	127
CZ03	77.2	22.8	10
CZ04	99.6	0.4	32
CZ11	90.2	9.8	617
CZ12	94.6	5.4	2875
CZ13	65.6	34.4	6770

The refrigerant-charge adjustment distributions for the 2006-2008 programs determined which degradation factors would apply to each unit in the program population. The amount of charge added or removed was characterized with a variable called dCharge, where negative numbers mean refrigerant was removed and positive numbers indicate that refrigerant was added to the air conditioner. The dCharge was developed as a percentage of the mass of refrigerant added or removed relative to the nameplate- or manufacturer-specified refrigerant charge. The charge adjustments were placed in four bins consistent with the definitions for the degradation factors. Small refrigerant charge adjustments, five percent or less added or removed, generally claimed no savings through the programs and were not included in the energy modeling. The evaluated savings in this study were not significant for this category and laboratory studies show minimal to no savings as well. The charge adjustment populations from the IOUs' HVAC databases were characterized by the five categories of charge adjustment. The data shown in Table 5-25 were the actual adjustments for all the SCE 2507 residential RCA measures during 2006-2008. The categories were units with greater than 20% removed, units that had between 5%-20% of charge removed, units with less than 5% of the factory charge adjustment in either direction, units that had between 5%-20% of charge added, and units with greater than 20% added.

Table 5-25: SCE 2507 Charge Correction Distribution

Charge Change Category	N	%
dCharge >= -20%	4,776	8%
dCharge -5 to -20%	17,757	31%
dCharge < ±5%	23,584	
dCharge +5 to +20%	23,433	41%
dCharge >=+20%	10,560	19%

The distribution of charge corrections for the PGE2000 residential RCA measures in the 2006-2008 programs were similar, as shown in Table 5-26.

Table 5-26: PGE2000 Charge Correction Distribution

Charge Change Category	N	%
dCharge >= -20%	15,112	7%
dCharge -5 to -20%	58,898	28%
dCharge < ±5%	65,083	
dCharge +5 to +20%	98,752	48%
dCharge >=+20%	34,319	17%

5.5.1.2 Monitored Results

The pre- and post-metering samples were evaluated on the basis of improvements in EER, capacity, and sensible capacity, as well as demand reduction. These values were converted into degradation factors against a standard set of eQuest models, which were used to calculate savings for the DEER database. If the degradation factors from the field M&V were equivalent to those used in the ex-ante RCA estimates, the gross realization rates would be 100%. Thus the monitored results make no revision to usage estimates, only to the efficiency impacts of RCA. The simulation model runs resulted in estimates of energy and demand savings by climate zone and building type. The results for each sampled unit, with valid data meeting the data quality-control protocols as outlined in the methodology, are presented below. These include units with no charge corrections and small charge corrections, and some with unrecorded amounts of adjustment. Only capacity and efficiency changes for units with charge adjustments of greater than 5% of factory-charge added or removed were used in the final modeled energy savings.

The pre-post results were developed in terms of ten parameters for each unit. The units rated capacity in tons of cooling, factory-charge amount in ounces, and the amount of charge adjustment in ounces and percentage of factory charge characterized the unit. The pre- and post-measured parameters were the airflow in cubic feet per minute (CFM), total and sensible cooling capacity, and condensing unit and fan electric power draw. The change from pre- to post-maintenance cases was normalized using the temperature-based performance of the unit. To compare performance at a specific set of outdoor and indoor temperatures and humidity, the conditions of the pre- and post-cases were input into standard efficiency curves with cycling adjustments used by a DOE-2 simulation to represent existing system efficiency in the DEER analysis. The measured unit capacities and efficiency relative to this curve were used to establish the change in each parameter and were then averaged into the degradation factors for the energy simulations.

In some cases, a majority of runtime data were collected at relatively similar temperature conditions in both pre- and post-maintenance cases. In other cases, the pre- and post-conditions covered very different temperature or occupancy patterns. For the units where the performance covered similar pre and post conditions, the average condition was used, as presented in summary tables in Appendix E, to represent the capacity and unit efficiency. For units where the post-maintenance conditions were generally different, the conditions relative to the standard curve were used to calculate a representative capacity and efficiency value for the temperature and humidity conditions seen before maintenance.

The changes in total and sensible cooling capacity and energy-input ratio[17] were developed as fractions to represent the pre-condition where the factors for the post-maintenance case would all be equal to one. Finally, the change in efficiency was expressed as the pre- and post-energy efficiency rating (EER). The results were organized by residential building type. The multifamily, single family, and mobile home unit-level results are described below.

Multifamily

The programs in 2009 were operating under bridge funding, which made it particularly difficult to perform pre- and post-monitoring of units at large multifamily complexes since some programs stopped serving this market segment. Arrangements were made to monitor 89 units serving apartments in moderate and hot climates. Of those units, 30 had sufficient data to meet all the criteria for inclusion in the analysis; the reasons for units being excluded are shown in Appendix E. The addition and removal of charge was recorded along with calculated pre- and post-cooling outputs and efficiencies. The summary of the average pre- and post- airflow in cubic feet per minute (CFM/ton), total cooling capacity in kBtu[18] per hour (Total Cap / ton), and sensible capacity in kBtu per hour (Sens Cap/ton) per nameplate ton of cooling are shown in Table 5-27. In general, correcting the refrigerant charge led to increased cooling capacities and

[17] Energy input ratio, (eir), is the amount of energy input per delivered energy output using the same physical units, such as Btu/Btu. It is the inverse of efficiency and to convert the equation is the following: 3.412 / EER.

[18] kBtu = 1000 British Thermal Units, which is a common unit of thermal energy

higher efficiency, while the airflows were unchanged from before to after RCA and were less than manufacturer specifications.

Table 5-27: Average Pre-Post Results for Multifamily Homes

Multifamily Summary	CFM/ton	Total Cap/ton	Sens Cap/ton	EER
Pre:	334.4	7.24	5.18	5.11
Post:	334.4	8.08	5.58	5.64

Single Family

The single-family homes that were monitored generally had two air-conditioning units and were coordinated through the programs in normal operation. The changes in system performance and degradation factors were calculated for all units. The average pre and post efficiencies and capacities are shown in Table 5-28. Since the single-family programs were operating under bridge funding as they had during 2006-2008, site and contractor variation was better captured than the coordinated efforts for multifamily homes.

Table 5-28: Average Pre-Post Results for Single-Family Homes

Single Family Summary	CFM/ton	Total Cap/ton	Sens Cap/ton	EER
Pre:	342.0	8.56	6.81	5.55
Post:	342.0	9.08	7.30	6.12

Manufactured/Mobile Homes

The third-party comprehensive manufactured and mobile-homes programs were also sampled for the residential RCA high-impact measure pre- and post-monitoring study, in addition to the mass-market programs presented above. The results are shown in Table 5-29 below.

Table 5-29: Average Pre-Post Results for Mobile Homes

Mobile Home Summary	CFM/ton	Total Cap/ton	Sens Cap/ton	EER
Pre:	279.1	5.74	4.51	4.77
Post:	286.1	7.00	5.15	5.94

The average total cooling, sensible cooling, and energy-input ratio degradation factor results of the three tables above for single-family, multifamily, and mobile homes were organized into change-in-charge categories, as shown in Table 5-30.

Table 5-30: Final M&V Results for Residential RCA

Final M&V Results		Residential Units (<= 5 tons)		
Charge Change Category	**N**	**Cap Frac**	**Sens Cap Frac**	**EIR Frac (comp and cond fan)**
dCharge >= -20%	4	0.81	0.97	1.36
dCharge -5 to -20%	6	1.04	1.01	1.07
dCharge +5 to +20%	10	0.92	0.95	1.07
dCharge >=+20%	12	0.84	0.88	1.08
dCharge < ±5%	4	1.02	1.00	0.96
dCharge = 0, N/A	6	0.95	1.00	1.09

The amount of charge correction for the sampled units could not be controlled to be mapped onto the program-level distributions. The result was that the small sample sizes for the charge-removed categories may not well-represent the very large program population of those units. The HVAC team decided to combine the results with all available data, namely the detailed field-collected data in similar format used to develop the DEER 2005 and 2008 measure savings. As described previously, the time-series performance of the pre- and post-study was summarized into a consistent format as the instantaneous change in efficiency data by normalizing the data to the most prevalent observed conditions in the pre-RCA period. The M&V results better sampled the large amount of charge-added category than the data used for DEER, and the DEER data had larger samples for charge removals. The complementary samples were combined into the final input factors, which are lower than those of the DEER inputs but likely well-represent the average savings for residential impacts from RCA, as shown in Table 5-31. The modeling results using only evaluated data were produced prior to combining the data with previously collected field performance data and showed lower savings for all categories. The precision of the inputs from the M&V data set and the precision of the inputs for the combined set of inputs are shown in section 5.3.2.

Table 5-31: Final Residential RCA Inputs

Charge Change Category	N	Cap Frac	Sens Cap Frac	EIR Frac (comp and cond fan)
dCharge >= -20%	21	0.822	0.905	1.359
dCharge -5 to -20%	28	0.931	0.964	1.133
dCharge +5 to +20%	27	0.897	0.926	1.099
dCharge >=+20%	17	0.843	0.884	1.104

The HVAC team provided the input parameters to the DEER modeling team to run the degradation factors through the 2008 DEER models to produce unit energy savings for all combinations of building type, vintage, and climate zone. These per ton of cooling savings estimates were then applied to the RCA measure populations within the sampled programs using all available data on change in charge, building, type, vintage, and installed tonnage. An example of the UES per ton for some selected combinations of climate zones and building types are shown below in Table 5-32. The full tables of UES savings for all combinations were applied to the program populations using the final 2006-2008 total tonnages by climate zone. Results from single family models were applied to single family participants, multifamily model results were applied to multifamily units, and mobile home model results were applied to mobile home participants. The final extrapolation required weighting the savings using the specific charge change categories and building types, described in the previous section 5.5.1.1, from data contained in separate databases from the final program tracking data.

Table 5-32: Example UES for Residential RCA

Residential Example - Existing Vintage kWh / ton			
Charge Change Category	Climate Zone - IOU	Multifamily	Single Family
dCharge >= -20%	CZ10 - SCE	35.5	43.5
dCharge >= -20%	CZ13 - PGE	59.0	65.4
dCharge -5 to -20%	CZ10 - SCE	34.0	40.1
dCharge -5 to -20%	CZ13 - PGE	58.2	58.9
dCharge +5 to +20%	CZ10 - SCE	45.2	50.7
dCharge +5 to +20%	CZ13 - PGE	77.9	73.8
dCharge >=+20%	CZ10 - SCE	117.9	133.9
dCharge >=+20%	CZ13 - PGE	202.2	196.4

5.5.2 Residential RCA Verification Findings

The HVAC team applied the data quality-control protocols used for M&V data to the contractor data that was being verified. The RCA analysis examined a variety of refrigerant and air conditions to determine whether the contractors' data were thermodynamically possible to achieve the reported savings. Since these data were not available for all RCA HIMs in the programs, only the field M&V data were used to develop the verification rate. For programs:

- SCE 2507 and PGE2068: detailed data for all units were supplied.
- PGE2000: sufficient information to conduct all of the data quality-control protocols was not supplied
- Mobile-home – SCE2502, PGE2078, and SDG&E3035: sufficient information to conduct all of the data quality-control protocols was not supplied

The full program population, site-visit samples, and achieved results for post-only RCA programs are indicated in the tables below. Recall that the samples were developed at the air conditioner unit level (verified units) and there were multiple units per site for multifamily sites and at some single family homes. The verified units were those where site measurements were completed according to the protocols described previously. The data quality-control protocols were applied to the raw collected data, which yielded the final number of air conditioner level tests (Units Passing Data QC), which were used in the installation rate analysis for each program-HIM combination.

Table 5-33: PGE2000 Residential RCA Verification Sample Achieved

RCA Status	Post Only Verification	
	MF	SF
Population - Program Tracking	43,710	10,928
Verification Sampling Target	120	30
Verified Sites	32	21
Verified Units	120	30
Units Passing Data QC	111	24

Table 5-34: SCE 2507 Residential RCA Verification Sample Achieved

RCA Status	Post Only Verification	
	MF	SF
Population - Program Tracking	37,232	10,501
Verification Sampling Target	70	20
Verified Sites	14	8
Verified Units	48	12
Units Passing Data QC	41	10

Table 5-35: CMMHP RCA Verification Sample Achieved

RCA Status	Post Only Verification		
Program	**SCE2502**	**SDGE3035**	**PGE2078**
Population - Program Tracking	4415	1872	1743
Verification Sampling Target	6	6	6
Verified Sites	6	6	6
Verified Units	6	6	6
Units Passing Data QC	6	6	6

Installation Rate Field Work

For systems with TXV, some programs for particular program years allowed an uncertainty of plus or minus five degrees of subcooling relative to target, while the industry standard, Title 24, and the HVAC team required plus or minus three degrees subcooling. Target superheat or subcooling values were obtained from nameplates, manufacturers' data, or calculated from the 2005 Residential ACM Approval Manual and compared to actual values. The units were also further analyzed using all data available, including the measured cooling output using the airflow, power, and temperature and humidity measurements. The secondary and tertiary criteria were applied due to the fact that some units may have received maintenance and the diagnostic values improved, but were not within fixed criteria after all adjustments. Units that were adjusted by the program and generally operating at optimal efficiency were considered passing, using the following criteria:

- Superheat / Subcooling Screen: Tests where the superheat or subcooling (TXV) values were within five or three degrees respectively of the target passed
- EER Screen: There were two possible ways a unit could pass the EER screen. If the unit in question passed one of these screens it was considered to be a passing unit.

1. The first method used nominal airflow and actual measured enthalpy to calculate output, which was then divided by the capacity. The tonnage was multiplied by 12,000 to convert it to Btuh. If the ratio of cooling output was 90% or higher of the capacity the unit was considered passing:

$$\frac{\left(h_{\mathrm{Return}} - h_{Supply}\right) \times \left(NomAirflow\right)}{Tonnage \times 12{,}000}$$

2. The second method used actual measured airflow and enthalpy to calculate output, which was divided by the nominal capacity Again, the tonnage needed to be converted to Btuh. If the ratio of output to capacity was 80% or higher the unit was considered passing:

$$\frac{\left(h_{\mathrm{Return}} - h_{Supply}\right) \times \left(MeasuredAirflow\right)}{Tonnage \times 12{,}000}$$

In PGE2000 RCA, 41.9% of the units passed the subcooling/superheat test and an additional 13 of the 69 failing units passed the EER target screening for a total pass rate of 51.5% (Table 5-36).

Table 5-36: PGE2000 RCA Verification Screen Results

	Superheat / Subcooling Target Screen	EER Target Screen	Final Screen Result
Pass	57	13	51.5%
Fail	79	66	48.5%
Total	136	79	100.0%

For SCE 2507, 16 units passed the superheat/subcooling diagnostic test and an additional 14 of the 39 failing units passed the EER screen for a final field passing rate of 54.5%, shown in Table 5-37.

Table 5-37: SCE 2507 RCA Verification Screen Results

	Superheat / Subcooling Target Screen	EER Target Screen	Final Screen Result
Pass	16	14	54.5%
Fail	39	25	45.5%
Total	55	39	100.0%

The RCA verification results for the CMMHP programs, PGE2078, SCE2502 and SDG&E3035, were generally better than the mass market programs, shown in Table 5-38. One program design distinction from the other RCA programs was the use of one primary service provider for all maintenance measures in the program.

Table 5-38: CMMHP RCA Verification Screen Results

	Superheat / Subcooling Target Screen	EER Target Screen	Final Screen Result
Pass	16	0	88.9%
Fail	2	2	11.1%
Total	18	2	100.0%

5.5.2.1 Program-Weighted Residential RCA Savings

Savings per installed air conditioner were calculated for PGE2000 as shown in Table 5-39, along with total annual energy savings in kWh. The total savings reported were rounded to one decimal place for demand (kW) and the nearest integer for energy savings (kWh). Savings were based on charge corrections within the program and on building type distributions (single-family or multifamily). The largest participation levels were in California Energy Commission climate zones (CZs) 12 and 13, where the building-type distributions were 94.6% multifamily in CZ12 and 65.6% in CZ13 as presented in Table 5-24. The proportion of building types and charge corrections were applied to create a weighted average for each climate zone UES estimate presented below. For PGE 2000, most units experienced a charge increase in the 5%-20% range. The units shown below are per air conditioner using the average tonnage of the units in the charge distribution database.

Table 5-39: PGE 2000 Residential RCA ex-post UES and Total Savings

	A	B	C	D	E	F
Climate Zone	kW/unit	kWh/unit	Therms/unit	Number of Units	Total kW [Column D * Column A]	Total kWh [Column D * Column B]
CZ1	0.024	7.09	0.000	2	0.0	14
CZ2	0.102	40.08	0.000	1248	127.7	50,018
CZ3	0.029	12.49	0.000	367	10.6	4,583
CZ4	0.048	27.37	0.000	667	32.2	18,257
CZ5	0.018	4.41	0.000	1	0.0	4
CZ11	0.156	132.04	0.000	3950	617.6	521,542
CZ12	0.145	73.41	0.000	19840	2875.0	1,456,387
CZ13	0.237	207.95	0.000	28562	6770.4	5,939,384
CZ16	0.062	28.86	0.000	1	0.1	29

Note: Numbers in the table have been rounded

Total annual savings and savings per installed air conditioner were calculated by climate zone for RCA measures in the SCE 2507 Program as shown in Table 5-40. Savings were driven by the fact that 78.4% of units were multifamily and that most units experienced charge corrections in the range of 5%-20% increases.

Table 5-40: SCE 2507 Residential RCA ex-post UES and Total Savings

	A	B	C	D	E	F
Climate Zone	kW/unit	kWh/unit	Therms/unit	Number of Units	Total kW [Column D * Column A]	Total kWh [Column D * Column B]
CZ6	0.049	50.65	0.000	5,292	261.5	268,035
CZ8	0.166	91.32	0.000	20,580	3409.3	1,879,450
CZ9	0.163	151.09	0.000	25,646	4183.1	3,874,966
CZ10	0.217	131.77	0.000	60,054	13027.8	7,913,285
CZ13	0.205	190.38	0.000	8,966	1836.8	1,706,911
CZ14	0.317	328.57	0.000	8,129	2580.6	2,670,937
CZ15	0.312	487.75	0.000	14,186	4430.3	6,919,272
CZ16	0.174	79.67	0.000	347	60.3	27,646

Note: Numbers in the table have been rounded

Total annual kWh savings and savings per ton for PGE 2078 were calculated and are shown in Table 5-41. These savings were based on building type and charge-correction distributions. For PGE2078, the savings for the mobile/manufactured home building type were applied to the total program tonnage in each of the charge categories and then extrapolated into the climate zones shown below.

Table 5-41: PGE 2078 Residential RCA ex-post UES and Total Savings

	A	B	C
Climate Zone	kWh/ton	Tons	Total kWh [Column A * Column B]
CZ02	52.96	71	3,760
CZ03	27.98	287	8,029
CZ04	55.39	881	48,796
CZ05	26.37	1	26
CZ11	108.43	304	32,962
CZ12	79.59	2079	165,461
CZ13	123.89	1603	198,595
CZ16	55.03	2	110

Note: Numbers in the table have been rounded

Total annual savings and savings per ton for SCE 2502 were calculated for each climate zone as shown in Table 5-42. Savings were calculated using the distributions of building type and charge correction.

Table 5-42: SCE 2502 Residential RCA ex-post UES and Total Savings

	A	B	C
Climate Zone	kWh/ton	Tons	Total kWh [Column A * Column B]
CZ06	68.51	648	44,395
CZ08	102.48	1823	186,818
CZ09	87.78	1411	123,854
CZ10	119.33	7315	872,866
CZ14	184.10	518	95,362
CZ15	235.90	1530	360,933

Note: Numbers in the table have been rounded

No per-site climate zone data for SDG&E3035 was available, so total savings and savings per ton were calculated together for all climate zones, as shown in Table 5-43. These results were based on building type and charge-correction data across all climate zones in SDG&E territory.

Table 5-43: SDG&E 3035 Residential RCA ex-post UES and Total Savings

	A	B	C
Climate Zone	UES kWh/ton	Tons	Total kWh [Column A * Column B]
All	80.54	5616	452,317

Note: Numbers in the table have been rounded

The final evaluated energy savings for the Residential RCA measures evaluated in the mass-market and CMMHP programs were combined with the calculated installation rates from the post-field verifications to produce the final installed energy savings.

The final ex-post gross electricity savings in kilowatt-hours (kWh), HIM realization rates, installation rates, and final installed gross energy savings are shown in Table 5-44. Note that the savings below do not include the effects of free-ridership which is described and applied in section 5.6. The difference between the ex-ante and ex-post estimates of performance increases due to application of RCA were reflected in the gross realization rate. Random samples of program participating units were used in a separate effort to determine the rate of proper installations. Units in the pre-post study that would not have passed the post verification were not included in the modeling inputs, thus the UES estimated are representative of passing units which the installation rate was applied to.

Table 5-44: Residential RCA ex-post Gross Annual Energy Savings

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	HIM Ex-ante Gross kWh Savings	HIM Ex-post Gross kWh Savings	HIM Gross kWh Realization Rate [Column B/Column A]	HIM Install Rate	HIM Installed Ex-post Gross kWh Savings [Column B * Column D]	HIM NTGR	HIM Ex-post Net kWh Savings [Column E * Column F]
Res RCA	PGE2000	28,966,327	7,990,218	28%	52%	4,114,962	0.63	2,592,426
	PGE2078	1,191,979	457,739	38%	89%	406,930	0.78	317,405
	SCE2502	3,760,920	1,684,228	45%	89%	1,497,279	0.78	1,167,878
	SCE2507	56,440,821	25,260,503	45%	55%	13,893,277	0.97	13,476,479
	SDGE3035	1,373,476	452,317	33%	89%	402,109	0.78	313,645

5.5.3 Commercial RCA Field Findings

For the SCE 2507 Program, of the 31 contractors listed as performing commercial service, six were willing to participate in the metering effort. The cutoff date for installing metering equipment was set at September 28, 2009, to allow for adequate data collection before the cooling season ended. The contractors had a limited number of sites available, as they would not perform RCA testing during the hottest months of summer. The temperatures remained unseasonably hot until late in the season, preventing contractors from pursuing RCA work until near or past the metering cutoff date. The team attempted to install as many meters as possible, which resulted with 42 meter installations. Mechanical issues, such as compressor and metering equipment failures, further reduced the sample size to 36 units in SCE territory.

The SDG&E 3043 Pre/Post Program used almost all of its rebate allocation within the first quarter of 2009, which resulted in sites being approved on a case-by-case basis only by the program implementer. Because few contractors participated, the sample size was smaller than expected with 16 meters installed. Due to unit mechanical failures and problems with metering equipment, the final sample size was reduced to 10 units.

The PGE2068 Program had few contractors with the capacity and willingness to field M&V sites, resulting in the majority of units needing to be monitored by one contractor. The HVAC team completed 53 unit installations, including several multistage units. These units presented analytical challenges that prevented many from being included in the final evaluation analysis.

No units were achieved for the PGE 2080 Program due to unsuccessful coordination attempts.

5.5.3.1 Program Demographics and Charge Distribution

The resulting energy savings from commercial RCA were dependent on building type and the amount of refrigerant-charge correction within program populations. The building types and climate zone distributions of the program populations guided the pre- and post-monitoring sampling and the resulting extrapolation of energy-savings results. Building-type distribution was recorded within each climate zone and is presented below in Table 5-45 for C&I RCA projects. The building types represent where the tracking records generally agreed with other information, such as the business name and or NAICS code. The "Other" category, unclassified building types, was generally comprised of the typical building types listed, but the HVAC team did not undertake assigning types to all sites in the program populations that were not well-tracked in the databases. The best judgment of the HVAC team was used to assign the "Other" category to building types for the savings analysis. For the PGE2068 "Other" category, roughly 40% of building types went to retail with the remainder distributed equally among offices and restaurants, while the PGE 2080 *unclassified* RCA measures were comprised of roughly 65% schools with the remaining measures equally distributed among the listed building types.

Table 5-45: C&I RCA Building Type Demographics

Project	Assembly	Education	Office	Restaurant	Retail	Residential	Other
PGE2068			9.6%	8.7%	22.6%		59.1%
PGE2080			1.8%	1.0%	1.1%		96.1%
SCE2507	2.7%	33.9%	20.0%	4.7%	31.8%	1.0%	5.9%
SDGE3043	20.0%	40.0%	20.0%	6.7%	13.3%		

The refrigerant-charge adjustment distributions for the 2006-2008 programs determined which degradation factor would apply to each unit in the program population. The amount of charge added or removed was characterized with a variable called dCharge, as it was in the residential analysis. The charge adjustments were placed in the same four bins as residential programs, consistent with the definitions for the degradation factors. However, no commercial units had charge changes over 20% or below -20%. Because of this, the two most extreme bins were left off the tables below. The change in charge for the population of units in the PGE 2080 Program, as recorded by contractors, was recorded and is shown in Table 5-46.

Table 5-46: PGE 2080 C&I RCA Charge Corrections

Charge Change Category	N	%
dCharge >= -20%	0	
dCharge -5 to -20%	10,512	100%
dCharge < ±5%	16,014	
dCharge +5 to +20%	0	
dCharge >=+20%	0	

The distribution of charge corrections for the SCE 2507 Program were predominantly within ±20%, as shown in Table 5-47 below.

Table 5-47: SCE 2507 C&I RCA Charge Corrections

Charge Change Category	N	%
dCharge >= -20%	13,005	5%
dCharge -5 to -20%	71,004	27%
dCharge < ±5%	117,777	
dCharge +5 to +20%	51,540	20%
dCharge >=+20%	4,970	2%

5.5.3.2 Monitored Results

Similar to the residential programs, the pre- and post-metering samples were evaluated on the basis of improvements in EER, capacity, and sensible capacity, as well as demand reduction. These values were converted into degradation factors against a standard set of eQuest models used to calculate savings for the DEER database. These runs result in estimated energy and demand savings for climate zones and building types. The results for each sampled unit are outlined in the methodology and are presented below, provided the data met established quality-control criteria.

The pre-post results were described in terms of ten parameters for each unit. The units rated capacity in tons cooling, factory charge amount in ounces, and amount of charge adjustment in ounces and percentage characterized the unit. The pre- and post-measured parameters were the airflow in cubic feet per minute (CFM), total and sensible cooling capacity, and condensing unit and fan electric-power draw. The change from pre- to post-cases were normalized using the temperature-based performance of the unit to compare performance at a specific set of outdoor and indoor temperature and humidity conditions, as described previously. Only runs of a minimal length that allowed the unit to reach a steady state were included in the subsequent analyses.

Single- and Dual-Compressor Commercial Results

The changes in total and sensible capacity and energy input ratio were developed as fractions to represent the pre-condition where the factors for the post-maintenance case would all be equal to one. Finally, the change in efficiency was expressed as the pre- and post-energy-efficiency rating (EER). The data have been divided into two separate tables, the first for dual compressor units, shown in Table 5-48 and then for single compressor units, shown in

Table 5-49.The airflow measurements of commercial units presented additional challenges depending on the unit configuration. The airflows of some units with issues slightly reduced the average flows and capacities calculated, but the relative pre- and post-performance were unaffected as the same measurement method was used pre and post for each unit. Only capacity and efficiency changes for units with charge adjustments greater than 5% of factory charge added or removed were used in the final modeled energy savings.

Table 5-48: Average C&I RCA Pre-Post Results for Dual Compressor Units

Dual Compressor Summary	CFM/ton	Total Cap/ton	Sens Cap/ton
Pre:	321.8	7.24	5.83
Post:	324.8	7.34	5.96

Table 5-49: Average C&I RCA Pre-Post Results for Single Compressor Units

Single Compressor Summary	CFM/ton	Total Cap/ton	Sens Cap/ton
Pre:	334.7	8.25	6.99
Post:	341.4	8.78	7.40

The team developed a normalization methodology involving ambient temperature to determine appropriate comparisons for EER and capacity between the pre- and post-conditions. Curve fits were developed for EER, capacity, sensible capacity, and total power based on ambient temperatures for each point. The team calculated specific EER, capacity, sensible capacity, and total power values based on the average combined ambient temperature using the curve-fit equation for each parameter. The average total cooling, sensible cooling, and energy-input ratio degradation factor results of the tables above for single and dual compressor units were organized into change-in-charge categories similar to residential RCA. The amount of charge correction for the sampled units could not be controlled to be mapped onto the program-level distributions. The result was that the small sample sizes for the charge-removed categories may not well-represent the very large program population of those units. The HVAC team decided to combine the results with all available data, namely the detailed data in similar format used to develop the DEER 2008 measure savings. The time-series performance of the pre- and post-study was summarized into a consistent format as the instantaneous change in efficiency data by normalizing the data to the most prevalent observed conditions in the pre-RCA period. The M&V results better sampled the large amount of charge-added category than the data used for DEER, and the DEER data had larger samples for charge removals. The complementary samples were combined into the final input factors, which are lower than those of the DEER inputs but likely well-represent the average savings for residential impacts from RCA, as shown in Table 5-50.

Table 5-50: Final M&V Results for C&I RCA

Charge Change Category	N	Cap Frac	Sens Cap Frac	EIR Frac (comp and cond fan)
dCharge -5 to -20%	19	0.936	0.947	1.053
dCharge +5 to +20%	4	0.989	0.986	1.045

One unit in SDG&E 3043 territory received a significant refrigerant charge addition of 36% of nameplate capacity. This significantly altered the performance of the unit, and reduced the EER by 44%, along with drastic reductions in capacity and sensible capacity. It was evident this unit had experienced performance issues which were misdiagnosed as an extreme refrigerant charge deficit. The contractor's action was not corrected and further degraded unit performance thus this adjustment yielded reduced rather than improved efficiency and capacity. Another unit from PGE2068 experienced a stuck closed economizer in the pre-case and drew appropriate minimum outside air in the post case. This unit showed a measured performance decrease as there was insufficient post period compressor usage to perform steady state comparisons. These results were considered outliers as each point was not representative of the unit energy savings with only one of each case and therefore removed from consideration in the degradation calculations for energy savings. It was intended that the installation rate comprised of post-only measurements would account for measure installation issues such as charging errors. No other units with significant corrections in the wrong direction were present in the pre- and post- monitoring samples. With additional sample points a performance penalty may be associated with small charge corrections and corrections in the wrong direction, but these could not be quantified with the current data. In the charge adjustment range of plus or minus five percent, adjustments may be made in the correct directions relative to factory specification that produce zero or slightly negative efficiency changes.

The primary savings evaluated were those for units that received an adjustment in refrigerant charge. However, many of the units with pre/post metering did not receive refrigerant charge adjustments. Some of those units were shown to be out of adjustment according to measurements prior to the meter installation; some could not be charged due to Santa Ana winds, and some had no records of the amount of charge correction. These units typically did receive some form of tune up adjustments, such as condenser coil cleaning, economizer repair, and airflow adjustments during the contractor's service calls, and the results of all units were outlined in Appendix E.

The HVAC team provided the input parameters to the DEER modeling team to run the degradation factors through the 2008 DEER models to produce unit energy savings for all combinations of building type, vintage, and climate zone. These per ton of cooling savings estimates were then applied to the RCA measure populations within the sampled programs using all available data on change in charge, building, type, vintage, and installed tonnage. An example of the UES per ton for some selected combinations of climate zones and building types are shown below in Table 5-51. The full tables of UES savings for all combinations were applied to the program populations using the final 2006-2008 total tonnages by climate zone. The final extrapolation required weighting the savings using the specific charge change categories and building types, described in the previous section 5.5.3.1, from data contained in separate databases from the final program tracking data.

Table 5-51: Example UES for C&I RCA Measures

C&I Example - Existing Vintage kWh / ton			
Charge Change Category	**Climate Zone - IOU**	**Office**	**Retail**
dCharge -5 to -20%	CZ10 - SCE	65.45	102.74
dCharge -5 to -20%	CZ13 - PGE	67.91	105.92
dCharge +5 to +20%	CZ10 - SCE	28.43	35.18
dCharge +5 to +20%	CZ13 - PGE	27.86	36.80

5.5.3.3 Commercial RCA Verification Findings

Based on the sampling methodology described above, the team randomly selected target units and sites for each program. For most sub-samples, only a portion of the sub-sample could be achieved. These sub-sample sizes were further reduced by a variety of issues related to equipment malfunction, bad data, or contractor error. The full program population, site-visit samples, and achieved results are indicated in the tables below. Recall that the samples were developed at the air conditioner unit level (verified units) and there were multiple units per site serviced by the programs. The verified units were those where site measurements were completed according to the protocols described previously. The data quality-control protocols were applied to the raw collected data, which yielded the final number of air conditioner level tests (Units Passing Data QC), which were used in the installation rate analysis for each program-HIM combination. The team experienced a number of difficulties in reaching the full site-visit sample, as outlined below.

SCE 2507 Verification: The only climate zone where the team met difficulty achieving the sample was CZ 8. The team called each site in the sample and backup list provided by KEMA and experienced a high rate of outright refusals for this climate zone. The remaining sites were called between 4 and 10 times, with a result of either no answer or one of the following responses: it was a wrong number and the correct one could not be determined, the site contact was not available, or the contact would refer the matter to their corporate office, after which we did not receive a reply. The final sample achieved was 47 units.

Table 5-52: SCE 2507 Verification C&I RCA Sample Achieved

RCA Status	Post Only Verification						
Climate Zone	**6**	**8**	**9**	**10**	**13**	**14**	**15**
Population - Program Tracking	1305	3254	798	4188	435	1265	108
Verification Sampling Target	4	13	8	16	5	2	1
Verified Sites	4	5	5	9	2	1	1
Verified Units	6	8	9	16	4	2	2
Units Passing Data QC	6	8	7	15	3	2	2

For SCE 2507 RCA measures, 25 units passed the superheat/subcooling diagnostic test and an additional six of the 20 failing units passed the EER screen for a final field passing rate of 67%, shown below in Table 5-53.

Table 5-53: SCE 2507 Verification Screening Results

	Superheat / Subcooling Target Screen	EER Target Screen	Final Screen Result
Pass	23	6	67.4%
Fail	20	14	32.6%
Total	43	20	100.0%

For the SDG&E 3043 Verification, the team did not experience any difficulty meeting the full sample for each of two climate zones. The final sample achieved was 20 units.

Table 5-54: SDG&E 3043 Verification C&I RCA Sample Achieved

RCA Status	Post Only	
Climate Zone	7	10
Population - Program Tracking	499	619
Verification Sampling Target	13	7
Verified Sites	8	5
Verified Units	13	7
Units Passing Data QC	11	4

The SDG&E 3043 RCA measures had six units passing the superheat/subcooling screen and an additional four of the nine passing the EER target screen for a total pass rate of 67% as shown below in Table 5-55.

Table 5-55: SDG&E 3043 Verification Screening Results

	Superheat / Subcooling Target Screen	EER Target Screen	Final Screen Result
Pass	6	4	66.7%
Fail	9	5	33.3%
Total	15	9	100.0%

For the PGE 2080 RCA measures, four units passed the superheat/subcooling screen and an additional one unit of the seven failing units passed the EER target screening for a total pass rate of 45.5%, as seen in Table 5-56. The sample design for each program was by climate zone, but the PGE2080 units had no physical identification or tracked serial numbers making most sample units unidentifiable for field testing.

Table 5-56: PGE 2080 Verification Screening Results

	Superheat / Subcooling Target Screen	EER Target Screen	Final Screen Result
Pass	4	1	45.5%
Fail	7	6	54.5%
Total	11	7	100.0%

For PGE 2068 RCA measures, eight units passed the superheat/subcooling diagnostic test and an additional five of the eleven failing units passed the EER screen for a final field passing rate of 68.4%, shown in Table 5-58. The PGE2068 sample included testing of units that were found to not be program participants according to the third-party tracking data and those tests were dropped resulting in the ultimately smaller sample.

Table 5-57: PGE 2068 Verification C&I RCA and Sample Achieved

RCA Status	Post Only Verification
Population - Program Tracking	3855
Verification Sampling Target	60
Verified Sites	14
Verified Units	28
Units Passing Data QC	19

Table 5-58: PGE 2068 Verification Screening Results

	Superheat / Subcooling Target Screen	EER Target Screen	Final Screen Result
Pass	8	5	68.4%
Fail	11	6	31.6%
Total	19	11	100.0%

5.5.3.4 Program Weighted C&I RCA Savings

The C&I RCA savings were lower on a per-ton and per air-conditioner basis than the ex-ante estimates for all of the programs. The program-calculated measure savings for C&I RCA often included additional maintenance not related to refrigerant charge, such as economizer repairs and correcting staging issues, which could have impacted energy savings. When comparing these total HIM savings to the ex-ante per-unit savings, it should be noted that other savings components were not included in the UES presented below.

Total annual savings and savings per air conditioning unit for PGE2068 were calculated as shown below in Table 5-59. The building types within the climate zones and relative balance of the charge corrections drove the savings per air conditioner to the levels below.

Table 5-59: PGE 2068 C&I RCA Ex-Post UES and Total Savings

	A	B	C	D	E	F
Climate Zone	kW/unit	kWh/unit	Therms/unit	Number of Units	Total kW [Column A * Column D]	Total kWh [Column B * Column D]
CZ Unknown	0.514	517.94	0.000	1,312	674.2	679,534
Z01	0.202	174.22	0.000	3	0.6	523
Z02	0.615	553.06	0.000	214	131.7	118,355
Z03	0.384	306.19	0.000	468	179.8	143,295
Z04	0.549	596.77	0.000	983	539.8	586,629
Z05	0.472	344.85	0.000	41	19.4	14,139
Z11	0.695	920.70	0.000	105	73.0	96,673
Z12	0.717	621.18	0.000	437	313.5	271,457
Z13	0.605	896.20	0.000	292	176.6	261,689

The annual savings per ton for C&I RCA measures within PGE 2080 were calculated as shown in Table 5-60.

Table 5-60: PGE 2080 C&I RCA ex-post UES and Total Savings

	A	B	C
Climate Zone	kWh/ton	Tons	Total kWh [Column A * Column B]
Education	35.12	-	-
Office	55.21	623	34,396
Restaurant	66.18	351	23,229
Retail	79.34	369	29,276
Other	58.97	33,147	1,954,679

The annual energy savings per ton for SCE 2507 C&I RCA measures were calculated as shown below in Table 5-61 using the savings per ton modeled.

Table 5-61: SCE 2507 C&I RCA ex-post UES and Total Savings

	A	B	C
Climate Zone	kWh/ton	Tons	Total kWh [Column A * Column B]
Z06	33.49	24,598	823,827
Z08	48.34	37,468	1,811,345
Z09	43.14	22,384	965,712
Z10	55.63	35,652	1,983,289
Z13	64.72	8,195	530,333
Z14	69.62	9,872	687,248
Z15	110.34	1,877	207,074
Z16	21.76	339	7,365

Note: Numbers in the table have been rounded

The annual energy savings per ton for C&I RCA measures SDG&E 3043 were calculated, as seen in Table 5-62, using the program's population of installed tonnage.

Table 5-62: SDG&E 3043 C&I RCA ex-post UES and Total Savings

	A	B	C
Climate Zone	kWh/ton	Tons	Total kWh [Column A * Column B]
CZ07	35.68	9,388	334,922
CZ10	55.14	5,163	284,676

Note: Numbers in the table have been rounded

The final evaluated annual energy savings for the C&I RCA measures within the four programs and the applicable installation rates were calculated as shown in Table 5-63. Recall that the implementation of RCA for commercial units often included additional measures that were not reflected in the gross realization rates calculated by comparing the tracking databases to the evaluated savings. Note that the savings below do not include the effects of free-ridership which is described and applied in section 5.6. The differences between the ex-ante and ex-post estimates of performance increases due to application of RCA were reflected in the gross realization rate. Random samples of program participating units were used in a separate effort to determine the rate of proper installations. Units in the pre-post study that would not have passed the post verification were not included in the modeling inputs, thus the UES estimated are representative of passing units which the installation rate is applied to.

Table 5-63: Commercial RCA ex-post Gross Annual Energy Savings

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	HIM Ex-ante Gross kWh Savings	HIM Ex-post Gross kWh Savings	HIM Gross kWh Realization Rate [Column B/Column A]	HIM Install Rate	HIM Installed Ex-post Gross kWh Savings [Column B * Column D]	HIM NTGR	HIM Ex-post Net kWh Savings [Column E * Column F]
C&I RCA	PGE2068	4,818,552	2,172,294	45%	68%	1,485,849	0.54	802,358
	PGE2080	9,161,619	1,814,383	20%	45%	824,720	0.55	453,596
	SCE2507	9,758,899	7,020,259	72%	67%	4,731,655	0.94	4,447,755
	SDGE3043	2,944,930	619,598	21%	67%	413,272	0.7	289,290

5.5.4 Other Findings

5.5.4.1 SCE 2507 Residential Pre/Post RCA Monitoring

Field work was restricted by contractors who are actively participating in the program. The HVAC team contacted 20 SCE participating contractors requesting their assistance to identify and recruit single-family and multi-family customers for the evaluation purposes. In the process the HVAC team discovered the majority of them were not utilizing the program to the extent the utilities had assumed for numerous reasons. As a result, the HVAC team was limited in fulfilling the sampling goals within the climate zones of interest.

Reduced incentives and locking cap mechanisms causes lower levels of participation. Multiple contractors were not able to accommodate the HVAC team's request to identify residential customers as they were not actively utilizing the program during the time of the evaluation.

SCE's requirements to use locking caps and hose fittings that limit refrigerant release to the atmosphere resulted in reduced levels of participation for some contractors. Contractors expressed that the cost of locking caps cut too far into their profit margin. Those who expressed this as an issue felt if SCE was going to require new equipment they should help cover the associated costs.

Limited use of the program during the bridge funding cycles resulted as several contractors were not aware that bridge funding was still available. Because of this, many had not engaged in RCA work for the program. Contractors were given a budget and when they exceed it many of them assumed there was no more funding available. Because of this, many were reluctant to ask their Verification Service Provider (VSP) for additional funding. However, because many contractors were not utilizing the bridge funding, VSPs were more than willing to provide additional financial support to participating contractors when the HVAC team asked for it. Many contractors were unaware they could serve other market segments than what they were currently serving. Market segments included single-family residential, multi-family, commercial and/or mobile homes. Contractors also expressed that they were unwilling to spend money on advertising their services coupled with program incentives when the incentives are not guaranteed. Stronger communication between VSPs and contractors would help to allocate funds in a more productive way.

Contractors utilize the program typically during the off peak season. The sample size was further reduced by many contractors refusal to perform RCA testing during the hottest months of summer as RCA measures sponsored by program incentives are not as profitable as the other non-program related work they perform. Contractors often utilize the program as a motivational aid. During peak cooling season they're often repairing units rather than servicing them. The temperatures remained unseasonably hot until later in the season than expected, preventing most contractors from pursuing RCA work until near or past the metering cutoff date.

5.5.4.2 SCE 2507 C&I RCA

Of the 31 contractors listed as performing commercial service, only six were willing to participate in the metering effort. Many of the remaining contractors could not be reached despite multiple attempts, were not participating in the SCE program, or agreed to participate but then refused to return phone calls.

5.5.4.3 SDG&E 3043 Pre/Post RCA Monitoring

Evaluation work was limited due to low levels of funding. Program 3043 exhausted the bulk of the rebate allocation within the first quarter of 2009. Restricted funding was offered during the metering cycle, and only on a case by case basis when approved by the program implementer. This limitation significantly reduced the number of contractors actively performing RCA tests sponsored through the program. However, the implementer SDG&E did aid in the metering effort by requiring each contractor to assist in the metering process as a stipulation to receiving the incentive. A number of sites had been proposed by SDG&E but the contractors were still experiencing delays due to contract negotiations with customers or faulty equipment at the site visits. In one instance, the contractor replaced a compressor and in doing so disconnected the metering equipment. There were also instances where the contractor did not perform the RCA test within the time frame given. As a result no post metering data was obtained at these sites.

5.5.4.4 PG&E 2068 Air Care Plus Pre/Post RCA

Evaluation efforts were successful due to actively engaged implementers. The evaluation efforts were highly successful as a result of the on-going dialog with program implementers. As with the other pre-post monitoring work, the HVAC team relied on the contractors to identify willing participants for the evaluation process. AirCare Plus implementers were in constant communication with both the evaluators and their participating contractors. Their hands-on approach helped to ensure the metering goals were performed within the limited time frame available.

Evaluation work needs to begin during the first quarter of the year to engage more contractors. KEMA was limited in representing the work of more than one contractor because other contractors were not prepared to assist in the evaluation efforts due to other commitments. Had the work started earlier in the year implementers could have prepared the contractors had had them engaged and committed to the process.

5.5.4.5 PG&E 2068 Post Only RCA

Customers are reluctant to participate without binding contracts. Customers who don't have binding contracts often refuse to participate in evaluation work and have little or no interest unless they are required to do so. Program implementers need to notify customers when they sign up to participate and have participants agree to terms and conditions that allow verification work upon request.

Some customers simply were unaware they participated; Air Care Plus Stickers helped to validate units were serviced. In many cases, identifying someone at the owner level who could acknowledge having participating in the program was an arduous process and required numerous calls and extreme persistence. Fortunately, the Air Care Plus Program requires contractors to apply stickers to all the units they service. These stickers are extremely useful as they provide proof that a service was previously performed. Customers are sometimes skeptical of the verification, but the stickers allowed KEMA recruiters to more easily identify and recruit units serviced by the program.

Serviced units need to be more easily identifiable and standardized within program databases. Utility databases need a defined linkage to identify units serviced. Pertinent information includes unit brand name, model number, location, customer contract information for the individual who agreed to the services and name of contractors servicing the units.

5.6 Net-to-Gross Findings (Residential and Commercial)

5.6.1 Net-to-Gross Findings

Participants who were involved in the decision-making process at each participating household or small commercial site were interviewed to measure a program's influence on respondents' decision-making. The survey obtained highly structured responses concerning the probability that the household or firm would have installed the same measure(s) at the same time in the absence of the program. The survey also included open-ended and closed-ended questions that focused on the household's or firm's motivation for installing the efficiency measure. These questions covered all the requirements provided in the *Guidelines*, such as multiple questions regarding efficiency level, likelihood of adoption, timing and quantity, and consistency checks.

Measures included in the HVAC program cluster utilized a modified version of the NTG Method to provide consistent questions to end-use customers where applicable. The program deliveries allowed flexibility to the contractor in terms of the marketing and incentive, especially for RCA and duct-sealing measures. This required a method that supplemented the participant self-report surveys with contractor surveys. The plan utilized participant contractor interviews to determine if the end-use customers were aware of the incentive and if the service was available outside the program. The simple NTG questionnaire included questions necessary to analyze the effect of the acceleration on the lifetime savings stream and partial increase in efficiency levels or quantities of efficient measures.

Surveys included an up-front line of questioning to identify whether or not participants were aware of the measures and what influence the contractors had on the implementation of RCA. Only information from survey respondents who were aware of the measure was included in the analysis. The survey instruments for residential and commercial RCA are presented in Appendix Z, AA, and BB.

The electric energy savings weighted results shown in Table 5-64 and Table 5-65, are specific to the RCA measures within those programs and not reflective of the total program net-to-gross ratios. The commercial C&I RCA measures within the IOU programs generally had higher free-ridership rates compared to residential measures with the PGE commercial RCA measures having a high free-ridership rate of 45% and 46%. The delivery of these measures should be closely monitored by early M&V and process evaluation for future applications of the measures to the multifamily and C&I market to address potential issues and whether or not they are related to program design, contractor delivery, or end user awareness.

Table 5-64: Residential RCA Net-to-Gross Ratios

Plan Name	IOU	EEGA ID	Customer Survey			
			Survey Sample Size	Survey Completes	FR	NTG
Res RCA	PG&E	2000R	300	135	37%	63%
Res RCA	SCE	2507	200	94	3%	97%
Res RCA	ALL	CMMHP	300	309	22%	78%

Table 5-65: C&I RCA Net-to-Gross Ratios

Plan Name	IOU	EEGA ID	Customer Survey			
			Survey Sample Size	Survey Completes	FR	NTG
C&I RCA	PG&E	2080	200	122	45%	55%
C&I RCA	SCE	2507	250	22	6%	94%
C&I RCA	SDG&E	3043	200	23	30%	70%
C&I RCA	PG&E	2068	250	92	46%	54%

NOTE: For the final ED staff report the HVAC Team will describe any cross-program applications of findings and the justification and rationale for applying those savings values, in consultation with the evaluation contractors as necessary.

The following stability analyses are presented to further explain free-ridership results. Free-ridership is an average of four components. These tables detail the number of components that feed into the final average. If a respondent was unable to answer questions feeding into one of the specific components, that component was not included in the final average.

Table 5-66: Residential Number of Respondents with FR Measurements

Number of Respondents with ___ FR measurements	PGE2000 MF Refrig	PGE2000 Single Fam - RCA	SCE Multifam - RCA	SCE Single Fam - RCA	PGE2078 AC Tune Up	SCE/SCG 2502 AC Tune Up	SDGE3035 AC Tune Up
No FR data	1	0	0	2	29	28	44
One	22	4	9	8	21	20	11
Two	0	10	8	5	24	30	21
Three	24	53	27	31	115	93	103
Four	1	20	0	4	-	0	0

Table 5-67: C&I Number of Respondents with FR Measurements

Number of Respondents with ___ FR measurements	SCE2507 C&I RCA	SDGE3043 C&I RCA	PGE2080 C&I RCA	PGE2068 C&I RCA
No FR data	12	4	38	51
One	9	11	36	54
Two	1	2	7	7
Three	0	0	5	5
Four	1	6	6	5

Free-ridership ratios range from 0.0 to 1.0. These tables detail the percentage of respondents that had free-ridership rates at the extreme ends of the spectrum. These extremes are defined as the 0.9-1.0 range and the 0.0-0.1 range. Note: Respondents with no FR measurements were not included.

Table 5-68: Proportion of Residential Respondents with an Extreme FR Ratio

Proportion of respondents with an extreme FR ratio	PGE2000 MF Refrig	PGE2000 Single Fam - RCA	SCE Multifam - RCA	SCE Single Fam - RCA	PGE2078 AC Tune Up	SCE/SCG 2502 AC Tune Up	SDGE3035 AC Tune Up
Proportion with 0 - 0.1 FR ratio	51.1%	0.0%	61.4%	39.6%	51.9%	54.6%	55.6%
Proportion with 0.9 - 1 FR ratio	8.5%	13.8%	2.3%	33.3%	5.0%	2.8%	1.5%

Table 5-69: Proportion of C&I Respondents with an Extreme FR Ratio

Proportion of respondents with an extreme FR ratio	SDGE3029 Res AC	SDGE3029 CI	SCE2507 C&I RCA	SDGE3043 C&I RCA	PGE2080 C&I RCA	PGE2068 C&I RCA
Proportion with 0 - 0.1 FR ratio	17.1%	9.5%	18.2%	47.4%	46.3%	33.8%
Proportion with 0.9 - 1 FR ratio	34.7%	59.0%	45.5%	26.3%	14.8%	19.7%

These tables detail the free-ridership ratio of respondents that stated the measure was already installed when they first heard about the program. This answer is only included in one of the components of the final free ridership ratio. Free-ridership should be high among these respondents. Note: The n represents all respondents that answered this question in that particular way, regardless of the measurement response. However the FR ratio does not include respondents with no FR measurements.

Table 5-70: Residential Respondents with Pre-Installed Measures

Number of respondents answering they already had installed measure before they learned of the program.	PGE2000 MF Refrig (n=N/A)	PGE2000 Single Fam - RCA (n=87)	SCE Multifam - RCA (n=0)	SCE Single Fam - RCA (n=4)	PGE 2078 AC Tune Up (n=1)	SCE/SCG 2502 AC Tune Up (n=1)	SDGE 3035 AC Tune Up (n=1)
Final average FR for these:	N/A	54.5%	N/A	77.4%	63.3%	100.0%	70.0%

Table 5-71: C&I Respondents with Pre-Installed Measures

Number of respondents answering they already had installed measure before they learned of the program.	SDGE3029 Res AC (n=0)	SDGE3029 CI (n=3)	SCE2507 C&I RCA	SDGE3043 C&I RCA (n=2)	PGE2080 C&I RCA	PGE2068 C&I RCA
Final average FR for these:	N/A	91.7%	N/A	100.0%	N/A	N/A

The following two tables detail the free-ridership ratio of those respondents that stated they never would have purchased any equipment without the program. Free-ridership should be low among these respondents. The only outlier is the PG&E single family survey where many respondents answered "Yes" to this question but had varying degrees of free-ridership. This was true of respondents that passed consistency checks. The impact of this result is lessened by the fact that multifamily measures comprised a majority of program savings. Note: The n represents all respondents that answered this question in that particular way, regardless of the measurement response. However the FR ratio does not include respondents with no FR measurements.

Table 5-72: Residential Respondents That Would Not Have Installed Without the Program

Number of respondents answering they never would have purchased equipment type without the program (efficient or inefficient).	PGE2000 MF Refrig (n=25)	PGE2000 Single Fam - RCA (n=46)	SCE Multifam - RCA (n=21, Q=67)	SCE Single Fam - RCA (n= 18)	PGE 2078 AC Tune Up (n=91)	SCE/SCG 2502 AC Tune Up (n=84)	SDGE AC Tune Up (n=94)
Final average FR for these:	5.3%	39.5%	1.6%	3.0%	5.2%	3.8%	6.5%

Table 5-73: C&I Respondents That Would Not Have Installed Without the Program

Number of respondents answering they never would have purchased equipment type without the program (efficient or inefficient).	SDGE3029 Res AC (n=50)	SDGE3029 CI (n=11)	SCE2507 C&I RCA	SDGE3043 C&I RCA (n=13)	PGE2080 C&I RCA (n=30)	PGE2068 C&I RCA (n=32)
Final average FR for these:	13.1%	7.7%	6.3%	5.4%	5.7%	6.7%

5.7 Findings and Recommendations

1. For both the residential and commercial sectors, the evaluated savings estimates were lower than the ex-ante estimates due to lowered performance degradation factors observed in the pre- and post-RCA metering. The residential UES showed continued potential for energy savings through proper application of the RCA measure. The C&I RCA results were lower on average and highly variable, which suggests the specific application of charge adjustments to small commercial units should be subject to additional M&V early on in future-programs to establish best and sustainable practices.

2. The installation rate for residential RCA was 52% and 55% for the largest programs and 89% for CMMHP. The installation rate for C&I RCA was between 45% and 68%. The HVAC team used instrumentation expected to produce more precise measurements and expected the rates to be lowered due to the use of more precise tools. The installation rates for C&I RCA were lower than expected and early M&V should further explore verification testing. The HVAC team recommends establishing an independent service tool list and protocol used for residential and C&I RCA verification testing and standard tables and data quality procedures to validate program-collected and evaluator-collected data.

3. For the residential sector, the evaluated results for the largest programs had lowered savings due to differing observed distributions than the ex-ante assumptions of the building type, vintage, charge correction, and in some cases tonnage or climate zone. Programs which had better tracking of the parameters in the ex-ante estimates than others tended to have higher gross realization rates.

4. For the C&I RCA measures, the low results for final net savings suggest that an approach not based on deemed unit savings may be appropriate such as a measured-

performance approach. Programs should consider measurements of the operating performance before and after servicing to better establish savings claims given the variability in observed measure performance. If larger future samples for the C&I measure are achieved that show similar results as this study, then the measured-performance approach would be strongly recommended.

5. The free-ridership rates for the programs evaluated with the standard method were higher than the ex-ante estimates and in some cases were extremely high. The respondents who were aware of the program may not have fully understood their contractor's participation and the contractors who were identified were less responsive than participants. The rates of free-ridership for future programs should be based on early M&V that is coupled with process evaluation to develop the most appropriate methods to mitigate and further evaluate mid-market incentives.

6. The program tracking data were generally not well linked to the detailed performance data on RCA maintenance and those data were obtained to varying degrees. The programs should have strong links of rebates and savings data to program units and contractor measurement data. Recommendations include a statewide unit identification standard and sticker, standard program measurement data table definitions, and development of common data definitions for key parameters. Program implementers need to notify and inform customers when they sign up to participate in programs. Implementers also need to attempt to get participants to agree to terms and conditions that allow measurement and verification work upon request.

7. The RCA programs were designed to collect system diagnostic and/or performance indicator data prior to applying measures. The diagnostic measurements taken by the contractor that determine whether or not the unit needs refrigerant added or removed must be recorded since these pre-maintenance data cannot be replicated after adjustments are made to refrigerant levels. Measurements of pre-conditions including factory charge, charge adjustments, power draw, and airflow should be recorded along with the diagnostic parameters.

Table 5-74: Summary of Savings for Refrigerant Charge and Airflow Measure

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	HIM Ex-ante Gross kWh Savings	HIM Ex-post Gross kWh Savings	HIM Gross kWh Realization Rate [Column B/Column A]	HIM Install Rate	HIM Installed Ex-post Gross kWh Savings [Column B * Column D]	HIM NTGR	HIM Ex-post Net kWh Savings [Column E * Column F]
Res RCA	PGE2000	28,966,327	7,990,218	28%	52%	4,114,962	0.63	2,592,426
	PGE2078	1,191,979	457,739	38%	89%	406,930	0.78	317,405
	SCE2502	3,760,920	1,684,228	45%	89%	1,497,279	0.78	1,167,878
	SCE2507	56,440,821	25,260,503	45%	55%	13,893,277	0.97	13,476,479
	SDGE3035	1,373,476	452,317	33%	89%	402,109	0.78	313,645
C&I RCA	PGE2068	4,818,552	2,172,294	45%	68%	1,485,849	0.54	802,358
	PGE2080	9,161,619	1,814,383	20%	45%	824,720	0.55	453,596
	SCE2507	9,758,899	7,020,259	72%	67%	4,731,655	0.94	4,447,755
	SDGE3043	2,944,930	619,598	21%	67%	413,272	0.7	289,290

6. Rooftop or Split System Air Conditioner Replacement

The rooftop or split system AC replacement measure provided incentives for replacement of both burnt-out AC units (Replace on Burnout) and those being replaced early with some remaining useful life in the unit (Early Replacement or ER). The replacement was a high-efficiency AC system which provided both energy and demand savings over the standard efficiency AC baseline. The evaluation's M&V entailed monitoring units with claimed savings from AC replacements and comparing the performance to a theoretical code minimum-efficient unit. In addition, the evaluation included performance monitoring of recently replaced units that were not high-efficiency (minimally code-compliant) units to estimate the actual field operating efficiency and usage of typical, standard efficiency replacements.

6.1 Evaluation Objectives

The HVAC Evaluation Team conducted M&V activities on AC replacement measures offered in the 2006-2008 program cycle and calculate energy and demand savings for the AC replacement measures. The evaluation study by the HVAC Evaluation Team calculated energy and demand savings from the monitored usage and efficiency over a range of operating conditions for 222 analyzed units. [19] In addition to the final evaluation parameters the primary data results will inform revisions or updates to future DEER estimates by producing detailed AC performance data for each unit metered.

6.1.1 Estimated Parameters

The evaluation used data collected through field engineering measurement data collected on a sample of AC units, user surveys, and market actor surveys to estimate the savings and other parameters required by the CPUC to estimate the cost-effectiveness of the IOU programs. These parameters included unit energy savings, NTG, and installation rates. The majority of the ex-ante savings estimates were based on the Database for Energy Efficiency Resources (DEER) estimate of unit energy savings (UES) for multiple categories of measures, building types, building vintages, and locations. These ex-ante estimates were used directly for each measure or weighted together by vintage and measure type in workpapers to produce average measure savings. Some workpaper estimates included savings of non-DEER measures using

[19] 310 units were monitored, but not metered data all passed data quality checks. The 222 units include 28 units monitored through another contract group's evaluation efforts.

effective full load cooling hour estimates from the IOUs. The ex-post results estimated the UES and measure load shape for AC replacement as administered amongst the various programs. The ex-ante NTGR for each program and measure combination used the IOU's default value, typically 0.80. The ex-post estimated NTG for each program and measure combination was developed using a consistent method approved by the NTG Working Group, consisting of Energy Division and its technical consultants. In addition to the final evaluation parameters the primary data results were sought to inform revisions or updates to the DEER estimates by producing detailed performance efficiency maps for each metered unit. Efficiency was then normalized to EER and power per ton for each climate zone.

6.1.2 Challenges to Achieving HIM Objectives

For the direct impact of the AC replacement measures, the complex issue was determining what would have occurred in the absence of the program. To truly evaluate the impacts of this measure, a matched sample of non-treated installations should be recruited and evaluated to generate realistic baseline system performance. The AC replacement on burnout measures within the PGE2080 program had the greatest impact and units replaced in CZ 13, which comprised the highest proportion of savings, were identified, recruited, and metered using identical protocols as participant replacements by the HVAC team. The commercial population was sampled using billing data and sector codes to define five summer electric consumption strata for small commercial accounts and a random digit-dialing survey was administered to identify replacements over the last three years within those strata. In addition, non-participant replacement units identified at sites with participant units were metered in equal numbers to achieve a matched sample of units serving similar zones in those site specific cases.

New residential HVAC installations performed under the 2005 standards mandate that all installations take the option of duct sealing or purchasing a high efficiency furnace to show compliance. Additionally, for new construction and retrofit compliance, TXV verification or RCA testing is another either/or option. These issues added uncertainty to any code level baseline approach and bolstered the case for using a non-participant sample as a baseline in both. Analysis of quality installations from testing and monitoring participant and nonparticipant samples resulted in an aggregate savings value for the measure. If the savings from the quality install measure were desired at the component level (sizing, duct leakage, RCA, or equipment efficiency), basic engineering principles and standard air conditioner performance curves were used to estimate savings at that level of granularity.

Ideally, units with remaining useful life would be metered prior to removal to establish performance and estimate remaining life based on loading and cycling. This was not an option for 2006-2008 M&V. The availability of replaced unit data was the only option for remaining useful life assessment and lack of availability was a primary issue.

For sites where AC systems were replaced early, remaining useful life of the AC was determined from the annual operating hours obtained from the extrapolation of logger data and from 15 years of equipment life.

6.1.3 Overview of Other Evaluation Objectives

The data collected through the AC replacement HIM evaluation was intended to inform future DEER estimates in addition to the primary parameters. Contextual data was collected to inform eQuest site or prototype models, should modeling of this type be employed in an analysis. This included measured conditioned square footage, building vintage, Manual J data and changes in home/electrical usage following installation of new AC. To confirm as well as provide a backup source for obtaining the compliance method used by the contractor, homeowners were asked if they recalled duct testing and or duct sealing performed by the installation contractor or independent home energy rating system rater.

6.2 Methodology

The full details of the analytic methodology used to evaluate AC replacement programs are discussed in the Appendix Section E. The evaluation's methodology is summarized in this section.

The high-efficiency AC replacement HIM evaluation used a methodology consistent with the CPUC Evaluation Protocols to estimate the parameters necessary to calculate energy and demand savings for the necessary samples. The Evaluation Team used engineering algorithms to combine the data collected into efficiency measurements and develop relationships of the performance to a range of operating conditions. The monitored cooling usage included the variability of user behavior and unique characteristics of the building and location that would be difficult to compare to results developed from standardized building models. The Evaluation Team used a regression model driven by the hourly outdoor temperature to calculate realized UES. The model was specified to apply to all commercial and residential AC units under 20-tons cooling capacity and account for differences in usage, multiple stage operation, part load operation, and other cases identified using pilot and initially collected meter data.

The NTG ratio was developed using a consistent method based on measure delivery channel with appropriate decision maker surveys administered to a representative sample. Sample sizes for field M&V and surveys were developed for each program and HIM measure combination based on improving the savings precision relative to the IOU program portfolio and relative to the total savings across IOUs for the AC replacement HIMs.

The next sections summarize sample size, on-site data collection, methods for calculating UES, and the surveys used to estimate the NTGR. The full methodology developed to analyze metered sites with the AC replaced can be found in the Appendix.

6.2.1 Sample Sizes for AC Replacement EM&V

For the HVAC HIM measures that were early replacement and replace on burnout, the issue of energy code baseline versus actual market replacements required metering non-participant units in addition to survey and on-site data collection to determine if complex code requirements were met. This was the best approach for residential measures where code compliance during the 2006-2008 program period was low for AC replacements. However, the overall savings of residential replacements did not justify the cost of a large non-participant sample to support the planned participant metering samples.

The analysis required engineering and statistical experts to develop an analytical framework to access the difference in precision from the standard assessment of a ratio estimation or population mean estimation. To this end, the Evaluation Team developed a model-based method to quantify the error associated with the final estimation and to show whether or not it met the 90/10 specification of confidence and precision for high impact measures. Similar to the initial approach, for the IOU programs that poorly tracked the key variables; the error ratio was increased by 0.1 for each factor to reflect the loss of precision associated with less detailed tracking data. The table below shows the sampling for these efforts. Metered sites were participant-only and post-only.

Table 6-1: Rooftop or Split System Planned Sample Sizes

HIM	Program ID	Surveys	Verific. Sites	Meter Sites
C/I Upstream A/C	PG&E2080	300	110	110
C/I Upstream A/C	SCE2507	100	70	10
Res Upstream A/C	SCE2507	0	0	10
Res Upstream A/C	PG&E2000R	0	0	0
ER - C/I Downstream A/C	SCE2507	200	60	60
ER - Res Downstream A/C	SCE2507	200	90	90
ER - Res Upstream A/C	SDG&E3029	300	90	90
ER - C/I Upstream A/C	SDG&E3029	200	60	60

The samples were designed to represent program units and in all cases samples were stratified by climate zone since AC location is the primary driver of the typical UES used in the program savings estimates. Wherever sampling efficiency could be improved using additional information from the program population, the samples were stratified based on additional parameters, such as climate zone, tonnage, and replacement type.

Survey sample sizes described here were prescribed by the *Evaluation Protocols*, at least 300 per program for NTG analysis where participation levels warranted. Where program delivery methods varied within a program, sample sizes were increased to address the different nature of contractor based and traditional residential and small commercial rebates. In some cases the actual number recruited for metering exceeded the minimum for the purpose of generating leads for site level M&V. Separate survey samples were designed for commercial and residential participants.

The sampling targets for on-site, short-term metering of commercial and residential units were designed to achieve precision of 10% and a confidence level of 90% over all HVAC programs in the 2006-2008 California IOU portfolios. The overall sample size for the on-site metering for commercial participants was determined using the proportion of individual IOU installations to total IOU installations for which savings are claimed during the 2006-2008 program cycle. Sample sizes for each stratum were based upon the proportion of savings of all IOU commercial and residential program participants in that stratum.

A larger discussion and examples of survey sample selection for selected programs can be found in Appendix Section Q.

6.2.1.1 Representativeness of Residential Metered Sample

Sampling stratification is generally informed by some foreknowledge of the effect of the particular measure as it may vary with participant demographics such as house size or energy use in order to assure ultimately that the analytical results are derived from a broad enough base that the sample can be generalized to the intended population. However, the composition of the realized sample will usually be determined and dominated by the difficulties of recruiting willing participants. In this case the intended residential metering samples of the M&V plan for SDG&E 3029 and SCE 2507 were based on annual energy savings by climate zone, which assumed that the average and distribution of energy use of the analysis group was the same as that of the whole participant group.

An initial trial analysis of 50 residential sites showed wide variability in the cooling energy use, especially in the mild areas where cooling was quite irregular and site specific. In this early analysis the cooling use was so irregular that it did not show any correlation to the usual stratification metrics such as house size, family size, energy use, etc. What is important here is to get a large enough sample in each climate zone for a range of tonnage sizes that an average savings per installed ton may be calculated for each climate zone.

To validate that the random samples of metered units generally represent the usage profile of the program participants, evaluators conducted a simple billing analysis of 2005 consumption data representing baseline energy use prior to any program AC replacements. The validation of the sample is not recommended as a means of re-weighting or extrapolating the sample, but it provides an independent check on the appropriateness of the actual M&V sample relative to another metric common across HIM programs.

The analysis included t-tests of the full participant population and the metered sample for SCE 2507 AC replacement. Shown below, neither the annual nor the summer months' results were statistically significant.

Table 6-2: 2005 Pre-period t-test Difference between Annualized Usage of Meter Sample vs. Tracking Database SCE 2507

	N	Min	Max	Mean	Std Dev	Std Error	Upper CL Mean	Lower CL Mean	t Value	P.
Participant Population	2,665	1,252	29,857	9983	5,290.80	102.49	10,184	97,829	0.64	0.5232
Metered Sample	54	2,713	25,470	9520	4,419.20	601.37	10,726	8,314		

Table 6-3: 2005 Summer Cooling Months SCE 2507

	N	Min	Max	Mean	Std Dev	Std Error	Upper CL Mean	Lower CL Mean	t Value	P.
Participant Population	2,714	742	27065	3740	2463.5	47.28	3833	2400	0.51	0.6082
Metered Sample	57	736	24466	3570	3284.7	435.07	4442	2773		

The analysis included t-tests of the full participant population and the various metered samples for SDG&E 3029 AC replacement. Shown below, neither the annual nor the summer cooling months results were statistically significant. For SDG&E 3029, the evaluators initially used the "Subcontractor Management And Reporting Tool" (SMART), a tracking database of all participants that third party implementers submitted to the IOU. The final IOU reporting database used to claim savings included a subset of the 2006-2008 SMART participant tracking database. The SMART database was initially used to select the sample for metering; however, not all 2006-2008 participants selected were included in the final IOU reporting database. Any differences between participants included in SMART and those in the final IOU reporting database was due to internal IOU accounting. Not all 2006-2008 participants were verified in time to be included in the final IOU reporting database. Therefore, several t-tests were conducted between the full population and the metered samples. There was no statistically significant difference between the groups.

Table 6-4: Program Participants and Metered Samples SDG&E 3029

SDGE 3029 2006-2008 Program Database	Number of participants
SMART 2006-2008 participant database	4159
Final IOU reporting database	2307
In SMART but not in Reporting database	1931
Metered customers in reporting database	46
Metered customers in SMART	33

The next two tables test the difference in consumption between the IOU final reporting database and the SMART tracking database.

Table 6-5: 2005 Pre-period t-test Difference Between Annualized Usage of Final Reporting Database vs. SMART Tracking Database SDG&E 3029

	N	Min	Max	Mean	Std Dev	Std Error	Upper CL Mean	Lower CL Mean	t Value	P.
SMART Reporting db	4,238	1236	39,906	7,858	4763.9	73.17	8,002	7,715	-0.83	0.4072
Final Reporting db	2,307	1,236	36,375	8,155	4,756.70	99.033	8,155	7,766		

Table 6-6: 2005 Summer Cooling Months Final Reporting Database vs. SMART Tracking Database SDG&E 3209

	N	Min	Max	Mean	Std Dev	Std Error	Upper CL Mean	Lower CL Mean	t Value	P.
SMART Reporting db	4,123	736	28,949	2,327	1837.7	28.62	2,383	2,270	-0.52	0.606
Final Reporting db	2,264	736	28,949	2,352	1866.6	39.22	2,428	2,275		

The following two tables test the difference between the SMART tracking database and the final metered sample. The difference in annual consumption and the cooling months between the two groups is not statistically significant.

Table 6-7: SDG&E 3029 2005 Pre-period t-test Difference between Annualized Usage of Metered Sample vs. SMART Tracking Database SDG&E 3029

	N	Min	Max	Mean	Std Dev	Std Error	Upper CL Mean	Lower CL Mean	t Value	P.
SMART Reporting db	4,159	1,236	39,906	7858	4771	73.97	8,003	4,671	-0.08	0.9372
Metered sample	79	2,446	30,687	7900	4408	495.9	8,888	3,812		

Table 6-8: 2005 Summer Cooling Months Metered Sample vs. SMART Tracking Database SDG&E 3209

	N	Min	Max	Mean	Std Dev	Std Error	Upper CL Mean	Lower CL Mean	t Value	P.
SMART Reporting db	4,045	736	28,949	2,329	1845.8	29.02	2,385	2,272	0.5	0.6181
Metered sample	78	743	9,628	2,224	1355.4	153.47	2,529	1,918		

The following two tables test the difference in annual consumption and cooling months between the metered sample and the final IOU reporting database. The difference in annual consumption and the cooling months between the two groups is not statistically significant.

Table 6-9: 2005 Pre-period t-test Difference between Annualized Usage of Meter Sample vs. Final Reporting Database SDG&E 3029

	N	Min	Max	Mean	Std Dev	Std Error	Upper CL Mean	Lower CL Mean	t Value	P.
Final Reporting db	2,221	736	28,949	2,353	1871	40	2,431	2,275	0.37	0.7112
Metered Sample	86	743	9,628	2,277	1407	174	2,624	1,930		

Table 6-10: 2005 Summer Cooling Months Meter Sample vs. Final Reporting Database SDG&E 3029

	N	Min	Max	Mean	Std Dev	Std Error	Upper CL Mean	Lower CL Mean	t Value	P.
Final Reporting db	2,261	1,236	36,375	7,960	4749	100	8,159	7,764	0.11	0.9122
Metered Sample	79	2,446	30,687	7,900	4408	496	8,888	6,913		

The final two tables test the difference in annual consumption and cooling months between the metered sample selected from the SMART database and the full metered sample. The difference in annual consumption and the cooling months between the two groups is not statistically significant.

Table 6-11: 2005 Pre-period t-test Difference between Annualized SMART Meter Sample vs. Final Meter Sample SDG&E 3029

	N	Min	Max	Mean	Std Dev	Std Error	Upper CL Mean	Lower CL Mean	t Value	P.
Final Metered Sample	46	2,446	30,687	7985	5189	765	9,526	6,444	-0.1	0.9255
SMART Metered Sample	79	2,446	30,687	7900	4408	496	8,888	6,913		

Table 6-12: 2005 Summer Cooling Months SMART Meter Sample vs. Final Meter Sample SDG&E 3029

	N	Min	Max	Mean	Std Dev	Std Error	Upper CL Mean	Lower CL Mean	t Value	P.
Final Metered Sample	43	743	9,628	2,277	1628	248	2,778	1,776	-0.19	0.8475
SMART Metered Sample	78	743	9,628	2,224	1355	153	2,529	1,918		

The previous t-tests demonstrate that the random samples of metered units generally represent the usage profile of the program participants. Therefore, no adjustments of the metered sample are needed in order for the results to represent the population.

6.2.2 On-site Data Collection

Measure-specific data (post-installation) collection involved gathering relevant parameters that served as input parameters to the evaluation algorithms. These parameters included AC manufacturer, model number and serial number, HVAC efficiency, refrigerant type, metering device, number of compressors, staging sequence, compressor rated load amps (RLA), condenser fan horsepower (hp), fan full load amps (FLA), evaporator coil manufacturer, evaporator coil model and serial number, cooling capacity, supply fan hp, fan control strategy, and fan FLA and efficiency. The following parameters were logged on site for four weeks to 100 days post installation to inform the regression models, including HVAC unit input power, supply temperature, return temperature and relative humidity, ambient temperature, indoor temperature, and return air flow.

The field measurement techniques for air conditioner efficiency do not have an industry standard. Various methods are available and wherever possible particular evaluation measurement techniques follow established ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), AHRI (Air Conditioning, Heating and Refrigeration Institute), and ACCA (Air Conditioning Contractors of America) guidelines, but only laboratory testing standards have been established for AC efficiency measurements.

Ideally, information regarding the outdated system prior to replacement would include AC manufacturer, model number and serial number, duct location, return air strategy, supply fan HP/Amps, condenser fan HP/FLA, comp motor HP and RLA, filter information, and thermostat settings before installation of new AC, but these were data not generally tracked by the program installation contractors.

The accuracy of the data logged on site was of utmost importance. The HVAC Evaluation Team maintained quality control at each step of evaluation, from collecting field data, monitoring performance data, to initial data entry, post analysis and reporting. Each of these steps was carried out by qualified professionals and cross checked by senior engineers to avoid inaccuracies. Field engineers were provided with tables that were populated with all expected input parameters to help avoid inconsistent field data.

Possible data sources included interviews, production or operation logs, mechanical or electrical plans, observations and spot measurements, metering previously installed by the IOU, metering installed for this evaluation, and manufacturers' literature and other published equipment specifications. Different time series data loggers were used to record various performance parameters of the HVAC system. Spot watt measurements were carried out for all the logging input parameters to cross verify the accuracy of the loggers. The following instrumentation, shown in Table 6-13, was used to measure the performance of the HVAC units:

Table 6-13: Measurement Points and Detail for AC Replacement

Function /Data Point to Measure	Equipment Brand/Model	Qty Req'd	Rated Full Scale Accuracy	Accuracy of Expected Measurement	Planned Metering Duration	Planned Metering Interval
Indoor Temperature	Hobo Microstation with 12 Bit Temp/RH	1	±0.36 ºF/ ± 3.5 %	±0.30 ºF/ ± 3.0 %	21 to 100 days	5 Minutes
Ambient Temperature	Hobo Microstation with S-TMB-M002smart sensor	1	±0.36 ºF	±0.30 ºF	22 to 100 days	5 Minutes
Supply Temperature/RH	Hobo Temp/ RH data logger	1	±2.5-3.5 RH	±3.5	23 to 100 days	1.5 to 5 minutes
Return temperature/RH	Hobo Temp/ RH data logger	1	±2.5-3.5 RH	±2.5	24 to 100 days	1.5 to 5 minutes
Power	Wattnode/WNB-3Y-480-P	1	± 0.05%	± 0.45%	25 to 100 days	1 to 2 minutes
Power	Hobo Energy Logger Pro with pulse adapter	1	±0.3	±0.4	26 to 100 days	1 to 2 minutes
Air flow	True flow meter & DG700 pressure gauge	1	± 7% CFM ± 1% Pa	+5%-15%CFM	Instant	5 minute average
Air flow	Anemometer	1	± 2.0%	D/K	Instant	5 minute average

Anemometers, devices used to measure air flow, were used to calculate the air flow in large units where the TrueFlow® flow plates could not be used. Data loggers and sensors used for power measurement were placed inside the air conditioner cabinet.[20] A smart temperature sensor with the weather station was mounted on the roof to record ambient temperature. The Evaluation Team used a smart sensor along with a HOBO Microstation to monitor supply and return temperature and humidity while a HOBO U10 was placed near the thermostat.

Both sampling and recording intervals for power monitoring were set to one to two minutes where as the temperature was and recorded instantaneously in an interval of one and one-half to five minutes. The setting was finalized based on testing for memory fill rate and battery drain.

6.2.3 Methods

The high efficiency AC replacement programs focused on the purchase of high-efficiency air conditioners in three contexts: (1) when replacing failed AC, i.e., units replaced on burnout (ROB); (2) as a preemptive replacement, i.e., early retirement (ER), and, (3) high efficiency HVAC installed in new construction. These contexts call for different base case conditions.

[20] Three voltage leads were directly connected to the two incoming terminal and the neutral respectively. Two split core current transformers were slipped onto the two phases of the incoming lines to the AC.

When replacing a failed HVAC or installing HVAC in new construction, the base case is current code installation standards pertaining to ductwork and unit sizing or SEER 13.

A preemptive replacement is more complicated. It has a compound base case. For the remainder of the useful life of the replaced unit, the base case is a SEER 10 unit without the code-required duct improvements and unit sizing. For the remainder of the useful life of the efficient replacement unit, the base case is SEER 13 with the code-required duct improvements and unit sizing. One IOU assumed a five year remaining useful life for all units replaced early; contractors collected data on existing units for very few participants so baseline data are incomplete. This evaluation determined first year savings but not lifetime savings. The analytical focus of this M&V was to measure and document the performance of the efficient unit and to estimate the performance of the base case unit under the same conditions of temperature and cooling load. In this M&V exercise, the measurements were made only on the post-retrofit situation, and the SEER 10 and SEER 13 base cases' performance is synthesized using general DEER performance functions. In the residential context the synthetic base cases are for SEER 10 representing the early replacement scenario, and for SEER 13 representing the replacement on burnout scenario. In the commercial context different synthetic base cases analogous to the SEER 10 and SEER 13 base cases were developed for three different unit size ranges: 0-5 tons, 5-10 tons, and 10+ tons.

However, in principal, there are two important auxiliary elements to the evaluation of this program. The first is an estimate of the remaining useful life on any unit that was preemptively replaced, and the second is an estimate of the energy savings to be attributed to the improvements in the duct work and to the resizing of the unit. Both of these auxiliary elements are not based on the monitoring data per se, and are brought into the analysis from external sources. For this analysis, the quantified measured savings are restricted only to the savings attributable to the higher efficiency features of the replacement unit and not to the resizing and duct repairs that may be associated with a preemptively replaced unit.

This analysis was based on the "in situ" cooling situation, where "in situ" includes all the cooling associated with the existing lifestyle patterns and with the existing structure details, including insulation, shading, and duct leakage. The analysis assumes the building or lifestyle did not change from the pre-installation condition.

This need to preserve the in situ situation poses a complication because residential HVAC usage in a mild climate such as Southern California can be quite irregular, depending on occupancy patterns, ventilation strategies, building thermal mass, and in rare cases, evaporative cooling. Such a variable cooling usage situation is very difficult to model rigorously without extensive occupancy detail, and a simple "canned" average occupancy description may not reflect a monitored situation. This analysis takes a middle course and posits a cooling model based on hourly outdoor temperatures that is constrained (calibrated) to report the same cumulative cooling energy as was monitored. In this way, the effects of occupancy irregularities and lapses are incorporated in the long-term cooling energy estimate. However, it needs to be noted that this analysis is restricted to estimates of the refrigeration-based cooling end use only and does not attempt to include cooling due to other viable cooling modes for this region, particularly night ventilation and evaporative cooling. Mechanical ventilation, absent compressor activity, is not included in this estimate.

Additional methodological details are provided in the Appendix Section E.

6.2.4 Vendor Survey

Vendor surveys were administered for several programs. The vendor survey examined vendor involvement with customer implementation, program influences on vendor recommendations, territory information, and items related to incentives. The vendor survey was administered by telephone to the top (by ex-ante savings) fifteen sales and installation contractors. The vendor survey was not triggered using the influence scores of the customer survey respondents.

A VMAX score was used to quantify a NTG value from these surveys. VMAX is a score which was designed by the CPUC Energy Division to capture the highest degree of program influence on the vendor's recommendation[21]. If no customer survey was implemented, the VMAX score (multiplied by 10) was used to represent the NTGR. If a customer survey was used, the VMAX score replaced the timing and selection score from the customer survey[22].

The evaluation included vendor surveys for these programs:

- PG&E 2080 C/I Upstream A/C
- SCE 2507 C/I AC Replacement
- SDG&E 3029 C/I AC Replacement
- SDG&E 3029 Residential AC Replacement

[21] California Public Utilities Commission Energy Division and the Master Evaluation Contract Evaluation Team. "Guidelines for Estimating Net-to-Gross Ratios Using the Self-Report Approaches." October 2007.

[22] Ibid.

6.3 Confidence and Precision of Key Findings

6.3.1 Planned Confidence and Precision

The overall verification and net savings sampling strategy was to first achieve 10% precision at the 90% confidence level for each measure by utility. For cooling measures, the participation in each utility service territory was focused in the hotter cooling climates and seemed to be very focused on particular CEC climate zones. As expected for weather dependent HVAC measures, the primary driver of expected savings on a per unit basis was the CEC climate zone defined by DEER and Title 24. The goals for the other climate zones were relaxed for climate zones with the smallest impacts such as the coastal zones with low participation. The sample stratification for verifications applied to the other IOUs, both residential and commercial.

Survey sample sizes described here were prescribed by the *Evaluation Protocols*, at least 300 per program for NTG analysis was suggested. Where program delivery methods varied within a program, sample sizes were increased to address the different nature of contractor based and traditional residential and small commercial rebates. In some cases the actual total exceeded the minimum for the purpose of generating leads for site level M&V.

The evaluation included a stratified sample of units based on savings subject to end-use metering at all of the verification sites. This approach was the only applicable option for AC early replacement savings for 2006-2008 units, as ideally units with remaining useful life would be metered prior to removal to establish performance and to estimate remaining life based on loading and cycling. However, it was not possible to meter existing units prior to replacement. The post-only metered usage calibrated a pre and post model and savings developed were compared to tracking estimates. Under this approach, the variation in usage of real buildings compared to models required an assumed error ratio greater than 0.5 for all cooling measures. For small residential packaged systems, which had the most variation, the Evaluation Team assumed an error ratio of 0.9. These error ratios were based on conversations with senior analysts, load researchers, and senior M&V staff. The Evaluation Team also expected that the error ratio would be greater in the cases where the tracking data did not describe the population well in terms of climate zone, building type and vintage, and tonnage class (size), as this reflected a limitation in our ability to take advantage of stratification to lower our estimation error. These stratification variables were well described for residential measures. For planning purposes, in the IOU programs that poorly track the key variables, the error ratios were increased by 0.1 for each factor to reflect the loss of precision associated with less detailed tracking data. Table 6-14 and Table 6-15 show the planned precision using our estimate of error ratio and the resulting error bound on electric energy savings.

Table 6-14: Planned Precision for Replace on Burnout AC HIMs

High Impact Measure	Program ID	Meter Sites	Error Ratio (er)	Sample RP at 90%CI	2006-08 kWh Savings	kWh Error Bound
C/I Upstream A/C	PG&E2080	110	0.7	11%	36,732,269	4,019,162
C/I Upstream A/C	SCE2507	10	0.5	26%	3,904,285	1,011,554
Res Upstream A/C	SCE2507	10	0.7	36%	194,086	70,381
Res Upstream A/C	PG&E2000R	-	-	N/A	10,146	10,146

Table 6-15: Planned Precision for Early Replacement AC HIMs

High Impact Measure	Program ID	Meter Sites	Error Ratio (er)	Sample RP at 90%CI	2006-08 kWh Savings	kWh Error Bound
ER - C/I Downstream A/C	SCE2507	60	0.7	14%	3,765,108	517,779
ER - Res Downstream A/C	SCE2507	90	0.9	13%	2,269,322	293,874
ER - Res Upstream A/C	SDG&E3029	90	0.9	15%	2,801,487	431,171
ER - C/I Upstream A/C	SDG&E3029	60	0.7	15%	3,226,165	469,996

6.3.2 Achieved Samples

6.3.2.1 Metered Sample Achieved

Achieved sample sizes for the HVAC replacement programs are shown in Table 6-16. The final sample was not met in all strata; there were a number of cancellations, samples were depleted, and/or new sites could not be fully metered in the allotted time frame. The following tables show the population, sample sizes and achieved sample per strata.

Table 6-16: Achieved Metered Samples

Specialized Commercial HVAC	Population (sites)	Population (reported units)	Target Completes	Hard Refusals	Unable to Reach	Language Barrier	Total Sheduled Units at Sites	Cancellations	No Shows	Could Not Meter Unit (due to location, unit type, non working unit, etc.)	Total Units Meters Installed/data collected
SDGE 3029 C&I Upstream AC Early Replacement Site Visits	427	1364	60	16	99	1	79	0	0	27	52
SCE 2507 C&I Downstream AC Early Replacement Visits	1331	3140	60	28	174	0	69	0	0	18	51
SCE 2507 Residential Downstream AC Early Replacement Site Visits	2146	2321	90	61	73	4	83	6	0	2	***76
SDGE 3029 Residential Upstream AC Early Replacement Site Visits	5203	5684	90	32	30	0	121	10	2	10	**99
PGE 2080	1871	20373	110	53	171	3	123	2	0	11	110
Total	**10978**	**32882**	**410**	**190**	**547**	**8**	**475**	**18**	**2**	**68**	**278**

Table 6-17 shows the metering sample plan for SDG&E 3029 residential AC replacement. There were six stratum based on climate zone and replacement status. Participants from each stratum who were willing to participate in onsite metering were recruited during the NTG survey. The initial planned metered sample size for SDG&E 3029 (Residential) was 100 metered units. The table below provides a summary of the population in each stratum, percent contribution to the population, minimum sample points per stratum, the number of survey completes, as well as the number of survey participants in each stratum who were willing to participate in onsite metering of their cooling equipment. There were no participants in stratum 5 (CZ10 replace on burnout) who were willing to be metered. The rightmost column shows the proposed meter sample, based on a total of 100 sample points, distributed proportionally. In all strata other than stratum 5, there were enough willing participants to fulfill the metered sampling targets.

Table 6-17: Residential Metering Sample Plan and Achieved Sample SDG&E 3029

Stratum	1	2	3	4	5	6	
Climate Zone	7	7	7	10	10	10	
Replacement Status	ER	RB	NC	ER	RB	NC	Totals
Population Units	2426	308	512	1991	238	209	5684
Percent of Total	43%	5%	9%	35%	4%	4%	100%
Survey Sample Points – Target	128	16	27	105	13	11	300
Survey Sample Points - Completes	133	19	30	111	15	14	322
Sites willing to be metered	80	11	13	64	0	7	175
Original Metering Sampling Target	43	5	9	35	4	4	100
Revised Metering Sampling Target	38	5	8	32	4	3	90
Metered Sites	44	7	7	30	0	3	91
Metered Units	47	7	10	32	0	3	99
Units Passing Data QC	35	6	6	31	0	3	81

The SDG&E 3029 commercial participant population was stratified into 3 tonnage strata based on the following stratum definitions: 5 tons and under; 6 to 19 tons; and 20 tons and greater. Participants from each stratum who were willing to participate in onsite metering were recruited during the NTG survey. The initial planned metered sample size for SDG&E 3029 (Commercial) was 60 metered units. In the large HVAC sample, many sites had multiple cooling units at one location. These could either be all new and rebated under the program, or some combination of rebated units and old units. Metered sample included only new units.

Table 6-18: Commercial Metering Sample Plan and Achieved Sample SDG&E 3029

Stratum	1	2	3	4	5	6	
Climate Zone	7	7	7	10	10	10	
Tonnage Category	0-5	19-Jun	20+	0-5	19-Jun	20+	Totals
Population Units	673	214	68	268	78	55	1356
Population Sites	230	82	27	85	36	10	470
Percent of total Units	50%	16%	5%	20%	6%	4%	100%
Survey Sampling Target	94	30	10	38	11	8	191
Survey Sampling Completes	49	21	5	22	7	1	105
Metering Sampling Target	30	15	7	5	2	1	60
Metered Sites	15	4	5	2	1	1	28
Metered Units	35	5	0	4	2	1	47
Units Passing Data QC	13	6	0	5	1	0	25

The nonparticipant sample metered for PGE is shown in column 1 of the following table. A total of 47 nonparticipant units were metered. Columns 2 through 6 indicate participant units.

Table 6-19: Commercial Metering Sample Plan and Achieved Sample PGE 2080

Stratum	1	2	3	4	5	6	Total
Climate Zone	NP - CZ13	CZ13	CZ12	CZ2	CZ3	Other	Total
Population - Program Tracking: Number of units in each stratum	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	20373
Metering Sampling Target by number of units	110	60	30	10	10	0	220
Metered Sites	16	11	4	2	4	0	37
Metered Units	47	32	11	7	9	0	106
Good Data	18	18	6	4	5	0	51

Table 6-20: Residential Metering Sample Plan and Achieved Sample SCE 2507

Stratum	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Climate Zone	**6**	**8**	**9**	**10**	**14**	**15**	**16**
Population Units	**147**	**642**	**476**	**1633**	**27**	**477**	**10**
Population Sites	135	594	454	1536	24	370	10
Metering Sampling Target Units	1	15	13	52	0	8	1
Metered Sites	1	22	12	32	0	2	0
Metered Units	1	25	14	34	0	2	0
Units Passing Data QC	1	16	8	17	0	0	0

Table 6-21: Commercial Metering Sample Plan and Achieved Sample SCE 2507

Stratum	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Climate Zone	**6**	**8**	**9**	**10**	**13**	**14**	**15**	**16**
Population Units	**477**	**984**	**737**	**635**	**66**	**164**	**62**	**15**
Population Sites	210	374	310	292	33	75	31	6
Metering Sampling Target Units	4	22	20	14	0	0	0	0
Metered Sites	3	12	9	9	0	0	0	0
Metered Units	3	20	14	13	0	0	0	0
Units Passing Data QC	2	11	4	6	0	0	0	0

6.4 Validity and Reliability

6.4.1 Uncertainty Analysis

The uncertainty of program level savings estimates will be presented and discussed in detail in Section 6.5.3. Those error bounds for program level savings implicitly include unit level uncertainty, but it is useful and informative to initially present a deconstruction of the program-level uncertainty into its contributing components: measurement accuracy, modeling error, and population variability. Following is a brief description of the approach taken to quantify uncertainty with respect to measurements and modeling. It is reliant on a basic familiarity of the unit level methodology as discussed briefly in Section 6.2.3 and extensively in Appendix E.

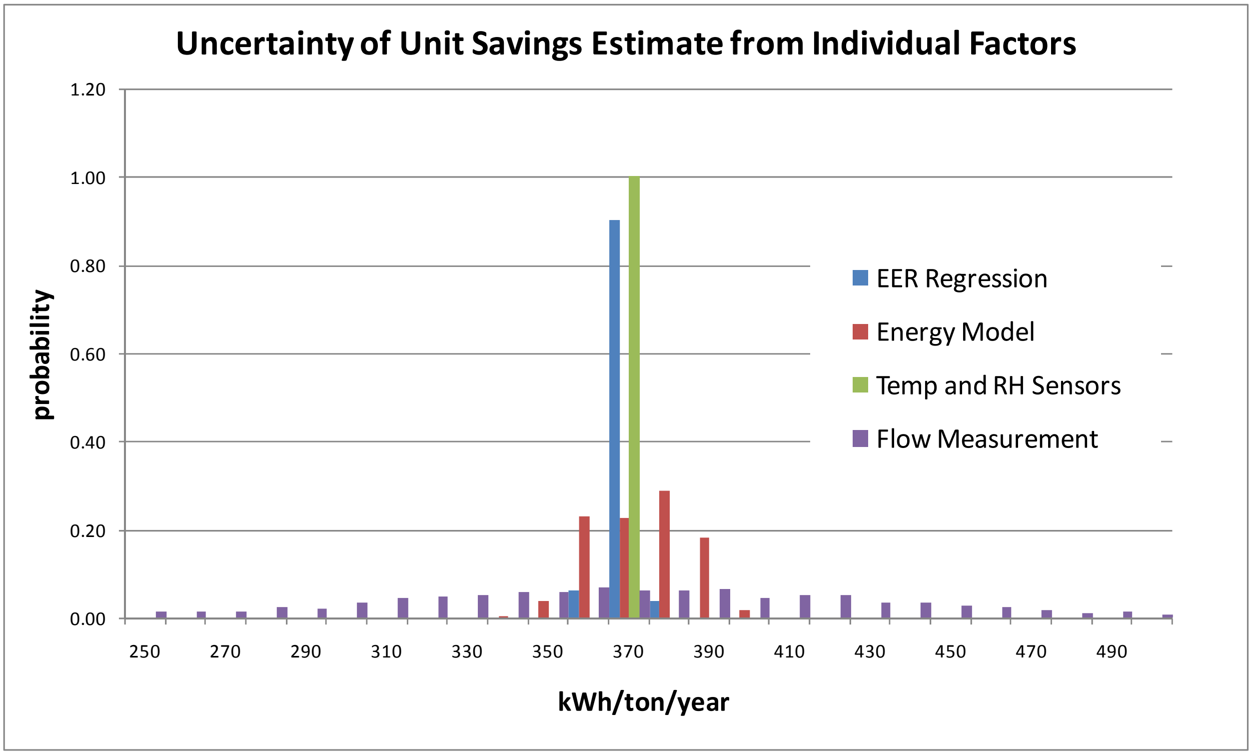
A Monte Carlo approach was used to assess measurement accuracy, in which several completed air conditioner (AC) unit analysis spreadsheets were combined with a spreadsheet-based Monte Carlo analysis tool. The basic process was to add random noise to the aggregated data of the same order as the expected measurement error of each measure quantity, then iterate an arbitrarily large number of times to numerically generate a distribution of AC unit savings with respect to uncertainty in that measurement. Note that it was important to perform these perturbations on an analysis spreadsheet for this project containing multiple time-series measurements and not simply feed sensor accuracy ratings into a simple, one-time propagation of error analysis. The unit savings calculation is driven by the interaction of the site-specific energy model and efficiency model with the vector of 8760 temperatures. This specific interaction can only be determined in the analysis spreadsheet for the specific unit in question.

The procedure for assessing error in the efficiency model and energy model was slightly different, but still relied on modifications to an existing analysis spreadsheet for a monitored AC unit.

For each unit, the energy model was calibrated to a set of hourly data points. Each point consisted of an average outdoor temperature, a 3-day running average outdoor temperature, and an observed energy consumption. To investigate uncertainty relating to the energy model, a new set of these points was generated by sampling with replacement from the original set. The energy model was recalibrated to this new set of points and the unit savings was tabulated, then the entire process was repeated an arbitrarily large number of times to generate a distribution of unit savings with respect to modeling error. Note that this is a higher dimensional form of the “bootstrapping” method, which is fully explained in Appendix section E.

A similar approach was employed to calculate uncertainty with respect to the efficiency model, in which the set of points used to calibrate the model was regenerated by sampling with replacement from the original set of points. As a linear regression of EER with respect to outdoor temperature, this was a simpler process for the EER model than for the energy model. For purposes of explanation and example, the results of these analyses for one Zone 10 unit are shown below in Figure 6-1.

Figure 6-1: Uncertainty of Unit Savings Estimate from Individual Factors



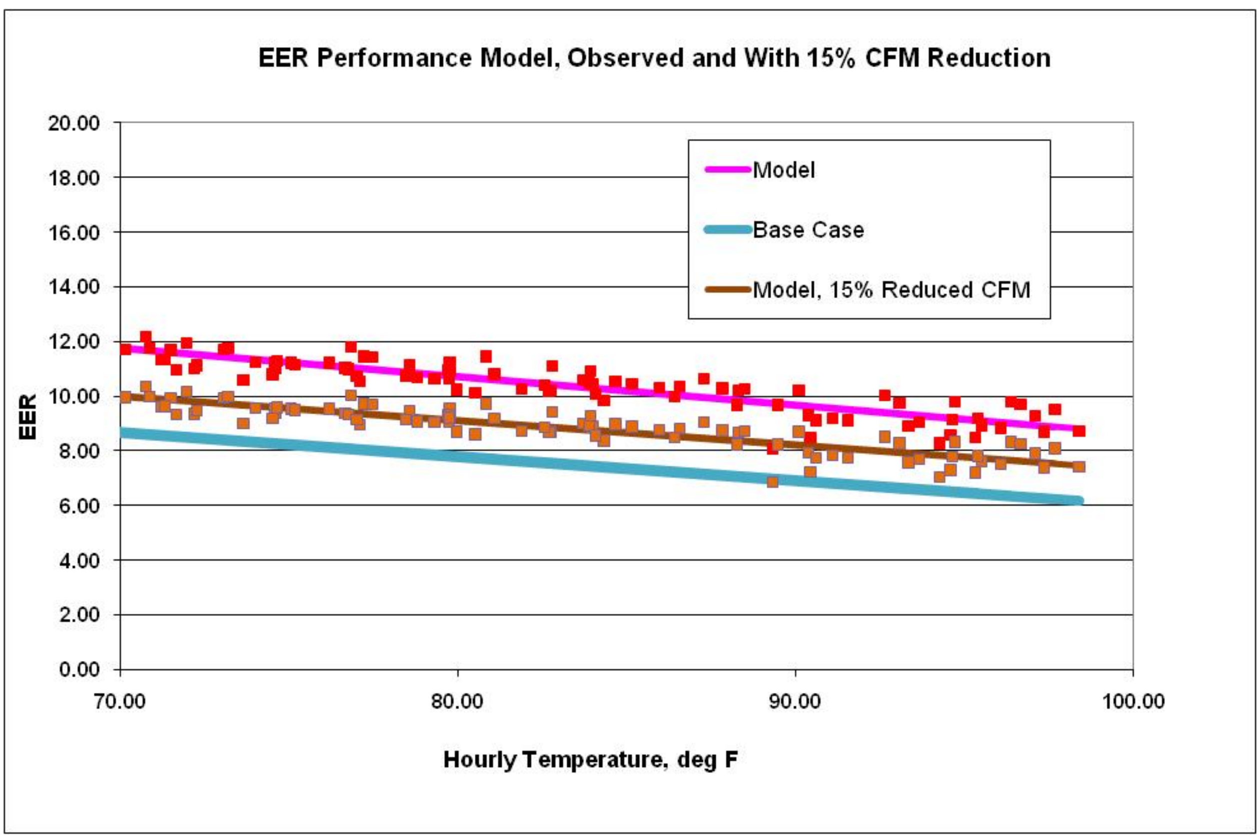
The smallest source of error on this graph is due to the temperature and relative humidity sensors, which had to be considered simultaneously because the relative humidity is dependent on the coincident temperature measurement. In fact, the resolution on the bins here is too coarse to capture the distribution—the 90% confidence bound on the savings estimate due to temperature and relative humidity readings is about 0.5%. This error is so small because the analysis was performed at the hourly level, and therefore many of the temperatures and humidities used in psychrometric calculations were averages of 10-12 sensor readings. The average of many readings is much more precise than that of a single reading.

The error associated with the EER regression was the second smallest source of error. The 90% confidence bound on the savings estimate due to the location of the regression line was 1.5%. This confirms the validity of treating EER as a single variate function of outdoor dry bulb temperature in the locations for this analysis, i.e. the air handler entering wet bulb varied so little that its affect did not need to be explicitly added as another variable to the equation.

Uncertainty associated with the energy model was around 6% for this unit at the 90% confidence level. This shows that the relationship between energy consumption and outdoor temperature is not quite as linear as that of EER and outdoor temperature, but that a linear energy versus temperature line interacting with a thermal mass temperature is sufficient to characterize cooling energy usage. It should be noted that this particular unit was metered for 46 days: typically a month or more of metering was necessary to achieve similar confidence in the reliability of the energy model.

It is immediately obvious from Figure 6-1 that almost all uncertainty for any individual calculated savings estimate is attributable to the flow rate measurement. As discussed in Section 5.4.3, the rated accuracy of the True Flow test under ideal conditions is 7%. To account for the non-ideal field conditions under which the test was performed, though, this range was roughly doubled to an assumed 15% error bound of the flow plate test for use in this analysis. This caused a 30% error bound in the unit savings, and on lower performing units, this scatter can be even more dramatic. The flow rate measurement has such tremendous leverage on the savings estimate because the calculated EER varies directly with measured flow, and the savings estimate is calculated by applying the ratio of observed efficiency and baseline efficiency to the energy use predicted by the energy model. Thus a 15% reduction in measured CFM (if the flow plate was reading at the upper end of its rated spectrum) causes a 15% reduction in calculated EER as shown below.

Figure 6-2: Affect of Flow Measurement Uncertainty on EER Model



This change could easily cut the calculated savings in half for an individual unit, or alternatively could double the calculated savings if the measurement was artificially low. It is important to note that the results will be correct on average, though, so the savings estimates will not be systematically biased; they will simply be more variable. A likely downward bias of the flow plate test was discussed in Section 5.4.3, but this bias would be shared by both monitored participant and non-participant units, leaving the ratio between the two efficiencies unchanged. This is why, even though the flow plate test may consistently underreport actual flow, the results will not be biased due to the occurrence of this downward pull on both new unit efficiency and baseline efficiency. In light of this information, the large samples necessary to calculate reliable unit savings estimates for any given climate zone and replacement type were essentially influenced by two factors: (1) the physical variability of installation, sizing, refrigerant charge, airflow, and other physical parameters that are non-homogeneous in field conditions, and (2) the high amount of leverage the flow measurement exerts on the savings estimate for any metered unit. The evaluation team believes that these issues of high unit level uncertainty have been properly compensated for through a more general treatment of the collected data as will be discussed in Section 6.4.3.

6.4.2 Procedures to Minimize Non-response Bias

Please reference Section 5.4.3 for details.

6.4.3 Residential AC Replacement

Table 6-22 summarizes the empirical findings of the residential sector participants. This table presents savings estimates on a per ton basis by climate zone. Each cell in this table has been populated from all available data, from all 151 successfully analyzed units across the IOU. This table reports annual cooling load, peak demand, estimated energy savings with respect to each replacement type, and estimated demand savings with respect to each replacement type. These values are presented by climate zone. Each usage and savings estimate is developed by driving the site-specific energy and efficiency models of a single monitored unit with the hourly average temperatures from a typical meteorological year (TMY). This is done with TMY temperatures not only from the climate zone the site was monitored in, but also from adjacent zones with similar cooling degree days and humidity patterns. The details of this approach to use a single unit model to drive multiple savings estimates across climate zones with similar geography, occupant behavior, and construction practices are described in Appendix section E. Due to the variability observed on the unit level, it has been important to use as many unit models as possible for each climate zone to obtain reliable distributions of performance.

As noted earlier, one baseline used for this analysis was derived from an analysis of 20 sites drawn from an IOU's RCA post-retrofit sample. These sites are intended to represent the performance of a typical existing residential unit with good charge and air flow, i.e., just after retrofit and are referred to here as the "RCA baseline." The savings for early replacement participants are described by the difference in the energy use specified in the RCA baseline and the monitored data.

The replace on burnout, or the new construction sites, are referenced to the designated SEER 13 to represent the performance of the code-compliant alternative. This baseline was derived by synthesizing a SEER 13 performance using DEER performance parameters and correcting that estimate by calibrating it to a sample of 20 SEER 13 units found in this analysis. This calibration sample is shown in Figure 6-3, which shows the individual site EER functions and the average EER function that was used as the calibration reference. Note in this figure the fairly wide range in performance for newly installed SEER 13 units. Also note that the DEER SEER 13 EER function forms an approximate upper bound on the results. The calibration was performed by comparing the total observed energy use of all monitored SEER 13 units to the total energy use predicted for those units by the DEER performance parameters: as a whole the monitored units used 39% more energy than was computed from the DEER performance curves for those units. All energy estimates from the synthesized (i.e., the engineering based estimate that proceeds from the DEER/DOE2 methodology for air conditioners) SEER 13 case were then scaled equivalently for use as the replace on burnout base case. This baseline was aggregated from the units shown in, Figure 6-3 which displays the linear regression function of EER against outdoor dry bulb for each unit.

Table 6-22: Residential Monitoring Results by Climate Zone

	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 13	Zone 14	Zone 15
Annual Cooling/ton (kWh)	57	93	171	260	297	441	422	884
Peak Demand/ton (kW)	0.057	0.094	0.295	0.372	0.407	0.461	0.467	0.549
Savings/nameplate ton/year SEER13 (replace on burnout base case) (kWh)	15	23	36	48	68	84	77	93
Savings/nameplate ton/year RCA (early retirement base case) (kWh)	25	39	67	99	100	143	136	251
Peak Demand Savings/ton SEER13 (replace on burnout base case) (kW)	0.018	0.026	0.06	0.07	0.113	0.121	0.118	0.124
Peak Demand Savings/ton RCA (early retirement base case) (kW)	0.028	0.045	0.119	0.149	0.151	0.168	0.166	0.2

The entries in Table 6-22 are the averages of performances which are quite diverse in each climate zone. Figure 6-4 shows empirically measured annual cooling energy per ton. In this figure and in the table, in milder climate zones (zones 6 and 7) there is very little cooling. In the hotter zones (13 and above) the annual cooling per ton is much greater. Figure 6-4 shows empirically measured annual cooling energy per ton. The cooling in the milder zones was somewhat erratic and often depended on a warm spell of several days to trigger cooling. Cooling in the warmer zones was much more regular.

Figure 6-3: SEER 13 Monitored Base Case Units

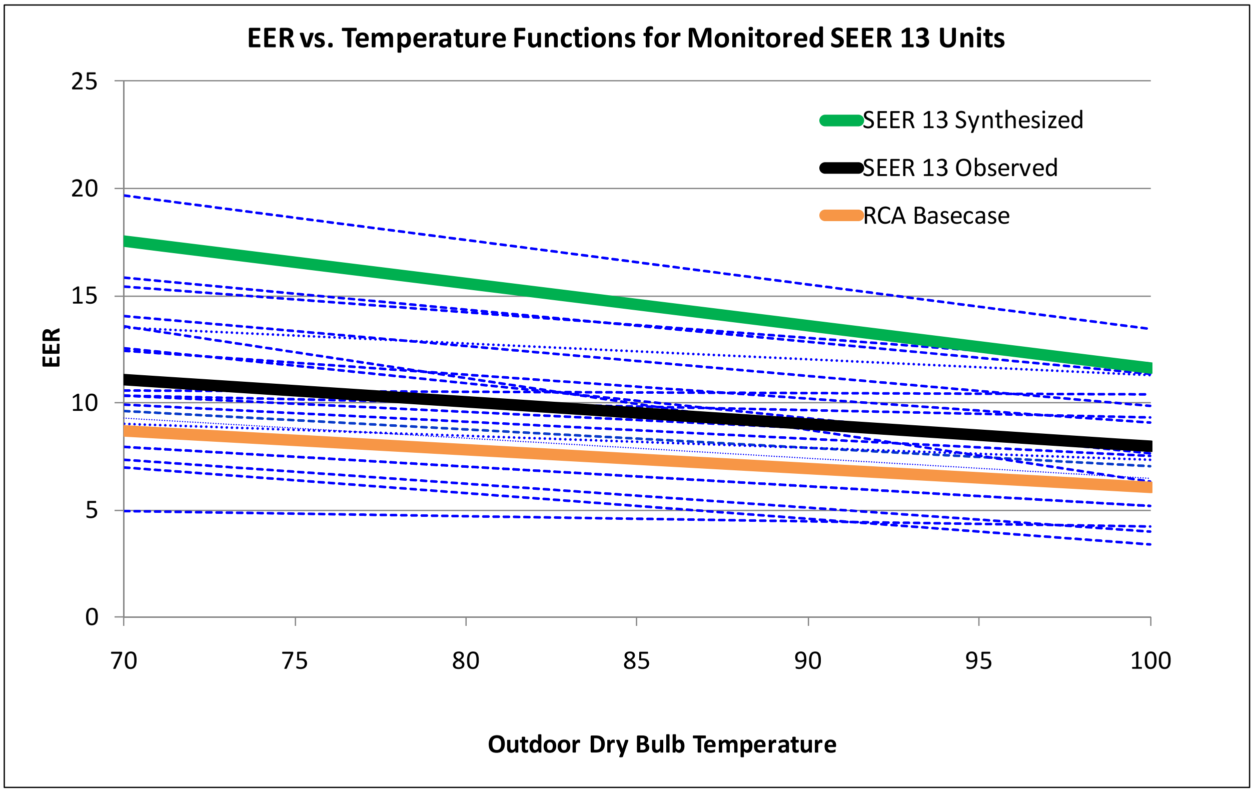
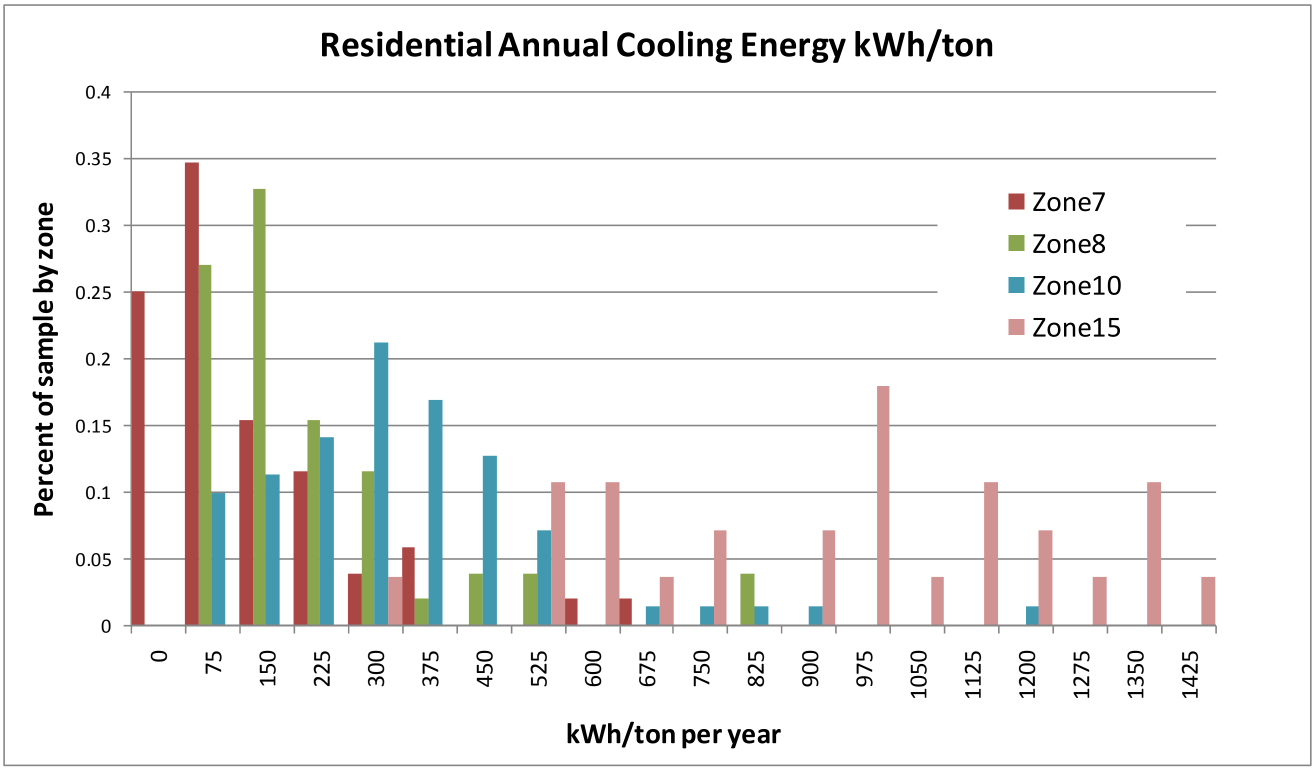
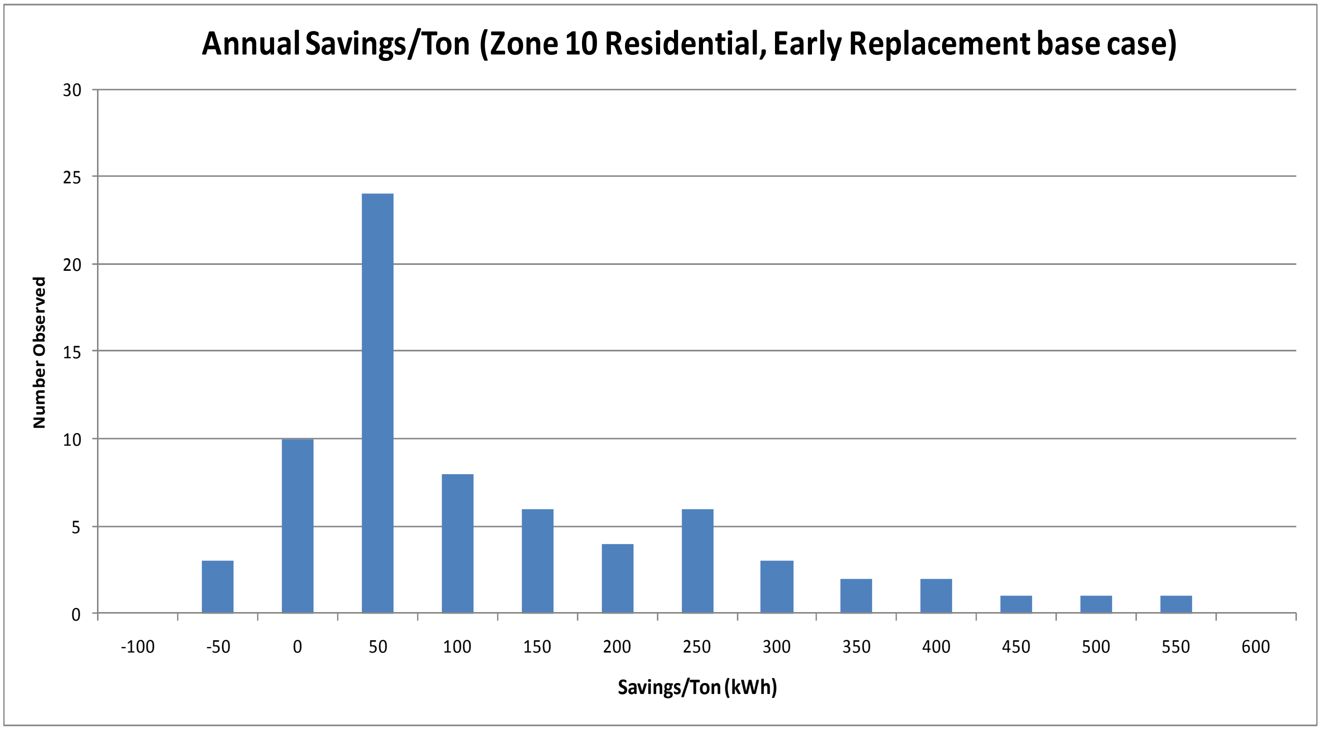


Figure 6-4: Monitored Units Cooling Energy per Ton



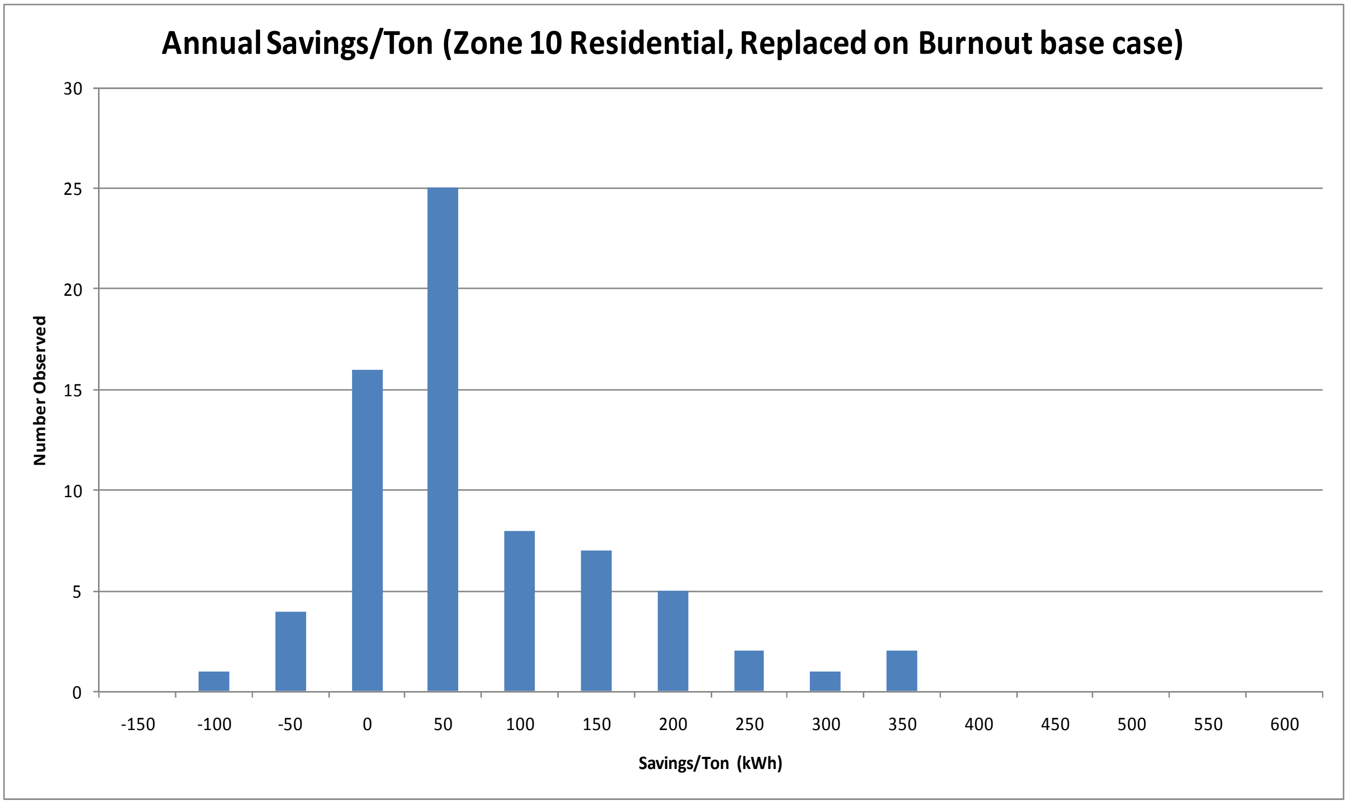
In general, the savings were distributed as shown in Figure 6-5 and Figure 6-6. In this graph, 16% of the units were SEER 13, and 84% were SEER 14 or better. These figures are shown for zone 10, the most populous zone; similar figures were derived for climate zone 7. In the early replacement situation, the savings are distributed about a mode of 50 kWh per year per ton with few negative savings and a tail of much higher savings in the range of 300 to 450 kWh/ton/year. This distribution leads to an average savings of 100 kWh/nameplate ton/year. With cooling energy of 297 kWh/ton/year, this represents savings of the order of 35%. Again, these savings represent an unbiased comparison of field measured efficiency between as-built and baseline units.

Figure 6-5: Savings Distribution, Early Replacement Zone 10



The distribution of the savings for the replace on burnout cases is also distributed around a mode of 50 kWh/ton/year, but has more negative savings such that the mean of these savings is 68 kWh/nameplate ton/year. With zone 10 cooling energy of 297 kWh/ton/year, this represents savings of the order of 23%.

Figure 6-6: Savings Distribution, Replace on Burnout Zone 10



6.4.4 Commercial AC Replacement

Table 6-23 summarizes the empirical findings of the commercial sector participants. . This table reports annual cooling load, peak demand, estimated energy savings with respect to each replacement type, and estimated demand savings with respect to each replacement type. These values are presented by climate zone. Each usage and savings estimate is developed by driving the site-specific energy and efficiency models of a single monitored unit with the hourly average temperatures from a typical meteorological year (TMY). This is done with TMY temperatures not only from the climate zone the site was monitored in, but also from adjacent zones with similar cooling degree days and humidity patterns. The details of this approach to drive multiple savings estimates in geographically and behaviorally similar climate zones from a single unit model are described in Appendix section E. Due to the variability observed on the unit level, it has been important to use as many unit models (unit analyses) as possible for each climate zone to obtain reliable distributions of performance.

Table 6-23: Commercial Monitoring Results by Climate Zone

	Zone 2	Zone 3	Zone 4	Zone 6	Zone 7	Zone 8	Zone 9
Annual Cooling/ton (kWh)	708	449	657	611	692	838	987
Peak Demand/ton (kW)	0.656	0.303	0.505	0.281	0.326	0.571	0.608
Savings/nameplate ton/year SEER13 (replace on burnout base case) (kWh)	94	35	81	64	81	115	149
Savings/nameplate ton/year RCA (early retirement base case) (kWh)	213	90	193	162	201	272	337
Peak Demand Savings/ton SEER13 (replace on burnout base case) (kW)	0.134	0.06	0.104	0.06	0.069	0.116	0.123
Peak Demand Savings/ton RCA (early retirement base case) (kW)	0.289	0.147	0.237	0.144	0.166	0.259	0.271
		Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15
Annual Cooling/ton (kWh)	-	1075	1075	1026	1277	1207	2373
Peak Demand/ton (kW)	-	0.827	0.827	0.779	0.889	0.891	1.054
Savings/nameplate ton/year SEER13 (replace on burnout base case) (kWh)	-	161	161	156	206	195	424
Savings/nameplate ton/year RCA (early retirement base case) (kWh)	-	356	340	255	441	414	852
Peak Demand Savings/ton SEER13 (replace on burnout base case) (kW)	-	0.184	0.175	0.186	0.196	0.196	0.224
Peak Demand Savings/ton RCA (early retirement base case) (kW)	-	0.355	0.339	0.356	0.373	0.374	0.416

While the higher numbered climate zones tend to be hotter, this relationship does not follow exactly. For example, zones 2 and 4 are much warmer than zones 3 and 6. The usage and savings in this table follows cooling degree days and peak temperatures of the typical meteorological year associated with that climate zone.

The information in this summary was calculated from 71 monitored units, which represent about 50% of all the monitored units. The principal cause of monitoring attrition was insufficient data caused by commencing monitoring too late in the cooling season.

There are two fundamental measurements that underlie results.

1. An estimate of the annual cooling energy use provided by fitting a simple temperature based model to the monitored energy use and projecting the model results to a normal year. For most sites the monitoring data included one to three summer cooling months, leading to reasonable annual cooling energy estimates.

2. An estimate of the efficiency of the net delivered thermal cooling. This efficiency measurement is provided in the form of an EER vs. temperature plot for each site. This permits a comparison of each site result to a theoretical performance expectation derived for that site using DEER based performance calculations. For each site a normalized annual cooling energy estimate is made by using a standard climate zone temperature year and by normalizing the resulting annual

cooling on a per nameplate ton basis. For all sites taken together the distribution of normalized cooling is shown in Table 6-7. Most of the observed annual cooling occurs at a rate of 200-600 kWh/yr/ton, but a small portion, of the order of 15%, occurs at much higher rates regardless of climate zone. This figure shows that behavior is an important driver for cooling, but weather is also important as shown in Figure 6-7.

For each site a normalized annual cooling energy estimate is made by using a standard climate zone temperature year and by normalizing the resulting annual cooling on a per nameplate ton basis. For Zones 7, 8, 10, and 14, the distribution of normalized cooling is shown in Figure 6-7. It is clear that the annual cooling energy is still dependent on climate zone, but there are also sites dominated by occupant behavior and internal gains, requiring a large amount of cooling energy regardless of temperature. While in the residential sector the observed usage was almost entirely a function of climate, commercial usage depended much more heavily on occupancy concerns and internal gains that were independent of outdoor temperature.

Figure 6-7: Commercial Normalized Annual Cooling Energy

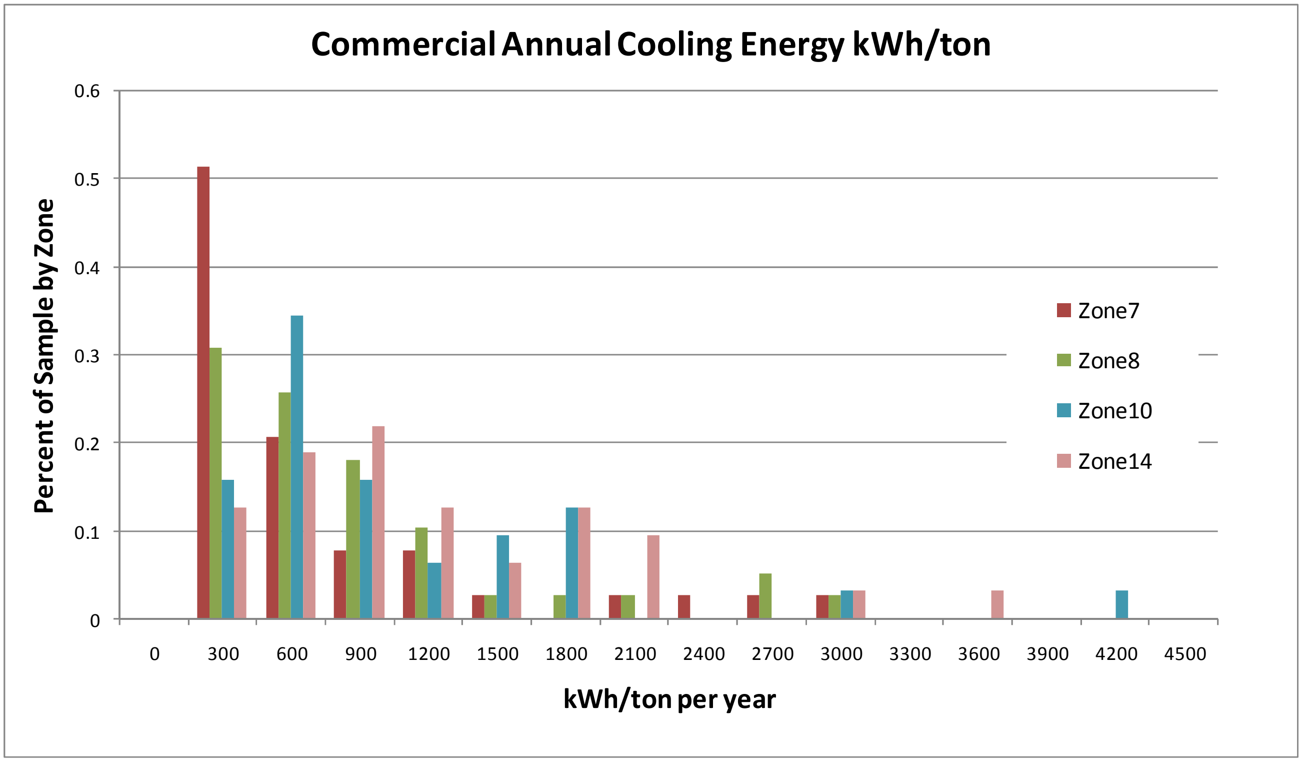


Figure 6-7 shows that much less cooling energy is required in the mild climate zones 6 and 7 than is required in the hotter zones 8, 9, and 10, as might be expected. The detailed site data generally showed that cooling use in climate zone 7 was strongly tempered by the mild climate, and the cooling use was much less than in the nearby, but much warmer, locations.

The operational efficiency of the units serving each site was characterized by a linear EER vs. temperature curve derived for each site from data for hours where the AC ran for more than 75% of the hour. Thus a line on a graph such as in Figure 6-8 characterizes the efficiency for each site. This figure also shows the efficiency expectations for a code level unit operating near ideal conditions as the solid line with triangles, an observed average code level unit as the solid line with squares, and an average as-found unit as the solid line with circles.

Figure 6-8: Commercial EER Functions

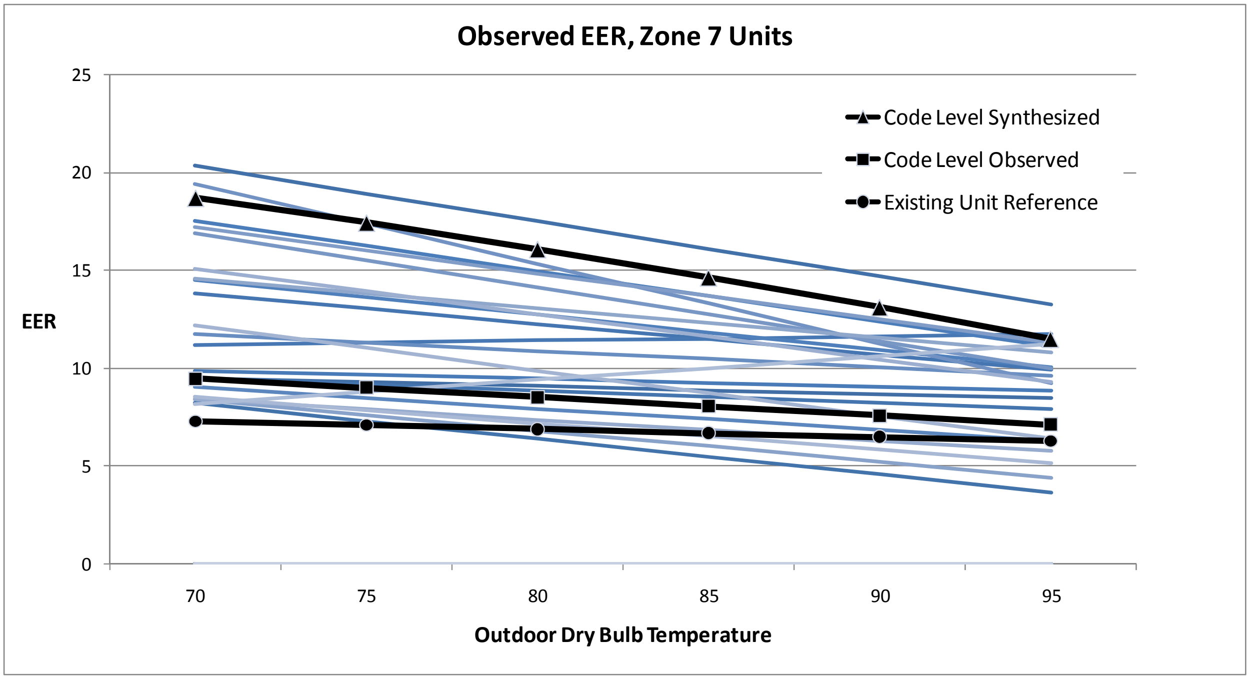


Figure 6-8 shows a wide variation in performance, with some sites showing better performance than the DEER ideal (as expected) and some sites showing very poor performance. Most sites perform better than the de-facto code base line (solid line with squares) which was derived from a sample of 11 nonparticipant code-qualifying units. Nonparticipants were a metered sample from the PG&E territory. These were selected by reviewing billing histories and identifying a sample with seasonal load who replaced their air conditioner between 2006 and 2008 with a unit manufactured after the SEER 13 code change.

This figure shows that the average efficiency of the code qualifying units is much less than the ideal DEER code-qualifying efficiency. Overall, about 10% of the monitored units performed at or better than the DEER expectation, and the rest of the units perform at a lower efficiency. This resulted in an average efficiency much lower than the ideal DEER efficiency for code qualifying units. The empirically based average was used as the code baseline in this analysis.

It is possible to attribute the wide scatter in the performance measurements as experimental variation in measured flow rate as discussed in Section 6.4.1. However, the potential bias introduced in the observed EER by a regular understatement of actual flow by the True Flow test would still leave the average true EER well below that developed with DEER unit performance functions. This data was taken to show that installed code-qualifying units, on average, perform at a lower efficiency than indicated by the DEER estimates, and that the relatively low average efficiency observed for the code-qualifying base case is a reasonable base case for code compliant systems.

This evaluation did not monitor the performance of the original unit replaced, that is, there is no matched-pair, pre-post base case of “as found” units. Therefore, the base case for the early replacement sites was derived from the empirical base case of code-qualifying units installed by nonparticipants, and informed according to the engineering (synthesized) estimates derived from DEER unit performance functions. The evaluators calculated the ideal DEER performance for “as found” units using a deteriorated nominal EIR to characterize these units. In addition, an ideal DEER characterization of the code-compliant units was calculated. These calculations of the ideal DEER performance included a correction for the condenser fan and for an assumed 15% outside air. The ratio of the DEER “as found” to the DEER ideal code-compliant unit is a number less than one, since the “as found” are generally less efficient. This number was applied as a correction factor to the empirical code-compliant base case to estimate the “as found” base case.

6.5 Detailed Findings

This analysis carefully used both a synthesized and an empirical baseline. As noted, the synthesized basecase is an engineering calculation based on the DOE2/DEER methodology for calculating the energy use of air conditioning units. The Evaluation Team carried a rigorous theoretical baseline derived from DEER performance parameters and driven by monitored conditions at the site. DEER expectations were met by a small percentage of the sites which suggests that the estimation process can accurately forecast the performance of a properly operating site. The remainder of the sites came up well short of the DEER expectation for unknown field installation reasons. These likely are related to duty cycle, outside air intake, charge conditions of the units; i.e., charge level and non-condensables. It was apparent that in most cases units were performing at an efficiency lower than the DEER baseline. This triggered additional review and a second inspection at a subset of sites, including additional spot measurements of air flow and fan power. This dissonance between theoretical baseline and empirical performance led the team to add an empirical base case to the analysis.

There is no question that the annual usage increases with hotter climates. In fact, the annual cooling does follow and increases from milder to more severe zones. The savings do not follow in such a simple manner. The difference in performance between base case and observed is greater in the milder climates at lower temperatures than in the more severe climates and creates the situation observed, i.e., the difference between the observed and base case is a temperature dependent function and the difference (savings) is lower at high temperatures than at low temperatures. Therefore, savings are temperature dependent but percentage-wise are less so at the high temperatures. Savings estimates also depend on the particular mix of observed sites in the climate zones.

The savings results summaries for the specific programs are presented in Table 6-24 through Table 6-32. For each utility, these tables show program participation by climate zone and participation type, early retirement or replace on burn out. The tables also show the evaluated savings estimates for these programs derived from the monitoring results and the reported utility participation data. Finally these tables report the program realization rates for annual kWh savings and peak kW savings as the evaluated savings/ utility claimed savings.

The monitored performance for the residential and commercial participants has been used as presented in Table 6-22, and Table 6-23. This information has been combined with utility program records that specify the number of participant units in each climate zone, nameplate tonnage of installed units, and the designation as early replacement or replace on burnout.

6.5.1 Residential Program Level Savings

Gross IOU energy and demand savings as well as evaluated gross savings are shown in the following tables. Each table depicts the IOU program evaluated and the stratum, including climate zone and replacement type. In each of these tables, the evaluated unit energy savings (kWh/yr/ton) are shown in column C. The IOU claimed number of tons installed is shown in column B. The program evaluated savings in column E are computed by multiplying the UES by number of tons.

Table 6-24: SDG&E 3029 Residential Energy Savings by Zone

		A	B	C	D	E	F
Climate Zone	Replace Type	IOU Claimed		Evaluated UES	IOU Claimed	Evaluated [Col. B * Col C]	Realization Rate [Col E / Col D]
		Units	Tons	kWh/yr/ton	kWh/yr	kWh/yr	kWh
7	Early	1,800	5,966	39	1,136,632	233,918	21%
7	Burnout	69	215	23	48,237	4,975	10%
7	New Construction	11	36	23	7,236	833	12%
10	Early	1,278	4,409	100	1,524,684	442,868	29%
10	Burnout	67	213	68	73,191	14,408	20%
10	New Construction	12	35	68	12,048	2,367	20%
	Total	3,237	10,874		2,802,029	699,369	25%

Table 6-25: SDG&E 3029 Residential Demand Savings by Zone

		A	B	C	D	E	F
Climate Zone	Replace Type	IOU Claimed		Evaluated UES	IOU Claimed	Evaluated [Col. B * Col C]	Realization Rate [Col E / Col D]
		Units	Tons	kW/ton	kW	kW	kW
7	Early	1,800	5,966	0.045	2,074	267	13%
7	Burnout	69	215	0.026	80	6	7%
7	New Construction	11	36	0.026	14	1	7%
10	Early	1,278	4,409	0.151	1,529	666	44%
10	Burnout	67	213	0.113	80	24	30%
10	New Construction	12	35	0.113	13	4	30%
	Total	3,237	10,874		3,790	967	26%

Table 6-26: SCE 2507 Residential Energy Savings by Zone

		A	B	C	D	E	F
Climate Zone	Replace Type	IOU Claimed		Evaluated UES	IOU Claimed	Evaluated [Col. B * Col C]	Realization Rate [Col E / Col D]
		Units	Tons	kWh/yr/ton	kWh/yr	kWh/yr	kWh
6	Early	94	342	25	29,723	8,400	28%
6	Burnout	53	188	15	2,619	2,830	108%
8	Early	459	1,731	67	375,202	116,809	31%
8	Burnout	183	713	36	23,029	25,416	110%
9	Early	320	1,226	99	323,674	121,912	38%
9	Burnout	156	612	48	17,145	29,262	171%
10	Early	1,195	4,410	100	1,336,735	442,968	33%
10	Burnout	438	1,613	68	58,283	109,107	187%
13	Early	2	10	143	4,000	1,433	36%
13	Burnout	23	76	84	2,329	6,381	274%
14	Early	15	54	136	9,929	7,277	73%
14	Burnout	12	45	77	911.9673	3,486	382%
15	Early	143	568	251	190,344	142,449	75%
15	Burnout	334	1,318	93	89,126	122,660	138%
16	Early	1	3	25	203	74	36%
16	Burnout	9	34	15	643	506	79%
Total		3,437	12,940		2,463,896	1,140,969	46%

Table 6-27: SCE 2507 Residential Demand Savings by Zone

		A	B	C	D	E	F
Climate	Replace	IOU Claimed		Evaluated UES	IOU Claimed	Evaluated [Col. B * Col C]	Realization Rate [Col E / Col D]
Zone	Type	Units	Tons	kW/ton	kW	kW	kW
6	Early	94	342	0.028	100	10	10%
6	Burnout	53	187.5	0.018	12	3	28%
8	Early	459	1,731	0.119	393	206	52%
8	Burnout	183	712.5	0.06	44	42	96%
9	Early	320	1,226	0.149	373	183	49%
9	Burnout	156	612	0.07	31	43	139%
10	Early	1,195	4,410	0.151	1,628	666	41%
10	Burnout	438	1,613	0.113	81	182	225%
13	Early	2	10	0.168	3	2	65%
13	Burnout	23	76	0.121	3	9	328%
14	Early	15	53.5	0.166	13	9	67%
14	Burnout	12	45	0.118	2	5	228%
15	Early	143	568	0.2	129	113	88%
15	Burnout	334	1,318	0.124	86	163	189%
16	Early	1	3	0.028	1	0	7%
16	Burnout	9	33.5	0.018	2	1	31%
Total		3,437	12,940		2,901	1,636	56%

The IOU deemed ex ante savings for all residential HVAC replacement measures was based on savings published in the DEER database. Evaluated energy savings at SCE fell short of the ex-ante claim, leading to a gross kWh realization rate of 46%. SCE claims for energy savings are unusually high in certain climate zones and are not consistent with SDG&E for the same climate zone. For example, in zone 10, SCE claims savings for early replacement units on the order of 1,100 kWh/unit/year (303 kWh/ton/year) and SDG&E claims about 1,190 kWh/unit/year (346 kWh/ton/year) (derived by dividing claimed savings by number of participants). However, for the units replaced on burnout, SCE claims savings of about 133 kWh/unit/year (36 kWh/ton/year) and SDG&E claims 1,092 kWh/unit/year (344 kWh/ton/year).

For SDG&E 3029, the IOU deemed savings for all residential HVAC replacement measures based on savings published in the DEER database. Evaluated energy savings at SDG&E fall far short of the ex ante claim, with a kWh gross realization rate of 25%.This is because more than half the units were installed in cooler climate zone 7. The IOU initially capped the number of units eligible for installation in this climate zone because the mild climate would not realize high savings. However, when the program did not enroll as expected, the IOU removed the cap on eligible units and decided to forego energy savings in favor of demand savings. However, since grid demand savings are proportional to energy savings, raising the cap did not disproportionately increase demand savings. The grid level system peak demand realization rate however is 26%. This is due to irregular residential cooling operation, with many hours of zero operation, including the peak hours. The evaluated savings for grid demand peak include hours of null operation to capture the diversity of unit operating patterns.

A useful perspective on the IOU claimed and achieved savings is provided by Figure 6-9 and Figure 6-10 where the metered annual cooling energy as well as the claimed and metered energy savings for each climate zone are presented together in the same graph.

Figure 6-9: SCE Residential Energy Use and Unit Savings

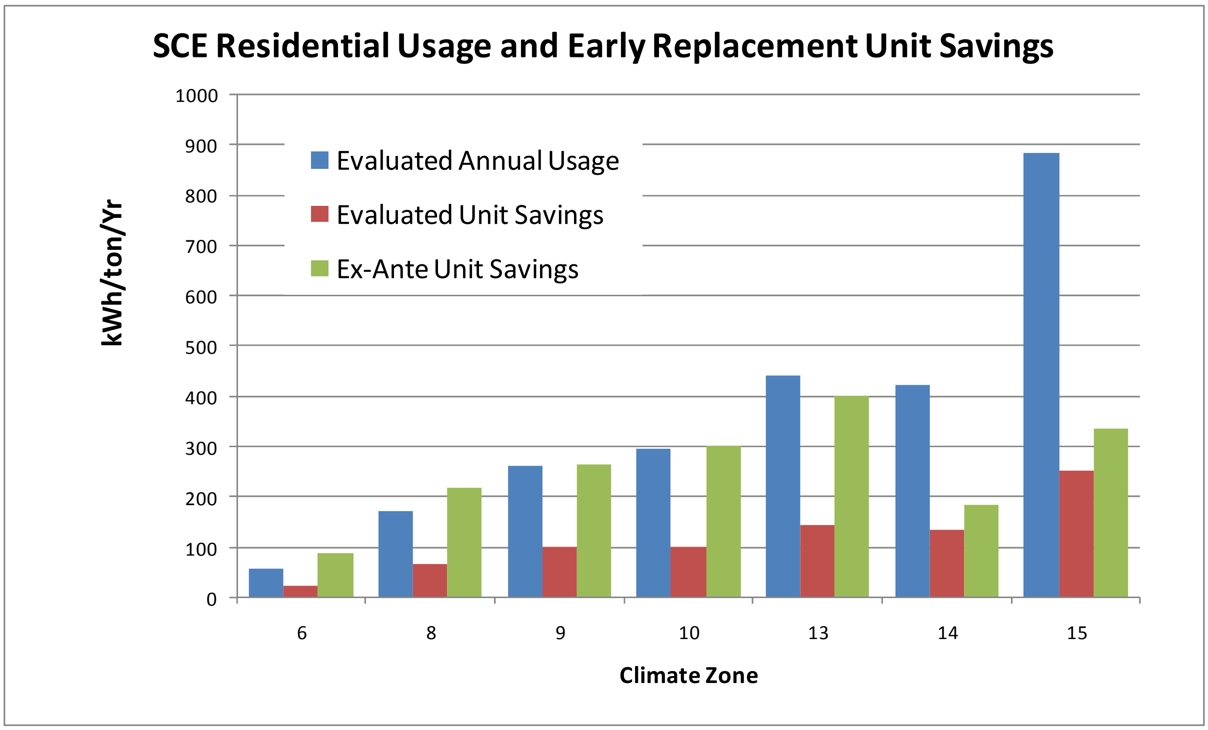
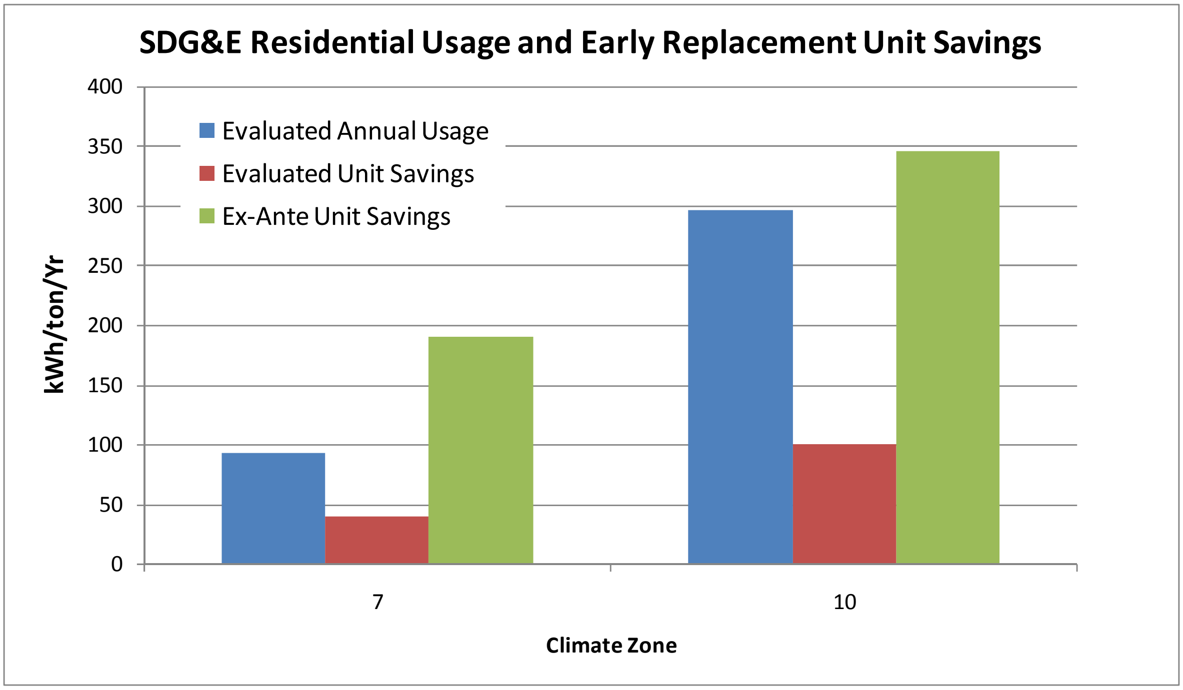


Figure 6-10: SDG&E Residential Energy Use and Unit Savings



These graphs show several significant strata where the claimed savings exceed the total metered cooling energy, which suggest that the cooling load for these strata has been over estimated.

The final aggregate results for both residential programs are reported in Table 6-28.

Table 6-28: Residential Aggregate Energy and Demand Savings by Zone

	Number of Participants	Total Tons	IOU Claimed kWh/yr	Evaluated kWh/yr	Claimed kW peak	Evaluated kW peak
SCE 2507 Residential	3,437	12,940	2,463,896	1,140,969	2,901	1,636
SDG&E 3029 Residential	3,237	10,874	2,802,029	699,369	3,790	967

6.5.2 Commercial Program Level Savings

The summaries for the specific programs are presented in the tables below. For each utility, these tables show program participation by climate zone and participation type, early retirement or replace on burn out. The tables also show the evaluated savings estimates for these programs derived from the monitoring results shown in Table 6-29 and the reported utility participation data (column B multiplied by column C). Finally, these tables report the program realization rates for annual kWh savings and peak kW savings (column E divided by column D).

For the PG&E 2080 program, a complete description of participant tonnage by climate zone was not available. The evaluation had detailed information regarding a subset of the program population, and the proportion of tonnage by climate zone in this subset was assumed to represent the proportion of tonnage by climate zone in the entire program. Using this distribution of tonnage, a weighted average unit savings was taken based on calculated climate zone unit savings and the estimated proportion of program tons in each climate zone. This weighted average was applied to all program tonnage. Due to the lacking data, however, it was not possible to present detailed tables of savings by climate zone for the PG&E 2080 program.

Table 6-29: SCE 2507 Commercial Energy Savings Results

		A	B	C	D	E	F
Climate	Replace	IOU Claimed		Evaluated UES	IOU Claimed	Evaluated [Col. B * Col C]	Realization Rate [Col E / Col D]
Zone	Type	Units	Tons	kWh/yr/ton	kWh/yr	kWh/yr	kWh
6	Early	282	1,935	162	375,854	312,496	83%
6	Burnout	208	1,942	64	313,653	123,660	39%
8	Early	699	5,358	272	1,395,649	1,455,508	104%
8	Burnout	283	4,294	115	840,167	495,122	59%
9	Early	427	4,109	337	1,131,917	1,384,771	122%
9	Burnout	312	3,171	149	685,131	472,049	69%
10	Early	306	2,416	356	687,228	859,488	125%
10	Burnout	339	5,056	161	1,129,250	813,683	72%
13	Early	4	27	441	11,876	11,684	98%
13	Burnout	62	768	206	190,239	158,293	83%
14	Early	56	321	414	104,307	133,010	128%
14	Burnout	109	1,903	195	417,037	371,197	89%
15	Early	11	154	852	52,669	130,828	248%
15	Burnout	51	960	424	328,239	407,403	124%
16	Early	4	50	162	5,609	8,077	144%
16	Burnout	1	5	64	567.9211	308	54%
	TOTALS	3,154	32,466		7,669,393	7,137,578	93%

Table 6-30: SCE 2507 Commercial Demand Savings Results

		A	B	C	D	E	F
Climate	Replace	IOU Claimed		Evaluated UES	IOU Claimed	Evaluated [Col. B * Col C]	Realization Rate [Col E / Col D]
Zone	Type	Units	Tons	kW/ton	kW	kW	kW
6	Early	282	1,935	0.144	237	280	118%
6	Burnout	208	1,942	0.06	198	116	59%
8	Early	699	5,358	0.259	1,038	1,386	134%
8	Burnout	283	4,294	0.116	615	497	81%
9	Early	427	4,109	0.271	917	1,115	122%
9	Burnout	312	3,171	0.123	534	391	73%
10	Early	306	2,416	0.355	561	857	153%
10	Burnout	339	5,056	0.184	905	933	103%
13	Early	4	26.5	0.373	10	10	103%
13	Burnout	62	767.51	0.196	149	150	101%
14	Early	56	321	0.374	91	120	132%
14	Burnout	109	1,903	0.196	355	374	105%
15	Early	11	153.5	0.416	32	64	198%
15	Burnout	51	960.31	0.224	193	215	111%
16	Early	4	50	0.144	8	7	90%
16	Burnout	1	4.83	0.06	1	0	46%
	TOTALS	3,154	32,466		5,841	6,514	112%

Table 6-31: SDG&E 3029 Commercial Energy Savings Results

		A	B	C	D	E	F
Climate	Replace	IOU Claimed		Evaluated UES	IOU Claimed	Evaluated [Col. B * Col C]	Realization Rate [Col E / Col D]
Zone	Type	Units	Tons	kWh/yr/ton	kWh/yr	kWh/yr	kWh
7	Burnout	311	2,628	81	706,601	211,886	30%
7	Early	645	4,289	201	1,251,553	861,963	69%
10	Burnout	131	977	161	345,988	157,241	45%
10	Early	277	2787	356	922,553	991,676	107%
	TOTALS	1,364	10,681		3,226,695	2,222,766	69%

Table 6-32: SDG&E 3029 Commercial Demand Savings Results

		A	B	C	D	E	F
Climate	Replace	IOU Claimed		Evaluated UES	IOU Claimed	Evaluated [Col. B * Col C]	Realization Rate [Col E / Col D]
Zone	Type	Units	Tons	kW/ton	kW	kW	kW
7	Burnout	311	2,628	0.069	456	182	40%
7	Early	645	4,289	0.166	797	710	89%
10	Burnout	131	977	0.184	244	180	74%
10	Early	277	2787	0.355	687	988	144%
	TOTALS	1,364	10,681		2,185	2,061	94%

A useful perspective on the IOU claimed and achieved savings is provided by Figure 6-11 and Figure 6-12 where the metered annual cooling energy as well as the claimed and metered energy savings for each program strata are presented together in the same figure.

Figure 6-11: SCE Commercial Energy Use and Unit Savings

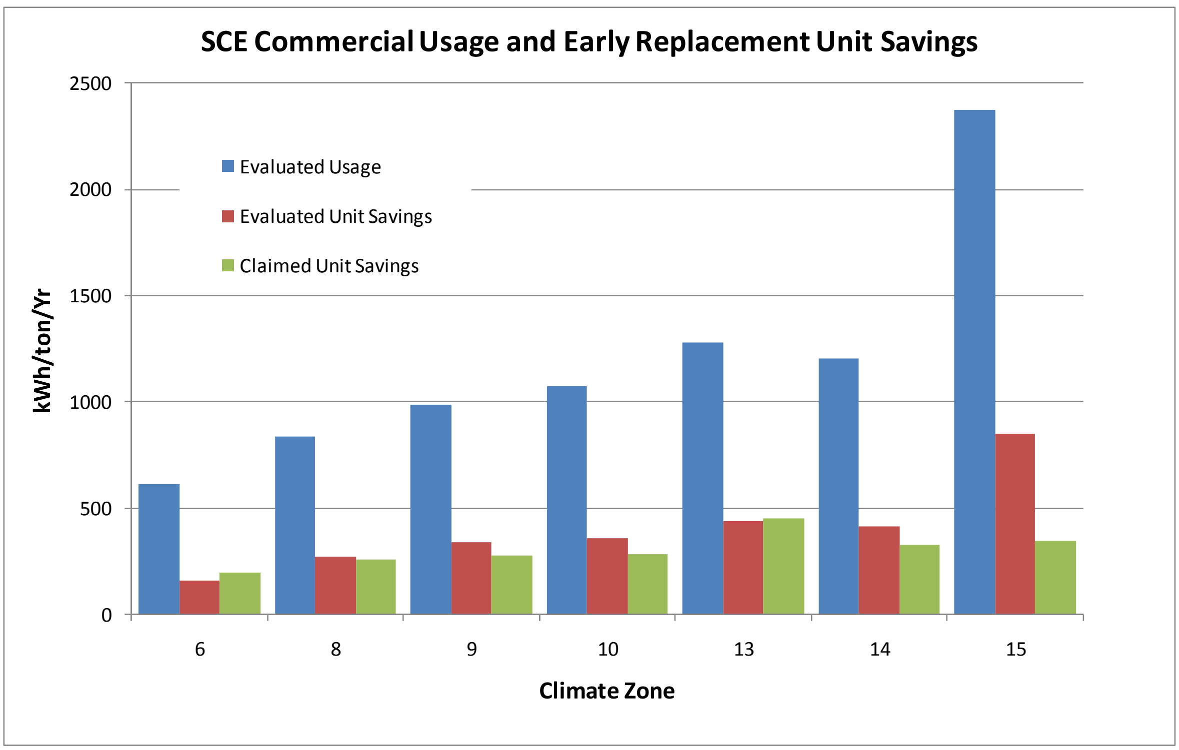
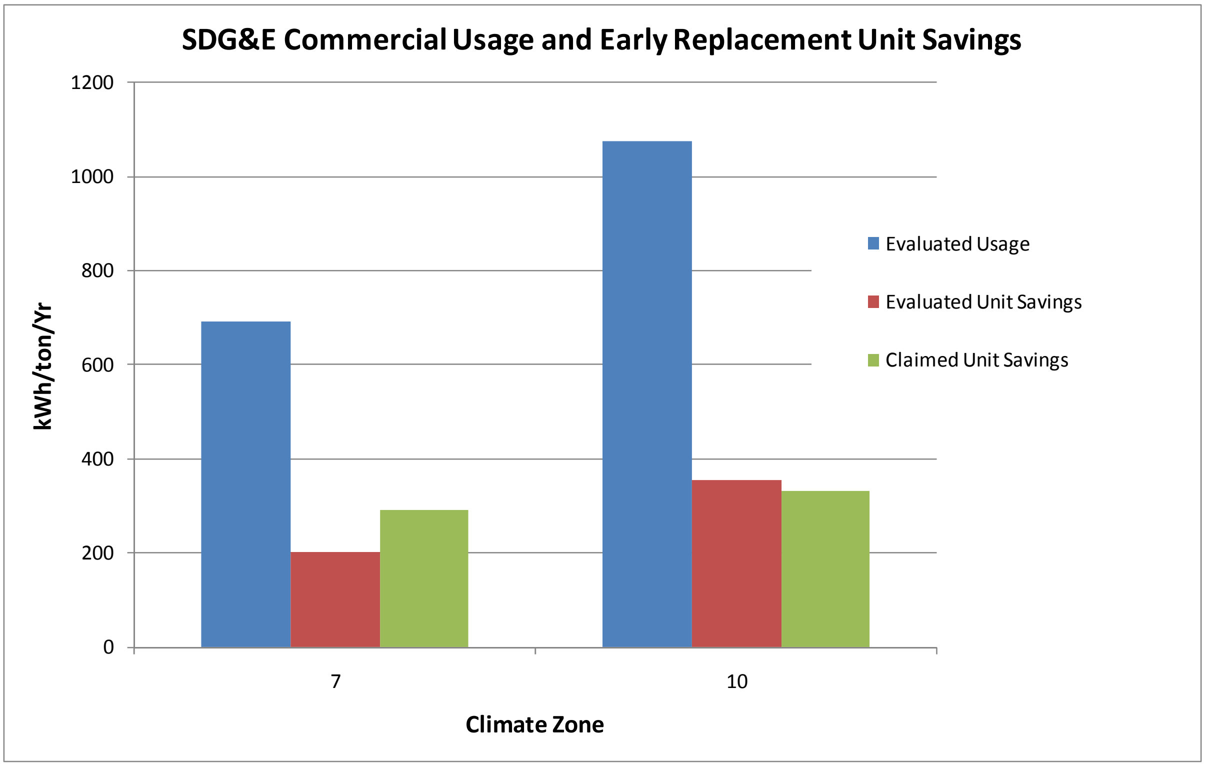


Figure 6-12: SDG&E Commercial Energy Use and Unit Savings



These figures show that commercial savings estimates are much more in agreement with annual usage as measured by the evaluation.

For SDG&E 3029, the IOU deemed savings for commercial HVAC replacement measures based on savings published in the DEER database.

The SCE program achieved 93% of its kWh ex ante estimates and 112% of its peak kW ex ante estimates. The SDG&E program achieved 69% of its kWh ex ante estimates and 94% of its peak kW ex ante estimates.

In these tables, the M&V work shows that both the kWh and kW savings were over estimated by the utilities in climate zones 6 and 7. This overestimate is due to the fact that the observed cooling energy for mild zones 6 and 7 is much less than for the warmer zones. The high preponderance of the mild zone 7 participants in the SDG&E program leads to the generally low realization rates observed for this program. . In the same way, the low realized savings for the PG&E 2080 energy savings is largely due to the prevalence of units in the temperate climate zone 3. The low observed annual usage in mild climate zones necessarily leads to low observed annual savings. On the other hand, the M&V work shows that the savings for the hotter regions exceed the utility estimates.

The final results aggregate results for both commercial programs are reported in Table 6-35.

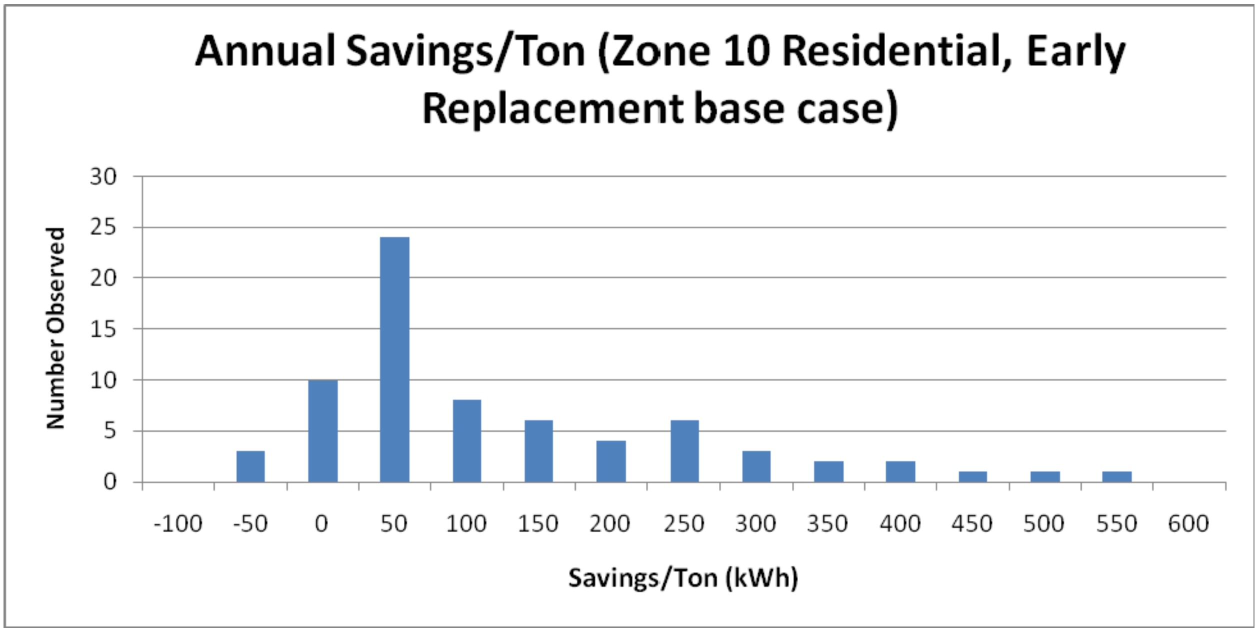
Table 6-33: Commercial Aggregate Energy and Demand Savings

Program	Number of Participants	Total Tons	IOU Claimed kWh/yr	Evaluated kWh/yr	Claimed kW peak	Evaluated kW peak
SCE 2507 C/I	3,154	32,466	7,669,393	7,137,578	5,841	6,514
SDG&E 3029 C/I	1,364	10,681	3,226,695	2,222,766	2,185	2,061
PG&E 2080 C/I	20,782	157,598	36,969,145	17,258,976	27,521	22,445

6.5.3 Achieved Precision

The precision presented here is the precision of the unit savings estimates by climate zone and replacement type, followed by a summary of overall precision by utility. The precision of the unit energy savings ultimately drive the total savings estimates and are therefore the relevant parameters to consider. In this estimate of the precision of unit energy savings, the precision presented implicitly includes all uncertainty on all levels of the analysis including metering data, spot measurements, site data, occupant behavior, data input, data aggregation, the energy use model, the efficiency regression model, the DEER performance parameters, the empirical base case parameters. That is, everything that induced randomness in the evaluation is contained within these observed distributions of savings per ton. . The principal challenge to high precision is the wide behavioral variation in energy use at any particular site. For example Figure 6-13 shows a wide and inherent variation in the energy savings for a particular climate zone. This wide variation applies in all climate zones, and it applies to estimates of annual cooling energy as well. This wide variation will necessarily lead to a broad confidence interval at the specified 90 percent confidence level. Even when the maximum number of sites are applied to the estimates for each climate zone as discussed above in 6.4.3 and 6.4.4, there will be a broad confidence interval.

Figure 6-13: Residential Zone 10 Savings Distribution



6.5.3.1 Residential Achieved Precision

The achieved precision applied to residential participants is presented in Table 6-34. Note in the table that the precision is estimated for each of the eight climate zones used in this analysis, and note also that the achieved precision is generally in the range of 20-40%. There is, however, a much larger band for the Zone 15 estimates and much fewer unit models used to generate those estimates. This was due to the vastly different occupant behavior and psychology in the severe heat of Zone 15, which prevented the application of the analysis models from any other climate zones.

Table 6-34: Residential Confidence and Precision of Savings Estimates

	Zone6		Zone7		Zone8		Zone9	
	Burnout	Early	Burnout	Early	Burnout	Early	Burnout	Early
Number of units used	47	52	47	52	47	52	47	52
Annual Usage/ton (kWh)	57		93		171		260	
Savings/ton (kWh)	15	25	23	39	36	67	48	99
Confidence Interval	6	9	8	13	11	16	14	22
Relative Precision	40%	39%	36%	33%	32%	24%	30%	22%
Peak Demand/ton (kW)	0.057		0.094		0.295		0.372	
Peak Demand Savings/ton (kW)	0.018	0.028	0.026	0.045	0.060	0.119	0.070	0.149

Confidence Interval	0.008	0.011	0.011	0.015	0.023	0.027	0.029	0.034
Relative Precision	45%	40%	42%	34%	38%	23%	42%	23%
	Zone10		**Zone13**		**Zone14**		**Zone15**	
	Burnout	**Early**	**Burnout**	**Early**	**Burnout**	**Early**	**Burnout**	**Early**
Number of units used	56	71	84	99	84	99	28	28
Annual Usage/ton (kWh)	297		441		422		884	
Savings/ton (kWh)	68	100	84	143	77	136	93	251
Confidence Interval	22	26	26	32	24	30	75	92
Relative Precision	32%	26%	31%	22%	31%	22%	81%	37%
Peak Demand/ton (kW)	0.407		0.461		0.467		0.549	
Peak Demand Savings/ton (kW)	0.113	0.151	0.121	0.168	0.118	0.166	0.124	0.200
Confidence Interval	0.054	0.049	0.042	0.041	0.043	0.041	0.071	0.077
Relative Precision	48%	32%	35%	24%	36%	25%	57%	38%

6.5.3.2 Commercial Achieved Precision

The achieved precision for the metered commercial sites is presented in Table 6-35. The 90% confidence intervals for the commercial sites ranges from about 30-50%, and is somewhat broader than the confidence intervals for the residential metered sites. The commercial savings were far more variable than the residential and the precision was affected by the lower sample sizes realized. The attrition rate for metered commercial sites was about 50% and the vast majority of those rejected were due to insignificant or nonexistent cooling activity. It should be noted that sites were only rejected if data was lacking or there appeared to be a problem with the data; sites with abnormally high or abnormally low performance were not rejected if the data were well behaved. Sites were rejected only if there appeared to be a compelling reason to question validity of the data. This also contributes to the spread of the observed savings as some apparent “outlier” sites were ultimately included upon finding no credible reasons to doubt their legitimacy.

Due to the unavailability of detailed, program level information, the evaluation was not able to consider the PG&E 2080 program with the same rigorous statistical methodology that was used to investigate SCE and SDG&E. However, it is assumed that statistical precision for PG&E 2080 estimates would closely follow the precision calculated for SCE and SDG&E, as the field and analytical procedures were identical.

Table 6-35: Commercial Confidence and Precision of Savings Estimates

	Zone6		Zone7		Zone8		Zone9	
	Burnout	Early	Burnout	Early	Burnout	Early	Burnout	Early
number of units used	39		39		39		39	
Annual Usage/ton (kWh)	611		692		838		987	
Savings/ton (kWh)	64	162	81	201	115	272	149	337
Savings/ton +-	31	56	36	63	46	72	55	83
Savings/ton +- %	49%	35%	45%	31%	39%	27%	37%	25%
Grid Demand/ton (kW)	0.281		0.326		0.571		0.608	
Grid Savings/ton (kW)	0.06	0.144	0.069	0.166	0.116	0.259	0.123	0.271
Grid Savings/ton (kW) +-	0.03	0.047	0.034	0.051	0.061	0.082	0.067	0.089
Grid Savings/ton (kW) +- %	51%	32%	49%	31%	53%	32%	54%	33%
	Zone10		Zone13		Zone14		Zone15	
	Burnout	Early	Burnout	Early	Burnout	Early	Burnout	Early
number of units used	32		32		32		32	
Annual Usage/ton (kWh)	1,075		1,277		1,207		2,373	
Savings/ton (kWh)	161	356	206	441	195	414	424	852
Savings/ton +-	56	106	70	122	66	113	150	228
Savings/ton +- %	35%	30%	34%	28%	34%	27%	35%	27%
Grid Demand/ton (kW)	0.827		0.889		0.891		1.054	
Grid Savings/ton (kW)	0.184	0.355	0.196	0.373	0.196	0.374	0.224	0.416
Grid Savings/ton (kW) +-	0.068	0.116	0.077	0.125	0.077	0.126	0.108	0.156
Grid Savings/ton (kW) +- %	37%	33%	39%	34%	39%	34%	48%	38%

	Zone6		Zone7		Zone8		Zone9	
	Burnout	Early	Burnout	Early	Burnout	Early	Burnout	Early
Number of units used	39		39		39		39	
Annual Usage/ton (kWh)	611		692		838		987	
Savings/ton (kWh)	64	162	81	201	115	272	149	337
Confidence Interval	31	56	36	63	46	72	55	83
Relative Precision	49%	35%	45%	31%	39%	27%	37%	25%
Peak Demand/ton (kW)	0.281		0.326		0.571		0.608	
Peak Demand Savings/ton (kW)	0.060	0.144	0.069	0.166	0.116	0.259	0.123	0.271
Confidence Interval	0.030	0.047	0.034	0.051	0.061	0.082	0.067	0.089
Relative Precision	51%	32%	49%	31%	53%	32%	54%	33%
	Zone10		Zone13		Zone14		Zone15	
	Burnout	Early	Burnout	Early	Burnout	Early	Burnout	Early
Number of units used	32		32		32		32	
Annual Usage/ton (kWh)	1,075		1,277		1,207		2,373	
Savings/ton (kWh)	161	356	206	441	195	414	424	852
Confidence Interval	56	106	70	122	66	113	150	228
Relative Precision	35%	30%	34%	28%	34%	27%	35%	27%
Peak Demand/ton (kW)	0.827		0.889		0.891		1.054	

Peak Demand Savings/ton (kW)	0.184	0.355	0.196	0.373	0.196	0.374	0.224	0.416
Confidence Interval	0.068	0.116	0.077	0.125	0.077	0.126	0.108	0.156
Relative Precision	37%	33%	39%	34%	39%	34%	48%	38%

Even though the confidence intervals for these metering results are broad, these measurements can provide a significant and useful reference for the ex-ante program savings estimates for each specific participant strata. Tables 6-36 to 6-43 show the 90% confidence upper and lower bounds on the savings measurements compared to the corresponding ex-ante estimate. It is clear in these tables that for some strata the ex-ante estimates are well outside the confidence intervals and that for some strata the difference is so large that it would be significant even with much larger confidence intervals.

These tables also contain overall confidence intervals for entire evaluated program savings, with all strata statistically considered together. The overall savings estimate for a utility was calculated as a linear combination of the average unit savings from each stratum, where the weighting factor was equal to the total program tons in that stratum. The variance of the overall savings estimate is then the variance of that sum. This issue was slightly complicated by the methodology of generating multiple savings estimates from a single unit model, i.e., the data from a unit metered and modeled in climate zone 8 was used to generate savings estimates for a zone 8 typical meteorological year (TMY) but also for a zone 6, 7, and 9 TMY. The details and rationale of using these aggregate behavioral zones are discussed in Appendix section E. This approach introduced a positive correlation between savings estimates in the same aggregate behavioral zone. The effects of this correlation were accounted for by not only estimating the variance of each average unit savings but also the covariance between average unit savings for cases where they were not independent.

Also note that the overall precision represents a narrower band than any individual precision. This is because the standard deviation of a sum is not simply the sum of the standard deviations, but, in the simplest case, it is the square root of the sum of squared standard deviations. These calculations were slightly more complicated by the positive correlation between some savings estimates, and that effect ultimately added 3-4% more to the program level error bounds than if all estimates had been independent.

Table 6-36: SDG&E Residential Energy Precision Results

		A	B	C	D	E	F
Climate	Replace	Evaluated Savings	Precision at 90%	Lower Bound for Savings [Col A * (1 - Col B)]	Upper Bound for Savings [Col A * (1 + Col B)]	Ex-Ante Savings	Realization Rate [Col A / Col E]
Zone	Type	kWh/yr	%	kWh/yr	kWh/yr	kWh/yr	%
7	Early	233,918	33%	155,586	312,250	1,136,632	21%
7	Burnout	4,975	36%	3,204	6,746	48,237	10%
7	New	833	36%	536	1,130	7,236	12%
10	Early	442,868	26%	326,080	559,655	1,524,684	29%
10	Burnout	14,408	32%	9,753	19,062	73,191	20%
10	New	2,367	32%	1,603	3,132	12,048	20%
	TOTALS	699,369	19%	565,259	833,478	2,802,029	25%

Table 6-37: SDG&E Residential Demand Precision Results

		A	B	C	D	E	F
Climate	Replace	Evaluated Savings	Precision at 90%	Lower Bound for Savings [Col A * (1 - Col B)]	Upper Bound for Savings [Col A * (1 + Col B)]	Ex-Ante Savings	Realization Rate [Col A / Col E]
Zone	Type	kW	%	kW	kW	kW	%
7	Early	267	34%	177	356	2,074	13%
7	Burnout	5.5	42%	3.2	7.8	80	7%
7	New	0.9	42%	0.5	1.3	14	7%
10	Early	666	32%	450	882	1,529	44%
10	Burnout	24	48%	13	35	80	30%
10	New	3.9	48%	2.1	5.8	13	30%
	TOTALS	967	23%	740	1,193	3,790	26%

Table 6-38: SCE Residential Energy Precision Results

		A	B	C	D	E	F
Climate	Replace	Evaluated Savings	Precision at 90%	Lower Bound for Savings [Col A * (1 - Col B)]	Upper Bound for Savings [Col A * (1 + Col B)]	Ex-Ante Savings	Realization Rate [Col A / Col E]
Zone	Type	kWh/yr	%	kWh/yr	kWh/yr	kWh/yr	%
6	Early	8,400	39%	5,166	11,635	29,723	28%
6	Burnout	2,830	40%	1,703	3,957	2,619	108%
8	Early	116,809	24%	88,277	145,340	375,202	31%
8	Burnout	25,416	32%	17,386	33,446	23,029	110%
9	Early	121,912	22%	95,497	148,327	323,674	38%
9	Burnout	29,262	30%	20,466	38,058	17,145	171%
10	Early	442,968	26%	326,154	559,782	1,336,735	33%
10	Burnout	109,107	32%	73,858	144,356	58,283	187%
13	Early	1,433	22%	1,113	1,754	4,000	36%
13	Burnout	6,381	31%	4,416	8,346	2,329	274%
14	Early	7,277	22%	5,662	8,893	9,929	73%
14	Burnout	3,486	31%	2,393	4,579	912	382%
15	Early	142,449	37%	90,101	194,796	190,344	75%
15	Burnout	122,660	81%	23,392	221,927	89,126	138%
16	Early	74	39%	45	102	203	36%
16	Burnout	506	40%	304	707	643	79%
	TOTALS	1,140,969	23%	876,689	1,405,249	2,463,896	46%

Table 6-39: SCE Residential Demand Precision Results

		A	B	C	D	E	F
Climate	Replace	Evaluated Savings	Precision at 90%	Lower Bound for Savings [Col A * (1 - Col B)]	Upper Bound for Savings [Col A * (1 + Col B)]	Ex-Ante Savings	Realization Rate [Col A / Col E]
Zone	Type	kW	%	kW	kW	kW	%
6	Early	10	40%	6	13	100	10%
6	Burnout	3	45%	2	5	12	28%
8	Early	206	23%	159	252	393	52%
8	Burnout	42	38%	26	59	44	96%
9	Early	183	23%	140	225	373	49%
9	Burnout	43	42%	25	61	31	139%
10	Early	666	32%	450	882	1,628	41%
10	Burnout	182	48%	95	269	81	225%
13	Early	2	24%	1	2	3	65%
13	Burnout	9	35%	6	12	3	328%
14	Early	9	25%	7	11	13	67%
14	Burnout	5	36%	3	7	2	228%
15	Early	113	38%	70	157	129	88%
15	Burnout	163	57%	70	256	86	189%
16	Early	0.1	40%	0.1	0.1	1.2	7%
16	Burnout	0.6	45%	0.3	0.9	1.9	31%
	TOTALS	1,636	21%	1,290	1,982	2,901	56%

Table 6-40: SDG&E Commercial Energy Precision Results

		A	B	C	D	E	F
Climate	Replace	Evaluated Savings	Precision at 90%	Lower Bound for Savings [Col A * (1 - Col B)]	Upper Bound for Savings [Col A * (1 + Col B)]	Ex-Ante Savings	Realization Rate [Col A / Col E]
Zone	Type	kWh/yr	%	kWh/yr	kWh/yr	kWh/yr	%
7	Early	861,963	31%	592,574	1,131,352	1,251,553	69%
7	Burnout	211,886	45%	116,092	307,679	706,601	30%
10	Early	991,676	30%	696,376	1,286,976	922,553	107%
10	Burnout	157,241	35%	102,852	211,631	345,988	45%
	TOTALS	2,222,766	22%	1,727,380	2,718,151	3,226,695	69%

Table 6-41: SDG&E Commercial Demand Precision Results

		A	B	C	D	E	F
Climate	Replace	Evaluated Savings	Precision at 90%	Lower Bound for Savings [Col A * (1 - Col B)]	Upper Bound for Savings [Col A * (1 + Col B)]	Ex-Ante Savings	Realization Rate [Col A / Col E]
Zone	Type	kWh/yr	%	kWh/yr	kWh/yr	kWh/yr	%
7	Early	710	31%	493	927	797	89%
7	Burnout	182	49%	93	271	456	40%
10	Early	988	33%	664	1,313	687	144%
10	Burnout	180	37%	113	247	244	74%
	TOTALS	2,061	23%	1,577	2,544	2,185	94%

Table 6-42: SCE Commercial Energy Precision Results

		A	B	C	D	E	F
Climate	Replace	Evaluated Savings	Precision at 90%	Lower Bound for Savings [Col A * (1 - Col B)]	Upper Bound for Savings [Col A * (1 + Col B)]	Ex-Ante Savings	Realization Rate [Col A / Col E]
Zone	Type	kWh/yr	%	kWh/yr	kWh/yr	kWh/yr	%
6	Early	312,496	35%	204,572	420,421	375,854	83%
6	Burnout	123,660	49%	63,163	184,158	313,653	39%
8	Early	1,455,508	27%	1,068,758	1,842,258	1,395,649	104%
8	Burnout	495,122	39%	299,688	690,556	840,167	59%
9	Early	1,384,771	25%	1,044,189	1,725,353	1,131,917	122%
9	Burnout	472,049	37%	296,862	647,237	685,131	69%
10	Early	859,488	30%	603,551	1,115,425	687,228	125%
10	Burnout	813,683	35%	532,232	1,095,133	1,129,250	72%
13	Early	11,684	28%	8,463	14,905	11,876	98%
13	Burnout	158,293	34%	104,863	211,722	190,239	83%
14	Early	133,010	27%	96,864	169,157	104,307	128%
14	Burnout	371,197	34%	246,133	496,261	417,037	89%
15	Early	130,828	27%	95,853	165,802	52,669	248%
15	Burnout	407,403	35%	263,733	551,074	328,239	124%
16	Early	8,077	35%	5,287	10,866	5,609	144%
16	Burnout	308	49%	157	458	568	54%
	TOTALS	7,137,578	21%	5,618,773	8,656,383	7,669,393	93%

Table 6-43: SCE Commercial Demand Precision Results

		A	B	C	D	E	F
Climate	Replace	Evaluated Savings	Precision at 90%	Lower Bound for Savings [Col A * (1 - Col B)]	Upper Bound for Savings [Col A * (1 + Col B)]	Ex-Ante Savings	Realization Rate [Col A / Col E]
Zone	Type	kW	%	kW	kW	kW	%
6	Early	280	32%	189	370	237	118%
6	Burnout	116	51%	57	175	198	59%
8	Early	1,386	32%	945	1,827	1,038	134%
8	Burnout	497	53%	234	761	615	81%
9	Early	1,115	33%	748	1,483	917	122%
9	Burnout	391	54%	178	603	534	73%
10	Early	857	33%	575	1,138	561	153%
10	Burnout	933	37%	587	1,278	905	103%
13	Early	10	34%	7	13	10	103%
13	Burnout	150	39%	91	209	149	101%
14	Early	120	34%	80	160	91	132%
14	Burnout	374	39%	227	521	355	105%
15	Early	64	38%	40	88	32	198%
15	Burnout	215	48%	112	318	193	111%
16	Early	7	32%	5	10	8	90%
16	Burnout	0.3	51%	0	0	0.6	46%
	TOTALS	6,514	26%	4,834	8,195	5,841	112%

6.5.4 NTG

6.5.4.1 NTG Analysis

The results of the NTG analysis are presented below for the following programs

- PG&E 2080 C/I Upstream A/C
- SCE 2507 C/I AC replacement
- SCE 2507 Residential AC replacement
- SDG&E 3029 C/I AC replacement
- SDG&E 3029 Residential AC replacement

6.5.4.2 Vendor Analysis

A vendor analysis was completed for three utilities:
:

- PG&E 2080 C/I Upstream A/C
- SCE 2507 C/I AC replacement
- SDG&E 3029 C/I AC replacement
- SDG&E 3029 Residential AC replacement

A more detailed description of the vendor analysis for each individual program as well as a summary of results and recommendations can be found in the Appendix Sections G and H.

No customer surveys were conducted for SCE 2507, commercial sector. The vendor surveys were used to establish the NTGR by using the VMAX score.

6.5.4.3 NTGRs

Table 6-44: Free-ridership and NTGR Findings

		Free-ridership Estimates and Net-to-Gross Ratio (NTGR) Findings kWh (ex ante savings) Weighted						
			NTGR % (1-% FR)	VMAX Score	Vendor Survey	End-User Survey	Survey Sample Targets	Survey Sample Completes
PG&E 2080	ROB C/I Upstream A/C	6%	94%	9.4	X		300	All Vendors
SCE 2507	C/I AC Replacement	4%	96%	9.6	X		100	All Vendors
SDG&E 3029	C/I AC Replacement	6%	94%	9.4	X	X	200	90
SDG&E 3029	Res AC Replacement	47%	53%	9.5	X	X	300	322
SCE 2507	Res AC Replacement	44%	56%			X	200	204
		Free-ridership Estimates and Net-to-Gross Ratio (NTGR) Findings kW (ex ante savings) Weighted						
			NTGR % (1-% FR)	VMAX Score	Vendor Survey	End-User Survey	End-User Survey Sample Targets	End-User Survey Sample Completes
PG&E 2080	C/I Upstream A/C	6%	94%	9.4	X		300	All Vendors
SCE 2507	C/I AC Replacement	4%	96%	9.6	X		100	All Vendors
SDG&E 3029	C/I AC Replacement	6%	94%	9.4	X	X	200	90
SDG&E 3029	Res AC Replacement	46%	54%	9.5	X	X	300	322
SCE 2507	Res AC Replacement	44%	54%			X	200	204

The CPUC residential and small commercial NTG survey was conducted for the AC replacement programs. The surveys were modified slightly to accommodate the program delivery channels. For example, in some upstream programs, the decision maker may not recognize that they "participated" in a program as such, because the incentive was given to the installation contractor. The contractor may have passed it on to the end-user, but may not have told the customer that the discount came from the utility via a specific program. Therefore, the survey was modified for two paths to the NTG battery, i.e., a path for those who did and did not know about the "program." Questions were asked to determine whether the contractor influenced the end-user's decision to purchase a high efficiency air conditioner, or whether the end-user's decision was influenced by the program.

Residential End User NTG Surveys

The two residential AC replacement programs, where the residential/small commercial NTG battery was administered, have consistent NTG ratios of 53% and 56% which are very reasonable considering the amount of "green" messaging from multiple sources during the last five years and the marketing around high efficiency air conditioners.

For SDG&E 3029 Residential AC Replacement, there were 322 survey sample completes, but only 153 were used to calculate the savings weighted NTG ratio. This is because the survey sample was pulled from the utility's program tracking database and the survey fielded before evaluators were aware that the IOU's reporting database did not include all records in the IOU's program tracking database. Because the savings weighted NTG approach required the program participant ex ante savings from the reporting database, only the records that were in this database could be used to calculate NTG. The unweighted NTG including all 322 respondents was 39.6%; and the unweighted NTG ratio for only those respondents included in just the reporting database was 37.4%.

Commercial End User NTG Surveys

The NTG end-user survey used for SDG&E 3029 commercial program does not appear to be a particularly good fit for that program; a vendor survey was also conducted. The high rate of free ridership (97%) suggests that nearly all commercial establishments planned to replace their air conditioners with high efficiency air conditioners without assistance from the program or their contractor. However, additional analysis shows that of the 90 respondents, 31% reported their purchase decision was influenced by the program (28 of 90), and 69% reported their purchase decision was influenced by their HVAC contractor (62 of 90). Half of those reporting the contractor influenced their decision were classified as 100% free riders using the NTG algorithm (31 of 62). Since the contractor influenced their decision, it is unlikely that the business was a total free rider. One key question that appears to lead to high free ridership scores refers to the likelihood customers would have purchased the same equipment without assistance from the program or contractor. The majority, 96%, of the 48 respondents classified as 100% free riders said they were very likely to purchase the same equipment without any assistance.

Notes on Vendor Surveys Used for Commercial Programs

Table 6-45 indicates which survey instruments were used to calculate the NTG ratios for various programs, as well as the VMAX score where a vendor survey was administered. The vendor survey VMAX score was designed to capture the highest degree of program influence on the vendor's recommendations to the customer. The survey is included in Appendix Section H and the scoring algorithm is described in a document titled, *"Proposed Net-to-Gross Ratio Estimation Methods for Nonresidential Customers."* The methodology was developed to address the unique needs of large nonresidential customer projects delivered through energy efficiency programs offered by investor-owned utilities and third-parties. The proposed approaches were designed to fully comply with the protocols developed for these evaluations conducted for the CPUC.

A VMAX score was calculated using the algorithm provided. The score can range from 0 (program having no influence on vendor sales) to 10 (program having significant influence on sales). When there are multiple questions that feed in to the scoring algorithm, the maximum score is always used. The rationale for using the maximum value is to capture the most important element in the respondent's decision making. Thus, each score is always based on the strongest influence indicated by the respondents. Because the VMAX score is based on the strongest influence indicated by the respondents, it will tend to be higher than other inputs into the larger NTG calculation.

The VMAX scores for these C&I AC replacement programs ranged from 9.4 to 9.6, with an average of 9.5. This indicates that the programs have a strong influence on vendor recommendations. However, the vendor survey and VMAX score were not designed to be the only determinant of the NTG ratio. They were designed to provide information as part of the Large Nonresidential Net-to-Gross Methodology Decision Maker Survey (end-user survey). In the absence of an end-user survey, the NTG ratio was calculated by using the VMAX score alone, and it is evident that relying on the vendor survey alone produces a high NTG ratio. This is the case for two of the three commercial programs reported in the preceding table. One program, SDGE 3029 C&I AC, also administered the residential/small commercial NTG battery to C&I customers. Reported in the detailed findings of the primary analyses, this battery did not appear to be a good fit for that customer class. That survey produced a savings weighted free-ridership score of 97% and NTG ratio of 3%. In that survey, the majority of customers indicated (through various survey questions) they were free riders.

A comparison of the commercial participant survey instruments used, and the VMAX scores, indicate that the source of the variation between the C&I AC replacement programs appears to be the vendor survey. Two programs' NTG ratios were calculated using the results of the vendor survey alone, while the SDGE 3029 C&I ratio was based on the results of the end-user survey. For consistency, therefore, all three commercial programs relied on the vendor survey VMAX score for the NTG ratio. Using these results, the NTG ratios for all three programs are consistent.

6.6 Findings and Recommendations

Summary statistics are presented in tables below.

Table 6-45: AC Replacement Energy Savings Summary

		A	B	C	D	E	F	G
High Impact Measure	Program With Measure	HIM Ex-Ante Gross kWh Savings	HIM Ex-Post Gross kWh Savings	HIM Gross kWh Realization Rate [Col B / Col A]	Install Rate	HIM Installed Ex-Post Gross kWh Savings [Col B * Col D]	Measure NTGR	HIM Ex-Post Net kWh Savings [Col E * Col F]
Res AC Replacement	SCE 2507	2,463,896	1,140,969	46%	100%	1,140,969	0.56	638,942
Res AC Replacement	SDG&E 3029	2,802,029	699,369	25%	100%	699,369	0.53	370,665
C/I AC Replacement	SCE 2507	7,669,393	7,137,578	93%	100%	7,137,578	0.96	6,852,075
C/I AC Replacement	SDG&E 3029	3,226,695	2,222,766	69%	100%	2,222,766	0.94	2,089,400
C/I AC Replacement	PG&E 2080	36,969,145	17,258,976	47%	100%	17,258,976	0.94	16,223,438

Table 6-46: AC Replacement Demand Savings Summary

		A	B	C	D	E	F	G
High Impact Measure	Program With Measure	Peak Ex-Ante Gross kW Savings	Peak Ex-Post Gross kW Savings	Gross Realization Rate [Col B / Col A]	Install Rate	Peak Installed Ex-Post Gross kW Savings [Col B * Col D]	Measure NTGR	Peak Ex-Post Net kW Savings [Col E * Col F]
Res AC Replacement	SCE 2507	2,901	1,636	56%	100%	1,636	0.56	916
Res AC Replacement	SDG&E 3029	3,789.54	967	26%	100%	967	0.54	522
C/I AC Replacement	SCE 2507	5,841	6,514	112%	100%	6,514	0.96	6,254
C/I AC Replacement	SDG&E 3029	2,185	2,061	94%	100%	2,061	0.94	1,937
C/I AC Replacement	PG&E 2080	27,521	22,445	82%	100%	22,445	0.94	21,098

1. For both the residential and commercial sectors, the IOU estimates for both energy savings and grid-level demand in milder climate zones, such as in climate zones 6 and 7, are too high and the deemed estimates need revision. This is most likely because the cooling need is less than the IOU anticipated.

2. For the residential sector, the evaluated results for the hotter climates exceeded the IOU expectations for units replaced on burnout. The evaluation used a lower efficiency empirically derived base case than was assumed by the utility, that is, the IOU assumed better performance for the average code-compliant unit than was observed.

3. For the commercial sector, the evaluated results showed greater realization rates for early replacement units than those replaced on burnout. This was due to the evaluation using a larger degradation from code-level baseline performance to early replacement baseline performance than the IOU estimates used.

4. In the commercial sector, while 10% of the installed units fit the DEER ideal performance estimated, the remainder of the units exhibited deteriorated performance. This deteriorated performance was confirmed in terms of unusually high supply air temperature and unusually high compressor power at times of low outdoor air temperature. The average performance for the code compliant unit is considerably less than the ideal unit and evidences the field installation issues that if corrected, would improve performance. The same finding applies to the residential sector.

5. The evaluated grid-level peak demand estimates differed from the IOU estimates because the evaluated grid-level peak demand estimates used the most recent ALJ definition of system grid peak. We recommend the IOU estimates use the most recent ALJ definition for consistency.

7. Duct Sealing

Duct leakage can but does not always result in conditioned air being lost to unconditioned space which leads to poor distribution system efficiency. Sealing the leaks increases the efficiency of the system and results in saved electric energy and demand for all-electric systems and saved electric energy and demand and natural gas energy for electric-gas systems. The IOU program incentive structure for the residential duct sealing measure was based around the programs' nature of testing pre-existing conditions, remedying the revealed deficiencies, and retesting implementation to ensure proper system performance. The programs paid a smaller incentive for, and claim no savings from, systems not requiring remediation. The evaluation's M&V entailed verification testing of units with claimed savings from duct sealing and limited testing of pre- and post-sealing performance.

The IOU program savings estimates were based on results in DEER. The current duct sealing savings estimates in the 2005 and 2008 DEER were based on the leakage reduction of 12% post duct sealing leakage from the an initial 24% or 40% existing system leakage. These data and analyses are part of the DEER 2005 Report[23].

7.1 Evaluation Objectives

The Evaluation Team conducted M&V activities to assess the energy savings of duct sealing measures implemented by 2006-2008 IOU programs. The Evaluation Team developed procedures and a methodology meeting the requirements for Enhanced Rigor for the necessary samples consistent with the CPUC *Evaluation Protocols* to estimate the parameters necessary to calculate energy and demand savings for the duct sealing measures. The evaluation study by the HVAC Evaluation Team calculated energy and demand savings through a measurement and verification study of leakage testing for 290 program units. In addition to the final evaluation parameters the primary data results were sought to inform revisions or updates to future DEER estimates by producing correlations of contractor-reported total leakages to actual estimates of system leakage during typical operation.

[23] http://www.deeresources.com/

7.1.1 Estimated Parameters

The evaluation used data collected by means of field engineering measurements on a sample of AC units, user surveys, and market actor surveys to estimate the savings and other parameters required by the CPUC to estimate the cost-effectiveness of the IOU programs. The HVAC HIM evaluation for duct sealing calculated the installation rate of measures claimed by the programs through field measurements. The evaluation also developed estimates of the duct sealing measure's NTGRs. These post evaluation, ex-post, estimates of the parameters were also compared to those filed by the IOUs with the CPUC, ex-ante estimates. Other intermediate parameters included the total leakage, system airflow, and leakage to outdoors as a function of system operating pressure.

The ex-ante gross energy and demand savings estimate for duct sealing was a DEER-based estimate of the UES based on multiple categories of duct leakage reductions, building type and vintage, and location. The ex-post results estimated the UES and measure load shape for duct sealing as administered amongst the various programs. The ex-ante NTGR for each program and measure combination used the default value, typically 0.80. The ex-post estimated NTGR for each program and measure combination was developed using a consistent method described in Section 5.2.4.

7.1.2 Challenges to Achieving HIM Objectives

The duct sealing programs were designed to collect system performance or performance parameter data prior to applying measures. This was the only opportunity to determine the baseline system performance for all units in the program and therefore the quality of these data is paramount to evaluating savings for units sampled in this evaluation.

One of the main issues raised was the lack of pre/baseline data on duct sealing and the uncertainty and potential bias of using contractor pre-measurements. Because there is an incentive for a contractor to find a problem to be fixed, there was the possibility of upwardly biased pre leakage and downwardly biased reporting of the post leakage. The solution was to conduct two evaluation visits and leave monitoring equipment behind to record usage values. The HVAC Evaluation Team worked with VSPs to develop a list of sites that were in line for participation in the program and would visit sites to perform initial tests. The contractor tested and fixed those units requiring remediation and evaluators returned to retest.

7.1.3 Overview of HIM objectives

The data collected through the duct sealing HIM evaluation was intended to inform future DEER estimates in addition to the primary parameters described in the sections above. As an intermediate step to calculating the UES for duct sealing measures, pre and post measure AC efficiency was calculated and applied to the same DOE-2 energy simulation models used for estimating UES for the DEER duct sealing measures. As part of the evaluation effort, appropriate site-level contextual data were also collected to inform building energy models for the DEER process. The contextual data included duct location, return air strategy, airflow, AC system capacity, conditioned square footage, building vintage, and building construction characteristics. The standard unit for duct sealing measures was per household consistent with DEER 2008. A complete list of parameters collected for all residential and commercial HVAC sites is listed in Appendix F.

7.2 Methodology

The HVAC Evaluation Team developed a methodology for the necessary samples consistent with the CPUC Evaluation Protocols to estimate the parameters necessary to calculate energy and demand savings for the duct sealing measures. The evaluation study was centered on producing actual system leakage estimates and comparing them to standardized measurements performed by the duct sealing contractors. This effort required development of field procedures using robust and cost-effective testing equipment. The Evaluation Team analyzed measurement uncertainty to specify tools and sensor arrays capable of measuring all parameters required to calculate an estimate of actual system leakage. The Evaluation Team also measured duct system leakage on a sample of AC units, chosen to best represent the claimed program savings for post diagnostic performance and compared the verification test results to the program-collected pre- and post-measurements of duct leakage.

Measured performance improvements were applied to standard representative building model loads to calculate realized UES. For these measures, significant M&V were required to develop the reduction in actual system leakage from the application of the measure. The technical challenges of large-scale testing deployment and anticipated site-to-site system configuration variability were two major issues that had to be addressed with M&V.

The next sections discuss sample sizes and field data collection. Details on the calculation of UES are presented in Appendix J.

7.2.1 Sample Sizes for Duct Sealing EM&V

Visual inspections were insufficient to verify that HVAC performance measures like duct sealing had been installed properly and were producing the desired energy savings. Some methods of duct sealing leave visual evidence but for the HIM measures evaluation, inspection was generally impossible given the time passed between sealing and inspection. The verification procedures for duct sealing required similar performance diagnostic tests as those used by program implementing contractors. The verification techniques were designed to go beyond the techniques used by implementers to provide greater certainty in the measurements and to best understand energy implications of the verification results. The performance tests included additional techniques, procedures, and carefully selected precision instrumentation. When estimating the expected variability of measured savings relative to the claim, the error ratio, the duct systems' operating efficiencies were described in terms of energy leakage percentages rather than total usage or total savings and thus more rigorous M&V and innovative fielding approaches were justified. The Evaluation Team assumed an error ratio value of 0.5 for planning purposes. Sample sizes are shown in Table 7-1 below.

Table 7-1: Duct Sealing Sample Sizes

HIM	Program ID	Surveys	Verific. Sites	Meter Sites
Res Duct Sealing	PG&E2000R	350	270	10
Res Duct Sealing	SCE2507	100	70	10
Res Duct Sealing	SCE2502	100	6	10
Res Duct Sealing	SDG&E3035	100	6	10
Res Duct Sealing	PG&E2078	100	6	-

7.2.2 On-site Data Collection

The total duct leakage test was the standard test performed by contractors. This test has a poor correlation to the actual leakage at system operating pressures and was only performed for comparative purposes to program tracking data. To measure the HVAC system total duct leakage, a Minneapolis Duct Blaster® was used. The Minneapolis Duct Blaster® measures the amount of leakage in the duct system by pressurizing the ducts with a calibrated fan and simultaneously measuring the air flow through the fan. The duct blaster fan was connected directly to the duct system in a house, typically at a central return, or at the air handler cabinet. The remaining supply and return registers and grilles were taped off with Duct Mask temporary register seal. The duct system was then pressurized to 25

Pascals (Pa) in relation to the house and duct system leakage was measured using a digital pressure gauge. The test was performed at least three times to ensure reasonable and consistent measurements.

The field measurement techniques for duct leakage do not have an industry standard. Various methods are available and wherever possible particular evaluation measurement techniques follow established American Society of Heating, Refrigerating and Air-Conditioning Engineers, American Society for Testing and Materials, and California building energy code (Title 24) guidelines.

To measure the HVAC system duct leakage to outside, a Minneapolis Duct Blaster® in conjunction with the Minneapolis Blower Door™ was used. The Minneapolis Blower Door™ used a fan and frame assembly that is temporarily sealed into an exterior doorway and the house was then pressurized in relation to outside. The duct blaster fan was connected directly to the duct system in a house, typically at a central return, or at the air handler cabinet. The remaining supply registers and grilles were taped off with Duct Mask temporary register seal. The duct system was then equilibrated to the house pressure by pressurizing the ducts to 0 Pa relative to the pressurized house. The fan airflow required to maintain duct pressure was the system leakage outside the thermal envelope of the home. The test was performed at least three times to ensure reasonable and consistent measurements. Generally and for the first verification, this test was performed at two reference pressures 25 Pa and 50 Pa. Recent study has shown weaker correlation of the test at 25 Pa to the actual leakage of systems at their standard operating pressure. Additional tests at fractions of system operating pressure were performed after study results were revealed. Initial data was adjusted using the two point leakage to outside tests to adjust to the leakage to outside at the measured or estimated system operating pressure. Table 7-2 outlines the instruments used:

Table 7-2: Duct Testing Instrument Accuracy

Function /Data Point to Measure	Equipment Brand/Model	Quantity Required	Rated Full Scale Accuracy	Accuracy of Expected Measurement	Planned Metering Duration	Planned Metering Interval
Air flow	True flow meter & DG700 pressure gauge	1	± 7% CFM ± 1% Pa	+5%-15%CFM	Instant	5 minute average
Total Duct Leakage	Minneapolis Duct Blaster	1	± 3%	± 5%	Instant	5 minute average
Total Duct Leakage	Minneapolis DG-700	1	± 1%	Included	Instant	5 minute average
Leakage to Outside	Minneapolis Duct Blaster	1	± 3%	± 7%	Instant	5 minute average
Leakage to Outside	Minneapolis Blower Door	1	± 3%	Included	Instant	5 minute average
Leakage to Outside	Minneapolis DG-700	2	± 1%	Included	Instant	5 minute average

7.3 Confidence and Precision of Key Findings

7.3.1 Planned Confidence and Precision

The overall verification and net savings sampling strategy was to first achieve 10% precision at the 90% confidence level for each measure by utility. For cooling measures, the participation in each utility service territory was focused in the hotter cooling climates and was very focused on particular CEC climate zones. As expected for weather dependent HVAC measures, the primary driver of expected savings on a per unit basis was CEC climate zone as defined by DEER and Title 24. For example, because in the PG&E residential program over 90% of installed cooling measures fall into climate zones 12 and 13, the verification sampling plan was to achieve 10% precision at the 90% confidence level for each climate zone. This goal was relaxed for climate zones with the smallest impacts such as the coastal zones with low participation. The sample stratification for both residential and commercial verifications applied to the other IOUs as well. On-site sample sizes described here were developed using a statistical model with an error ratio (er) of 0.5 and a z-value of 1.645. In some cases the actual total exceeded the minimum for practical reasons. The UES ex-ante estimates for gas savings had similar variation as the electric savings. The samples focused on verification rate applied to electric savings as those parameters defined the measure as an HIM for the program portfolios.

Survey sample sizes described here were prescribed by the *Evaluation Protocols* at least 300 per program for NTG analysis. Where program delivery methods varied within a program, sample sizes were changed to address the different nature of contractor based and traditional residential and small commercial rebates. Table 7-3 shows the precision expected from the planned pre-and post-duct sealing measurements and does not quantify the precision of the additional comparative analysis to reported leakage reductions.

Table 7-3: Planned Confidence and Precision

HIM	Program ID	Pre-Post Units	Error Ratio (er)	Sample RP at 90%CI	2006-08 kWh Savings	kWh Error Bound
Res Duct Sealing	PG&E2000R	10	0.5	26%	6,148,183	1,598,933
Res Duct Sealing	SCE2507	10	0.5	26%	508,596	132,209
Res Duct Sealing	SCE2502 (CMMHP)	10	0.5	26%	2,245,083	583,573
Res Duct Sealing	SDG&E3035 (CMMHP)	10	0.5	26%	900,668	234,116

7.3.2 Achieved Confidence and Precision

The pre- and post-duct sealing M&V was not able to include the metering as originally intended and the issues of measurement uncertainty and correlation uncertainty of leakage measurements to actual energy savings led to the HVAC team's ultimate acceptance of the ex-ante savings claims. The verification activities to establish installation rates were the primary driver of evaluated gross savings and the achieved precision results for those tests are shown below. The precision presented were for the installation rate given the lack of ex-post UES estimates. Thus the precision is ultimately on the pass fail of the estimated leakage rates. The UES values which were passed through are assumed to add no error to the estimates.

Table 7-4: Achieved Installation Rate Confidence and Precision

HIM	Program ID	Verific. Units	Sample RP at 90%CI	2006-08 kWh Savings	kWh Error Bound
Res Duct Sealing	PG&E2000R	177	13%	7,095,797	894,070
Res Duct Sealing	SCE2507	53	22%	508,596	111,891
Res Duct Sealing	CMMHP	18	47%	3,560,203	1,673,295

7.4 Validity and Reliability

7.4.1 Uncertainty Analysis

The final M&V plans considered the optimal overall uncertainty for the approved budget through the potential addition of testing and other measurements relative to sampling uncertainty. A CPUC uncertainty working group, comprised of Energy Division and its technical advisors, developed a framework for explaining the overall uncertainty and standardizing methodologies in parallel to the HVAC Evaluation Team efforts. The HVAC Evaluation Team defined modeling context parameter uncertainty and its overall affect on hourly load shape uncertainty.

This evaluation piloted a leakage diagnostic method developed by Lawrence Berkeley National Lab called DeltaQ[24], a testing software developed to offer greater accuracy and better estimation of uncertainties in the measurement of the supply vs. return leakage split than traditional duct leakage tests. One of the main problems with current duct pressurization methods is that they cannot measure the air leakage under actual operating conditions and are not able to separate the supply from return leakage or the total leakage from the leakage outside the conditioned space. The DeltaQ test is based on measuring the change in flow through duct leaks as the pressure across those leaks is changed. The changes in duct leakage pressure difference are created by pressurizing and depressurizing the whole house. A blower door is used to both create and measure the flows occurring through the duct leaks and the building envelope. All pressurization and depressurization tests are performed twice: once with the air handler on and once with it off. The duct operating pressures used in the calculation procedure are determined by measuring the static pressures in the supply and return plenums relative to the conditioned space. All tests are recorded on a laptop, analyzed in the field and saved by the DeltaQ software. Unfortunately, since sampled units cannot always be tested at times with minimal wind influence, the pilot revealed large uncertainties. Other repeatability tests by the software developers showed the DeltaQ test for typical residential systems was extremely sensitive to ever changing conditions.

7.4.2 Procedures to Minimize Non-response Bias

Please reference Section 5.5.3 for details.

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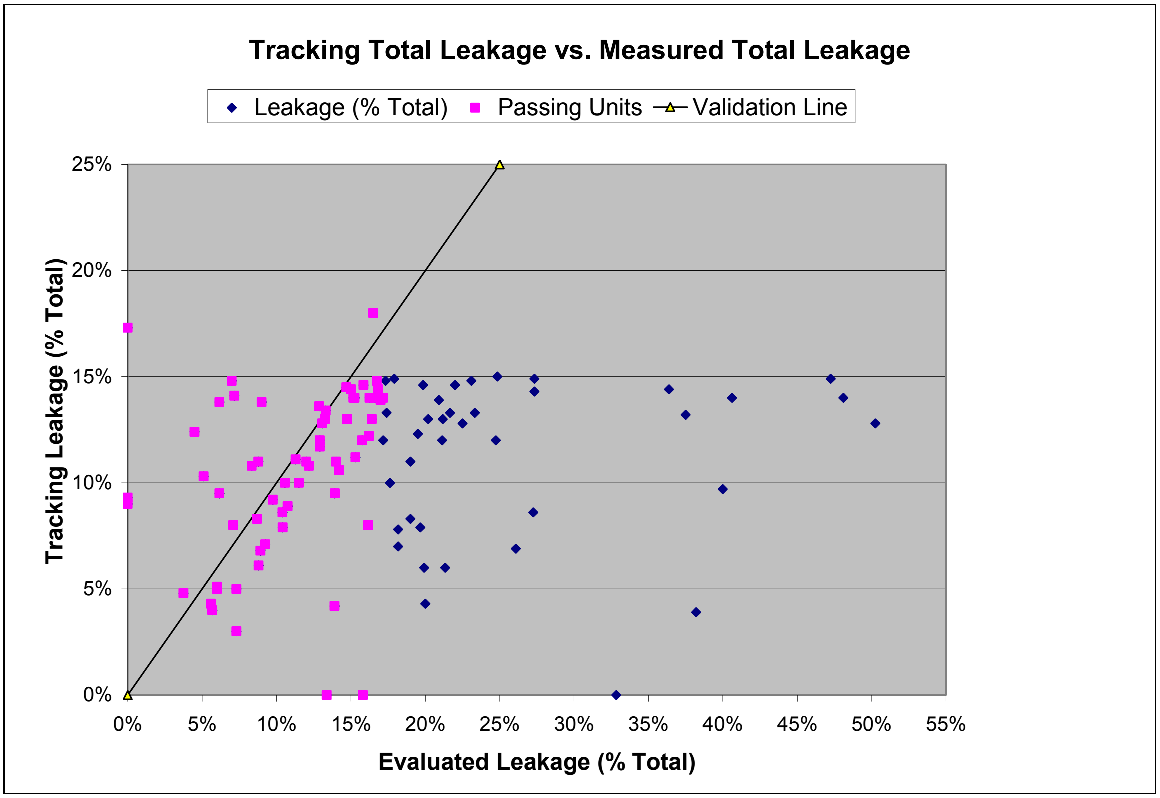
[24] The DeltaQ duct leakage test has been developed over the past several years as an alternative to duct pressurization testing. Details of the development of the DeltaQ test can be found in Dickerhoff et al. (2004), Walker et al. (2004), and Walker et al. (2002). The DeltaQ test is one of the test methods included in ASTM E1554 “Determining External Air Leakage of Air Distribution Systems by Fan Pressurization” (ASTM 2003).

7.5 Detailed Findings

7.5.1 PGE2000

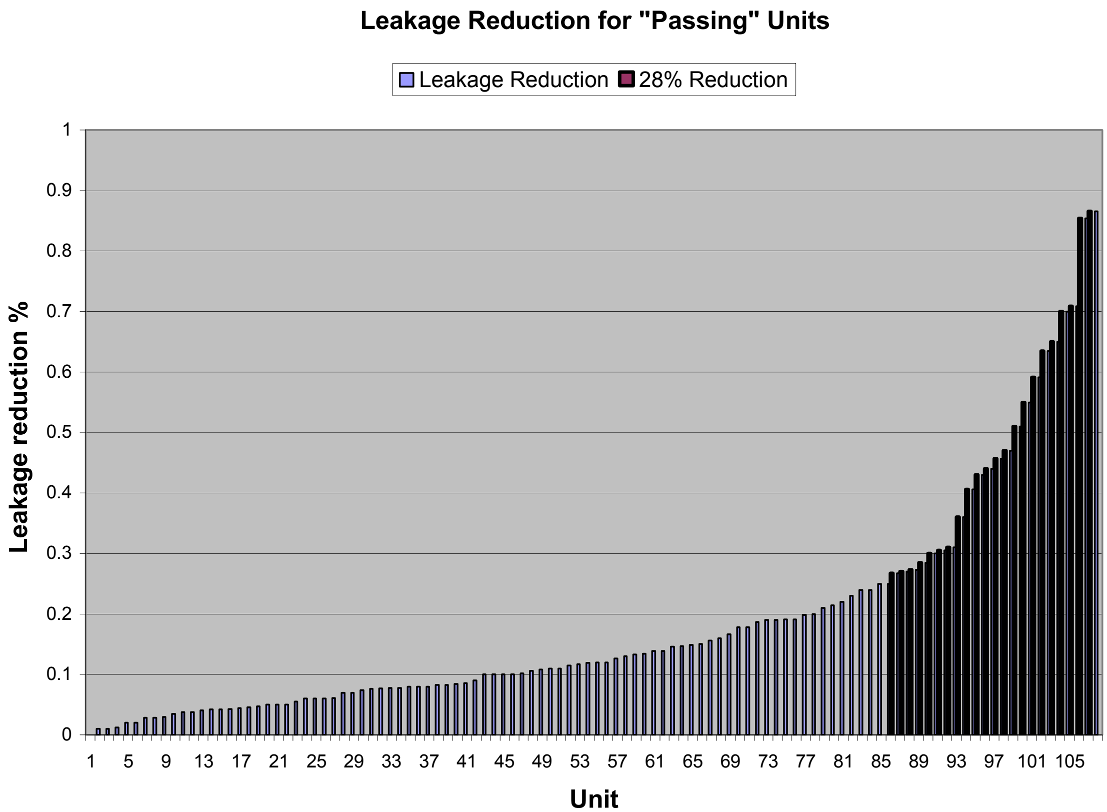
The criterion for passing units was that final evaluator measured leakage was 15% or less as all randomly sampled units had contractor recorded leakages of 15% or less. The HVAC team was able to review contractor leakage results for both the onsite sample and the population. We first compared the tested units from the post-only verifications to determine if the contractor-recorded results were reliable for their post test. The team hypothesized that contractor-recorded leakage reductions could be used or deemed unreliable based on whether or not the unit passed the HVAC team's leakage test. Figure 7-1 shows that the passing tests are generally reliable and the failing units have large deviations in measured leakage. This illustrates that failing leakages generally had very different measurements than the recorded tracking leakage of 15% or less. Failing units were predominantly not close to the 15% level and if the evaluated post leakage is subtracted from the recorded pre-sealing leakage, the leakage reductions for failing units are generally much smaller than assumed reductions in the ex-ante UES estimate.

Figure 7-1: PGE 2000 Tracking Total Leakage vs. Measured Total Leakage



If the total leakage difference between pre- and post-sealing cases for passing units was on average 28% of nominal system fan flow or greater then the DEER values used would be justifiable. If the differences in total leakage were less than 28% on average then we would proportion down the savings based on the DEER values. Figure 7-2 shows that an 80% majority of these units have leakage differences less than 28% with an average leakage difference of 18% for 108 systems tested with reliable tracking data available. Note the darker lines indicate leakage differences greater than 28% total leakage and some differences at the high end were viewed as unreasonable, but were preserved to illustrate the reporting.

Figure 7-2: PGE 2000 Pre to Post Leakage Differences for Units Passing M&V



Based on these findings, the original work paper assumptions seemed much more reasonable by assuming that only half the systems would achieve 28% reductions with the other half achieving 12% reductions in duct leakage. For the duct sealing high impact measure, we also reviewed the population of tracking data available. Although we can not validate the data as we did in Figure 7-1, for all entries in the program leakage measurement database, the results still produced interesting data on the actual achieved reductions. In the database analysis 85% of the systems had leakage reductions less than 28% total leakage with an average reduction of 14% for over 25,000 units with reasonable values.

The post only testing was primarily performed to compare HVAC team measurements of the standard total leakage test to the contractor recorded values of the same test. Generally, the program had a criteria of reducing leakage to a level of 15% total leakage and therefore units measured by the HVAC team with total leakage of 16% or greater were considered failing unless there was a contractor measurement after sealing greater than 15%. Based on the post only duct testing by the HVAC team, the final installation rate for duct sealing measures in the

PGE2000 program was 54%. Shown below in Table 7-5 are the pass and fail rate for all units sampled.

Table 7-5: Unit Pass Rates for PGE 2000

	Number of Units	Percent of Sample
Pass	86	54.0%
Fail	91	46.0%
Total	177	100.0%

The total leakage per ton and leakage to outside per ton were calculated for each unit. Shown in Table 7-6 are average values for both passing and failing units. Failing units had significantly greater total leakage and leakage outside the thermal envelope.

Table 7-6: Average Leakage for PGE 2000

	Average Total Leakage (CFM/ton)	Average Leakage to Outside (CFM/ton)
Pass	40.9	30.8
Fail	117.3	76.6

The ex-ante gross savings were accepted as being the reasonable potential savings for properly installed duct sealing measures and only the installation and NTGR lowered the ex-post net savings for duct sealing measures. The results of the average leakages in the verification tests suggest that significant leaks remained for units which failed the verification test such that the work was done to seal leaks that were not to the outside, sealing was done poorly, or sealing was not done. The causality could not be established from the testing, but the failing units were assumed to have very little to no savings. The aggregate duct sealing savings results for PGE2000 are shown below:

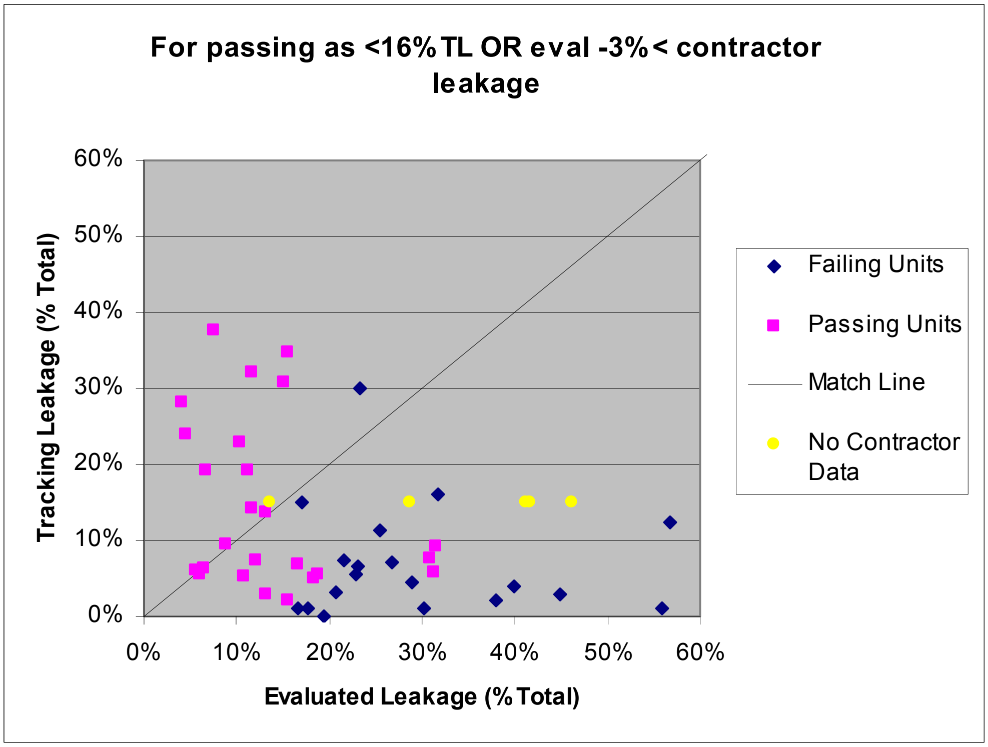
Table 7-7: Summary of Gross Savings for PGE 2000

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	HIM Ex-ante Gross kWh Savings	HIM Ex-post Gross kWh Savings	HIM Gross kWh Realization Rate [Column B/Column A]	HIM Install Rate	HIM Installed Ex-post Gross kWh Savings [Column B * Column D]	HIM NTGR	HIM Ex-post Net kWh Savings [Column E * Column F]
Res Duct Seal	PGE2000	6,148,183	6,148,183	100%	49%	3,012,610	0.54	1,626,809

7.5.2 SCE 2507

The criterion for passing units was that final evaluator measured leakage was 15% or less or within 3% of the contractor recorded final leakages. The HVAC team was able to review contractor leakage results for both the onsite sample and the population. We first compared the tested units from the post-only verifications to determine if the contractor-recorded results were reliable for their post test. The team hypothesized that contractor-recorded leakage reductions could be used or deemed unreliable based on whether or not the unit passed the HVAC team's leakage test. Figure 7-3 shows that the passing tests are generally reliable and the failing units have large deviations in measured leakage. This illustrates that failing leakages generally had very different measurements than the recorded tracking leakage. Failing units were predominantly not close to the contractor measurement. If the evaluated post leakage is subtracted from the recorded pre-sealing leakage, the leakage reductions for failing units are generally much smaller than assumed reductions in the ex-ante UES estimate of 12% or 28%.

Figure 7-3: SCE2507 Tracking Total Leakage vs. Measured Total Leakage



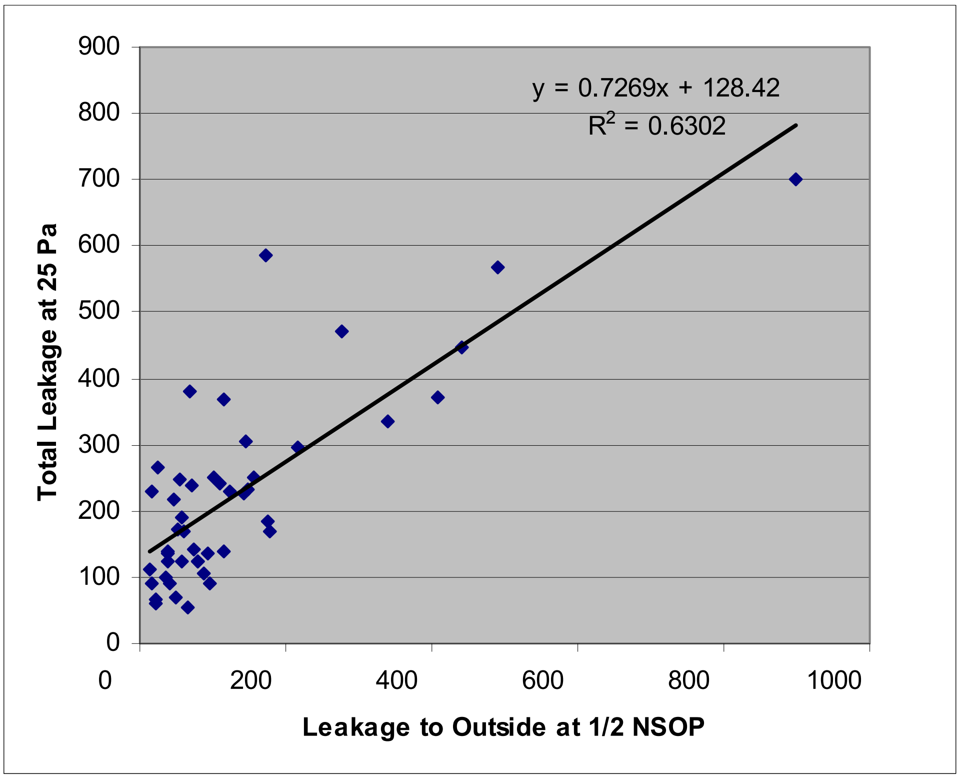
In an effort to realistically measure the leakage at system operating conditions, we modified the leakage to outside test so that the house and duct system was pressurized to half the normal system operating pressure (NSOP). The pressures downstream from the supply plenum, where NSOP is measured, will be lower during actual system operation than NSOP. Pressure measured at a supply register, downstream, equal to one-half NSOP created a more realistic condition for testing. Another benefit to the method is that the data could be compared in the future to the early M&V work for the SCE2507 program [25]which used the leakage to outside (LTO) at one half NSOP test. This leakage was plotted against the HVAC team measured total leakage at 25 Pa for the same unit, which was the test used to determine units passing or failing and compared to contractor recorded values of total leakage. The slope of the line is 0.73 with a fit coefficient of 0.63. Examining the results on the graph it can be observed that while the slope for all the plotted points is 0.73, the slope would be closer to 1 for units with leakage to the outside levels below 200 CFM. This indicated that most units had a leakage profile where 30% of the total leakage measured at 25 Pa was inside conditioned space and not contributing to lost

[25] ADM Associates for SCE. *MARKET ASSESSMENT AND FIELD M&V STUDY FOR COMPREHENSIVE PACKAGED A/C SYSTEMS PROGRAM*. July 2009.

http://www.calmac.org/startDownload.asp?Name=CPACS_Assessment_Final_Report_7-24-09.pdf&Size=1468KB

cooling energy. The actual leakage profile from unit to unit was highly variable Some units had system operating pressures that were much higher than the standard 25 Pa total leakage test leading to some results where leakage to outside at half NSOP measurements were greater than total leakage measurements. The goal was to compare the standard test used by the program to actual leakage conditions, so the leakage to outside was measured at a different pressure than 25 Pa for most cases. Units with lower leakage rates had nearly equal total leakage at 25 Pa and leakage to the outside of the measured space. The HVAC team did not assess the leakage from space to space for multifamily buildings. The resulting findings are presented below in Figure 7-4.

Figure 7-4: SCE 2507 Leakage to Outside at ½ NSOP vs. Total Leakage at 25 Pa



The post only testing was primarily performed to compare HVAC team measurements of the standard total leakage test to the contractor recorded values of the same test. Generally, the program had a criteria of reducing leakage to a level of 15% total leakage and therefore units measured by the HVAC team with total leakage of 16% or greater were considered failing unless there was a contractor measurement after sealing greater than 15%. The final installation rate for SCE residential duct leakage verification was 49%. Shown below in Table 7-8 are the pass and fail rate for all units sampled.

Table 7-8: Unit Pass Rates for SCE 2507

	Number of Units	Percent of Sample
Pass	27	49.1%
Fail	26	50.9%
Total	53	100.0%

The total leakage per ton and leakage to outside per ton were calculated for each unit. Shown in Table 7-9 are average values for both passing and failing units.

Table 7-9: Average Leakage for SCE 2507

	Average Total Leakage (CFM/ton)	Average Leakage to Outside (CFM/ton)
Pass	48.7	28.6
Fail	165.9	90.4

The ex-ante gross savings were accepted as being the reasonable potential savings for properly installed duct sealing measures and only the installation and NTGR lowered the ex-post net savings for duct sealing measures. The results of the average leakages in the verification tests suggest that significant leaks remained for units which failed the verification test such that the work may have been done to seal leaks that were not to the outside[26], sealing may have been done poorly, or sealing may not have been done at all. The causality could not be established from the testing, but the failing units were assumed to have very little to no savings. The aggregate duct sealing savings results for SCE 2507 are shown below.

[26] Contractors were testing to a total leakage number, so it was possible that they sealed leaks that did not affect the LTO.

Table 7-10: Summary of Savings for SCE 2507

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	HIM Ex-ante Gross kWh Savings	HIM Ex-post Gross kWh Savings	HIM Gross kWh Realization Rate [Column B/Column A]	HIM Install Rate	HIM Installed Ex-post Gross kWh Savings [Column B * Column D]	HIM NTGR	HIM Ex-post Net kWh Savings [Column E * Column F]
Res Duct Seal	SCE2507	508,596	508,596	100%	51%	259,384	0.96	249,009

7.5.3 Comprehensive Manufactured-Mobile Home Programs (CMMHP)

The post only testing was primarily performed to compare HVAC team measurements of the standard total leakage test to the contractor recorded values of the same test. Generally, the program had a criteria of reducing leakage to a level of 15% total leakage and therefore units measured by the HVAC team with total leakage of 16% or greater were considered failing unless there was a contractor measurement after sealing greater than 15%. The final installation rate for CMMHP duct leakage verification was 41%. The savings summary is presented in the overall results in Section 7.7.

Table 7-11: Unit Pass Rates for CMMHP

	Number of Units	Percent of Sample
Pass	7	41.2%
Fail	10	58.8%
Total	17	100%

7.6 Residential Duct Sealing Net-to-Gross Findings

Participants who were involved in the decision-making process at each participating residential site were interviewed to measure a program's influence on respondents' decision-making. The survey obtained highly structured responses concerning the probability that the household would have installed the same measure(s) at the same time in the absence of the program. The survey also included open-ended and closed-ended questions that focused on the household's or firm's motivation for installing the efficiency measure. These questions covered all the requirements provided in the CPUC's *Guidelines for Estimating Net-to Gross Ratios Using the*

Self-Report Approach, such as multiple questions regarding efficiency level, likelihood of adoption, timing and quantity, and consistency checks.

Measures included in the HVAC program cluster utilized a modified version of the NTG Method to provide consistent questions to end-use customers where applicable. The program deliveries allowed flexibility to the contractor in terms of the marketing and incentive, especially for RCA and duct-sealing measures. This required a method that supplemented the participant self-report surveys with contractor surveys. The plan utilized participant contractor interviews to determine if the end-use customers were aware of the incentive and if the service was available outside the program. The simple NTG questionnaire included questions necessary to analyze the effect of the acceleration on the lifetime savings stream and partial increase in efficiency levels or quantities of efficient equipment.

Surveys included an up-front line of questioning to identify whether or not participants were aware of the measures and what influence the contractors had on the implementation of duct sealing. Only information from survey respondents who were aware of the measure was included in the analysis. The survey instruments for residential duct sealing are presented in Appendix Z, AA, and BB.

The electric energy savings weighted results shown in Table 7-12, are specific to the duct-sealing measures within those programs and not reflective of the total program net-to-gross ratios. The PGE2000 Duct Sealing measures had the highest free-ridership rate at 36%; the lowest free-ridership rate was in the SCE2507 duct-sealing measures at 4%. The delivery of these measures should be closely monitored by early M&V and process evaluation for future applications of the measures to the residential market to address potential issues and whether or not they are related to program design, contractor delivery, or end user awareness.

Table 7-12: Duct Sealing Net-to-Gross Ratios

			Customer Survey			
Plan Name	IOU	EEGA ID	Survey Sample Size	Survey Completes	FR	NTG
Res Duct Seal	PG&E	2000	300	211	36%	54%
Res Duct Seal	PG&E	2078	100	103	15%	85%
Res Duct Seal	SCE	2502	100	102	21%	79%
Res Duct Seal	SCE	2507	100	112	4%	96%
Res Duct Seal	SDG&E	3035	100	102	20%	80%

The following stability analyses are presented to further explain free-ridership results. Free-ridership is an average of four components. This tables details the number of components that feed into the final average. If a respondent was unable to answer questions feeding into one of the specific components, that component was not included in the final average.

Table 7-13: Number of Respondents with FR Measurements

Number of Respondents with ___ FR measurements	SCE/SCG 2502 DTS	PGE2078 DTS	SDGE3035 DTS	PGE2000 Single Fam - DTS	SCE Single Fam - DTS	SCE Multifam - DTS	PGE2000 MF DTS
No FR data	14	17	22	0	0	1	1
One	10	8	4	11	1	0	2
Two	11	10	8	22	3	2	8
Three	70	68	68	121	7	6	0
Four	0	-	0	46	1	0	0

Free-ridership ratios range from 0.0 to 1.0. This table details the percentage of respondents that had free-ridership rates at the extreme ends of the spectrum. These extremes are defined as the 0.9-1.0 range and the 0.0-0.1 range. Note: Respondents with no FR measurements not included.

Table 7-14: Respondents with an Extreme FR Ratio

Proportion of respondents with an extreme FR ratio	SCE/SCG 2502 DTS	PGE2078 DTS	SDGE3035 DTS	PGE2000 Single Fam - DTS	SCE Single Fam - DTS	SCE Multifam - DTS	PGE2000 MF DTS
Proportion with 0 - 0.1 FR ratio	68.1%	73.3%	68.8%	0.0%	75.0%	37.5%	70.0%
Proportion with 0.9 - 1 FR ratio	1.1%	0.0%	0.0%	14.0%	8.3%	0.0%	0.0%

This table details the free-ridership ratio of respondents that stated the measure was already installed when they first heard about the program. This answer is only included in one of the components of the final free-ridership ratio. Free-ridership should be high among these respondents. Note: The n represents all respondents that answered this question in that particular way, regardless of the measurement response. However the FR ratio does not include respondents with no FR measurements.

Table 7-15: Respondents With Prior Installed Measures

Number of respondents answering they already had installed measure before they learned of the program.	SCE/SCG 2502 DTS (n=N/A)	PGE 2078 DTS (n=1)	SDGE 3035 DTS (n=2)	PGE2000 Single Fam - DTS (n=200)	SCE Single Fam - DTS (n=0)	SCE Multifam - DTS (n=0)	PGE2000 MF DTS (n=N/A)
Final average FR for these:	0.0%	50.0%	62.5%	56.8%	N/A	N/A	N/A

This table details the free-ridership ratio of those respondents that stated they never would have purchased any equipment without the program. Free-ridership should be low among these respondents. The only outlier is the PG&E single family survey where many respondents answered "Yes" to this question but had varying degrees of free-ridership. This was true of respondents that passed consistency checks. The impact of this result is lessened by the fact that multifamily measures comprised a majority of program savings. Note: The n represents all respondents that answered this question in that particular way, regardless of the measurement response. However the FR ratio does not include respondents with no FR measurements.

Table 7-16: Respondents That Would Not Have Installed Without the Program

Number of respondents answering they never would have purchased equipment type without the program (efficient or inefficient).	SCE/SCG 2502 DTS (n=68)	PGE 2078 DTS (n=66)	SDGE 3035 DTS (n=64)	PGE2000 Single Fam - DTS (n=104)	SCE Single Fam - DTS (n=9)	SCE Multifam - DTS (n=3, Q=28)	PGE2000 MF DTS (n=8)
Final average FR for these:	3.5%	2.9%	3.9%	43.9%	4.8%	0.0%	4.7%

7.7 Findings and Recommendations

1. Measured leakage data for all of the sample groups showed diversified results. After reviewing the data for the SCE 2507 and PGE 2000 sample groups, at least 32% of the units had measured total leakage at 25 Pa over double the target maximum allowable leakage rate of 15%. While it is possible that the service contractors at the sites made some efforts to seal the duct work, we believe at least some of these units never had any work performed.

2. Correlating field leakage measurements to energy savings was not accomplished by the evaluation due to the lack of refinement of advanced test methodologies. Techniques to estimate leak location and leakage rates at typical system operating conditions must be used to establish energy savings. The advanced methods available for large samples of homes have not been established as repeatable. Existing and current research support the current UES estimates from duct sealing being used until advanced methods can be

applied to large samples to establish program-HIM level estimates. Programs should support advancements in test methods to establish benchmark tests that can be widely applied to estimate how well implementing contactors are sealing leaks in terms of energy impacts.

3. The time required to do a good job of duct sealing is likely much greater than the time it takes to do a less rigorous job. With a standard financial incentive for all sealing jobs, there may be disincentive to do good sealing jobs. Direct field oversight and risk-reward mechanisms should be explored to ensure rebates are provided for quality sealing jobs, mediocre sealing jobs are addressed, and incomplete work is punished.

The final results for all the residential DTS measures in the evaluated following programs are shown below.

Table 7-17: Summary of Savings for Duct Sealing Measure (kWh)

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	HIM Ex-ante Gross kWh Savings	HIM Ex-post Gross kWh Savings	HIM Gross kWh Realization Rate [Column B/Column A]	HIM Install Rate	HIM Installed Ex-post Gross kWh Savings [Column B * Column D]	HIM NTGR	HIM Ex-post Net kWh Savings [Column E * Column F]
Res Duct Seal	PGE2000	6,148,183	6,148,183	100%	49%	3,012,610	0.54	1,626,809
Res Duct Seal	PGE2078	414,452	414,452	100%	41%	170,657	0.85	145,058
Res Duct Seal	SCE2502	2,245,083	2,245,083	100%	41%	924,446	0.79	730,312
Res Duct Seal	SCE2507	508,596	508,596	100%	51%	259,384	0.96	249,009
Res Duct Seal	SDGE3035	900,668	900,668	100%	41%	370,863	0.80	296,691

Table 7-18: Summary of Savings for Duct Sealing Measure (therms)

		A	B	C	D	E	F	G
High Impact Measure	Program with Measure	Measure Ex-ante Gross therms Savings	Measure Ex-post Gross therms Savings	Measure Gross therms Realization Rate [Column B/Column A]	Measure Install Rate	Measure Installed Ex-post Gross therms Savings [Column B * Column D]	Measure NTGR	Measure Ex-post Net therm Savings [Column E * Column F]
Res Duct Seal	PGE2000	886,905	886,905	100%	49%	434,583	0.54	234,675
Res Duct Seal	PGE2078	70,615	70,615	100%	41%	29,077	0.85	24,715
Res Duct Seal	SCE2502/ SCG3539	84,490	84,490	100%	41%	34,790	0.79	27,484
Res Duct Seal	SCE2507	-	-	100%	51%	-	0.96	-
Res Duct Seal	SDGE3035	195,696	195,696	100%	41%	80,581	0.80	64,464

8. Management Affiliates Partnership Program

8.1 Program Description

The Commercial Real Estate Management Affiliates Partnership Group Program, or MAP Energy Efficiency Program (SCE 2537), primarily focused on commercial office buildings, retail department stores, and other business buildings ranging from 20,000 to over 1 million square feet. The program was offered to property management companies to expand the use of emerging technologies with proven performance or enhancements of existing technologies, but which were not yet in general use in the market. Among the most significant barriers to the adoption of energy-efficiency technologies in the commercial office building and retail market segments are split incentives and a lack of access to decision makers. The program provided an opportunity to address these barriers by partnering with decision makers within property management companies to secure preferred access to the management companies' clients. Implementers expected property managers would be directed by their management to work with the program to identify and implement energy-efficiency opportunities.

MAP offered multiple technologies that included but were not limited to the following: the Lighting Power Regulator for indoor and outdoor lighting; HVAC Cycle Manager for packaged HVAC; CO Sensing System for garage exhaust fans; CO_2 sensing system for Demand Control Ventilation; and Turbocor Oil-Free Compressors. Additional new measures added midway into the program included four technologies: Daylight Harvesting; Hotel Keycard Energy Control System; Delta P Pressure Independent Valve; and Fan Wall. Miscellaneous measures were also installed within the MAP program but were not evaluated; these technologies included retrofit lighting packages, window film, and VFD motor controls upgrades.

Table 8-1: Program Specific Evaluations

	Verification	*Gross Savings*		*Net Savings*	
Evaluation Methods	***Surveys, on-site Audits***	***Billing Analysis***	***Field measurement***	***Participant Self Report***	***Discrete Choice***
Report Section	*Parameters Estimated or evaluated outputs*				
Lighting Power Regulator: Appendix, Closure Memo	On-Site Pre Post Survey (2-sites)	No	None	Ex ante	Ex ante
HVAC Cycle Manager: Appendix, Closure Memo	None	No	None	Ex ante	Ex ante
Turbocor Oil-Free Compressor: MAP Evaluation Chapter, Performance Case Report	Performance data	No	Condenser & chilled water entering and leaving temperature, kW, OAT, Flow	Ex ante	Ex ante
CO Sensing Systems for Garage Exhaust Fans: MAP Evaluation Chapter	On-Site Pre Post Survey (4 sites)	No	kW	NTG Ratio	NTG Ratio
CO2 Sensing Systems for Demand Control Ventilation: Appendix, Entertainment Centers Evaluation Chapter	Apply realization rates and findings from SCE 2561	No	Apply realization rates and findings from SCE 2561	Apply NTG SCE 2561	Apply NTG from SCE 2561
Additional Measures: Closure Memo	None	No	None	Ex ante	Ex ante

8.2 Key Program Elements

The Southern California Edison Management Affiliates Program (MAP) 2006–2008 program cycle originally projected net energy savings of 7,196 MWh[27] and summer peak demand savings of 1.85 MW. The program exceeded these ex-ante goals and expanded with three Change Orders.[28] The program's current net ex-ante goals are 29,867 MWh and summer peak demand savings of 8.06 MW.

[27] This was the annual MWh adjusted for NTG and not the program projected compliance filing of 6,936 MWh and 1.73 MW.

[28] Change Order 1: September 2007, SCE approved $829,000 increase in funding for MAP, an increase from $1,800,000 to $2,629,080. The increase in funds also increased the program energy savings goal from 7,195,704 to 10,795,704 net kWh and the demand savings goal from 1,846 to 2,556 net kW.

Change Order 2: May 2008, SCE approved $2 million in additional funding for MAP, an increase from $2,629,080 to $4,629,080. This amount was to be allocated to all the current committed and new customers to finish the 2008 cycle. This included funds for the additional measures as well as the existing technologies.

The delivery strategy was originally based on incentives that paid up to 80% of installed costs for demonstration projects, while other projects typically were rebated at 15.42 cents per gross kWh saved, and covered anywhere from 20% to more than 60% of installed costs, depending on the technology. This incentive changed as part of the second Change Order, decreasing for certain technologies to the Minimum Performance Standard incentive of roughly 5 cents per kWh.

8.3 Evaluation Objectives

The MAP evaluation plan objectives were revised in response to the CPUC's redirection of evaluation efforts toward High Impact Measures (HIM). In a conference call with the CPUC on November 11, 2008, the Specialized Commercial CG Evaluation Team reviewed the nine primary MAP technologies and discussed the recommended evaluation approach. Each technology within MAP was at a different stage in their respective evaluations, and required a different approach to complete or close the evaluation. The following table shows the resulting approaches by technology.

Table 8-2: Evaluation Approach

Measure	Resulting Evaluation Approach
CO Sensors (CO)	Complete evaluation as originally planned
Turbocor (TC)	Change evaluation plan to focus on market and technology performance
CO_2 DCV (CO2)	Apply realization rates from SCE 2561 Entertainment Centers analyses
Lighting Power Regulator (LPR)	Closure memo
Cycle Manager (CMU)	Closure memo
Daylight Harvesting (DH)	Stop evaluation of DH, DP, FW, HK, and MM. Minimal closure memo noting high-level activity or observations.
Hotel Key Card (HK)	
Delta P Pressure Valve (DP)	
Fan Wall (FW)	
Misc. Measures (MM)	

The increase in funds also increased the program energy savings goal from 10,795,704 to 22,240,939 net kWh, and the demand savings goal from 2,556 to 5,244 net kW.

Change Order 3: July 2008, SCE approved $2.27 million in additional funding for MAP, an increase from $4,629,080 to $6,896,792. This amount was to be allocated to all the current committed and new customers to finish the 2008 cycle and continue recruiting for 2009-2011 program year. This included funds for the additional measures as well as existing technologies. The increase in funds also increased the program energy savings goal from 22,240,939 to 29,867,446 net kWh, and the demand savings goal from 5,244 to 8,055 net kW.

Of all MAP technologies, only the evaluation of CO sensors was completed as originally planned. The following sections of this report discuss CO sensors, Turbocor oil free compressors, and the closure discussions for the remaining MAP technologies.

8.4 Confidence and Precision of Key Findings

8.4.1 Planned Confidence and Precision

MAP was a protocol-guided, full-impact evaluation using a Basic level of rigor for estimating energy impacts (kWh) and demand impacts (kW). NTG estimation also used the Basic level of rigor stipulated by the CPUC. Net impacts at the Basic rigor level were estimated using self-reports, enhanced by other data sources relevant to the decision to install measures. These could include: reviews of business policy, reviews of papers, examination of other decisions, and interviews with market actors. Evaluators administered interview questions during site visits with participants and through telephone surveys with market actors to estimate free-ridership, using the approved Joint Simple self report (SR) NTG method for each measure installed.

Evaluating program measures that incorporated protocol-guided evaluation and M&V criteria, and applying a Basic level of rigor consistently across all program measures was adequate to achieve detailed resolution. Evaluation goals were designed to ensure reliable estimates of energy savings. Table 8-3 shows evaluation rigor levels. We concurred these levels of rigor were appropriate for the MAP program, and proposed no changes to rigor levels.

Table 8-3: CPUC-Stipulated and Final Evaluation Rigor Levels for SCE 2537

Evaluation Component	CPUC Stipulated	Final Rigor Levels
Energy	Basic	Basic
Demand	Basic	Basic
NTG	Basic	Basic

To meet Basic levels of rigor, the CA Protocols call for sample sizes that meet 90% confidence and 30% precision. This 90/30 sampling plan was used for CO sensors and Turbocor, the two technologies evaluated.

8.5 CO Sensors

8.5.1 Measure Description

CO Electrochemical Sensor systems with variable frequency drives (VFDs) operate garage fans only when detecting carbon monoxide. VFD control maintains base ventilation and avoids on-off operation of fans. Depending on the baseline conditions of each site, buildings either have constant speed or variable speed fans installed. The largest energy impacts are obtained when the system is upgraded from constant speed operation to the CO sensors with VFDs.

8.5.2 Estimated Parameters

The ex-ante gross energy and demand savings for CO sensors were based on an estimate energy calculation from the implementer's site audit to determine UES based on multiple categories of operating hours, fan power, and potential CO savings. The standard unit for this measure was per garage exhaust system. The ex-post results estimated the UES. The ex-ante NTG ratio for each program and measure combination used the default value, typically 0.80. The ex-post estimated NTG for each program and measure combination was developed using a consistent method approved by the NTG Working Group, consisting of Energy Division and its technical consultants. In addition to the final evaluation parameters, the primary data results were sought to inform revisions or updates to the DEER estimates.

8.5.3 Methodology

The EM&V approach for this program was a short-term monitoring plan per International Performance Measurement and Verification Protocol (IPMVP), Option A, Partially Measured Retrofit Isolation, which required measurement of some parameters, and allowed stipulation of others. Measured parameters were exhaust fan power (kW) and operating hours for each controlled fan. For pre-retrofit fan conditions, where it was anticipated the fan operated at a constant speed/on-off operation, fan power only needed a one-time measurement and confirmation of operating hours. Operating hours were verified by either a time clock or recording with a simple on/off data logger. We did not monitor any pre-retrofit fan conditions where fans operated at variable speeds; there was only one in the sample and it was not properly functioning.

Post-retrofit monitoring included true root mean square (RMS) power measurements to accurately determine kWh impacts. To determine project savings, pre- and post-data were used in standard engineering algorithms to calculate the fan power reduction factor applied to the operating hours for each controlled fan. External influences, such as the seasonality of CO levels, prevailing winds, number of cars, and temperature effects on CO, could distort extrapolating annual energy savings. These issues were variable, and may or may not have had an impact on these parameters.

8.5.3.1 Methods Used in this EM&V Activity

8.5.3.1.1 Sample Sizes for CO Sensors

Metering included a sample of pre- and post-installation monitoring. Confidence and precision levels of 90% confidence and 30% precision were employed, in keeping with impact evaluation work using protocols for Basic levels of rigor. The program anticipated sampling from an estimated population of 14 sites; meeting the 90/30 criteria required a sample size of five site visits. The sample selection table is shown below. By the end of the project, 16 sites enrolled.

Table 8-4: CO Sensors Population and M&V Meter Sample

Sample Section	Estimated Number of Program Sites	Number of Sites with Measure Installations	Evaluation Sample
On-site participant survey	14	16	5 sites
On-site verification and of engineering estimates	14	16	5 sites
On-site metering of CO Sensors	14	16	5 sites

8.5.3.2 On-site Data Collection

The Specialized Commercial CG Evaluation Team monitored 10 units at five different parking structures; four sites were used in the analysis. Field activities provided verification of program records with respect to overall project goals. This process confirmed several key components needed to accurately analyze program impacts, gross energy savings, and net energy savings achieved. Field activities were designed to:

1. Verify baseline conditions and assumptions.
2. Verify measure installations.
3. Verify energy savings assumptions.
4. Correlate installation reports with participant interviews.

When feasible, the following nameplate information was taken during the initial site visit:

1. Number of Fans
2. Fan Type
3. Manufacturer Name
4. Model Number
5. Serial Number
6. Name Plate: HP
7. Name Plate: Amps FL
8. Name Plate: V/RPM/PH/Hz

The following parameters were logged for two weeks pre- and post-installation: current (motor run time), true RMS power, and total unit power.

Table 8-5 indicates data collected by the Specialized Commercial CG Evaluation Team by quantity, meter device, and model.

Table 8-5: CO Sensor Logged Measurements at Each Unit

Monitoring Equipment Summary						
Function/ Data Point to Measure	Equipment Brand/Model	Qty	Rated Full Scale Accuracy	Accuracy of Expected Measurement	Planned Metering Duration	Planned Metering Interval
Power	Fluke Power Analyzer 43	1	± (2 % + 6 counts) Total Power	± (2 % + 6 counts) Total Power	Instant	Instant
Current (motor run time)	HOBO Data Logger U12-012	1	± 2.5%	± 2.5%	2 Weeks	5 minutes
Current (one phase)	100 amp CT HOBO Smart Sensor CTV-C	1	±4.5%	±5.0% of full scale	2 Weeks	N/A
True RMS Power, kW	DENT Elite Pro	1	<1% of reading, exclusive of sensor (0.2% typical)	<1% of reading, exclusive of sensor (0.2% typical)	2 Weeks	5 minutes
Total unit power (460v / 3 phase)	100 amp CT T-MAG-SCT-100	3	±1% (from 10% to 130% of rated current)	±1% (from 10% to 130% of rated current)	2 Weeks	N/A

8.5.3.3 Verification and NTG Data Collection

The overall verification and net savings sampling strategy was to first achieve 30% precision at the 90% confidence level for this measure. The evaluation plan called for verifying installations at five sites retrofitted with CO sensors for garage exhaust fans.

The Specialized Commercial CG Evaluation Team conducted a NTG survey for each of the on-site visits, using the Joint Simple Self-Report (SR) NTG Method. The NTG method prescribed a set of questions and scoring procedures. The intent of the Joint Simple SR NTG method was to ensure a common set of questions, interview protocols, and scoring procedures were used. However, some questions were tailored for particular programs and/or measures to make the questions better understood by respondents, to ensure more complete, reliable, and accurate responses.

8.5.3.4 Reference and Background for the Method Applied

To inform the savings algorithm, the main source of collected data was a metered sample of CO sensors installed in the MAP program. A period of at least two weeks pre- and post-installation was metered. This time period captured the normal operating conditions of the buildings where CO sensors were installed.

To determine project savings, pre- and post-data were used in standard engineering algorithms to calculate the fan power reduction factor applied to the operating hours for each controlled fan.

Calculations to determine impact savings included:

Figure 8-1: Impact Savings Equation

$$kW = \frac{A \times V \times \sqrt{3} \times PF}{1000}$$

$$Annual\ kWh_{baseline} = kW \times Annual\ Operating\ Hours$$

$$Annual\ kWh_{COsensor} = kW \times FullLoadHours$$

$$Annual\ Savings\ kWh = Annual\ kWh_{baseline} - Annual\ kWh_{COsensor}$$

Demand savings were based on the reduction of peak kW demand pre- and post-retrofit. Difficulties emerged in determining kW savings from CO sensor controls due the variability in CO amounts triggering changes in fan operation. Post-retrofit monitoring data from the fan operation helped determine if there were significant predictable patterns that could capture system coincident peak data. The fan operation pattern was then correlated to the DEER peak period, averaged over the three hottest consecutive workdays during the monitoring period.

The calculation to determine demand savings was:

Figure 8-2: Demand Savings Equation

$$kW_{Peak\ Demand\ Savings} = kW_{baseline} - kW_{COsensor}$$

Demand savings are the average of nine hours (3 hours over 3 days):

$$\text{Peak\_kW\_Svgs} = \sum_{d=Jul17}^{Jul19}\left(\sum_{h-15}^{17}\left(\text{baseline\_power}_{d,h} - \text{as\_built\_power}_{d,h}\right)\right) \Big/ 9$$

where:

Peak_kW_Savings	=	peak demand savings for the project
h	=	hours
d	=	days
9	=	number of peak demand hours

8.5.4 Confidence and Precision of Key Findings

8.5.4.1 Planned Confidence and Precision

MAP was a protocol-guided full impact evaluation using a Basic level of rigor for estimating energy impacts (kWh) and demand impacts (kW). The overall verification and net savings sampling strategy was designed to achieve 30% precision at the 90% confidence level for this measure. The evaluation plan called for verification and monitoring at five sites retrofitted with CO sensors for garage exhaust fans.

8.5.4.2 Achieved Confidence and Precision

The achieved verification and net savings sampling was at four sites retrofitted with CO sensors for garage exhaust fans. The fifth site was visited pre- and post-installation, completing the measure verification. Monitored data were not available for this evaluation. The resulting confidence was 37% precision at the 90% confidence level.

Table 8-6 details CO sensor installations and ex-ante savings by site within the MAP program.

Table 8-6: CO Sensor (CO) Technology Installations and Ex-ante Savings

Site ID	Building Type	MAP Project Number	Climate zone	Ex-ante Gross kWh savings	Ex-ante Gross kW Savings	Ex-ante NTG	Ex-ante Net kWh Savings
1	Misc. Commercial	01-01-1	6	235,164	26.1	0.8	188,131
2	Misc. Commercial	01-02-1	6	242,630	84.8	0.8	194,104
3	Misc. Commercial	01-03-1	9	279,957	52.2	0.8	223,966
4	Misc. Commercial	02-01-1	9	611,794	88.1	0.8	489,435
5	Misc. Commercial	03-04-1	9	1,502,387	157.9	0.8	1,201,910
6	Hotel	07-03-1	6	705,492	78.3	0.8	564,394
7	Small Office	07-06-1	9	744,921	78.3	0.8	595,937
8	Misc. Commercial	07-07-1	6	18,617	1.9	0.8	14,894
9	Small Office	07-11-1	6	301,154	39.1	0.8	240,924
10	Misc. Commercial	08-01-2	9	303,403	55.5	0.8	242,723
11	Misc. Commercial	08-06-2	9	244,962	65.3	0.8	195,970
12	Trans/Comm/Util	08-08-1	9	166,054	29.5	0.8	132,843
13	Large Office	11-01-1	8	147,303	22.3	0.8	117,842
14	Large Office	11-02-1	8	60,176	8.5	0.8	48,141
15	Library	12-01-1	6	102,360	19.6	0.8	81,888
16	Auto dealership	07-22-1	6	121,462	13.0	0.8	97,170

Miscellaneous buildings included public buildings such as libraries, police stations, city halls, as well as office buildings.

The program enrollments occurred quickly, and many sites had measures installed before the evaluation commenced. As pre-installation monitoring could be conducted, the Specialized Commercial CG Evaluation Team worked with the implementers to identify sites interested in the program but which had not already installed CO sensors. Sites were selected based on whether pre-installation metering could be completed. Sites where metering was completed are included in Table 8-7.

Table 8-7: Ex-ante CO Sensor Metered Sites

Site ID	Building Type	MAP Project Number	Climate zone	Ex-ante Gross kWh savings	Ex-ante Gross kW Savings	Ex-ante NTG	Ex-ante Net kWh Savings
10	Misc. Commercial	08-01-2	9	303,403	55.5	0.8	242,723
12	Trans/Comm/Util	08-08-1	9	166,054	29.5	0.8	132,843
13	Large Office	11-01-1	8	147,303	22.3	0.8	117,842
14	Large Office	11-02-1	8	60,176	8.5	0.8	48,141
15	Misc. Commercial	12-01-1	6	102,360	19.6	0.8	81,888

8.5.5 Validity and Reliability

8.5.5.1 Measurement and Calculated Uncertainty of System Efficiency

Uncertainty analysis was conducted to increase the reliability of the results by reducing random measurement error, and identifying and mitigating potential sources of systematic bias. The evaluators explored the uncertainties related to using the current instrumentation suite and some form of these approaches to estimate instantaneous system performance. The Specialized Commercial CG Evaluation Team also developed a monitoring plan to record required parameters and estimate system performance over varying operating conditions. Measurement error is discussed in Table 8-5, above.

The Specialized Commercial CG Evaluation Team worked with program management and their implementation contractors to pursue monitoring sites where CO sensors were installed. Five sites were metered, with both pre- and post-installation data gathered; four sites were analyzed. Including fewer sites in the analysis decreases the precision of the estimates and increases the uncertainty. At each of the sites, a NTG survey was conducted with decision makers.

8.5.6 Detailed Findings

8.5.6.1 Ex-ante Savings Estimate Review

Prior to installing the CO sensors, the implementer estimated potential energy savings. The vendor and installing contractor of the CO sensors provided a CO ventilation system energy analysis prior to measure installation. This documentation was provided to the customer and SCE for approval. The energy analysis included an estimate of the affected fan's annual operating hours, energy consumption, and percent of energy savings. The basic methodology follows:

Annual Operating Hours = Weekly Hours x 52

$kW_{TotalFankW} = (HP_{Fan\ 1} + HP_{Fan\ 2} + HP_{Fan\ N}) \times 0.746$

Annual kWh Baseline = $kW_{TotalFankW}$ *x Annual Operating Hours*

Percent Savings = Operating time reduction with CO: Ranged from 80% to 95% (varied by site)

Annual kWh Savings = Annual kWh Baseline x Percent Savings

The method to determine kW demand reduction was not explicit, but consisted of the following:

$$kW\ Peak\ Demand\ Savings = kW_{TotalFankW}\ x\ 87.5\%$$

This 87.5% demand savings represented the average (80%, 95%) potential savings from the installation of the CO sensor controls and resulting reductions in fan operating times.

8.5.6.2 Ex-ante Assumptions Review

Annual operating hours, fan kW, and percent savings were the main assumptions that varied from site to site. Using monitored data of baseline conditions, the Specialized Commercial CG Evaluation Team verified operating hours and fan power draw (kW). Spot measurements of fan kW were consistently lower than energy savings analysis provided by implementer. The implementer did not take spot measurements. The implementer's method took the rated motor horsepower and converted it to kW using 0.746 kW/HP as a multiplier. This method did not account for oversizing fan motors or motor operating conditions; assumed motor efficiency was 1.0.

Estimated hours of fan operation were less consistent and varied substantially from site to site. The following table shows the variation between implementer's recorded operating hours and the evaluator's monitored hours of fan operation.

Table 8-8: CO Sensor Estimated and Monitored Fan Operating Hours by Site

Site ID	Estimated Fan Operating Hours	Monitored Fan Operating Hours	Realization Rate (%)
12	5,293	5,877	111%
13	6,205	4,345	70%
14	6,205	2,811	45%
15	5,084	4,124	81%

The fan audits estimated 23% fewer operating hours than monitored operating hours. Of sites visited, all either had analog or digital time-clocks to schedule the parking exhaust fan operation. Annual operating hours were determined using the monitored data of the average weekly fan operating hours during baseline conditions:

$$Annual\ Operating\ Hours = Average\ Weekly\ Hours\ x\ 52$$

In cases where sites were monitored over holidays and the fans were turned off, operating hours were adjusted, assuming six Federal holidays taken at those sites. The six days were assigned to the holiday day type and not included in the workday calculation. Where no holidays were observed or the fan operated during holidays, full annual operating hours were assumed, that is, the fan operation is the same for all day types. This difference in baseline operating hours had significant implications for the overall energy saving impacts. It is recommended that the initial site energy analysis and documentation of fan operating hours be more stringent to provide more accurate estimates of energy consumption and energy savings.

In each site energy analysis, the implementer provided an estimated reduction in operating time expected by installing the CO sensor. The percent reduction (or savings) ranged from 80% to 95%. Using the final IOU ex-ante gross kWh, we back-calculated the percent savings and found CO sensor kWh savings ranged from 90% to 95%. It was not apparent if changes were made during installation of the CO sensors to account for the difference in the initial energy analysis to the final submitted saving estimates. For example, some sites installed VFDs in conjunction with the CO sensors and some did not. Some sites with VFDs may require a minimum exhaust air flow, and the VFD maintains a constant flow using 20% to 40% power. Evaluators recommend a final updated energy analysis be conducted after project completion to document final site conditions and the project's outcome.

8.5.6.3 Energy Savings Analysis

In the summers of 2008 and 2009, the Specialized Commercial CG Evaluation Team monitored a total of 12 fans at five sites, for a minimum of two weeks before and after CO sensor controls were installed. Of the 12 sets of monitored data, four data sets at one site (Site 10) were discarded due data loss after logger download. Evaluated energy savings for the eight fans with CO sensors are summarized in Table 8-9. Savings are shown on a per fan and site basis.

Table 8-9: CO Sensor (CO) Installations and Evaluated kWh Savings by Fan and Site

Site ID	Fan ID	Ex-ante Gross kWh Savings	Pre-CO: Monitored Hours of Operation	Pre-CO: Fan kW	Pre-CO: Annual Usage (kWh)	Post-CO: Annual Usage (kWh)	Post-CO: Savings (%)	Monitored Savings Per Fan (kWh)	Total Savings Per Site (kWh)
12	1	166,054	4,778	14.9	71,295	3,812	94.7%	67,482	150,906
	2		4,715	18.7	87,943	4,520	94.9%	83,423	
13	1	147,303	4,345	15.0	65,214	5,660	91.3%	59,554	98,439
	2		4,345	10.0	43,425	4,541	89.5%	38,885	
14	1	60,176	2,566	5.6	14,358	No fan operation	100.0%	14,358	23,930
	2		2,566	3.7	9,572	No fan operation	100.0%	9,572	
15	1	102,360	3,693	10.6	39,188	6,062	84.5%	33,125	72,214
	2		3,837	10.2	39,252	163	99.6%	39,089	

The energy savings of the eight fans with CO sensors ranged from 84.5% to 100%, with a weighted average (kWh savings) of 93.5%. Site 14 achieved 100% savings and was found to have zero fan consumption during the monitored period. Metering equipment was in working order and extended the monitoring period to a total of 35 days for fan 1 and 86 days for fan 2 (maximizing the meter memory), resulting in zero consumption. The facility engineer was not surprised the fan did not consume energy during the monitored period. He stated that particular building had a 40% building occupancy rate at that time, and building tenants did not park their cars in the lower section of the garage.

As part of the CO installation, sites 12, 13, and 15 also had VFD controls installed. This strategy of installing VFD controls and CO sensors was common practice within MAP projects. Typically, VFDs maintained a minimum exhaust air flow set at 20% to 40% during operating hours. Site 14 had a constant volume (same flow rate) pre and post CO installation. The bulk of the savings can be attributed to the installation of the VFD working in tandem with the CO sensor.

The following four figures display monitored daily energy use (kWh) pre- and post-installation of CO sensor controls.

Figure 8-3: Site 12 CO Sensor Pre–Post Daily Energy Use

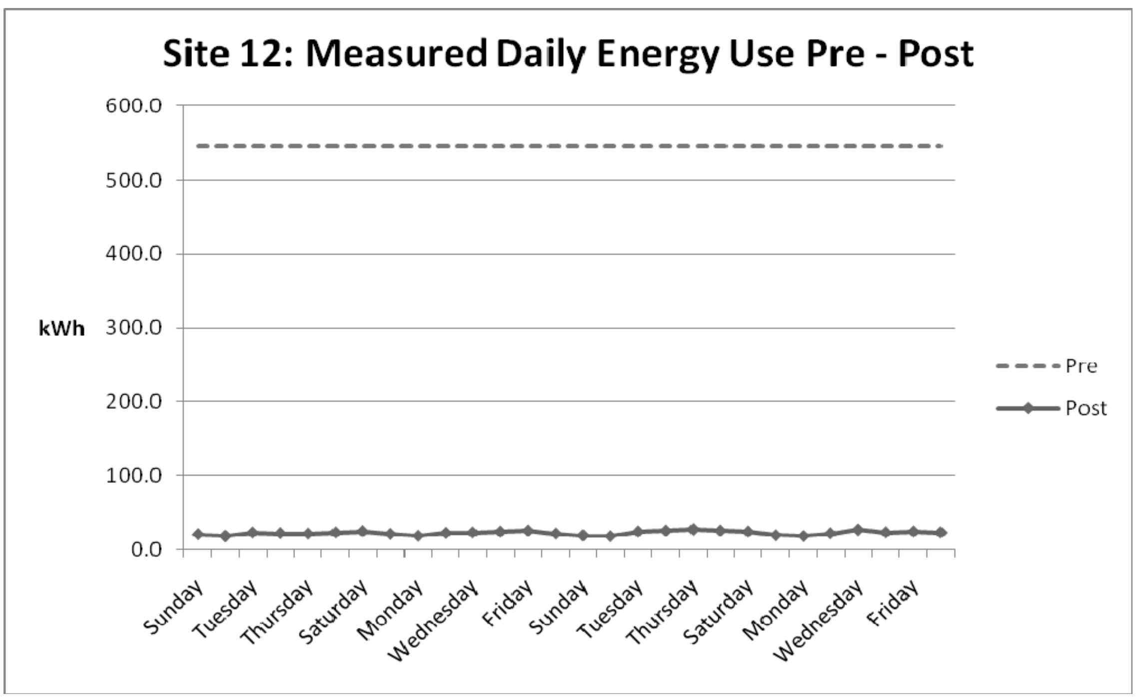


Figure 8-4: Site 13 Pre–Post CO Sensor Daily Energy Use

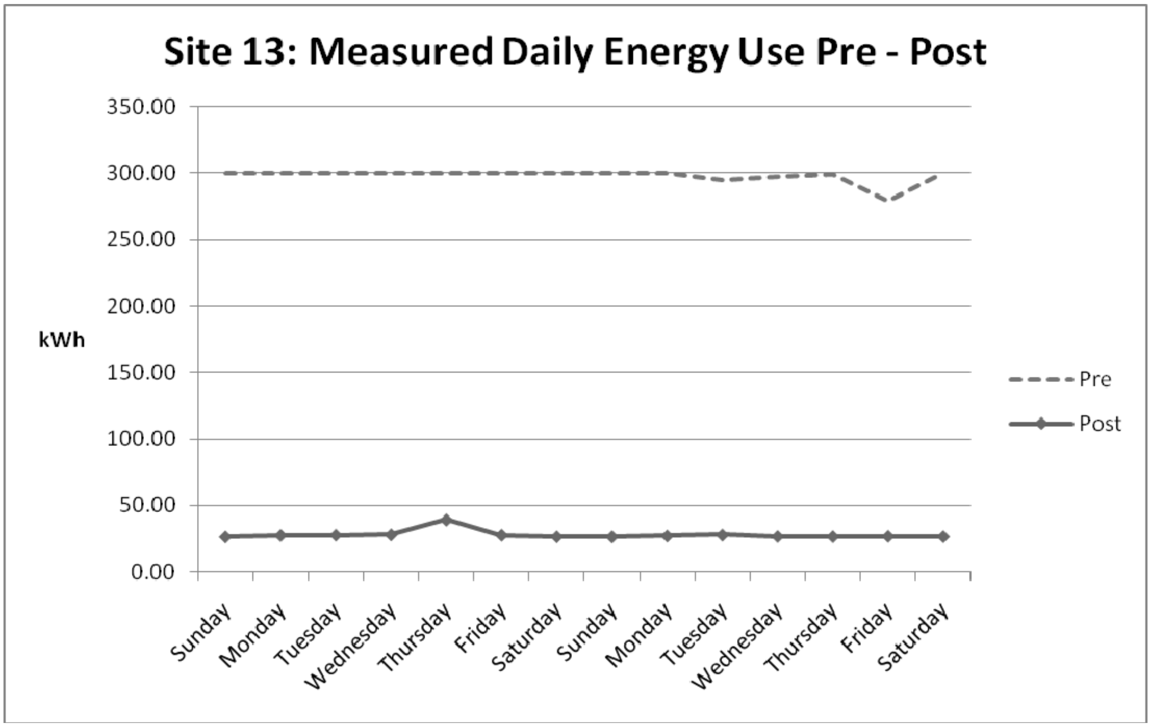


Figure 8-5: Site 14 Pre–Post CO Sensor Daily Energy Use

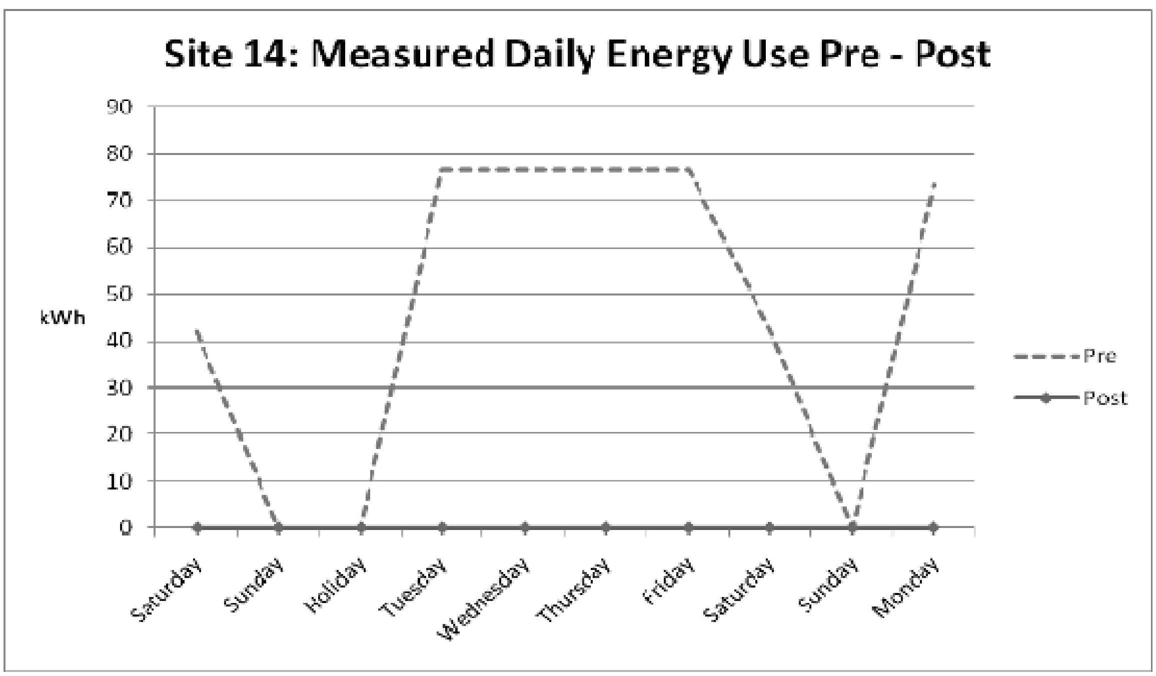
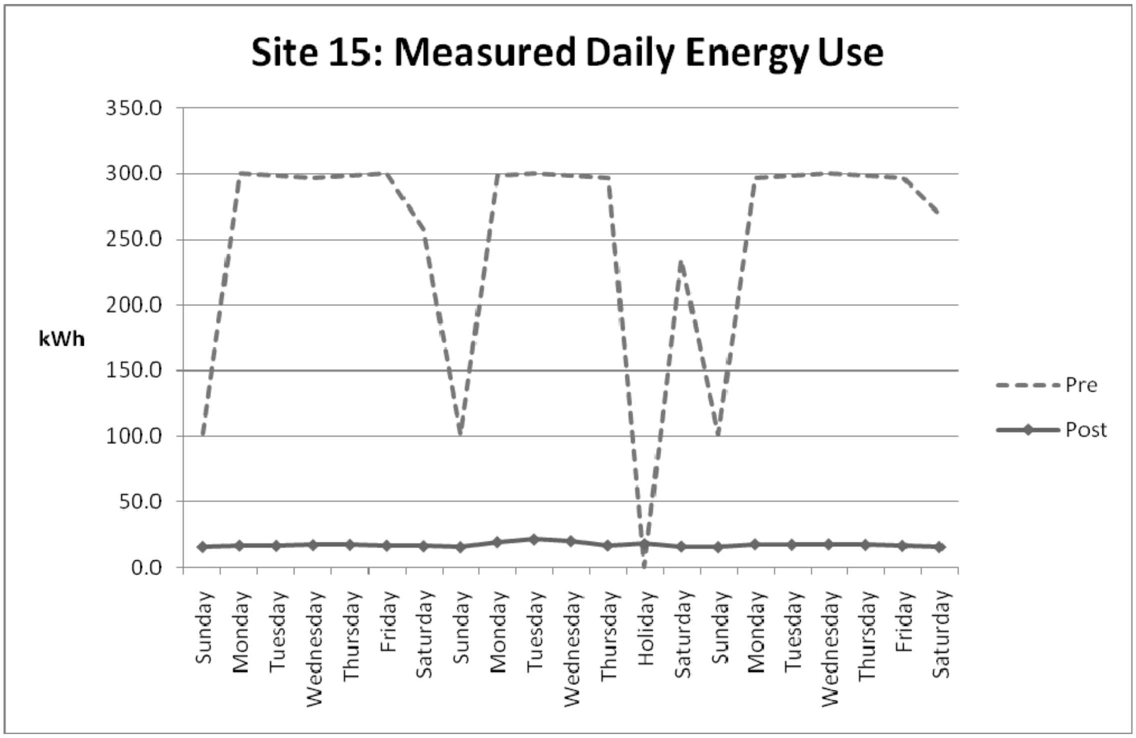
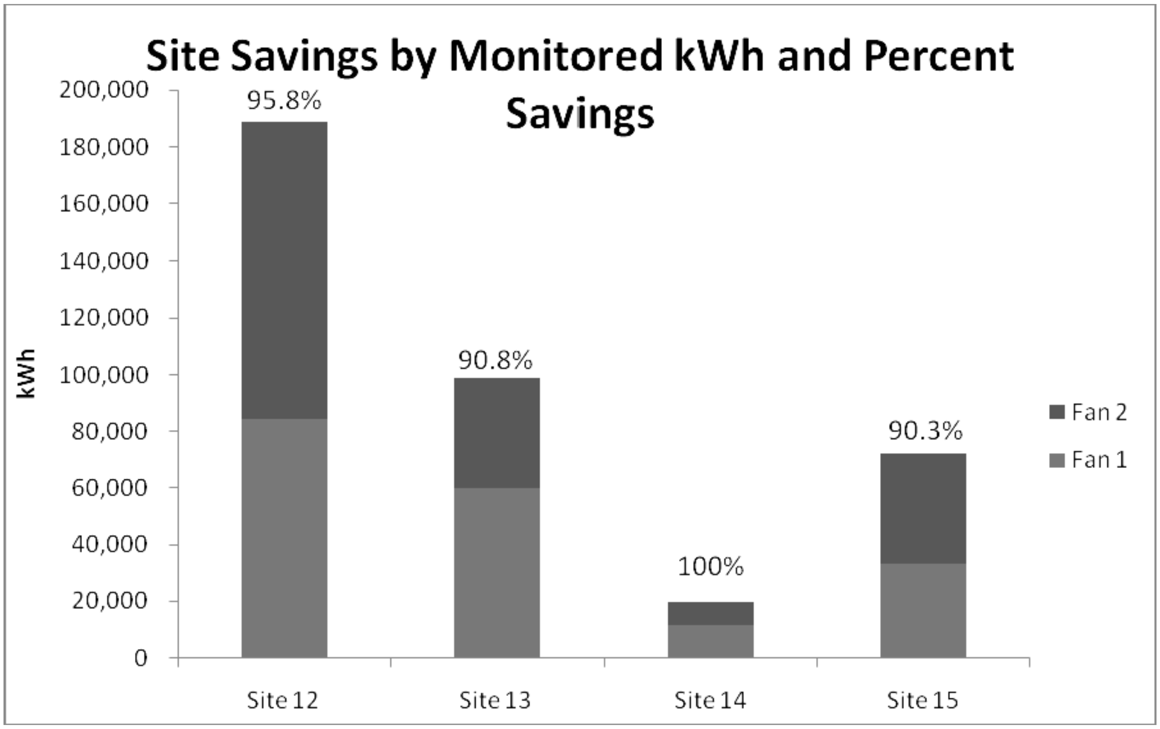


Figure 8-6: Site 15 Pre–Post CO Sensor Daily Energy Use



The final figure (Figure 8-7) summarizes monitored kWh savings and achieved percent savings by site. For example, Site 13's monitored savings were 108,640 kWh, where fan 1 contributed 60% to savings, with overall savings of 90.8% of the monitored baseline. The average (non-weighted) energy savings across the four sites was 94.2%.

Figure 8-7: CO Sensor Monitored kWh and Percent Savings by Site



The gross savings realization rate for the four monitored sites ranged from 32% to 114%. The gross kWh realization rate of the four sites together (unweighted) was 81%.

Table 8-10: CO Sensor Percent Difference in Ex-ante to Monitored Savings

Site ID	Ex-ante Gross Savings	Evaluated Savings (Monitored Sites)	Gross Savings Realization Rate
12	166,054	188,965	114%
13	147,303	98,654	67%
14	60,176	19,534	32%
15	102,360	77,608	76%
Total	475,893	384,760	81%

8.5.6.4 Grid Peak Demand Savings Analysis

Demand reduction is noticeably high. This is explained by several factors. The pre-program operating conditions indicate constant volume fans were installed. All units were operating during the pre-period. In the pre-conditions, fans appear to be massively oversized to meet the ventilation requirement to exhaust critical levels of CO in a very short time period; hence, the air volume is very high. In the post case, variable air volume fans operated with 20-40% of the air flow in the pre-condition. Moving smaller volumes of air continuously keeps CO levels from reaching critical levels. When indicated by the CO sensor, a small increase in fan operation is triggered by the garage exhaust buildup.

A review of the situation also showed the cubed law of fan power to fan flow indicated the nominal operating power of the fan at 20% of the flow was only 3% of the nominal full load power. The instances of increased fan flow over the peak time were brief and rarely increased the operating power more than 10% of the optimal full load power. The max KW occurred during time periods when people were exiting the garage, but, even then, the fans were not on at full. In all the cases observed, only one case showed increased operating power at more than 50%. However this occurred outside the peak window between the 5:00 pm to 7:00 pm hours for this site.

One metered site was a two-speed fan operating full time in pre-period, and in post not properly functioning. In this situation, the nameplate data were used in place of post period measurements.

The grid level peak demand KW impacts were determined using the CPUC peak period definition. Peak periods are defined by the average temperatures over the three hottest consecutive workdays, from 2:00 pm to 5:00 pm. Using this definition, peak period KW demand was reduced 97%.

Table 8-11: CO Sensor Grid Level Peak Demand Reduction

Site ID	Climate zone	Pre kW DEER Peak Average	Post kW DEER Peak Average	kW Demand Percent Reduction
12	9	33.6	1.0	97%
13	8	25.0	1.1	95%
14	8	7.0	0.0	100%
15	6	20.8	0.7	97%
Total		86.4	2.9	97%

8.5.7 NTG Analysis

A modified version of the Nonresidential Net-to-Gross Methodology Participant Survey was conducted for the SCE 2537 MAP CO Sensor participants. Results of the survey were used to assess free-ridership in the program and to determine whether the NTGR of 0.9 used in program planning assumptions should be adjusted for actual free-ridership.

For CO Sensor participants, there were a total of 11 decision makers at 16 sites. NTG surveys were conducted at the four sites visited where metering equipment was installed. The evaluation team was able to contact three additional participants by phone, for a total of seven completed surveys.

A net-to-gross ratio was calculated from survey responses as per the “Proposed Net-to-Gross Ratio Estimation Methods for Nonresidential Customers”. The NTG was then weighted by the ex ante savings associated with the survey respondents. The evaluated savings-weighted net-to-gross ratio calculated for the SCE 2537 MAP CO Sensor participants was 0.87.

8.5.8 Program Specific Results

To extrapolate savings to the entire program population installing CO sensors, the evaluation team calculated the savings weighted realization rate for gross energy savings. Due to the variation in HP, operating hours, and savings estimated for the limited number of sites sampled, we applied a savings-weighted realization rate to the full population. Based on the limited sample of sites monitored, the evaluation found 81% of the ex-ante gross kWh savings. The large portion of this reduction in kWh was attributed to differences in observed fan operating hours. Monitoring determined the original operating hours were over estimated.

The IOU claimed NTG was 0.80. Surveys with seven participant decision makers found 0.87 NTG for kWh and 0.84 for kW.

Table 8-12: CO Sensor Evaluated Gross Savings

CO Sensor	IOU Ex-ante Gross Savings	Gross Realization Rate	Evaluated Adjusted Gross Savings
kWh	5,787,836	81%	4,688,147
KW	820	110%	906

The evaluated net savings in Table 8-12 are 110% of the ex-ante savings. The ex-ante savings were based on demand reduction of 87.5%. Realized savings are based on measured demand savings of 96.7%.

Table 8-13: CO Sensor Evaluated Net Savings

CO Sensor	Evaluated Adjusted Gross Savings	Ex-ante NTG	Evaluated NTG	Evaluated Net Savings
kWh	4,688,147	.8	.87	4,078,688
KW	906	.875	0.84	761.04

Table 8-14: CO Sensor Energy Savings Summary

Program Name	Measure Ex-ante Gross kWh Savings	Measure Ex-post Gross kWh Savings	Install Rate	Measure Installed Ex-post Gross kWh Savings	Measure NTG	Measure Ex-post Net kWh Savings
MAP SCE 2537 CO Sensors	5,787,836	4,688,147	100%	4,688,147	0.87	4,078,688

Table 8-15: CO Sensor Demand Savings Summary

Program Name	Measure Ex-ante Gross kW Savings	Measure Ex-post Gross kW Savings	Install Rate	Measure Installed Ex-post Gross kW Savings	Measure NTG	Measure Ex-post Net kW Savings
MAP SCE 2537 CO Sensors	820	906	100%	906	0.84	761.04

8.5.9 Findings and Recommendations

The measure appears to have the potential to generate large energy and demand savings. For large savings relative to current use, the implementer may have overestimated operating hours and, therefore, overestimated savings.

The evaluation of CO sensors in the SCE 2537 MAP program found a decrease from the ex-ante net kWh savings estimates and an increase from ex-ante net kW savings estimates. The reductions in kWh savings were primarily due to the implementer's inaccurate estimates of fan operating hours. Granted, this is a small sample, and further monitoring is warranted to increase the validity of the results.

Through this evaluation and other case studies, this technology has been shown to save both kWh and kW. The combined VFD controls and CO sensors are ideal in most applications. Going forward, the following program recommendations are:

1. Improve the methodology to determine fan motor hours of operation.

2. Extrapolate the savings from site basis savings to savings for a single fan controlled by the CO sensor.

3. Spot measure fan kW and compare to calculated kW, based on nameplate HP.

4. Submit a revised energy analysis after project completion to account for final project installations and site conditions.

5. Obtain better documentation of estimated percent fan reduction from contractors.

6. Obtain better documentation of the set minimum exhaust air flow when the VFD will maintain on.

7. Subset energy savings based on sites that install VFDs and those installing the CO sensor on a constant volume system.

8. Monitor additional sites in appropriate climate zones and building types to increase the validity of the results.

8.6 Turbocor Oil-Free Compressors

8.6.1 Measure Description

The Turbocor (TC) oil-free refrigerant compressor with a variable frequency drive (VFD) was specifically designed for the Heating, Ventilation, Air Conditioning, and Refrigeration (HVACR) industry. High friction losses and maintenance-intensive hardware and controls are associated with conventional oil lubricated bearings. TC technology eliminates oil lubrication by utilizing modern magnetic bearing technology. Literature claims TC compressor technology enables high energy efficiency and reliable, long-life frictionless operation, using as little as 0.375 kW/ton.[29,30] It is a fraction of the size and weight of conventional compressors, quiet, and virtually vibration-free.

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[29] San Diego. *Regional Energy Office. Retrofitting a Water-Cooled Chiller with Turbocor's Newest Oil-Less Compressor*. Jan. 2006. Oct. 30th 2007 < www.sdenergy.org>

[30] Sacramento Municipal Utility District. *Energy Efficiency & Customer Research & Development, Technology Brief…The Turbocor Compressor.* 2004. Oct. 30th. 2007 <http://www.smud.org/education/cat/index.html>

We revised the initial evaluation plan to complete the project as a technology performance study of the TC technology. Since there were limited monitored performance data available for this technology, metering and performance data collected added significantly to the existing body of knowledge.

8.6.2 Overview of Market and Technology Report Objectives

The study's goal was to better understand TC performance as it compared to similar compressors made by other manufacturers. Due to the unique nature of each installation, the focus of the study was not on analyzing energy savings, but was directed toward examining in situ Turbocor compressors.

It was important to understand how this new technology performed at full and part load conditions. Because TCs have been applied not only in water-cooled chiller systems but also in direct expansion (DX) configurations, there has been additional interest to understand how they perform in the latter case. To do so, we collected trend data from seven sites and monitored performance at three of these. Resulting data were used to create actual performance curves for each site, which were compared to performance data from other compressor manufacturers. The results are presented as six case studies, one for each site monitored, and the final one for three DX sites at which we collected only trend data.

8.6.3 Methodology

8.6.3.1 Methods Used in this EM&V Activity

8.6.3.1.1 Population and Sample Sizes for Turbocor Oil-free Compressors

Characteristics of the installations completed within the MAP 2006–2008 program cycle are shown in Table 8-16 below, summarized by climate zone within the SCE territory, ex-ante savings, and building type; the bulk of the projects were clustered in climate zones 6 and 9.

Table 8-16: Turbocor Installation Characteristics

Climate Zone	Building Type	Count of Building Type	kWh Savings (Net)	kW Savings (Net)
6	Large Office	11	1,819,150	551
	Misc. Commercial	1	194,888	78
	Small Office	1	336,627	136
	Zone Total	13	2,350,665	765
8	Large Office	2	331,729	194
	Mall	2	308,578	109
	Small Office	1	218,080	54
	Zone Total	5	858,387	356
9	Hospital	1	690,493	208
	Large Office	5	1,838,779	546
	Zone Total	6	2,529,272	754
Program Total		24	5,738,324	1,875

*Excludes two incomplete installations

The initial sample plan called for metering six sites, a sample size that met the 90% confidence and 30% precision prescribed by the CPUC protocols for measures evaluated at Basic levels of rigor. The initial sampling plan called for targeting locations with the greatest kWh savings for metering, stratified by climate zone and by building type .

However, during the process of arranging sites to monitor, the Evaluation Team discovered more than half of the TC compressors served air-cooled DX refrigerant coils, not water-cooled chillers as expected. Because such a high percentage of installations were in DX systems, it was also important to understand how the TC compressors performed in this application. The final sample was comprised of seven sites, including three water-cooled chillers and four DX systems. At all sites, one year of 15-minute trend data were downloaded from the TC monitoring software. All chiller sites were monitored.

The following table shows selected sites from the total available pool of 24 participants with completed projects.

Table 8-17: Turbocor Participants and M&V Sample Selection

Application	Available Sites	Sites Monitored	Trend Data Collected
Water cooled chiller	7	3	3
DX system	16		3
Flooded coil system	1		1
Project not yet completed	2		
Total	**26**	**3**	**7**

Office #1 was monitored in fall 2008, and two additional sites, Hospital #1 and Office #2, were metered summer 2009, based on the criteria above. At that point, the first indication emerged that meeting the goal of six sites would be a challenge. Except for one chiller site with hard-jacketed insulation, which would increase the time and expense of metering, and another site where the Turbocor compressor served a rarely-used chiller, all other sites had refrigerant DX coils. To get capacity and efficiency, air flow was required, and finding a way to accurately measure air flow across the coil proved a challenge.

With chillers, a flow meter is used to measure water flow, but no such tool exists to monitor air flow in a DX system. The Evaluation Team spoke with another consulting firm that designed a Pitot tube array, specified and tested for this application; they provided the specifications and described how to build and use the tool. However, this posed additional challenges because not only must the tool be calibrated in the field, adding time to the process, but it must be built to specifications of the specific duct where it will be used. Before building the tool and ordering parts, the following information was needed:

1. Duct dimensions
2. Supply fan CFM
3. Duct static pressure
4. Duct configuration

If multiple air handlers tie in to one TC, air flow must be measured on each, with a separate Pitot tube array for every air handler. Also, a minimum length of straight duct work on the supply side is needed to ensure non-turbulent airflow for measurements. This length is determined by duct size, with larger ducts requiring a greater distance. The consulting firm that previously built the pitot array had used their tool in a relatively small duct compared to the duct sizes in the MAP participant systems. The recommended pitot array was not feasible for a number of reasons. For example, at one site, there was only a common plenum running through the building. Another site had two common fans with one coil face, but the proximity of the shaft to the fans made it difficult to achieve steady flow without turbulence. A third site sent their plans, which showed two supply fans with 52” X 70” ducts running 52” before transitioning into 84” X 54” ducts.

The challenges encountered when attempting to select and monitor sites are summarized below:

Table 8-18: Turbocor Compressor Monitoring Challenges for 25 Projects

Challenge	Frequency
No monitoring challenges	3
Chillers with a complicated piping setup with hard shell insulation. It would be costly and increase monitoring installation time.	1
Chillers with Turbocor used only when load is small (winter)	1
Flooded coil setup	1
DX setup*	17
Site cannot be monitored (ownership changed, issue with insurance)	1
Project has not been completed	2
Total sites	26

*Within the DX systems, flow measurements were impossible at 12 sites due to physical layout of the distribution system (insufficient straight run of duct to allow installation of flow measurement station. The remaining 5 with DX setup did not respond.

Given these challenges, a revised study approach focused on data downloaded from the TC Monitoring Software, along with the published TC compressor maps, to calculate performance. The benefit of this approach was the availability of one full year of trend data from more sites than would have been possible through monitoring alone.

8.6.3.1.2 On-site Data Collection

Data were collected from seven of the 24 participant sites with completed projects: three with chilled water systems and four with DX AC units. Trend data were collected from all sites, and all chilled water sites were monitored. Baseline monitoring was conducted at one of the three chilled water sites. Challenges for data collection are summarized in Table 8-18 above.

At each site visited, existing conditions were verified with the building facility manager, who provided details on operating schedules, equipment specifications, and other relevant information. In addition, we reviewed all TC installed within the program, and generated market and application characteristics (e.g., building type and TC application, type of compressor replaced, reasons for replacement, and limitations of TC technology). We collected this information directly from the implementer and, as needed, through survey interviews with appropriate facility personnel.

At the three monitored chilled water sites, we conducted post-installation monitoring at two sites and baseline monitoring at one site. The following data points were collected for a duration of approximately 12 weeks during 2008 and 2009 cooling months, from June through September:

1. Chilled water supply temperature
2. Chilled water return temperature
3. Compressor power
4. Chilled water flow (short spot monitoring duration only for a one hour period; the monitored loop was constant volume)
5. Outside air temperature and relative humidity

At the four sites with DX air handlers instead of chilled water systems, we used a different approach of downloaded trend data because of the difficulty of accurately measuring air flow. The following data points were collected:

1. Suction temperature
2. Suction pressure
3. Discharge temperature
4. Discharge pressure
5. Compressor power
6. Compressor demand percentage
7. Shaft speed
8. Inlet guide vane percentage open
9. Outside air temperature from a local weather station

At the three monitored sites, we used metering equipment, including current transformers, data loggers, true RMS (root mean square) power meters, and simple on/off operation data recorders. The metering equipment, with intervals, duration, and accuracy, is presented in the following table.

Table 8-19: Turbocor Compressors: Logged Measurements at Each Monitored Unit

Metering Equipment	Parameter	Units	Interval	Duration	Accuracy
GE PT878 Panametrics Portable Ultrasonic Liquid Flowmeter	Flow: FT, FC	^{Gal}/Min	1 minute	Spot: 24 hrs	Pipe ID>6 in (150 mm): ±1% to 2% of reading typical
DENT Elite Pro w/ CTs	True Power: kW	kW	5 minutes	45 days	DENT <1% of reading, CT: ±1% of rated current
Onset HOBO U12-012 $_{Logger}$ w/ external TMC1-HD Temp Sensor	Temp: CHWR, CHWS, EWT, LWT (chilled water return & supply, entering wet bulb temp, leaving wet bulb temp)	^{o}F	5 minutes	45 days	Accuracy ±0.45° at 68°F
Onset HOBO H21-002 Micro Station Data Logger w/ S-THB-M002 Temp/RH Sensor and RS3 Solar Radiation Shield	OAT, RH (outside air temp, relative humidity)	^{o}F ,RH	5 minutes	45 days	Temp: 0.36°F over 32° to 122°F, RH: +/- 2.5% from 10% to 90% RH

Temperature sensors were wrapped with insulation and strapped to the condenser and chilled water pipes at two of the three monitored sites.

8.6.3.2 Description of the Baseline

All of the sites from which complete trend and monitored data were collected were retrofits and not new installations. Much, if not all, of the supporting equipment remained the same. This could also be considered a repair, not invoking Title 24, and the exiting compressor or normal replacement compressor would be the baseline. Therefore, Title 24 would not have been an applicable baseline for these cases. The baseline is the existing equipment, but for two reasons a comparison cannot be made. First, no baseline and post-installation monitoring was conducted. Second, the efficiency of the baseline compressor is not unknown because inefficiencies have accumulated in the equipment over time, and these cannot be calculated. Further discussion of these challenges can be found in the detailed findings section. Entergy, the program's third-party implementer, calculated the ex-ante energy savings with the following equation, using integrated part load value (IPLV) data:

$$AnnualSavings[kWh] = (Q_{Existing}[ton] \times \eta_{Existing}\left[\frac{kW}{ton}\right] - Q_{TC}[ton] \times \eta_{TC}\left[\frac{kW}{ton}\right]) \times Hours$$

Where:

$Q_{Existing}$ = Existing IPLV capacity
$\eta_{Existing}$ = Existing IPLV efficiency
Q_{TC} = Turbocor IPLV capacity
η_{TC} = Turbocor IPLV efficiency
Hours = Number of hours compressors run each year

8.6.3.3 Reference and Background for the Method Applied

To inform the savings algorithm, the main source of collected data was a metered sample of sites with DX and chilled water systems. The algorithm for analyzing the trend data from the DX sites is presented in the DX case study. The discussion below references chilled water systems.

8.6.3.4 Turbocor and Chilled Water System Evaluation Objectives and Algorithms

Examination of the Turbocor performance with chilled water systems included four objectives:

1. Calculate chiller efficiency (kW/ton) as a function of both the condenser entering water temperature (T_{ECW}) and the chilled water supply temperature (T_{CHWS}) at varying loads and compare to manufacturer's data.[31]

2. Determine part-load efficiencies (kW/ton) to calculate IPLV of Turbocor chillers for comparison to both the Turbocor published performance data and the appropriate baseline.

3. Develop performance curves in a format suitable for use in the DOE-2.2 building energy simulation program. The DOE-2 curves developed include:

   Cooling capacity (tons) as function of T_{CHWS} and T_{ECW}.
   Full-load efficiency (kW/ton) as function of $T_{CHWS,}$ T_{ECW}.

[31] This is a quadratic formula to curve fit the monitored data, making it suitable for the DOE-2.2 building energy simulation program.

Part-load efficiency (kW/ton) as a function of part-load ratio and "lift" (T_{ECW} - T_{CHWS})

4. Quality assurance procedure to check metered data results.

The following algorithms use the metered data and provide the approach to meet the evaluation objectives.

Evaporator capacity (tons)

$$Q_{EVAP} = F_{CH}\left[\frac{gal}{min}\right] \times 8.33\left[\frac{lbs}{gal}\right] \times 60\left[\frac{min}{hr}\right] \times C_p\left[\frac{Btu}{lb-F}\right] \times \Delta T_{CH}\left[{}^{o}F\right] \times \frac{1}{12{,}000\left[\frac{Btuh}{ton}\right]}$$

Q_{EVAP} = Cooling output
F_{CH} = Chilled water flow
8.33 = Gallons to pounds conversion
60 = Minutes to hours conversion
C_p = Specific heat of water (@ 59 °F)
ΔT_{CH} = Chilled water temperature difference (T_{CHWR} - T_{CHWS})
12,000 = Btuh to tons conversion

Condenser capacity (tons)

$$Q_{COND} = F_{C}\left[\frac{gal}{min}\right] \times 8.33\left[\frac{lbs}{gal}\right] \times 60\left[\frac{min}{hr}\right] \times C_p\left[\frac{Btu}{lb-F}\right] \times \Delta T_{C}\left[{}^{o}F\right] \times \frac{1}{12{,}000\left[\frac{Btuh}{ton}\right]}$$

Q_{COND} = Heat rejected
F_C = Condenser water flow
8.33 = Gallons to pounds conversion
60 = Minutes to hours conversion
C_p = Specific heat of water (@ 59 °F)
ΔT_C = Condenser water temperature difference (T_{LCW} – T_{ECW})
12,000 = Btu/h to tons conversion

Quality check and heat of compression

The condenser capacity should remain larger than evaporator capacity. In addition, the rejected heat can be determined from:

Condenser capacity (Q_{COND}) > Evaporator capacity (Q_{EVAP})
Q_{COND} – Q_{EVAP} = Heat of Compression

The heat of compression equals the input power to the compressor (converted to Btu/hr), less any losses from the compressor to the environment (which are expected to be small).

8.6.3.5 Measure Performance Assumptions

This study included a review of manufacturer's performance data of TC and a sample of major manufacturers' compressors of comparable performance characteristics. Performance data consisted of rated efficiencies for kW/ton and IPLV at full and partial loads. We developed performance curves for the TC technology based on two different approaches, one using monitored data and one using TC trend data. These performance curves will be discussed within each case study.

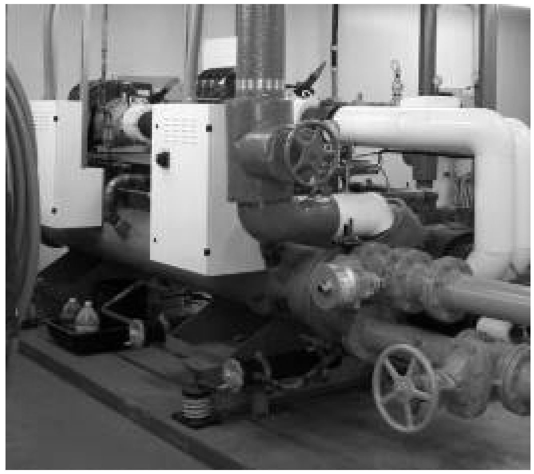
8.6.3.5.1 Case Studies: Chilled Water Sites

The case studies include a description of baseline and post-installation conditions and chiller operation. Each site visited was unique, both in its Turbocor application and system configuration. When possible, monitored and trend data were used to calculate capacity and efficiency. With the exception of Office #2, the Turbocor installations were retrofits, and compressors were the only major equipment replaced; all other supporting equipment remained the same. This situation differed from a new installation because the age and condition of the supporting equipment affect system performance and was usually less efficient than a new system. Because manufacturer performance data addresses all new equipment, the comparison between these data and these retrofits cannot be entirely on equal footing.

8.6.3.5.2 Case Study: Office #1

This was a 100,000 square foot office building in climate zone 6. The four original reciprocating compressors were replaced with four 60-ton R-134A Turbocors. Each pair of compressors served one chiller in this constant volume system. The chillers ran in series and were sequenced so the first operates as primary and the second runs only as needed to supply the one main AHU serving the entire building.

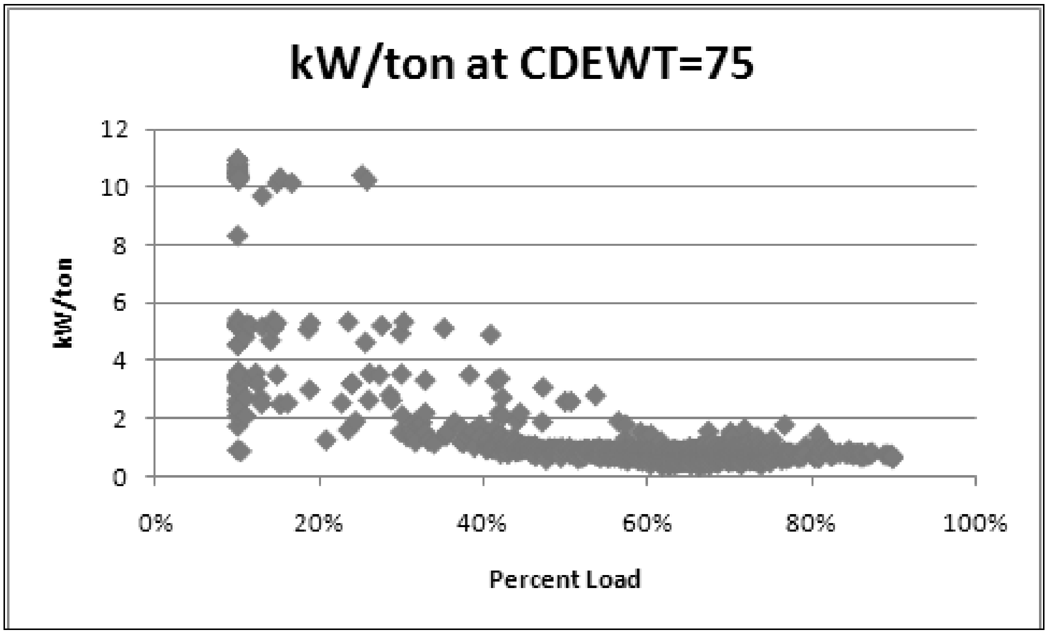
Figure 8-8: Case Study Office #1



In addition to the monitored data, one year of trend data were downloaded from the controls system. From the monitored data, flow with all four compressors operating was found to be 350 gallons per minute. The trend data at these times showed the system to be stable, at 76% load. Calculated capacity was 170 tons, with an efficiency of 0.78 kW/ton at a condenser entering water temperature (CDEWT) of 78 degrees.

Turbocor literature states the compressors operate most efficiently at part loads less than 60%; so Turbocor performance was examined at different loads, where condenser entering water temperatures ranged from 69 to 79 degrees. In each case, the chiller system efficiency (kW/ton) was nearly constant from a 50 to 90% load and decreased considerably at loads less than 40 to 50%, with 10% loads showing a sharp decrease in efficiency. Figure 8-9 shows the efficiency curve at a 75 degree condenser entering water temperature using metered data. Each point on the x-axis represents a percent load reading, that were taken in 15-minute intervals over one year. The kW/ton efficiency on the y-axis was calculated from applying the data from the flow measurements that were taken for one hour at full flow, during the site visit to install metering equipment. Here, average efficiency was 0.75 kW/ton when the load was greater than 50%, but decreased sharply below a 50% load.

Figure 8-9: Efficiency Curve at Office #2 for Condenser Entering Water Temperature of 75 Degrees



This monitored system did not perform as efficiently as Turbocor literature claims, but, again, the entire system had to be considered. This was a retrofit with existing equipment, not an entirely new system installation, and inefficiencies of the supporting equipment had to be taken into account.

Figure 8-10: Total Power Input Versus Percent Load at Office #1

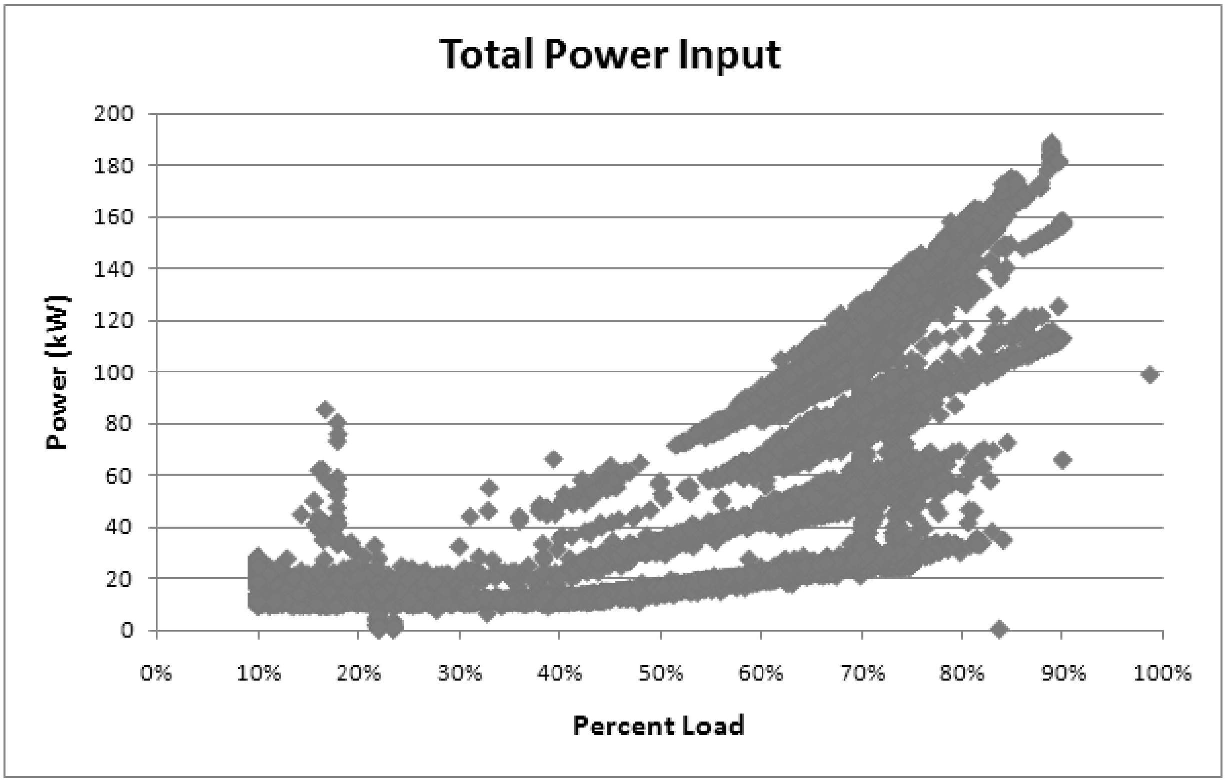


Figure 8-10 shows total power input (kW) versus percent load for this site. Percent load is calculated from the controller and represents the requested motor power demand as a percentage of the maximum motor power in kW. This system operated at 10-90% load, and it appears that from 10-40%, load only one or two compressors were operating; above a 40% load, any number of compressors could be operating. Clear distinctions in power consumption occur when different numbers of compressors are running. Applying the information from this figure to that shown in Figure 8-10, system efficiency at this site was driven by percent load more than the number of compressors operating. This system operated most efficiently at a 50-85% load.

8.6.3.6 Case Study: Hospital #1

As this 144,000 square foot hospital operated around the clock, properly functioning equipment was critical. Baseline units were two 30-year-old compressors, one rated at 500 tons and one at 320 tons.

Figure 8-11: Case Study: Hospital #1A

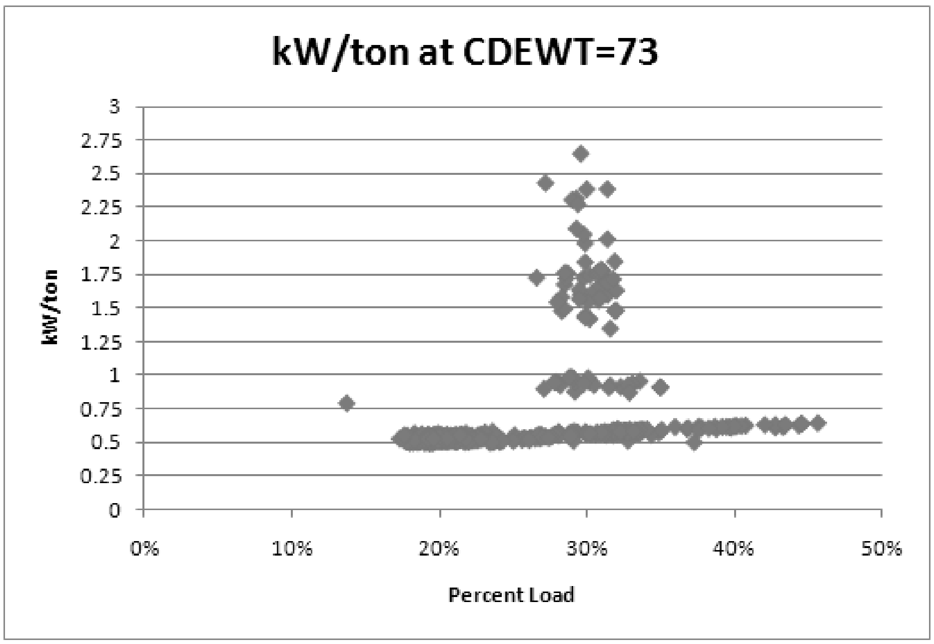
Figure 8-12: Case Study: Hospital #1B

Originally, the 500-ton unit supplied cooling for the summer and the 320-ton unit ran in winter, but, with age and decreases in efficiency, both units had to run to meet the building's summer cooling load. In February 2007, five 100-ton R-22 Turbocor compressors were installed in place of the 500-ton unit. The original 320-ton unit remained in the building as a backup. The five TC compressors ran independently of each other, and each one was separately piped into the evaporator barrel.

At this site, condenser water entering and leaving temperatures were monitored as was condenser flow and outside air temperatures. In addition, one year of trend data were downloaded from the controls system. To calculate chilled water flow, the typical condenser flow of 3 gpm/ton and chilled water flow at 2.4 gpm/ton were applied as a ratio to the flow measured on the condenser. One could assume the condenser water flow rate varied with the number of operating compressors, but when condenser flow was measured with all five compressors running, only those points were considered for this analysis.

It should be noted at this site, all five compressors were running for just less than 50% of the operating hours in the past year, although the chiller ran at a relatively low load. The majority of the time, the system operated at 20-40% load, as seen in Figure 8-13. Efficiency was less than 1 kW/ton, except at a 30% load, as was the case at other condenser entering water temperatures.

Figure 8-13: Hospital #1 Efficiency at 73 Degrees Condenser Entering Water Temperature



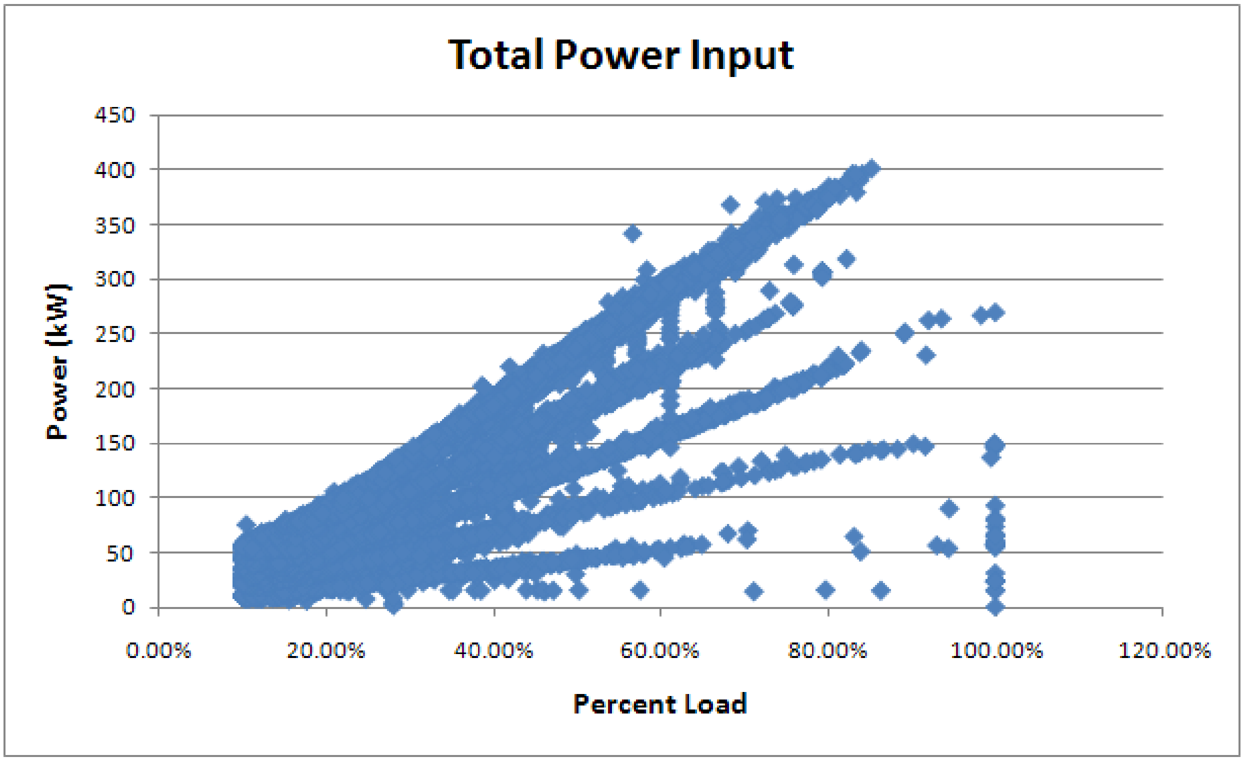
Part load efficiencies with five compressors running were calculated at 25%, 50% and 75% load, as shown in Table 8-20.

Table 8-20: Hospital #1 Part Load Efficiencies

Percent Load	Capacity (tons)	Input Power (kW)	CDEWT (°F)	Efficiency (kW/ton)
25%	168	107	73.4	0.714
50%	302	234	83.9	0.753
75%	399	353	90.9	0.884

Efficiency was slightly better at lower loads, although not as low as Turbocor literature suggested. Again, because this was a retrofit and only the compressor was replaced, it differed from the published performance data that considered only entirely new systems.

Figure 8-14: Total Power Input Versus Percent Load at Hospital #1



The total power versus percent load graph in Figure 8-14 shows each of the five compressors in operation. The system usually ran at a 10-85% load, with power increasing linearly as percent load increased. In this case, it translated into a nearly constant efficiency, as shown in Figure 8-14. The low efficiency at 30% load could be caused by fewer than five compressors running, as seen in Office #1. It may also have been a result of measurement error, as at the lower loads, there is a lower delta T, and typical sensor accuracy results in uncertain delta T measurements at low loads.

8.6.3.7 Case Study: Office #2

The existing chillers in the central plant serving Office #2 had reached the end of their useful life and were not able to adequately serve the system's load during peak cooling requirements. The previous upgrade was in 1988, with the installation of existing chillers and a chilled water thermal energy storage (TES) system providing chilled water to the three nearby buildings. The baseline plant was not energy efficient, and it needed to be upgraded to current technologies. In addition, the baseline McQuay R500 chillers had the following operational issues to be addressed: the chillers were extremely noisy and disrupted functions; they had lost capacity over time; they were consistently cycling off during operation; and they were unreliable. In addition, the control panels on the chillers were obsolete, and repair parts were not available.

Figure 8-15: Case Study: Office #2

During the upgrade, the existing chillers were replaced with two new chillers with Turbocor R-134A compressors. Variable speed drives were installed on the central plant chilled water pumps. Existing chilled water piping was reconfigured to allow for dedicated pumps for each chiller. The plant manager divulged that the site was already planning to install a more efficient chiller system. They waited an extra year to install the new chiller system, to take advantage of the Turbocor technology and program incentive—a clear case of free-ridership.

This site was monitored before the upgrade but not after. No post operation data were available for analysis.

8.6.4 Case Study: DX Sites

The majority of built up systems in the United States are chilled water systems, but, in California, built-up direct expansion (DX) systems account for a high percentage of the built up systems population. Because most of the 26 Turbocor installations through the MAP program were in DX systems, it was important to understand this application. Consequently, the evaluation team applied three different approaches to understanding and quantifying performance at the DX sites.

8.6.4.1 Approach: Pitot Tube Array

In chilled water systems, flow was captured with an ultrasonic flow meter; a comparable tool for the air side was a pressure rake—a custom-built tool measuring air flow and using an array of pitot tubes inserted into the side and top of the duct. These tubes were connected to an averaging chamber and a pressure transducer, and measurements were recorded on a data logger. To ensure accuracy, the tool had to be calibrated both when constructed and again on-site. Because parts such as the pressure transducer and Pitot tube length affected construction, certain site-specific variables had to be known before building this tool:

- Duct dimensions;
- Duct static pressure;
- Supply fan CFM; and
- Number of air handlers: air flow must be measured on each.

Also needed was a minimum length of straight ductwork far enough downstream from the supply fan; so air flow was not turbulent, and constant volume air flow provided more accurate measurements. All DX sites in the sample were contacted and asked for site-specific information needed to build the pitot tube array, but the sites were either variable volume or inaccessible for this approach. Supply fans at these buildings served ducts 4' X 6' or larger, making tool construction more difficult. Turbulence was a concern for one site where the dimensions of the duct increased a few feet down from the supply fan, and this tool was not be applicable at the site that had a common plenum. Other approaches were considered.

8.6.4.2 Approach: Trend Data

One service contractor installed the Turbocor compressors on many of the DX sites. All sites had the original controls system, which stored one-year trend data at 15-minute intervals over a number of relevant points, including: condenser and evaporator entering and leaving temperatures, input power, and chiller demand percent. These controls had a compressor performance map that outputs estimated efficiency and capacity based on inputs, including compressor capacity and temperature set-points. These two programs together could deliver the desired results; therefore, we collected trend data from four DX sites.

A newer controls system was designed to eliminate many known issues and to specifically address performance of a DX system. Measurements were taken at five-second intervals.

These controls took into account the unique configurations of each site, and additional measurements and fine tuning were performed upon installation to accurately calculate capacity and efficiency. This system had been installed at one of the DX sites, but was not yet configured to calculate efficiency and capacity.

8.6.4.3 Approach: Meeting with Multistack's Turbocor Retrofit Division

One company selling chillers with Turbocor compressors agreed to a meeting with three representatives from their retrofit division, who had all previously worked for Turbocor. Although they declined to share the Turbocor selection software, they provided information on the reasons DX performance might not be optimal in these installations:

- The supporting equipment not replaced, such as the condenser, air handler units (AHUs), and evaporator coils, was not as efficient as the new equipment.
- If the Turbocor compressors were R-134A and installed in systems that previously had R-22 refrigerant, the supporting equipment might not be able to accommodate the flow of the new refrigerant.
- All new Turbocor installations used R-134A refrigerant, but all DX installations examined in this project had R-22 refrigerant, and performance data were different. However, R-22 data were no longer available.
- Turbocors operated best with electronic expansion valves (EXVs) because they did not require the pressure differential that thermal expansion valves require, and they could better ratchet down to control capacity. However, not all retrofits included a switch to EXVs.
- A stage-up percentage set point was an entered input that determined how closely the system ran to surge speed or choke speed. Surge speed was ideal for efficiency; it represented the minimum speed at which the compressor operated to meet demand, meaning it took the least amount of power. Choke speed was the opposite and least efficient speed. Efficiency of the system was affected by how close this value was set to 0% (surge speed) or 100% (choke speed).
- Controls are well-suited for chilled water at steady state systems, without large fluctuations in demand.

8.6.4.4 Case Study: Office #3

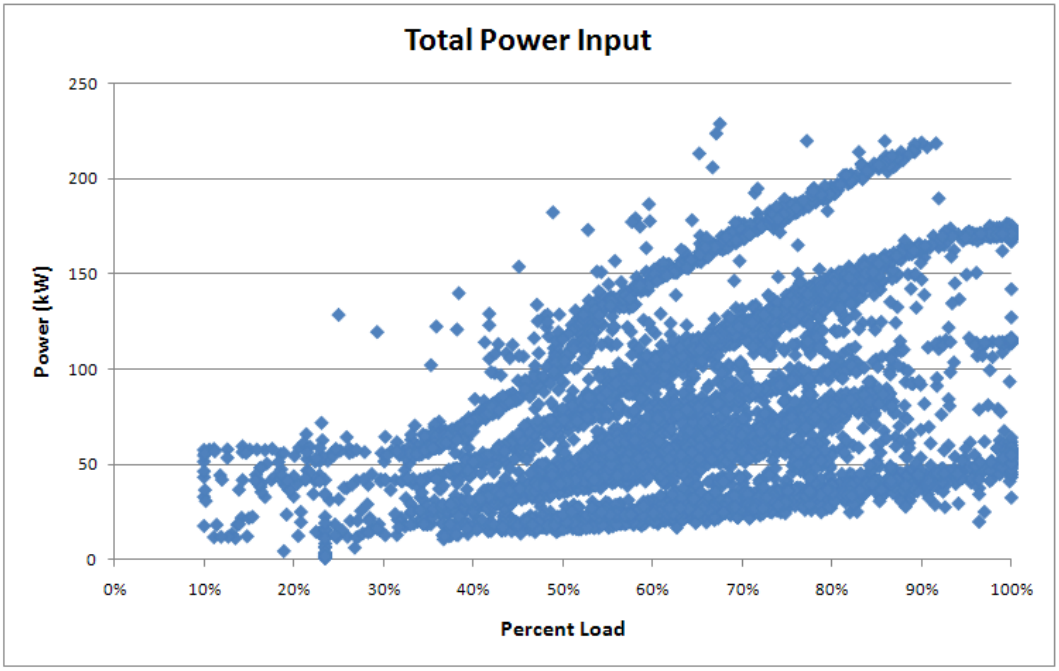
This was a 101,000 square foot office building in climate zone 6, operating Monday through Friday. This system was constant air volume, and the compressors delivered refrigerant to DX coils on a dual duct system. The top coil served the hot duct, and the lower coil served the cold air duct. Baseline equipment was two 150-horsepower motors each attached to one 80-ton and one 75-ton compressor. This configuration was inefficient because the motor constantly ran at full speed, even while only one compressor was operating. In addition, the compressors were more than 20 years old. These factors influenced the owners' decision to install the four 80-ton R-22 Turbocor compressors in October 2007. The only additional change at the time of the Turbocor installation was to restage some of the cooling coils.

Figure 8-16: Case Study: Office #3

At the time of the site visit in late September, the compressors were cycling frequently. Controls were installed and configured so that four compressors were sequenced to start at the same time. Each pair of compressors served one cooling coil face; so at least two compressors had to run to meet the cooling load. During the height of the cooling season, four compressors might be necessary to satisfy the cooling load. .

Significant savings were expected from the VFDs on the compressors modulating compressor speeds. Changing to four individual Turbocor compressors was a considerable improvement over running two 150-HP motors. Additional savings could be achieved by sequencing compressors to start up with one pair first, then running the second pair only if the first could not satisfy the cooling load; so this site was not realizing its full potential.

Figure 8-17: Total Power Input Versus Percent Load at Office #3



Although efficiency could not be calculated because system flow was unknown, it was still possible to gain some understanding of performance from power and percent load. The power graph for this site, shown in Figure 8-17, indicates the system operated from 10-100% load, with the majority of its time above 35% load. The power input was relatively high in the 10-35% load; comparing this to data at the monitored chiller water sites suggested the efficiency in that range was lowest. The difference between this site and the chilled water sites was the distinctions between one, two, three, and four compressors running were not as clear.

8.6.4.5 Case Study: Office #4

This 150,000 square foot office in climate zone 8 typically operated Monday through Friday, with occasional Saturday operation and closure on Sundays.

The baseline equipment was two 150-ton compressors, each serving one supply fan that operated on a VSD. In April 2007, these were replaced with four 70-ton TT300 R-22 Turbocor compressors, with one pair of compressors serving each supply fan. Each pair had its own condenser. In May 2009, contractors upgraded to two new condensers, with VSDs on the fans. The current controls sequence operated one fan at a time and varied the speed to meet the load. If the first supply fan could not meet the load, the second supply fan would run.

Figure 8-18: Case Study: Office #4A

In July 2009, controls were upgraded, but the necessary sensor installation, measurements, and fine-tuning had not been completed; this was planned for fall 2009. Once completed, this system would provide accurate data on system performance.

Figure 8-19: Total Power Input Versus Percent Load at Office #4

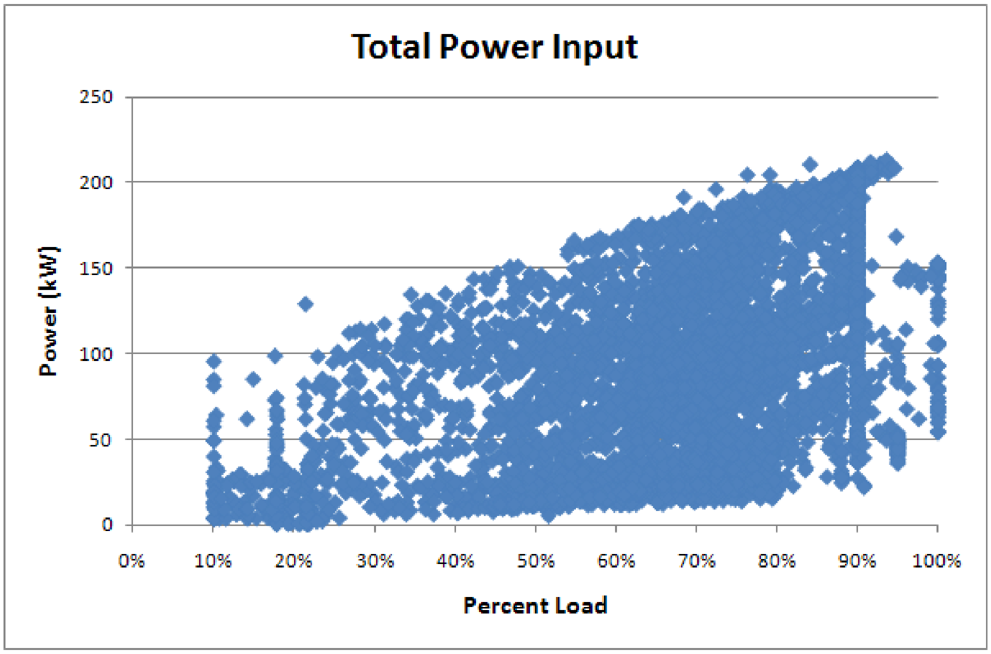


Figure 8-19 is notable because it shows no distinctions between the power profiles of one, two, three, or four compressors, as there were on all previous power graphs. It also shows, even at lower loads, all four compressors were running. This was confirmed in the trend data: there were points at 10% load, with all four units in operation. The power input at 10% load was nearly half of that at a 100% load; efficiency data would likely show poor performance in the 10-30% range. The controls should be examined for improvement opportunities.

Figure 8-20: Case Study: Office #4B

8.6.4.6 Case Study: Office #5

This 150,000 square foot office building in climate zone 8 operated weekdays, with some Saturday and no Sunday operations. This site originally had two 125-ton screw compressors and a 320-ton, oversized cooling tower that was more than 20 years old. This chiller was not able to meet the cooling load, causing discomfort for the occupants. The chiller was a flooded coil system, a large packaged unit with water in the tubes and refrigerant around them. This particular installation was built in the factory and assembled on-site. It could deliver 40 degrees F supply air.

In May 2007, three 100-ton TT300 R-22 Turbocor compressors were installed. At the same time, they installed VSDs on the supply fans, and replaced the overhead steel lines with copper. Although system tonnage increased from 250 to 300, the occupants were comfortable, and the compressors met the cooling load. Participants estimated they used about the same amount of energy with the increased tonnage.

Figure 8-21: Total Power Input Versus Percent Load at Office #5

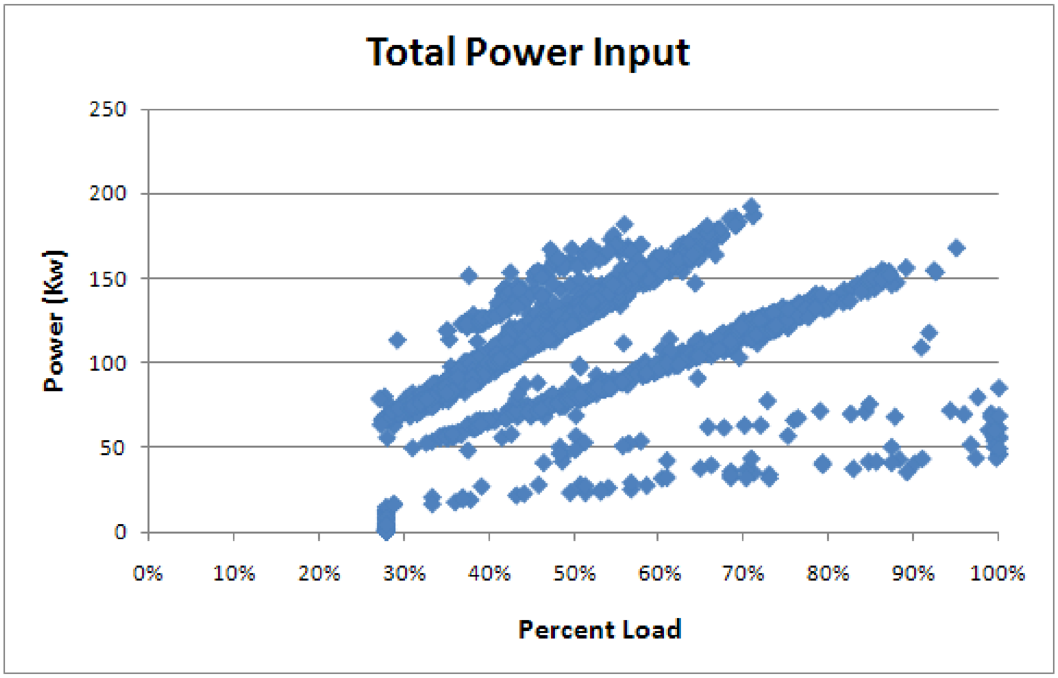
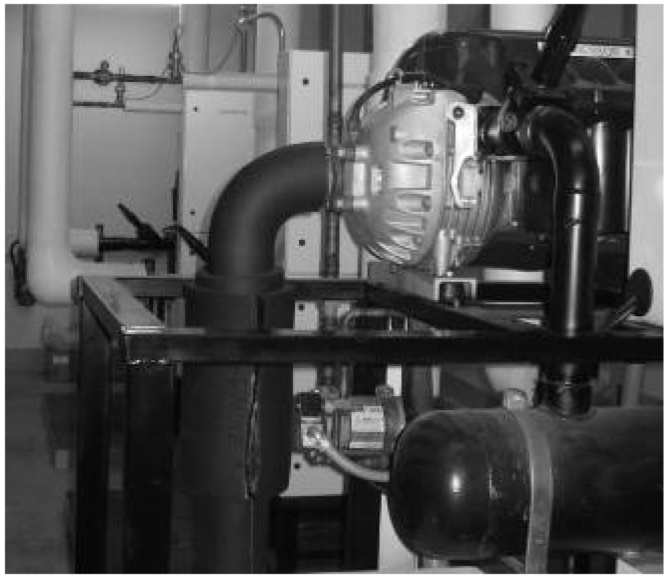


Figure 8-21 shows a unique pattern of operation. The system operated only as low as about 28% load and up to 100% load, but, whereas at other sites each compressor had nearly equal representation above 50% load, this site rarely operated only one compressor. Most of the operation was with two or three compressors. The high power input at lower loads was also not evident in this graph; this site could be operating more efficiently than the others at lower loads.

8.6.4.7 Case Study: Office #6

This 150,000 square foot office building in climate zone 6 operated weekdays and was normally closed on weekends. Baseline equipment was four screw compressors, two at 120 tons and two at 60 tons; the site was retrofitted with two 120-ton and two 70-ton Turbocor compressors. There were three separate circuits, with each of the 120-ton compressors serving one circuit and the two 70-ton compressors serving the third. The first two Turbocors served circuits next to each other; so, when both compressors ran, the second quickly shut off because the air had already been cooled by the first compressor, causing cycling.

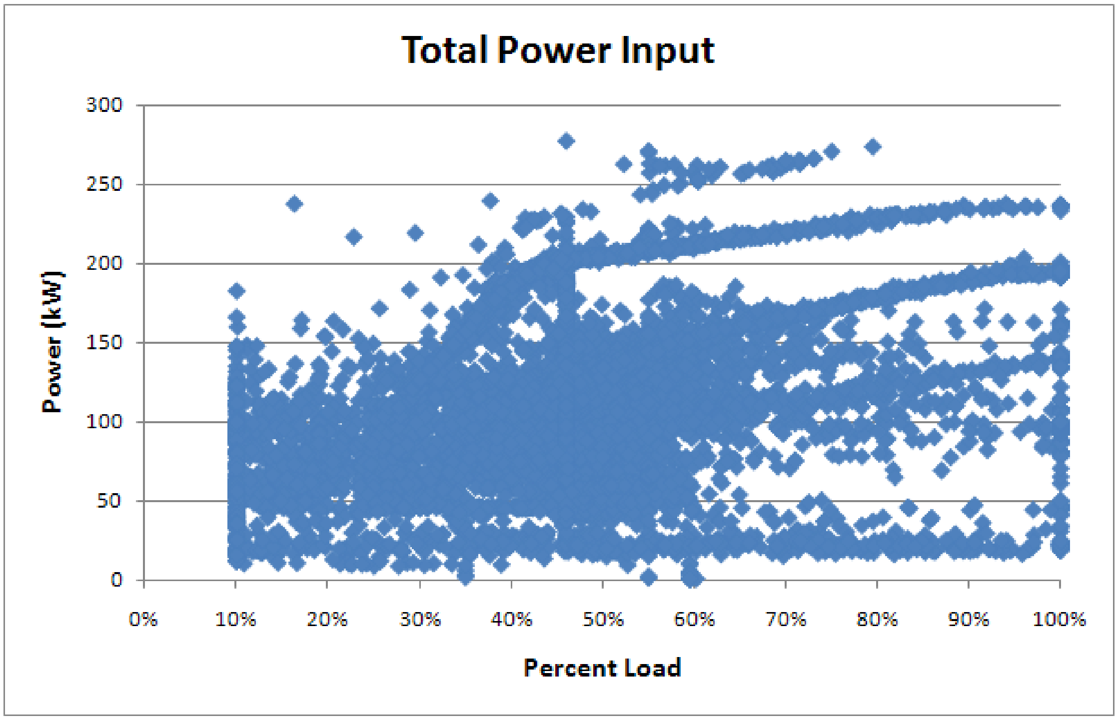
Figure 8-22: Case Study: Office #6



This site has had other operating issues with the new compressors. First, the two 120-ton compressors were not installed with an accumulator, a device that separates gaseous from liquid refrigerant. This caused some refrigerant floodback, which, in turn, created ice build-up on the two compressor caps. In addition, minimum achievable supply air temperature in summer 2009 was 65 degrees, but the facility manager expected this issue to resolve when the TXVs were replaced with EXVs. Finally, the Turbocors took an hour or more to adjust to changes in load, temperatures, or reset values; this was resolved by optimizing control settings.

This site had many examples of issues that can arise when equipment and settings are not optimized upon installation. As this facility manager discovered, Turbocor performance could be improved with supporting equipment, such as the EXVs and accumulators, and controls optimization. These steps should be followed in every retrofit to ensure peak performance.

Figure 8-23: Total Power Input Versus Percent Load at Office #6



The power profile in Figure 8-23 is very similar to that of Figure 8-19, with load ranging from 10-100%, and indistinct differences between one, two, three, and four compressor operations. Most of the time, this system operated at a 30-60% load. Power was especially high at 10%, more than half the maximum power consumption of 270 kW, and efficiencies were likely poor at the low loads.

8.6.5 Discussion of Findings

This study uncovered many variables affecting Turbocor performance, especially in DX systems. When Turbocors were installed as a retrofit with existing equipment, the unknown efficiencies in this equipment affected overall system performance. In addition, some changes, such as the electronic expansion valves (EXVs), were technically optional, but they affected performance, as experienced at Office #6.

Turbocor DX retrofits should be configured to maximize efficiency. The controls can be optimized by sequencing the compressors to run at their optimal part load settings. In addition, inputs such as the stage-up percent should be set to operate the compressors close to the surge speed. TXVs should be replaced by EXVs that do not require the pressure differential and can control capacity. In future retrofits, coils should be checked to make sure they can accommodate the change from R-22 to R-134A refrigerant.

Participants discussed non-energy benefits of Turbocor compressors, including:

- Compressors weighed 250 pounds, so no crane was needed to install them.
- No oil leaks as they were oil-free.
- Less maintenance as they were oil-free.
- Permanent magnet for shaft speed with a 2/1000" clearance:
    - Since there was no friction, all energy used to run the compressor translated into work, with no losses.
- Inlet guide vanes were included in the setup:
    - The TC had an internal control to modulate the inlet vanes.
- Less noise and disruption for tenants, meaning building owners could rent spaces (top floors) more readily.

8.6.6 M&V Lessons Learned

This research uncovered much information about Turbocor compressors and provided a deeper understanding of performance. The unique installations and configurations at each site significantly affected the efficiency of the system. To fully understand this equipment, further study is needed. Often, the only equipment change made during a retrofit was the compressor. Because of the supporting equipment inefficiencies, a Title 24 comparison to new equipment is not valid. Instead, pre- and post-installation monitoring would provide a way to quantify the difference in performance for this new equipment.[32] P Efficiency at DX sites may be quantified via the upgraded controls, and getting these data could be a low-cost way to quantify Turbocor efficiency in this application.[33] Although not in the MAP program, currently five SCE sites have new controls configured, and one site in the MAP program has the controls and plans to install

[32] Because most TCs were installed in the winter, monitoring for almost a year would be needed to capture baseline and post-installation operation in the summers before and after installation. Baseline data were collected at one site, but despite repeated follow up, BAS trend data could not be collected from the on-site contact.

33 All sites visited had the old Kiltech controls. The only site in the MAP program that had MagLev was not configured to measure efficiency and capacity.

additional sensors to measure efficiency and capacity. Further research into these areas will provide the performance information.

To quantify the savings ex post, additional analysis and data collection is needed. The IOU claimed net-to-gross ratio is 80. No net-to-gross surveys were conducted; evaluators accept the IOU claimed savings and NTG ratio.

Table 8-21: Turbocor Energy Savings Summary

Program Name	Measure Ex-ante Gross kWh Savings	Measure Ex-post Gross kWh Savings	Install Rate	Measure Installed Ex-post Gross kWh Savings	Measure NTG	Measure Ex-post Net kWh Savings
MAP SCE 2537 Turbocor	7,019,603	7,019,603	100%	7,019,603	.80	5,615,682

Table 8-22: Turbocor Demand Savings Summary

Program Name	Measure Ex-ante Gross kW Savings	Measure Ex-post Gross kW Savings	Install Rate	Measure Installed Ex-post Gross kW Savings	Measure NTG	Measure Ex-post Net kW Savings
MAP SCE 2537 Turbocor	2,369	2,369	100%	2,369	.80	1895.20

9. Energy Efficiency Program for Entertainment Centers

9.1 Program Description

The Energy Efficiency Program for Entertainment Centers (SCE 2561) was part of SCE's 2007-2008 Innovative Designs for Energy Efficiency Activities (IDEEA) Portfolio, which focused on different marketing or delivery methods, different market segments, and/or new and emerging technologies not typically offered in the SCE portfolio. Cooling savings were the sole focus of the program at its onset, but, because demand-based, preprogrammed ventilation controls (DCVs) allows for significant savings in heating months as well, the program became a joint effort with Southern California Gas.

The Energy Efficiency Program for Entertainment Centers was designed to reduce movie theaters' heating and cooling loads in low use or no use theater units (screening rooms). Cooling and heating loads inside a movie theater come from two primary sources: occupancy and fresh outdoor air intake to satisfy the need for fresh air, as required by code in a room designed for full capacity. During sparsely attended early shows on hot weekday afternoons, the few people present contribute very little heat gain to the room; however, the ventilation systems are typically set to provide fresh air at one of two levels, either a high minimum level (typically 50% to 60% outside air), or at full capacity, flooding the theater with hot afternoon air, which then needs to be cooled. Unused screening rooms are often cooled and ventilated even though they are unoccupied because it is simpler to opt for a regular cooling schedule for the entire season rather than change cooling settings every week. During summer, this excess ventilation occurs during hot weather, when electricity demand is at its peak.

To decrease such demand on the system, the program offered a cleaning service for condenser and evaporator coils, and DCVs installed on a customer's existing HVAC units.

Table 9-1: Program Specific Evaluations

	Verification	*Gross Savings*			*Net Savings*	
Evaluation Methods →	*Surveys, on-site Audits*	*Billing Analysis*	*On-site M&V*	*Additional*	*Participant Self Report*	*[Add as necessary]*
	Installation Rates				NTG Ratio	
Energy Efficiency for Entertainment Centers	On-site metering, surveys	None	OAT, SAT, MAT, RAT, total unit kW, fan kW, CO2 voltage		NTG survey with all decision makers	

Parameters metered included outside air temperature (OAT), supply air temperature (SAT), mixed air temperature (MAT), return air temperature (RAT), along with total unit W, fan power (kW), and CO_2 sensor voltage.

9.2 Key Program Elements

DCV applications conserve energy by admitting lower quantities of outside air when the air is unnecessary. Typically, a unit may have its minimum outside air set too high to serve occupancy for partially occupied periods. With an active CO_2 sensor controlling the outside air damper, the outside air minimum can be lower, and will be increased only when justified by CO_2 sensor readings. The economizer's role is to allow an abrupt increase in outside air quantity only as necessary when driven by occupancy or favorable outside air temperatures, allowing much lower volumes of outside air to be admitted at other times.

DCV controls use the amount of CO_2 present in the return air as a proxy for the number of occupants in a room, adjusting the flow of fresh, outside air (which needs cooling) into the room to provide an adequate amount of code-specified ventilation per occupant. In theory, the units also demand less energy on hot summer days, reducing their contribution to the California's system peak.

The program provided a financial incentive to a third-party implementer for installation of each controller; this incentive was used to buy down total equipment and installation costs. The program initially required a $300 customer co-payment to the implementer for every modified HVAC unit, but because there were also potential gas savings, Southern California Gas (SCG) became a co-funder to the project, and subsidized $150 of the $300 initially required from the customer. SCG claimed the gas savings achieved.

The program fielded with the two utility sponsors late October 2007. The original program plan was limited to theaters in climate zones 6, 8, 9, and 10. During the first quarter of 2008, given the late start and low program participation, the program expanded to include customers in climate zones 13, 14, 15, and 16. It also allowed heat pump retrofits.

9.3 Evaluation Objectives

9.3.1 Measure Description

The controls allow fully-integrated economizer capability based on occupancy data, which are estimated using temperature and CO_2 sensors. The California Energy Commission included demand-based ventilation controls in the 2006 Title 24 requirements for spaces with single-zone HVAC systems and an occupant density of 25 people/ 1,000 sq. ft. or higher. This program used the technology in a retrofit application in theater multiplexes, most of which were built within the last 20 years, but prior to the new Title 24 efficiency requirements.

9.3.2 Estimated Parameters

This measure does not exist in the DEER database. Implementers researched the impacts of DCV installation and coil and evaporator cleaning for movie theater rooftop units (RTUs), and presented their results in work papers. Implementers looked at both air conditioners and heat pumps and based market potential estimates on an ASHRAE Journal article from February 2001, which discussed the increase in use of CO_2 demand control ventilation. Ex ante energy savings estimates were calculated using DOE-2 simulation runs, with the base case entered as a packaged, single-zone RTU, where outside air dampers were open to 50% for ventilation to the space.[34]

The standard unit for DCV measures is per ton of installed cooling. The ex-post results estimated the UES and measured load shape for DCV. The ex-ante NTG for the program used by implementers had the default value of 0.80. The ex-post estimated NTG for this program was developed using a consistent method approved by the NTG working group.

[34] Matrix ESI workpaper, WPMSCEDCVHP0708, p8-9.

9.3.3 Overview of Evaluation Objectives

The DCV evaluation objective was to determine whether installing DCV controls and cleaning coils led to energy savings during peak periods for unoccupied theaters. When occupancy was zero, there was no need to provide ventilation to the room. Relevant parameters were monitored before and after servicing to assess the effect of DCV controls.

9.3.3.1 Pre Measure Application System Performance Data

All RTUs were monitored without DCV controls. Implementers installed DCV controls and cleaned coils on all 31 RTUs in their sample after at least two weeks of baseline monitoring. The Specialized Commercial CG Evaluation Team monitored eight of 12 RTUs during the true baseline case, when the RTUs had not yet been serviced. A third, additional site was later added to capture the effect of DCV controls in the desert climate. The four RTUs at this site were monitored one year after CO2 controls had been installed and coils cleaned. For these units, CO2 controls were disabled to simulate the baseline case and enabled for the post-installation case. No additional coil cleaning was performed at this site during the evaluation monitoring period.

9.3.3.2 Weather Dependence

This study focused on the effect of installing DCV controls on existing RTUs to reduce demand during peak summer cooling hours. So, all RTUs were monitored during the cooling season. As expected for weather-dependent HVAC measures, the primary driver of expected savings on a per unit basis was the CEC climate zone, as defined by DEER and Title 24. The saving amounts vary by climate zone; weather data for each monitored zone were applied in the analysis.

9.4 Methodology

9.4.1 Methods Used in this EM&V Activity

9.4.1.1 Description of the Study Methodology

The Specialized Commercial CG Evaluation Team monitored 12 units at three different multiplex theater complexes. In addition, Implementers monitored 19 RTUs in the fall of 2008. The analyses were conducted with these two sets of data, for a total of 31 packaged air conditioning units (RTUs).

Field activities were designed to:

1) Verify baseline conditions and assumptions.
2) Verify measure installations.
3) Verify energy savings assumptions.
4) Correlate installation reports with participant interviews.

9.4.1.2 Sample Sizes for DCV EM&V

This project had a Basic rigor level for energy, demand, and NTG. Basic rigor for energy and demand required a sample size consistent with 90% confidence levels and 30% precision. For a total of 632 planned installations, 90/30 required a sample size of seven. However, because ex-ante savings estimated in the Program Implementation Plan differed for the four climate zones in SCE's service territory, the evaluation included a metered sample size of 12 to provide sample points in the major climate zones. Basic levels of rigor for NTG relied on participant self-reporting with a census of participants. Free-ridership was estimated using the approved Joint Simple SR NTG Method, including surveys with all participants included in SCE's reporting database.

Table 9-2: Rigor Levels for Energy Efficiency Program for Entertainment Centers

Evaluation Component	CPUC-Stipulated*	Revised
Energy	Basic	Basic
Demand	Basic	Basic
Net-to-Gross	Basic	Basic
*California Energy Efficiency Programs for 06-08_Final.xls		

The original evaluation plan included a sample of eight units, but expanded to 12 to include sites in three climate zones (including the desert).

Only services performed and DCV hardware installed by December 31, 2008, (up to 632 installations) were eligible for an incentive under SCE's Energy Efficiency Program for Entertainment Centers. Records for all equipment rebated under the program during the 2006–2008 program cycle were stored in SCE's program tracking database, known as SMART (Subcontractor Management And Reporting Tool). Records in the participant database were used to calculate claimed savings for the Energy Efficiency Program for Entertainment Centers for the 2006–2008 program cycle. It is important to note, however, not all records in the SMART database contributed to 2006–2008 claimed savings for this program. Savings claimed under the 2006–2008 program cycle included only records where invoicing had cleared SCE's accounting system by March 24, 2009. These records were aggregated into a database containing, in a unified format, program participant data from all California investor-owned utilities' energy-efficiency programs. Because of the cutoff date for inclusion into the reporting database, some equipment recorded in SMART was installed during the 2006–2008 program cycle but not included in the utility tracking database. (Savings for these records would be claimed as part of the 2009 bridge funding period.)

The time involved in contract negotiations between sponsoring utilities delayed the program start, and it was not fielded until October 2007. In addition, many months were needed to market the program to a large cinema chain, expected to ensure many installations for the program. Therefore, most program installations occurred toward the end of the program period, during the late summer and early autumn of 2008. At this same time, SCE implemented new accounting software, and clearing program invoices through the new accounting system presented challenges. Because of these mitigating factors, many services provided and measures installed under the program were not included in the utility's tracking database, and therefore, did not contribute toward the 2006–2008 kWh and kW claimed savings.

Since most installations for this program occurred in the late summer and early autumn of 2008, the window for collecting metered data for this program was very narrow. The Specialized Commercial CG Evaluation Team worked closely with the program implementer to identify sites at which on-site, metered data could be collected. These data were collected at two sites during September and October 2008. Unfortunately, both sites were not included in the final tracking database. The Specialized Commercial CG Evaluation Team conducted on-site metering at an additional site during August through September 2009 to collect data from Climate Zone 15. This site was included in the tracking database.

9.4.1.3 On-site Data Collection

The following RTU nameplate data were collected during the initial site visit: RTU manufacturer, model and serial number, compressor voltage/amps, and evaporator and condenser fan quantity/phase/HP/voltage/rated amps. Instantaneous site measurements included: supply fan power, total RTU power CO_2 voltage, and air flow. Air flow was measured with TrueFlow plates.

The following parameters were logged for four to six weeks post-installation: return, supply mixed and outside air temperatures and RH, differential pressure, CO_2 voltage and supply fan, and total RTU power. Seasonal variations on both the load profile and operating hours of the RTU were accounted for in the analysis.

Table 9-3 indicates data collected by the Specialized Commercial CG Evaluation Team, with the quantity, meter device, and model. All measurements were taken at the same time interval on each RTU. The majority of RTUs were monitored in five-minute intervals, and a small percentage was monitored in 15-minute intervals. Units were monitored for at least two weeks without a CO_2 sensor and two weeks with a CO_2 sensor. Collected data were intended to provide information required to independently estimate ex-post savings resulting from coil cleaning and installation of DCV controls.

Table 9-3: Entertainment Center Demand Controlled Ventilation: Logged Measurements at Each Unit

Qty	Parameter	Metering Equipment	Units	Accuracy	Interval
1	Return air temp, RH	Onset S-THB-M008 temp/RH sensor	°F, RH	Temp: 0.36°F over 32° to 122°F RH: +/- 2.5% from 10% to 90% RH	5 or 15 mins
1	Supply air temp, RH	Onset S-THB-M008 temp/RH sensor	°F, RH	Temp: 0.36°F over 32° to 122°F RH: +/- 2.5% from 10% to 90% RH	5 or 15 mins
3	Mixed air temp, RH	Onset S-THB-M008 temp/RH sensor	°F, RH	Temp: 0.36°F over 32° to 122°F, RH: +/- 2.5% from 10% to 90% RH	5 or 15 mins
1	Total unit power	Onset S-UCC-M006 pulse input adapter with WattNode and CTs	kW	Onset: 45 μs +/- 10%; CT: ±1% of rated current	5 or 15 mins
1	Outside air temp, RH	Onset HOBO H21-002 Micro Station Data Logger w/ S-THB-M002 Temp/RH Sensor and RS3 Solar Radiation Shield	°F, RH	Temp: 0.36°F over 32° to 122°F RH: +/- 2.5% from 10% to 90% RH	5 or 15 mins
1	Supply fan power	Onset S-UCC-M006 pulse input adapter with WattNode and CTs	kW	Onset: 45 μs +/- 10% CT: ±1% of rated current	5 or 15 mins
2	kWh transducer (supply fan & total unit)	Continental Control Systems WattNode T-WNB-3D-480*	N/A	±0.5% of reading	5 or 15 mins
1	Unit air pressure differential	Setra T-SET-265-005 pressure differential transducer**	0-5" WC	±1% accuracy	5 or 15 mins
1	CO2 control input signal	U30-VIA CO2 sensor (from Implementers)	0-5 vDC		5 or 15 mins

* 24 voltage probe sets for WattNode devices (3 phase) - 2 sets / RTU

** 18 AWG shielded 3-conductor cable for pressure differential transducer - 1 / RTU

SCE required the implementer to conduct short-term monitoring of 10% of the DCV installations, recording measurements for a minimum of one week pre- and post-installation. Measurements included: return air temperature, outdoor air temperature, supply air temperature, mixed air temperature, CO2 level, and compressor and fan operation.

9.4.1.4 NTG Data Collection

Evaluators used a jointly defined, consistent, self-report NTG method for the DCV measures. This approach to measuring participant spillover and free-ridership was jointly developed by the NTG Working Group, consisting of Energy Division its technical consultants and evaluators.. Use of this common method helped to ensure uniformity in evaluation techniques across programs and contractors, and provided greater transparency and reliability. We refer to this as the Joint Simple SR NTG Method. The NTG Method prescribed a set of questions and scoring procedures. The intent of the Joint Simple SR NTG Method was to ensure a common set of questions, interview protocols, and scoring procedures was used. However, some questions were tailored for particular programs and/or measures to make the questions better understood by respondents as a way to ensure complete, reliable, and accurate responses. A dual-path survey was utilized for HVAC measures that initially asked about program awareness and influence questions to determine whether a customer or contractor/vendor path should be pursued.

Measures included in the HVAC program cluster utilized a modified version of the Joint NTG Method to provide consistent questions to end-use customers, where applicable. The program deliveries allowed flexibility to the contractor in terms of marketing and incentive, which evolved over the course of the program. This required a method that supplemented the participant self-report surveys with an interview with the contractor that installed the DCV through this program.

9.4.2 Reference and Background for the Methods Applied

This program claimed energy savings from two measures: coil cleaning and the installation of DCVs. To assess gross energy impacts from coil cleaning, the evaluation relied on secondary research and an examination of the work papers submitted by the third-party implementer.

SCE-required records of pre-installation existing equipment and work papers were requested and reviewed to establish baseline energy and demand consumption for the HVAC units prior to DCV retrofit and coil cleaning.

To assess gross energy impacts associated with the installation of DCVs, the Specialized Commercial CG Evaluation Team used an approach consistent with Enhanced rigor levels, per the IPMVP Option D, unit-specific calibrated engineering model, using data collected from short-term monitoring conducted both by the implementer and the evaluators. IPMVP Option D whole building analysis was not employed as the whole building data applied to many other end uses in addition to cooling.

The unit-specific, calibrated engineering model utilized data from sampled units, which were monitored for two to three weeks before and after installation of the DCV CO_2 sensors, during periods of low theatre use and peak demand periods. This evaluation measured: return air temperature, outdoor air temperature, supply air temperature, mixed air temperature, and CO_2 levels. Empirical measurements of the outside air fraction were taken via mixed air, outside air, and return air temperatures. Metered data were used to create an hourly model and estimate annual savings using a temperature bin data to extrapolate to total annual energy.

Gross demand was assessed using the same actual pre-installation and post-installation measured usage collected in the short-term monitoring of the 12 treated HVAC units.

The Specialized Commercial CG Evaluation Team reviewed the implementer's work papers on DCV controls for AC units, DCV controls for heat pumps and condenser, and evaporator coil cleaning. They presented two ex-ante savings approaches: one for the DCV and another for the evaporator and condenser coil cleaning measure.

Implementers based the ex-ante savings for DCV controls on DOE-2 runs for a typical theater in each of the climate zones. Peak demand savings were calculated in each climate zone, based on savings from 2:00 to 5:00 PM, during the hottest three consecutive weekdays found in the California weather data. All savings were presented on a per unit basis, and they assumed an equal distribution over climate zones and RTU capacity in the existing population. This methodology was used to calculate ex-ante savings for heat pumps and gas/electric RTUs.

For condenser and evaporator coils, Implementers conducted a laboratory test to determine operating parameters for the baseline and retrofit RTUs before and after coil cleaning. They combined these results with DEER building types and input them into eQuest for analysis. Savings were weighted with California CEUS data. These results were compared to the DEER values for condenser coil cleaning, but, as there were no data on the combined effect of cleaning both evaporator and condenser coils, Implementers could not make a direct correlation. Rather, they compared results to ensure theirs were within reason.

9.4.2.1 Savings Algorithm

For this evaluation, the Specialized Commercial CG Evaluation Team extrapolated annual savings using California climate zone Typical Meteorological Year (TMY) data and a histogram of temperature bins, using the baseline and post-installation monitored data. The first step was to aggregate the monitored data from the five- or 15- minute intervals into hourly averages and/or sums. Hourly averages were calculated for:

- Outside air temperature
- Supply, mixed, and return air temperature
- Total unit power
- CO2 concentration in parts per million (ppm)

In addition to the hourly averages, hourly maximum power was identified. This hourly information was then worked into an energy signature that plotted the daily average kWh against temperature. A horizontal line was used to represent fan energy, and a linear equation was used to fit the second, sloped line to the data points. For sites where there were distinct differences in energy usage based on full, partial, and unoccupied states, the line was fitted to each of these three sets of points, and weighted according to the number of days in each state during the monitored period.

Taking the number of days in each temperature bin from the TMY data and the energy use in kWh/day from the analysis, the number of days in each bin times the energy use for each bin were multiplied using the baseline and post-servicing data.

For each temperature bin:

$$AnnualEnergyUse = \#\,BinDays \times EnergyUse\left[\frac{kWh}{day}\right]$$

Totals were summed for each bin to get the annual energy use for all temperatures. From this, annual savings were calculated:

$$AnnualSavings\left[\frac{kWh}{yr}\right] = AnnualBaselineEnergy\left[\frac{kWh}{yr}\right] - AnnualPostEnergy\left[\frac{kWh}{yr}\right]$$

9.4.3 Sampling Methodology

9.4.3.1 Sample Descriptions

For the Energy Efficiency Program for Entertainment Centers, a participant was defined not as one DCV installation, but rather as the decision maker for a theater or theater chain, responsible for making the decision to participate. Although there were 382 HVAC units retrofitted with DCV equipment for which savings were claimed under the 2006–2008 program period, there were only eight actual participants (or theater decision makers). There were additional participants reported in the 2006-2008 SMART reporting database, and some were not included in the final tracking database for accounting reasons. Four participants included in the SMART database (but not the final tracking database) were included in the metered sample. Therefore, 12 participant decision makers were included in the population.

Table 9-4: IOU Claimed Demand Control Ventilation Installations and Savings

Site	City	Number of RTU serviced	Climate zone	Ex-ante Gross kWh savings	Ex-ante Gross kW Savings	Ex-ante NTG	Ex-ante Net kWh Savings
1	South Gate	33	8	171,875	113	0.9	154,688
2	Rialto	4	10	22,748	8	0.9	20,473
3	Lake Elsinore	18	10	100,426	24	0.9	90,383
4	Camarillo	4	6	19,298	22	0.9	17,368
5	Cathedral City	15	15	200,789	99	0.9	180,710
6	Oxnard	4	6	16,194	11	0.9	14,575
7	Huntington Park	4	8	30,916	16	0.9	27,824
8	Santa Ana	5	8	14,055	7	0.9	12,650
9	Santa Ana	9	8	80,665	43	0.9	72,599
10	Garden Grove	29	8	170,711	107	0.9	153,640
11	Temecula	12	10	68,530	25	0.9	61,677
12	Fontana	13	10	82,460	30	0.9	74,214
	Total	150		978,667	505		880,801

Cadmus monitored 12 RTUs: four per site in three climate zones. Implementers monitored 18 RTUs, three to four per site in four climate zones. All 30 RTUs were manufactured by Trane. The following tables summarize the sample characteristics.

Table 9-5: Evaluator's Sample Characterization

RTU#	Climate Zone	Capacity	Age	Type
HP1_09	15	15	11	Heat pump
HP2_09	15	15	11	Heat pump
HP3_09	15	12.5	11	Heat pump
HP4_09	15	6	11	Heat pump
GP1	8	8.5	13	Electric cooling/gas heat
GP2	8	10	13	Electric cooling/gas heat
GP3	8	13	13	Electric cooling/gas heat
GP4	8	15	13	Electric cooling/gas heat
GP5	9	9	13	Electric cooling/gas heat
GP6	9	12.5	13	Electric cooling/gas heat
GP7	9	8.5	13	Electric cooling/gas heat
GP8	9	15	13	Electric cooling/gas heat

Table 9-6: Implementer's Sample Characterization

RTU#	Climate Zone	Capacity	Age	Type
HP2_08	15	15	11	Heat pump
HP3_08	15	12.5	11	Heat pump
HP5_08	15	10	11	Heat pump
GP9	10	8.5	11	Electric cooling/gas heat
GP10	10	17.5	11	Electric cooling/gas heat
GP11	10	17.5	11	Electric cooling/gas heat
GP12	8	15	13	Electric cooling/gas heat
GP13	8	12.5	13	Electric cooling/gas heat
GP14	8	10	13	Electric cooling/gas heat
GP15	8	12.5	13	Electric cooling/gas heat
GP16	10	15	10	Electric cooling/gas heat
GP17	10	12.5	10	Electric cooling/gas heat
GP18	10	15	10	Electric cooling/gas heat
GP19	10	25	10	Electric cooling/gas heat
GP20	9	8.5	13	Electric cooling/gas heat
GP21	9	10	13	Electric cooling/gas heat
GP22	9	8.5	13	Electric cooling/gas heat
GP23	9	10	13	Electric cooling/gas heat

9.4.4 Sources of Baseline Data

The evaluators requested raw data from SCE for the sites Implementers monitored. In addition, this evaluation conducted similar, short-term monitoring of 12 DCV installations, collecting measurements of the same data points. The monitored pre-installation data from both SCE and the evaluation were compared and were used to establish baseline usage.

9.5 Confidence and Precision of Key Findings

9.5.1 Planned Confidence and Precision

The overall verification and net savings sampling strategy was to first achieve 30% precision at the 90% confidence level. This sample called for metering seven units. As expected for weather-dependent HVAC measures, the primary driver of expected savings on a per unit basis was the CEC climate zone, as defined by DEER and Title 24.

As there were only eight decision makers for the 382 RTU retrofitted with DCV controls, NTG surveys were planned for each decision maker. Only one contractor installed the DCV for this program; we worked closely with the implementer to schedule monitored sites.

9.5.2 Achieved Confidence and Precision

The 90/30 requirements were exceeded by monitoring 12 units (about 90/23). In addition, we analyzed monitored data collected by implementers. Altogether, 30 RTUs were monitored and analyzed, increasing the precision to about 14% at the 90% confidence level.

The sampling plan and achieved sample are shown in Table 9-7.

Table 9-7: Metering Sample Plan and Achieved Sample

	Coastal Climate Zone	Inland Climate Zone	Desert Climate Zone
Stratum	1	2	3
Climate Zone	6	8, 9, 10	15
Number of Units Retrofitted	8	130	15
Number of Units Metered	0	8	4

Evaluators succeeded in contacting five decision makers to conduct the NTG survey. One decision maker refused to participate in the survey, and four NTG surveys were successfully completed for achieved confidence of 90% and precision of 30%.

9.6 Validity and Reliability

9.6.1 Measurement and Calculated Uncertainty of System Efficiency

Uncertainty analysis was conducted to increase the reliability of the results by reducing random measurement error and by identifying and mitigating potential sources of systematic bias. The evaluators explored the uncertainties related to using the current instrumentation suite and some form of these approaches to estimate instantaneous system performance. A monitoring plan was also developed to record required parameters and estimate system performance over varying operating conditions. We worked with program management and their contractors to pursue pre-post monitoring of sites receiving DCV controls in conjunction with RTU servicing through the program. The goal was to record data for 12 RTUs, and we were able to meet this number. The final four RTUs had already been serviced through the program, and baseline conditions were simulated by removing the CO_2 DCV controls.

9.6.2 Procedures to Minimize Non-response Bias

Non-response bias occurs when investigators are unable to conduct data collection on a unit selected for the sample. Such non-response bias could affect telephone surveys, site visit recruiting, and on-site data collection efforts.

The Specialized Commercial CG Evaluation Team took rigorous approaches to minimize non-response bias for each data collection mode. For example, in telephone surveys for this program, senior staff conducted the survey. Further:

- Extensively training and monitoring interviewers ensured they used effective introductions, followed professional survey research techniques, and used rapport-building techniques to keep respondents on the phone.
- For all site visits, the evaluation team worked closely with the implementer to select sites for metering, worked with the theatre staff for access to RTU, and worked with the implementer to meter the RTU.

Technicians used a data collection form to consistently collect data at each site. Data items not collected during installation were flagged for collection at meter pick-up.

In some cases, on-site sampling of multiple units was employed and used accepted randomization techniques. Technical leads placed limits on the maximum number of units to be sampled per site to avoid “convenience sampling” by technicians and engineers. Issues were called in to project managers to determine if there were technical feasibility issues with units selected through the randomization process to ensure only units not capable of following the M&V plan or out of scope were “skipped” by field workers.

9.7 Detailed Findings

In the summers of 2008 and 2009, Cadmus and Implementers monitored a total of 31 RTUs at five sites, for a minimum of two weeks before and after DCV controls were installed and coils cleaned; economizer repair was also performed as needed. Some of the units were not included in this total, for the reasons detailed in the table below.

Table 9-8: Disposition Table of Evaluated RTUs

Cause	Frequency
No power measurements; could not analyze.	1
Highly negative savings; causes unknown but appear to be faulty measurements. After one point, all counts for the fan and total unit doubled, causing calculated fan kW to increase from 450 W to 4500 W. Data were discarded.	1
Site monitored twice, in 2008 for three units during initial DCV controls installation, and again in 2009 for four units when the baseline was simulated by disabling DCV controls. Because these four RTUs monitored in 2009 did not start at the same baseline as the other units, and they did not receive the servicing performed on all other units at the time of DCV controls installation, they are discussed as a separate case.	4
Less than 10 days of pre- or post-measurements and energy signature were not clear.	1
Total Units Analyzed	**24**

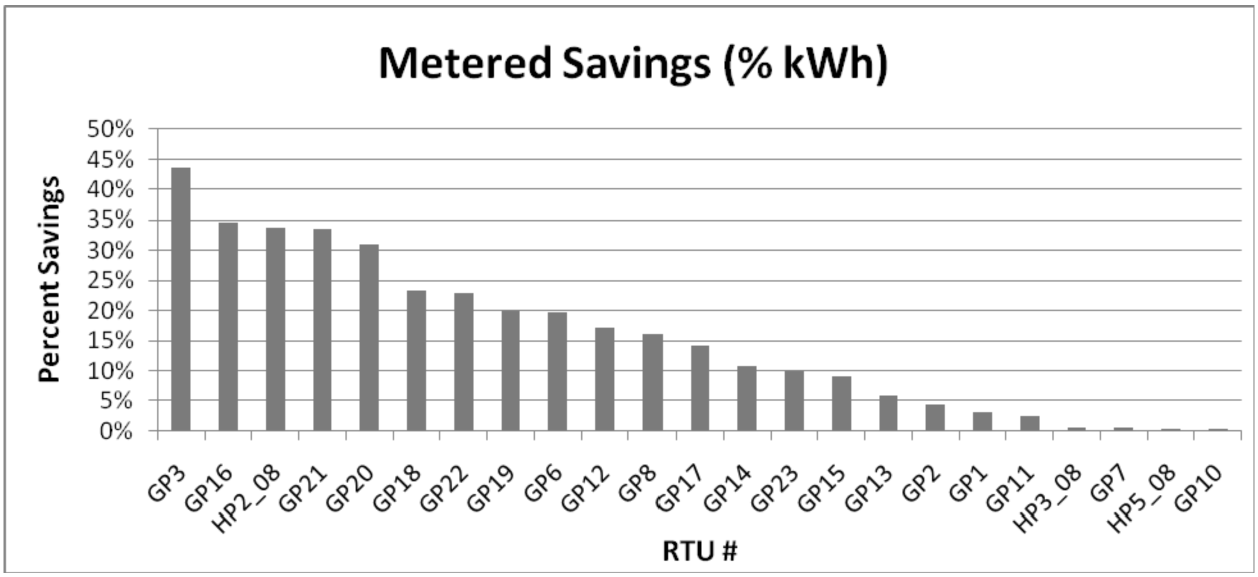
Evaluated energy savings for the remaining 24 RTUs are summarized in Table 9-9, in descending order by evaluated percent savings. Savings are shown on a per unit basis and per nominal ton of cooling. Heat pumps and electric cooling/gas heating units are identified in the RTU name as HP and GP, respectively.

Table 9-9: Summary of Savings for 24 Analyzed RTUs

RTU #	Metered By	Climate Zone	Metered Savings (% kWh)	Metered peak demand reduction kW	Metered Savings (kWh)	Tons	Metered Savings/Ton
GP3	Cadmus	8	44%	1.80	7,562	12.5	605
GP16	Implementers	10	35%	2.13	2,681	15	179
HP2_08	Implementers	15	34%	7.11	19,186	15	1,279
GP21	Implementers	9	33%	0.11	6,011	10	601
GP20	Implementers	9	31%	0.64	3,459	8.5	407
GP18	Implementers	10	23%	4.71	3,405	15	227
GP22	Implementers	9	23%	1.16	3,194	8.5	376
GP19	Implementers	10	20%	8.37	17,342	25	694
GP2	Cadmus	8	19%	1.09	2,828	10	283
GP12	Implementers	8	17%	4.27	8,551	15	570
GP9	Implementers	10	17%	1.12	14,368	8.5	1,690

RTU #	Metered By	Climate Zone	Metered Savings (% kWh)	Metered peak demand reduction kW	Metered Savings (kWh)	Tons	Metered Savings/Ton
GP8	Cadmus	9	16%	1.50	10,600	15	707
GP17	Implementers	10	14%	1.06	1,575	12.5	126
GP14	Implementers	8	10%	1.42	1,782	10	178
GP23	Implementers	9	10%	0.58	1,682	10	168
GP15	Implementers	8	9%	1.09	1,313	12.5	105
GP13	Implementers	8	6%	1.45	1,222	12.5	98
GP6	Cadmus	9	5%	0.22	292	10	29
GP1	Cadmus	8	3%	0.31	362	8.5	43
GP11	Implementers	10	2%	(0.60)	2,920	17.5	167
HP3_08	Implementers	15	1%	1.43	271	10	27
GP7	Cadmus	9	0%	(0.95)	161	12.5	13
HP5_08	Implementers	15	0%	(1.66)	449	12.5	36
GP10	Implementers	10	0%	5.08	76	17.5	4

Figure 9-1: Percent Savings on 24 Metered RTUs



Energy savings on the 24 units ranged from 0 to 44%, as seen in Table 9-10. Savings for heat pumps were on average slightly higher than those for combination electric cooling and gas heating units. The greatest average savings were in the hotter desert climate zone 15 and in the inland zone 10.This was expected because these sites had the largest cooling loads.

Table 9-10: Average Savings by Climate Zone for 24 Metered RTUs

Climate Zone	Average Metered Savings (% kWh)	Average Metered Savings (kWh)	Average Metered Savings/ton
8	15%	3,374	269
9	17%	3,628	329
10	16%	6,052	441
15	12%	6,635	447

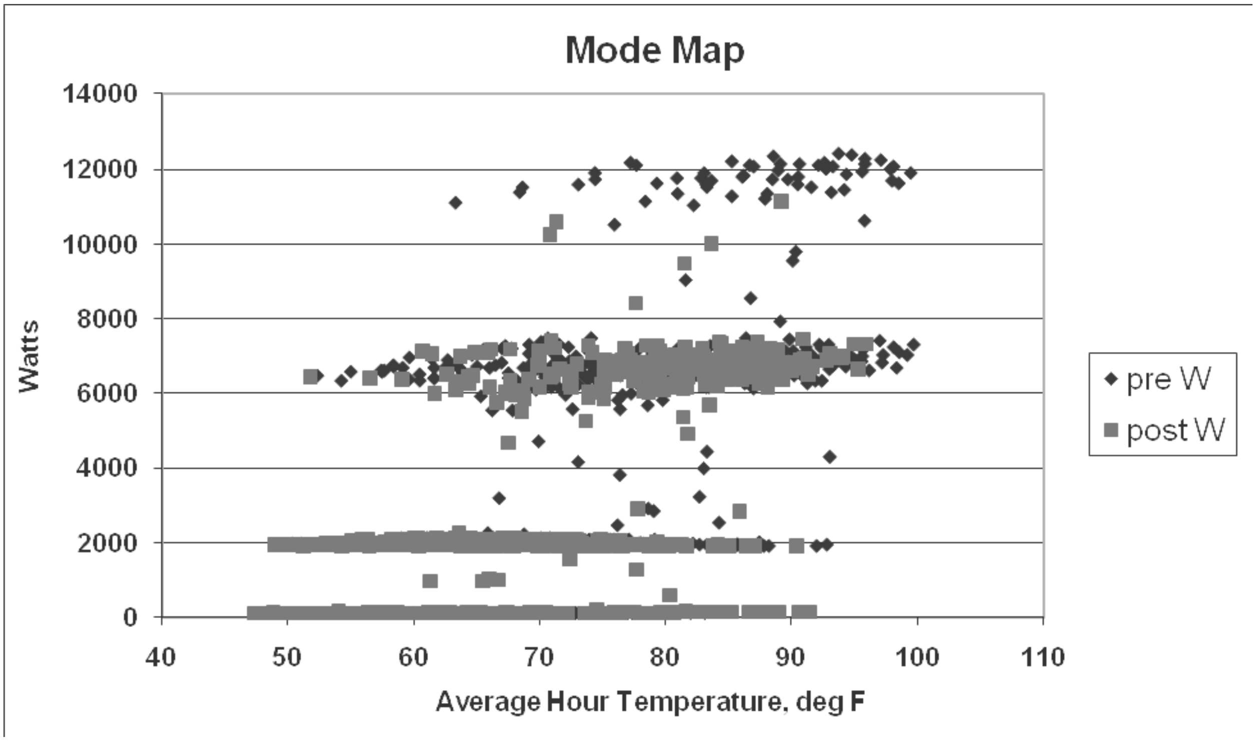
9.7.1 Overview of Savings

The DCV controls, in conjunction with RTU servicing, generated energy savings in multiple ways. First, the DCV controls reduced mechanical cooling because the RTU did not run until CO_2 levels increased, suggesting the space was occupied. This also affected the number of hours of operation for the RTU, and the daily baseline energy usage, as defined by the compressor and fan kW times the number of hours of operation per day. Daily hours of operation decreased as a result of installing control sensors. Second, the servicing restored economizer functionality for those units where dampers were set in a fixed position that admitted higher than necessary outside air fraction at all times when the fan was on, and not modulating too close as temperatures rose. In addition, the minimum ventilation on some RTUs was set lower than in the baseline case; so those RTUs allowed in less hot air after servicing, which reduced the cooling load. These changes combined to have a considerable effect on annual energy usage.

9.7.1.1 DCV Controls: Less Mechanical Cooling

Before the DCV controls were installed, the RTU operated to maintain a cooling temperature set point. This would often require mechanical cooling throughout the day. However, after the CO_2 sensors were installed, cooling was dictated by occupancy, and unoccupied spaces no longer had to be cooled. This change can be seen in the mode map, as shown below, where hourly average Watts are plotted against temperatures, with the diamond-shaped points before servicing and the square-shaped points after servicing. The line at about 2000 W is the fan energy, with first-stage cooling around 7,000 W and second stage cooling at 12,000 W. There are very few points in second-stage cooling after servicing, and many more at the level of fan energy.

Figure 9-2: Hourly Average Watts on GP6 During Pre and Post Servicing Periods

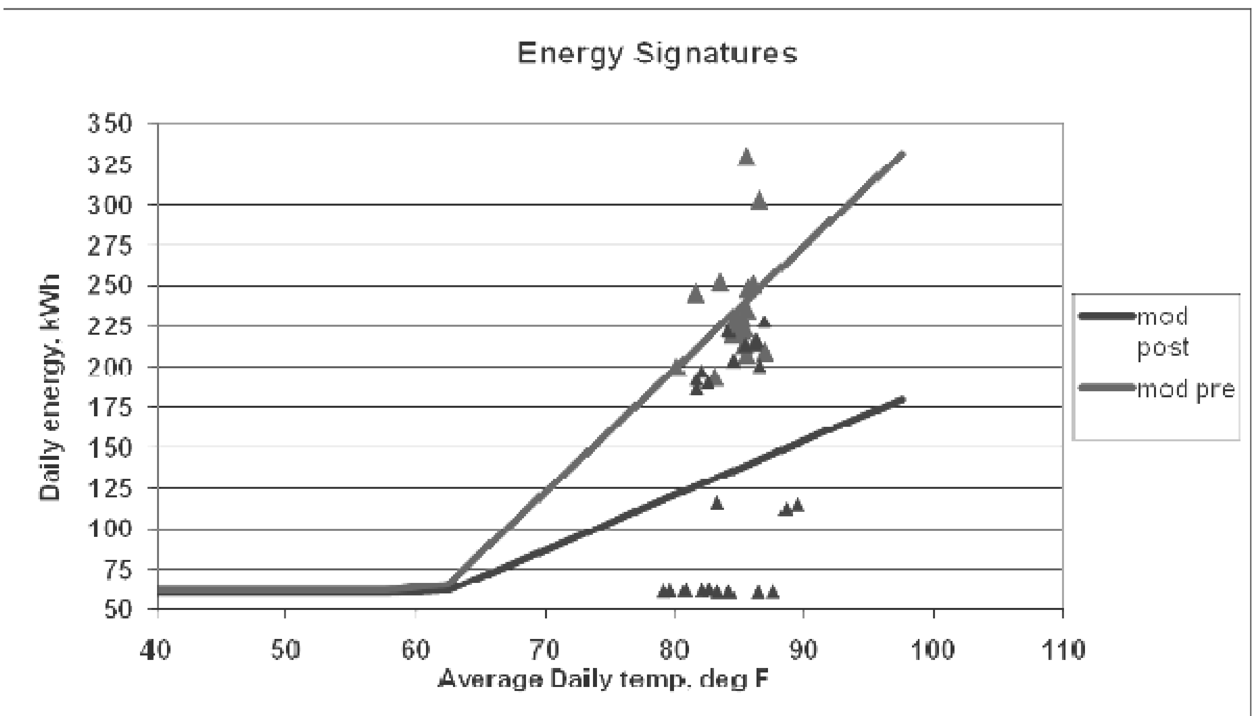


Because the DCV controls allowed for less operation when the space was not occupied, occupancy levels were often more clearly defined on the daily energy graph in the post cases. In some cases, a fully occupied, partially occupied, and an unoccupied state could be seen, with the unoccupied hours characterized by fan-only operation or no operation. CO_2 sensors are located in the return air stream and require fan operation for an accurate reading. Savings resulted from the reduction in RTU operation, especially in the zero occupancy state, when operation was at a minimum.

The energy signature plot is a graph used to extrapolate energy savings in monitored data into annual energy savings. An energy signature is shown in Figure 9-3. For each monitored day, there is a point characterized by the average outdoor temperature for the 24-hour period (td) and the total electric energy used by the unit (kWh/day). These daily aggregates are plotted as in the figure. The horizontal portion refers to the base load. The sloping portion is added to the horizontal portion, and is driven by the energy used when the compressor provides mechanical cooling. The slope is a rather complex result of the specific factors in the conditioned space. These factors include: internal gain to the space, external temperature of the space, the amount of fresh air admitted to the space, the cooling set point temperature, and the efficiency of the cooling unit itself.

Note in Figure 9-4, the lines identified as the pre- and post-performance models are constrained to pass through the data in such a way that the total energy predicted by the models will be equal to the total energy indicated in the data. This modeling approach is intended to produce performance models representing the mean performance of the unit rather than the performance associated with a particular high or low day. This is different than the typical fitting criteria used in most regression work. Data for this site as well as most of the others in this particular research work involve a high variation in occupancy, especially between weekends and weekdays. The fitted line is intended to construct the long-term average weekly energy use, which combines high and low use days. Occupancy is highly irregular and we feel the average best represents the building energy use. We found our initial attempts to use squared regression criteria were seriously biased with respect to reconstructing the original energy use records.

Figure 9-3: Occupancy Levels on HP2_08



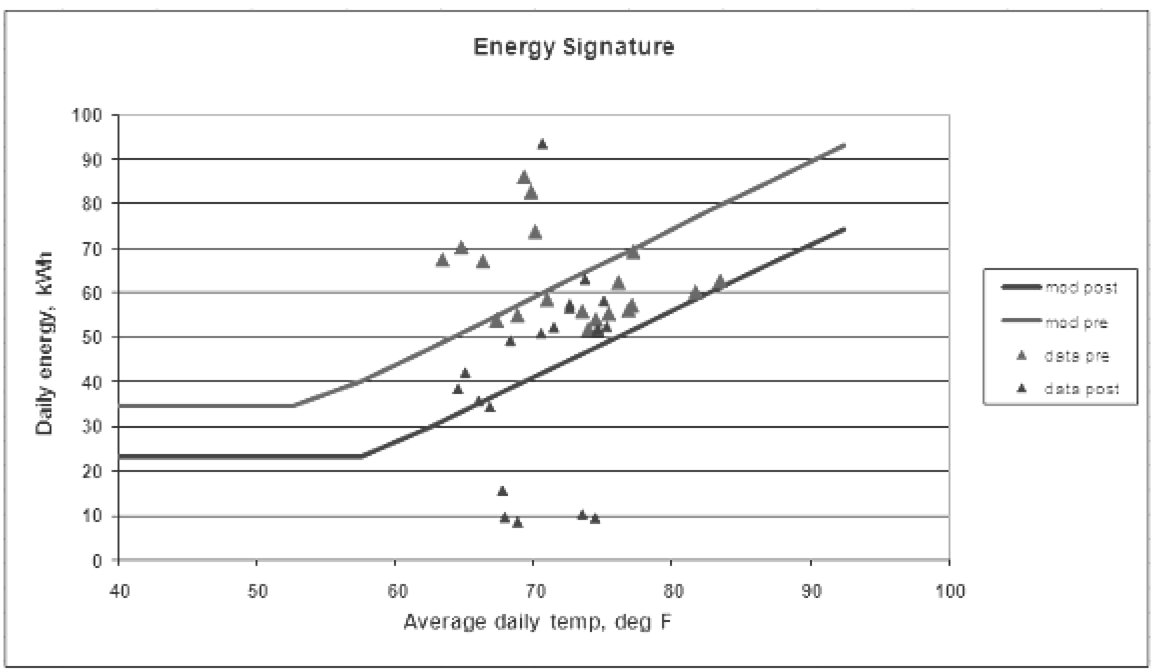
This energy signature chart shows daily average energy in kWh versus average daily temperature. For this RTU, not only is overall energy consumption reduced in the post case, but it is also divided into three states of occupancy at the same average daily outside temperatures. These correspond to full, partial, and unoccupied times, but, in the baseline case, the points are a cluster.

This clearly shows the DCV controls influenced energy use in this space. When the space was unoccupied, daily energy use was the same as fan-only operation because the compressor did not run. At partial occupation, there was some compressor operation, and at full occupancy, there was the highest amount of compressor operation. Since these all vary at the same outside air temperatures, it was reasonable to conclude the difference in demand was caused by internal loads (i.e., occupancy).

9.7.1.2 DCV Controls: Fewer Operating Hours

DCV was most effective in situations where there were long, often irregular, unoccupied periods, when ventilation could be significantly restricted, and the unit did not require operation for as many hours. Allowing the RTU to stay at minimum ventilation levels reduced the demand on the unit, and it did not have to run until the DCV controls received a signal that the CO_2 levels are too high, when people had entered the space. In turn, this reduced the daily base load of the unit, as defined by the number of hours of fan run time each day times the fan kW, independent of compressor operation. This is often indicated in the time series graph, where shorter kW intervals on post-servicing days meant less frequent operation. Baseline kWh for each day was calculated by the operating hours times the fan kW, and it appeared in the daily energy signature. The multiplex movie theaters studied here were conspicuously irregular in operation, with strong activity on weekends and evenings, and minimal activity otherwise.

Figure 9-4: Energy Signature, Fewer Operating Hours



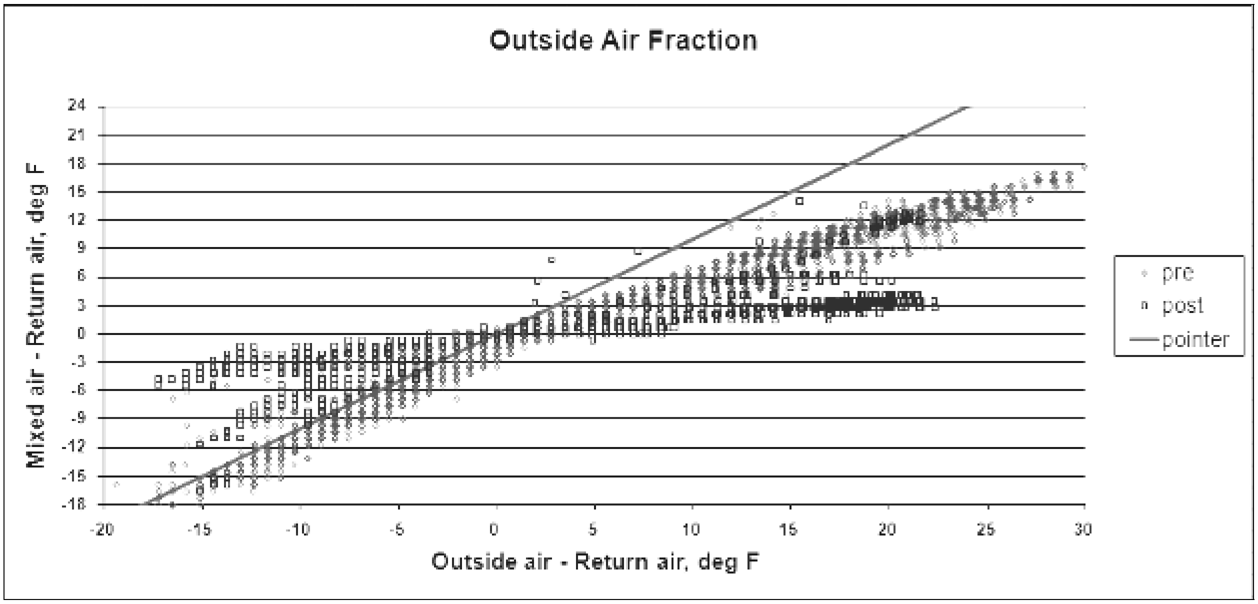
9.7.1.3 RTU Servicing: Restored Economizer Functionality and Minimum Ventilation

One measure in the DCV servicing package was designed to verify economizer operation and fix any broken actuators or linkages needed to restore damper modulation. By examining the percentage of outside air at minimum and maximum ventilation levels, both before and after servicing, we confirmed this improvement in a number of RTUs. This caused a moderate decrease in the energy usage, since, before servicing, the RTU had to constantly cool down the hot air at all hours of the day; after servicing, dampers could modulate to allow minimum outside air.

In Figure 9-5, the hourly temperature information is plotted in a common format used to assess the level of outside air induced into the unit. The horizontal axis is the difference in the average hourly minus return air temperature. This essentially shows the difference between the outside air and conditioned space. The vertical axis is the temperature difference of the mixed air minus the return air. At a maximum, this number will be the same as the difference between the outside air and the return air because there is no mix; only outside air is being admitted. At a minimum, the absolute value of the temperature difference between the mixed air and the return air will be zero, because the mixed air is composed entirely of the return air, and no outside air is being admitted. The choice of using these temperature differences as axes was informed by a common air mass mix equation; so the geometric slope revealed in this plot is the same as the percentage of outside air admitted to the circulation air stream.

For example, in a plot such as Figure 9-5, the slope of the pattern of points indicates the fraction of outside air mixed into the unit. In this figure, the diamond-shaped pre-retrofit points cluster about a dark line labeled as pointer. The slope of the line in this example is about 1.00, indicating an air mix with 100% outside air. The pre-retrofit points in the upper right of quadrant of the plot demonstrate the dampers at minimum ventilation, and fitting the pointer to these shows minimum ventilation before servicing is only at .6 or 60%. In this figure, it is evident most of the post-retrofit activity improved, as the maximum ventilation had a lower air mix of about 70%. Note the less-steeply sloped cluster of darker, round points in the center of the plot. These points show a slope of 0.15, evidence that at minimum ventilation, the unit allows only 15% outside air. Note this plot includes all operating intervals. Each point represents the conditions prevailing for one hour (the five-minute data logger interval points being aggregated to an hourly average).

Figure 9-5: Outside Air Fraction on GP19



From this figure, an improvement can clearly be seen from restoring damper modulation and from reducing the minimum ventilation levels and preventing excessive hot air from entering the RTU, requiring cooling before delivery to the space, although dampers still do not modulate to a maximum 100% outside air.

9.7.1.4 Baseline Simulation at Desert Site

As noted, one site was monitored in both 2008 and 2009. In 2008, monitoring was performed in conjunction with the initial DCV controls installation and RTU servicing. In 2009, the same site was monitored, and the baseline case was simulated by disabling the CO_2 sensor. Note the heat pumps HP1–HP5 in Table 9-11 all have either "_08" or "_09" appended to their names. The three units metered by Implementers when the DCV controls were first installed are denoted by "_08". The "_09" RTUs were those four monitored in 2009. HP2 and HP3 were metered twice: during the initial installation and again in summer 2009. Energy savings were different in each case, and we expected savings to be lower in the more recent metering as no additional servicing was performed.

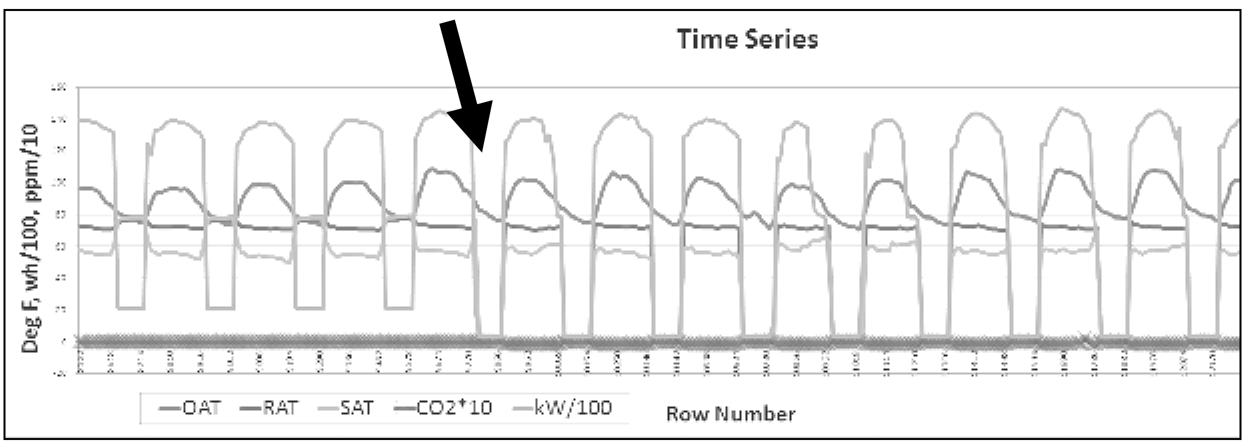
However, this was not the case. In HP2_09 and HP3_09, the fan ran "24-7" both before and after DCV controls were initially installed on all RTUs at this site. However, in the second round of metering, the fan schedule on both HP2 and HP3 were changed during the baseline metering period, from constant operation to turning off at night. Although unrelated to the CO_2 sensor, this change had a significant impact on the energy savings for both RTUs, as seen in Table 9-11.

Table 9-11: Site in Climate Zone 15 Monitored Twice

RTU #	Meter Period	Metered savings (kWh)	Metered savings (%)	Tons	Metered savings/ton
HP1_09	2009	835	7%	15	56
HP2_09	2009	10,680	20%	15	712
HP3_09	2009	12,594	25%	10	1,259
HP4_09	2009	147	1%	7.5	20
HP2_08	2008	19,186	34%	10	1,279
HP3_08	2008	271	1%	10	27
HP5_08	2008	449	0%	12.5	36

The time series plot in Figure 9-6 shows evidence of this change. Hourly averages of outside air, return air, and supply air temperatures and fan energy (orange) are plotted over time. Values on the left correspond to temperatures and fan kW times 10. The fan energy is plotted in orange, with one consisting of the curve showing compressor operation up to about 140 (14 kW) during the day, and the flat line at 20 (2 kW), showing fan energy at about 2 kW overnight. Nearly halfway through the graph, as indicated by the black arrow, instead of the fan operating at night, the energy goes to 0, meaning the fan stops running overnight. This pattern continues throughout the rest of the monitored period. There is no significant drop in outside air temperature or change in any of the other plotted temperatures; so this further supports the conclusion that the building personnel made this change that positively influenced energy usage.

Figure 9-6: Hourly Time Series Plot of HP3_09



9.7.1.5 M&V Lessons

The CO_2 sensors in this study did not accurately capture the amount of CO_2 in the space, and more research is needed to identify the ideal CO_2 sensor location. The sensors in this study were located in the return air plenum. The graph of CO_2 versus the percent of outside air was inconclusive in most cases.

9.8 Detailed Findings

To extrapolate savings to the entire sample, we calculated average savings for each capacity unit within each climate zone in the sample. Since savings were highly dependent on the climate zone, this was an essential filter. The monitored sample contained units in climate zones 8, 9, 10, and 15, whereas the entire population included climate zone 6. Climate zone 8 was used as a proxy because this zone had the most similar cooling degree day profile. In addition, there were units as small as 5 tons, but the smallest in the monitored sample was 8.5 tons.

The evaluation team computed average savings for each RTU capacity within each climate zone, and these values are shown in Table 9-12, in the second-to-last column. The evaluators calculated average savings per climate zone by calculating average savings per ton from all metered units within each climate zone. The values in the far right column in are average savings per ton for all units within each climate zone.

Table 9-12: Metered Savings (kWh) per Ton by Climate Zone

Climate Zone	# of RTUs	RTU Capacity	Average Metered Savings (kWh)	Average savings for each RTU size (kWh/ton)	Average savings for the climate zone (kWh/ ton)
8	1	8.5	362	42.6	269
8	2	10.0	2,305	230.5	269
8	3	12.5	3,366	269.3	269
8	1	15.0	8,551	570.1	269
9	2	8.5	3,326	391.4	329
9	3	10.0	2,662	266.2	329
9	1	12.5	161	12.9	329
9	1	15.0	10,600	706.7	329
10	1	8.5	14,368	1,690.4	441
10	1	12.5	1,575	126.0	441
10	2	15.0	3,043	202.9	441
10	2	17.5	1,498	85.6	441

Climate Zone	# of RTUs	RTU Capacity	Average Metered Savings (kWh)	Average savings for each RTU size (kWh/ton)	Average savings for the climate zone (kWh/ ton)
10	1	25.0	17,342	693.7	441
15	1	10.0	271	27.1	447
15	1	12.5	449	35.9	447
15	1	15.0	19,186	1,279.1	447

We extrapolated the calculated values from the sample above to the entire population of RTUs in the Energy Efficiency Program for Entertainment Centers. Results are shown in Table 9-13. The same process was followed to compute demand reduction. Summaries are shown at the program level, by climate zone.

Table 9-13: Evaluated Savings (kWh) Extrapolated to Entire Population

Climate Zone	RTU Capacity	Number of RTUs	Average savings/ton/ climate zone (kWh)	Savings per RTU by capacity	Total Savings by RTU capacity by climate zone (kWh)
6	12.5	8	269	3,362.5	26,900
6	20	2	269	5,380.0	10,760
8	5	6	269	1,345.0	8,070
8	8	2	269	2,017.5	4,035
8	9	21	269	2,286.5	48,017
8	10	14	269	2,690.0	37,660
8	12.5	15	269	3,362.5	50,438
8	15	9	269	4,035.0	36,315
8	20	7	269	5,380.0	37,660
8	25	5	269	6,725.0	33,625
10	5	13	441	2,205.0	28,665
10	8	4	441	3,307.5	13,230
10	9	3	441	3,748.5	11,246
10	10	16	441	4,410.0	70,560
10	12.5	10	441	5,512.5	55,125
10	15	1	441	6,615.0	6,615
15	12.5	13	447	5,587.5	72,638
15	20	2	447	8,940.0	17,880
				Total Savings	**569,437**

9.8.1 Summer Grid Level Peak Demand Savings

Because these sites were irregularly occupied (as is the nature of theaters), it was difficult to predict whether demand reduction would occur during the three hours of the summer peak period (2:00 pm to 5:00 pm), defined by the CPUC. To examine energy demand during each climate zone's peak periods, we used the hourly average kWh from the monitored pre- and post-periods. A trend line fit to these data was used to predict performance for each RTU at the given peak period temperatures. Each of the nine temperatures was then input into the pre- and post-predictive equations, the results were averaged, and post-period demand was subtracted from pre-period demand. This evaluated peak demand reduction is shown in Table 6-14.

Table 9-14: Metered Units: Savings, Demand, and Realization Rates

RTU #	IOU Claimed savings kWh	Metered savings kWh	Metered Savings (pre-post) percent	Realization rate kWh	IOU Claimed peak demand reduction kW	Metered peak demand reduction kW	Realization rate kW
GP3	5,661	7,562	44%	134%	3.73	1.80	0.48
GP16	7,630	2,681	35%	35%	8.36	2.13	0.26
HP2_08	16,514	19,186	34%	116%	7.45	7.11	0.95
GP21	4,031	6,011	33%	149%	2.01	0.11	0.05
GP20	3,426	3,459	31%	101%	1.71	0.64	0.37
GP18	7,630	3,405	23%	45%	3.13	4.71	1.50
GP22	3,426	3,194	23%	93%	1.71	1.16	0.68
GP19	12,716	17,342	20%	136%	5.23	8.37	1.60
GP2	4,031	2,828	19%	70%	2.98	1.09	0.36
GP12	6,793	8,551	17%	126%	4.47	4.27	0.96
GP9	N/A*	14,368	17%	N/A*	N/A*	1.12	N/A*
GP8	6,047	10,600	16%	175%	3.02	1.50	0.50
GP17	6,359	1,575	14%	25%	2.61	1.06	0.41
GP14	4,439	1,782	10%	40%	2.98	1.42	0.48
GP23	4,031	1,682	10%	42%	4.02	0.58	0.14
GP15	5,661	1,313	9%	23%	3.73	1.09	0.29
GP13	5,661	1,222	6%	22%	3.73	1.45	0.39
GP6	N/A*	292	5%	N/A*	N/A*	0.22	N/A*
GP1	3,850	362	3%	9%	2.53	0.31	0.12
GP11	N/A*	2,920	2%	N/A*	N/A*	(0.60)	N/A*
HP3_08	11,009	271	1%	2%	4.96	1.43	0.29
GP7	5,039	161	0%	3%	2.51	(0.95)	(0.38)
HP5_08	13,761	449	0%	3%	6.20	(1.66)	(0.27)
GP10	N/A*	76	0%	N/A*	N/A*	5.08	N/A*

* Estimates for these four RTUs were not available in the program tracking database

9.8.2 NTG Survey Analysis

A modified version of the Joint Simple NTG survey was conducted for the Energy Efficiency Program for Entertainment Centers. Results of the survey were used to assess free-ridership in the program and to determine whether the NTGR of 0.9 used in program planning assumptions should be adjusted for actual free-ridership.

Although 12 theaters were included in the IOU's final tracking database there were only eight decision makers to interview because some decision makers were responsible for more than one theater. The Specialized Commercial CG Evaluation Team successfully contacted five decision makers and completed four interviews. One decision maker refused to take part in the interview or spend time on the survey. The Specialized Commercial CG Evaluation Team was unable to reach the remaining three decision makers.

A net-to-gross ratio was calculated from survey responses as per the "Proposed Net-to-Gross Ratio Estimation Methods for Nonresidential Customers". This value was then weighted by the savings associated with the survey respondents. The evaluated net-to-gross ratio calculated for the Energy Efficiency Program for Entertainment Centers is 0.94 for both energy and demand.

9.8.3 Program Level Savings

The IOU claimed gross savings (which were the same as the ex-ante savings) for the population were 978,667 kWh. Evaluated program level savings were 569,437 kWh. The overall gross energy savings realization rate was 58%. The survey results suggesting a NTG ratio of 0.90 are used here to adjust the gross savings.

Table 9-15: Program Level Savings Realization Rate

DCV (CO_2 sensor)	IOU gross ex-ante	IOU gross claim	Evaluated	NTG	Net Evaluated	Realization Rate
kWh	978,667	978,667	569,437	.9	512,493	58%
KW	495.83	495.83	496.96	.9	447.3	100%

Table 9-16: Program Level Savings by Climate Zone

Climate Zone	Average Unit Savings By Climate Zone (kWh/Ton)	Average Unit Savings By Climate Zone (kWh)	Total Program Energy Savings By Climate Zone (kWh)	Average Unit Demand Reduction By Climate Zone (kW/Ton)	Average Unit Demand Reduction By Climate Zone (kW)	Total Program Demand Savings By Climate Zone (kW)
6	242	3389	25,985	0.27	3.6	38
8	242	2914	230,237	.027	3.6	256
10	397	3551	166897	0.15	1.8	64
15	402	5432	81,466	0.45	6.3	90

Table 9-17: Program Level Savings Summary

High Impact Measure	Measure	IOU	EEGA ID	Meter Sites	Error Ratio (er)	Sample RP at 90% CI	2006-08 kWh Savings	kWh Error Bound	2006-08 kW Savings	kW Error Bound
No	DCV (CO_2 sensor)	SCE	SCE 2561	12	.5	14.5%	512,493	74,311	447	65

Table 9-18: Energy Efficiency Program for Entertainment Centers Energy Savings Summary

Measure	Program with Measure	Measure Ex-ante Gross kWh Savings	Measure Ex-post Gross kWh Savings	Measure Install Rate	Measure Installed Ex-post Gross kWh Savings	Measure NTGR	Measure Ex-post Net kWh Savings
DCV	SCE2561	978,667	569,437	100%	569,437	0.938	534,132

Table 9-19: Energy Efficiency Program for Entertainment Centers Demand Savings Summary

Measure	Program with Measure	Measure Ex-ante Gross Peak kW Savings	Measure Ex-post Gross Peak kW Savings	Measure Install Rate	Measure Installed Ex-post Gross Peak kW Savings	Measure NTGR	Measure Ex-post Net Peak kW Savings
DCV	SCE2561	496	497	100%	497	0.946	470

9.9 Findings and Recommendations

RTUs showing the greatest savings were influenced by a combination of the following factors after servicing and DCV controls installation:

- Less second-stage cooling;
- More fan-only operation (less mechanical cooling);
- Fewer hours of RTU operation; and
- More hours at minimum ventilation.

These changes all improved performance by decreasing the number of mechanical cooling hours and reducing demand on the unit. Table 9-20 shows changes in RTU operation after servicing, as observed in the data. RTUs were sorted by greatest percent savings in descending order. The greatest savings were realized in units where mechanical cooling and operating hours were reduced. For example, in GP3, the unit with the greatest percent savings, the only clear change in the RTU performance was less second-stage cooling. The degree of change has an effect; if a unit reduced its second-stage cooling hours for only a small percentage of the time it was running, savings would not be as great. Those RTUs in which adjustments were the most extreme realized the greatest savings.

Although operating schedule adjustment was not a measure in this program, it was important to show how much of an effect that adjustment had on RTU energy consumption. As noted, the schedules on HP2_09 and HP3_09 were changed at some point during the baseline monitoring to turn the fan off at night. This change alone impacted savings on these units that did not receive any servicing during this monitoring period.

Table 9-20: Adjustments Made During Servicing

RTU #	Less Second Stage Cooling	Less Mechanical Cooling; More Fan Only Operation	Fewer Operating Hours	More Hours At Minimum Ventilation	Evaluated Savings (%)
GP3	Y	N	N	N	44%
GP16	N	N	Y	N/A*	35%
HP2_08	Y	Y	N	N	34%
GP21	N	N	Y	N/A*	34%
GP20	Y	Y	N	N/A*	31%

RTU #	Less Second Stage Cooling	Less Mechanical Cooling; More Fan Only Operation	Fewer Operating Hours	More Hours At Minimum Ventilation	Evaluated Savings (%)
HP3_09	N	N	Y	N	25%
GP18	Y	N	N	Y	23%
GP22	Y	Y	N	N/A*	23%
HP2_09	N	N	Y	N	20%
GP6	Y	Y	N	N	20%
GP19	N	N	Y	Y	20%
GP9	Y	N	N	N	17%
GP12	N	Y	N	N	17%
GP8	Y	N	N	N	16%
GP17	N	N	N	Y	14%
GP14	Y	Y	N	N	11%
GP23	N	Y	N	N/A*	10%
GP15	Y	N	N	N/A*	9%
HP1_09	N	N	N	N	7%
GP13	N	N	N	N	6%
GP2	N	Y	N	N	4%
GP1	N	N	N	N	3%
GP11	N	N	N	N	2%
HP4_09	N	N	Y	N	1%
HP3_08	N	N	N	N	1%
GP7	N	N	N	Y	0%
HP5_08	N	N	N	N	0%
GP10	Y	N	N	N	0%

* MA and RA data were not available, so minimum ventilation could not be examined

Units with the least savings did not make as many improvements in reducing time in first- and second-stage cooling, decreasing operating hours, or increasing time at minimum ventilation settings. Although some adjustments may have been made in time spent in mechanical cooling or the time spent at minimum ventilation, the improvements were not enough to affect energy usage as much as in those RTUs with larger savings. Reasons for this fall into two categories. In the first case, the units were already performing well. In the baseline case, GP7 turned off for 10 hours each night, the economizer dampers were functioning, and it frequently operated fan only. The same was true for GP1 and GP2.

In some cases, such as GP10, the dampers were adjusted, but they still allowed in more outside air than necessary, even after servicing; the damper change was from 92% open to 70% open. Unit HP5_08 ran only in mechanical cooling and did not run only the fan.

9.9.1 Enhanced Servicing Program

The DCV program included some elements of a regular RTU servicing program in the coil cleaning and economizer inspection and repair. It could be valuable to combine more RTU servicing elements with this program, such as adjusting the thermostat settings. This no-cost opportunity for improvement was indicated in the monitored data. In five of the 29 units with metered data, the fan operated “24-7.” As evidenced by the changes in HP2_09 and HP3_09, reducing operating schedules alone could generate significant savings.

A screening process could be another means to improve the program by better identifying units that could benefit the most from DCV controls and servicing. Referring back to Table 9-20 with average savings by climate zone, it is clear the greatest savings were in climate zones 10 and 15. It could be in the program’s best interest to target specific climates with greater heating and cooling loads that could best benefit from DCV. Since some RTUs were already operating optimally in the baseline case, they did not realize the expected savings.

10. Non-HIM Programs

10.1 Upstream HVAC/PTAC

10.1.1 Program Description

The Upstream HVAC/Motors program, offering PTAC (Packaged Terminal AC) as one facet of SDG&E 3029, was designed to stimulate the supply and sales of premium-efficiency HVAC systems and motors at the upstream and midstream levels. It provided incentives to participating contractors and equipment specifiers and end-users who installed qualifying premium efficiency central air conditioning systems in commercial, residential, replacement, and new construction applications. Participating motor distributors received incentives for premium-efficiency electric motor sales.

This program's initial focus was primarily educating contractors and manufacturers about ways to promote sales and quality installation of premium-efficiency equipment rather than equipment that merely met code, and incenting them for each sale of premium-efficiency equipment. The program differed from other HVAC programs with the rebate payment going to the contractor, rather than the equipment purchaser. The contractor could choose to give all or part of the rebate to the equipment purchaser, but this was entirely up to the contractor.

Air-conditioning is a major contributor to summer peak load in California, and increasing the efficiency of all HVAC equipment is a priority. During the course of the program, however, it became obvious to the implementer that the upstream/midstream marketing was not pushing the market as fast as program planners originally thought it would, hence the push needed to be downstream. In addition, there were commercial market segments not traditionally part of the contractors' customer base. As a result, the implementer also marketed the program directly to these customers. Therefore, a program that initially began with the contractors as the primary target market evolved into a more traditional energy-efficiency program marketing directly to customers, that is, those who purchased and installed the equipment.

10.1.2 Key Program Elements

One of the market segments not traditionally part of HVAC contractors' customer base was the hotel/motel segment. Hotels and motels typically use packaged terminal air conditioners (PTACs) or heat pumps (PTHPs) in guest rooms. As a result, the program was amended in May 2007 to include packaged terminal air conditioners and heat pumps. Only commercial packaged terminal units installed in hotel guest rooms and motels built before January 2002 or after January 2006 (new construction) qualified for the program. Customers could not have participated in SDG&E's Savings by Design program or had already been rebated for the equipment through other public goods charge programs. On-bill financing was available to participating customers. Implementers developed marketing materials and Web pages specifically for the hotel/motel market segment. In addition to stressing the considerable energy savings available to hotels, Implementers marketed the program as a green challenge, declaring they were looking for50 hotels to step up and reduce carbon emissions.

Energy use, specifically electricity, is a major component of a typical hotel's operating costs. Nationally, the hospitality industry spends $3.7 billion per year on energy. Electricity use accounts for 60%–70% of the utility costs of a typical hotel, and, for hotels in SDG&E's service territory, is second only to lighting as the building operation with the highest energy use. Because electricity is such a major contributor to hotel operating costs, this program was very attractive to hotels and motels in SDG&E's service territory. In addition, hotels could and did replace units in multiple waves, which allowed them to take advantage of bulk purchase discounts from the equipment manufacturers on top of the program rebates of $50–$75 per ton. The program also enabled the hotels to spread capital costs of equipment replacement over multiple years.

The replacement PTAC system is comprised of high-efficiency packaged terminal air conditioning/heat pump units and associated controls in hotel guest rooms. The replacement units include improved refrigeration components to increase energy performance resulting in reducing cooling energy consumption (kWh) and demand (kW) for the HVAC end user.

10.1.3 Evaluation Objectives

Only commercial packaged terminal units installed in hotel guest rooms and motels built before January 2002 or after January 2006 (new construction) qualified for the program. Minimum efficiency requirements are shown in the table below:

Table 10-1: Minimum Efficiency Requirements

Packaged Terminal Air Conditioners and Heat Pumps			
Minimum Efficiency Requirements			
Cooling Capacity	**Under 7,000 Btu/h**	**7,000 to 15,000 Btu/h**	**Over 15,000 Btu/h**
Replacement	11.0 EER	10.0 EER	9.0 EER
New Construction			
AC	13.0 EER	12.0 EER	10.0 EER
HP	12.8 EER	12.0 EER	10.0 EER

This program was very well-received by hotels and motels in SDG&E's service territory because of the advantages noted previously. The original evaluation plan for the Upstream HVAC/Motors program did not address the evaluation of savings specifically from packaged terminal units as a separate measure. As the program progressed, however, and the number of packaged terminal installations was noted, PTACs/PTHPs were singled out for a separate evaluation of energy savings. Although packaged terminal units are HVAC equipment, they do not save energy at the same level as large packaged or unitary HVAC units, or residential HVAC units. Therefore, they were evaluated as a non-high-impact measure and were selected to inform the DEER database.

There were 768 PTAC and PTHP units installed under the SDG&E 3029 HVAC/Motors program.

Table 10-2: PTAC Installation Ex-ante Savings

Climate zones	Number of PTAC/PTHP	Ex-ante Gross kWh savings	Ex-ante Gross kW Savings	Ex-ante NTG	Ex-ante Net kWh Savings
7	538	424, 945	168	0.8	339, 956
10	230	167, 455	82	0.8	133, 964
Total	*768*	*592, 399*	*250*	*0.8*	*473, 919*

10.1.4 Methodology

10.1.4.1 Methods Used in this EM&V Activity

10.1.4.1.1 Sample Sizes for PTAC EM&V

Initially, PTACs were not a large component of this program or a focus of the evaluation. When the number of installed units increased dramatically, the evaluation team proposed evaluating PTAC units. The rigor level proposed for this technology was basic for energy, demand, and NTG. Basic rigor for energy and demand required a sample size consistent with 90% confidence levels and better than 30% precision. We determined seven units stipulated with a 90/30 sampling plan were too few to draw meaningful conclusions. The budget did not allow for sampling at the 90/10 level for this non-HIM measure. Therefore, we chose a sample that provided better than the 90/20 level of confidence and precision that could inform the evaluation of PTAC units.

The on-site metering performed for the PTAC/PTHP measure was developed to provide an estimate of savings pre- and post-installation of the equipment. This evaluation was based on a pre/post metering approach. The fieldwork for the packaged terminal evaluation did not occur until after the end of the 2006–2008 program cycle, when all program installations had already been completed. Therefore, it was not possible to obtain pre-installation electric consumption. Pre- and post-monitoring were conducted concurrently at the same hotel site. To approximate pre-installation consumption, electricity consumption for 20 existing packaged terminal units and 20 packaged terminal units replaced under the program were monitored at two different hotels (10 pre-post at each of two hotels). The 20 existing packaged terminal units served as a proxy for pre-installation consumption. The hotels were carefully selected to be similar to other hotels in the SDG&E service territory, and all units selected for monitoring were chosen with consideration for the rooms' solar exposure.

10.1.4.1.2 On-site Data Collection

Visual verification inspections were not performed as they were precluded by metering participant and non-participant units. The following information was collected prior to the initial site visit: Site ID, site address, primary site contact, secondary contact, phone, e-mail address, measure name, installation date, unit quantity, total annual savings, and climate zone.

Post-Installation data collection involved gathering relevant parameters to serve as inputs to the evaluation algorithm. The following unit nameplate information was taken during the initial site visit: PTAC manufacturer, model number and serial number, cooling rated efficiency, refrigerant type, metering device, airflow, and cooling capacity, filter information, room and cooling load characteristics were be collected during on-site visits. Data collected on-site are shown in Table 10-3.

Table 10-3: PTAC Data Collected On-Site

DEER Parameter	Data Collection
CTZ - California Thermal Zone	Observed
Installation Date	Surveyed
Unit Quantity	Observed
Total Annual Savings	Calculated
Cooling Rated Efficiency	Observed/ Lookup from Model#
Refrigerant Type	Observed/ Lookup from Model#
Airflow	Observed/ Lookup from Model#
Cooling Capacity	Observed/ Lookup from Model#
HVAC unit compressor runtime	Measured
Supply Air Temperature	Measured
Return Air Temperature	Measured
Ambient Temperature	Measured

The following parameters were logged for a minimum of 30 days for both the pre- and post-conditions: unit compressor runtime, supply air temperature, return air temperature and humidity, and outdoor ambient temperature and humidity. There were seasonal and occupancy variations on both the load profile as well as on the operating hours of the PTAC unit.

10.1.4.1.3 Data Accuracy and Instrumentation

Data accuracy is the foundational dimension of data quality. We maintained quality control at each step of evaluation, starting from field data collection, monitoring performance data initial data entry, post analysis, and reporting. Each of these steps was carried out by qualified professionals and cross checked by senior engineers to avoid inaccuracies. Field engineers were provided with a table that was populated with all expected input parameters to help avoid inconsistent field data. Each data logger was downloaded prior to leaving the site, and all data values were examined for completeness.

Time series data loggers were used to record various performance parameters of the PTAC units. Instantaneous measurements were conducted for the various cooling and fan operation modes to identify the unit current draw and true power in each mode. Current draw and true power instantaneous measurements were taken using a Fluke 43B Power Quality Analyzer or similar equipment. The following instrumentation was used to monitor the performance of the PTAC units.

A 20-amp current transformer connected directly to a HOBO U12-006, 4-channel external data logger, used to meet power measurement criteria. This recorded compressor current was a proxy for runtime as the compressor turned on and off, enabling the calculation of the annual equivalent of full load hours. The correlation of current at various operating modes to instantaneous power measurements was intended to yield cooling kWh consumption.

PTAC supply temperature was measured with an Onset external temp sensor connected to the HOBO U12-006 data logger. Return air temperature and humidity were measured with the HOBO U12-011 data logger with internal temperature/RH sensor. Outdoor air temperature/RH was measured with a HOBO S-THB-M006 Smart Sensor, connected to a HOBO micro station with solar shield on the building roof. The following table outlines the instruments used in pre-post-installation logging and metering.

Table 10-4: Measurement Points and Instrumentation Detail for PTAC Metering

Function/ Data Point to Measure	Equipment Brand/Model	Qty Req'd	Rated Full Scale Accuracy	Accuracy of Expected Measurement	Planned Metering Duration	Planned Metering Interval
Data Logger	HOBO U12-006	1			30 days	
Supply Air Temp	Onset TMC6-HD	1	±0.45 ºF	±0.45 ºF	30 days	2 Minutes
Unit Amperage	Onset CTV-A20 amp split-core current transducer	1	±4.5%	±4.5%	30 days	2 Minutes
Return Air Temp/RH	Internal temp/RH (HOBO U12-011)		±0.63 ºF ±2.5% RH	±0.63 ºF ±2.5% RH	30 days	2 Minutes
Data Logger	HOBO micro weather station	1			30 days	
Outdoor Ambient Temp/RH	S-THB-M002 smart sensor	1	±0.36 ºF 3.5% RH	±0.36 ºF 2.5% RH	30 days	2 Minutes

The HOBO U12-011 data logger has an internal temp/RH sensor, which, in this application, was intended to capture the return air condition. This data logger was placed inside the PTAC cabinet, behind the front panel in the return air stream. An external temperature sensor connected to a HOBO U12-006 data logger was placed in the supply air stream. One split-core current transformer was placed onto one leg of the PTACs main power line and plugged into the U12-006 data logger. This data logger was placed inside the PTAC cabinet. A smart temperature sensor with a solar shield connected to the HOBO weather station was mounted on the roof to record ambient temperature and relative humidity.

10.1.4.1.4 NTG Data Collection

We used a jointly defined, consistent, self-report (SR) NTG method for simple, straightforward measures. This approach to measuring participant spillover and free-ridership was developed jointly by the residential, small commercial, and government partnership contract groups. Use of this common method helped to ensure uniformity in evaluation techniques across programs and contractors and provided greater transparency and reliability. The Joint Simple SR NTG Method prescribed a set of questions and scoring procedures. The intent of the Joint Simple SR NTG Method was to ensure a common set of questions, interview protocols, and scoring procedures was used. However, some questions were tailored for particular programs and/or measures to make the questions better understood by respondents as a way to ensure complete, reliable, and accurate responses. A dual-path survey was utilized for HVAC measures that initially asked program awareness and influence questions to determine whether a customer or contractor/vendor path should be pursued.

10.1.4.2 Reference and Background for the Methods Applied

The PTAC is a weather-dependent summer cooling load savings measure. The evaluation required airflow verification similar to Title 24. The actual temperature split between supply and return dry bulb was calculated as shown in the steps below and compared against the target split, as outlined in the 2005 Residential ACM Approval Manual. The method essentially verified that flow was greater than 350 cfm/ton for a large percentage of units based on empirical data.

1. Calculate the Actual Temperature Split as follows: Actual Temperature Split = $T_{return,\ db} – T_{supply,\ db}$

2. Determine the Target Temperature Split using the appropriate tables from the 2005 Title 24 Residential ACM.

3. Calculate the difference between the actual and target values as follows: Actual Temperature Split – Target Temperature Split

4. If the absolute value of the difference is less than or equal to 3, then the system has adequate airflow.

    a. If the difference is greater than 3, the airflow is too low.

    b. If the difference is less than -3, it is unlikely the airflow is too high. Most likely the capacity is low on the system.

10.1.4.2.1 Baseline Assumptions

Savings for all commercial PTAC and PTHP replacement measures were deemed based on savings published in the DEER database. The baseline for this measure was the existing equipment with remaining useful life (RUL). The RUL was determined from the difference between the DEER effective useful life of 15 years and the age of the unit at the time of replacement.

In cases where an existing unit was replaced on burnout (instead of on an early retirement basis), the baseline would be per Title 20, 2006 Appliance Efficiency Regulations, Table B-3, Standards for PTACs and PTHPs. Standard baseline cooling efficiency ranges from 7.60 to 8.88 EER relative to PTAC cooling capacity.

10.1.5 Confidence and Precision of Key Findings

10.1.5.1 Planned Confidence and Precision

Survey sample sizes described here were prescribed by the Protocols,[35] calling for at least 300 samples per program for NTG analysis. Where program delivery methods varied within a program, sample sizes were increased to address the different nature of contractor-based and traditional residential and small commercial rebates. In some cases, the actual total exceeded the minimum for the purpose of generating leads for site level M&V.

For the packaged terminal installations of the Upstream HVAC program, a participant was defined not as a PTAC or PTHP installation, but rather as a decision maker for the hotel responsible for making the decision to participate in the program. Although there were 768 PTAC/PTHP units for which savings were claimed under the 2006-2008 program period, there were only 12 actual participants, or hotel decision makers. Therefore, the survey population included all program participants.

The sampling plan for metering the 20 PTAC participant and nonparticipant units included two hotels. The plan was designed so simultaneous pre- and post-installation data from PTAC metering were conducted at the same site (collecting participant and nonparticipant data). We selected and recruited the hotels that met metering needs, including: electrical wiring configuration to be wall outlet plug-in type; delivered voltage to be single phase; and a sufficient quantity of guest rooms with pre-existing PTACs. Sampling was conducted to select particular

[35] *California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals*. Prepared for the CPUC by the TecMarket Works Team.

PTAC units for metering, matching the participant and non-participant room characteristics. Every effort was made to ensure we had an appropriate mix of room orientations and sizes, but, to some degree, these selections were made based on guest room availability and technical compatibility. Ideally, the plan called for selected guest rooms grouped together by exposure: north and east; and south and west. Additionally, hotel management was asked to log the days of occupancy for each sample room during the monitoring period for correlation to PTAC operation. Guest rooms with "smart" controls were identified and documented.

10.1.6 Achieved Confidence and Precision

The M&V plan targeted 40 total units for metering, including 10 new units and 10 old units in each of two different hotels. The hotels were located in two different climate zones. The target sample plan was achieved, with two hotels agreeing to participate.

10.1.7 Validity and Reliability

10.1.7.1 Measurement and Calculated Uncertainty of System Efficiency

The HVAC non-HIM team worked with ED technical advisors to define modeling context parameter uncertainty and overall affect on 8760 load shape uncertainty.

Table 10-5: Accuracy of Equations

Instrumentation error	± 4.5	%
Converting from proxy measurement to energy (e.g. amp to kW)	± 1.0	%
Extrapolating from short-term metering to annual hourly loads	± 10	%
Adjustment between measurement year and typical year weather data	± DK	%
Assumptions, engineering theory vs. real world performance	± DK	%
Bill data extrapolation	± NA	%
Post-retrofit schedule estimation	± NA	%
Pre-retrofit schedule estimation, if different	± NA	%

10.1.7.2 Procedures to Minimize Non-response Bias

As noted in the California Protocols, non-response bias occurs when we are unable to conduct data collection on a unit selected for the sample. This non-response bias could affect telephone surveys, site visit recruiting, and on-site data collection efforts.

The Specialized Commercial HVAC Team took rigorous approaches to minimize non-response bias for each data collection mode. For example, our team approached telephone surveys in several ways, including:

- Extensively training and monitoring interviewers to ensure they used effective introductions, followed professional survey research techniques, and used rapport-building techniques to keep respondents on the phone.

- Using CATI software that managed call queues; so numbers are called back at different times of the day and days of the week, at regular intervals, and at times that respondents requested.

- Using veteran interviewers to convert soft refusals.

Regarding data collected at the site, technicians used a data collection form. Data items not collected during installation were flagged for collection at meter pick-up.

10.1.8 Savings Algorithm

The initial focus of this plan was to determine the annual equivalent full loads for the PTAC in the cooling mode. PTAC units are designed as single-stage cooling without capacity control capability; therefore, when the compressor is activated it is inherently at full load.

In practice, PTAC monitoring was complicated due to multiple levels of fan speed, possible outside air ventilation, and variable room occupancy. Also, for the purposes of cost-effectiveness analysis, the observed PTAC performance had to be expressed at the hourly (8760) level.

Therefore, the monitoring and subsequent calculation of savings became more involved than an equivalent full-load hours estimate. The savings estimation process was coordinated to produce performance functions that could be used to give 8760 output for defined normal annual CZ conditions, and also to estimate savings for a specified "normal occupancy level."

10.1.8.1 Energy and Demand Models

For each monitored room, two energy-use functions were developed from the monitored data. These two energy use functions (signatures) were identical in form, and describe the energy use for the occupied and unoccupied states of the room operation as a function of outside air dry bulb temperature. The occupied and unoccupied energy use results were weighted depending` on the annual occupancy rate.

The energy use function was a simple linear function of the form:

*Hour Energy = (t db out- t balance point)*Cool Slope*

If tdb out < t balance point, Hour Energy =0
Data kWh = Ahr * W

Where:

Hour Energy = PTAC hourly energy use at temperature tdb out
t db out = average hourly outside air dry bulb temperature
t balance point = temperature below which Hour Energy = 0
Cool Slope = increase in Hour Energy per degree increase in tdb out
Data kWh = monitored PTAC hourly energy use
Ahr = total hourly amp-hours derived from amperage monitored data
W = amps to watts conversion factor derived by correlation of monitored amperage values and snapshot measurement of true power taken during logger set up.

The model was fitted to all the data, including the zero energy hours; so that it estimated the energy use for an hour at a specified temperature, including the effect of the non-operation hours. In this manner, the energy model could reconstruct the observed total energy. Typically, the energy-use model would be used with a histogram of the normal annual hourly outside air temperatures to develop a normal annual energy-use estimate.

In this case the energy-use function was used with standard climate zone weather data to define the hourly temperature sequence to allocate the energy use and demand into the appropriate 8760 energy costing bins (which would sum to the annual normal energy use).

10.1.8.1.1 Occupancy Normalization

The energy use by monitored room varied considerably depending upon occupancy. The final results were normalized to a common occupancy rate (as well as common weather conditions) for a valid energy use comparison. The occupancy normalization was achieved by combining the two energy use functions in a weighted fashion to develop a single energy-use function corresponding to a specified normal occupancy level. This combined energy-use function was driven by the standard climate zone weather data to develop the energy use and savings numbers. The monitoring data for all rooms were worked into occupied and unoccupied energy-use functions, which were then blended into the combined energy use functions of these rooms at the same normal occupancy level.

The two hotels monitored followed different policies for operating the PTAC units when rooms are not occupied. One hotel turned off the PTAC units when rooms are not occupied. The other hotel set the PTAC at about 70 degrees and let it operate when the room was not occupied.

10.1.8.1.2 Room Orientation

It was likely the energy use functions for similar rooms with significantly different exposures to sun (fully exposed south facing, interior shaded courtyard, etc.) could differ. For this reason, the monitored sites were distributed between the two or three most significant orientations. Recognizing occupancy patterns in occupied rooms vary widely even in “occupied” rooms, it was necessary to group rooms with similar orientations for analysis to develop aggregated energy use functions for different orientations.

10.1.8.1.3 Auxiliary Measurements

The monitoring data included measurement of the return and supply air temperature at each PTAC. These monitored variables were used to develop a broader working understanding of the PTAC operation in practice. In the foregoing discussion, these variables are not explicitly used in the development of the energy use functions, but these variables were used to understand the operation of the PTAC modes in practice. For example, fan-only operation could be distinguished from cooling operation by inspection of the return and supply temperatures. The return air temperature and humidity were also useful as a description of interior conditions and could be necessary to develop a normalizing correction of results for interior conditions.

10.1.9 Detailed Findings

Table 10-6 presents the projected annual energy use by the average room in the existing unit sample and in the new unit sample. The annual energy use was estimated by projecting an annual kWh for the average room in the existing unit sample and in the new unit sample. This projection assumes the occupancy pattern observed during the occupancy interval of one month persists for the entire year. The occupancy patterns for lodging units were observed to be very irregular with instances of units being left on for days at a time, or not used at all for long periods. The use of cooling during times when the outdoor air was cooler than the indoor air was quite frequent. The annual estimate intends to capture this irregular occupancy.

For Site 1 it is apparent that the new units project significant annual savings relative to their counterparts. This hotel replaced Carrier PTAC with Amana PTAC.

At Site 2, the annual projected savings for the new units are negative, that is, the new units consume more energy than their counterparts. This appears largely due to room occupancy and PTAC usage patterns. At this site, the replaced units were heat pumps (PTHP) and the new units installed were electric resistance heat, air conditioners (PTAC). The savings at Site 2 will be more negative if the increased heating energy caused by the resistance heating elements in the new units is included in the analysis. The analysis has been restricted to cooling performance only.

It is interesting to note that Site 1 is in a mild climate zone, climate zone 7, and Site 2 is in the hotter climate, climate zone 10. Yet, the cooling use of the existing units in the milder zone 7 sites (942 kWh) was more extensive than the cooling use of existing units (709 kWh) in the much warmer zone 10. This apparently contradictory result is traceable to very different operating philosophies in the two hotels. The milder zone 7 hotel was an upscale establishment (tourist and business hotel) that kept rooms comfortably conditioned for any arriving guests. The zone 14 hotel was a “super economy” residence hotel that turned off all units if the room was not occupied.

Table 10-6: Monitored Annual Energy Usage

	Climate Zone	Unit Condition	Number of Qualifying sites	Average Annual Energy Use (kWh)	Average Grid Demand (kW)	Average Annual Savings (kWh)
Site 1	7	New	9	521.9	0.324	
	7	Existing	9	941.5	0.884	419.6
Site 2	10	New	9	1024.0	0.898	
	10	Existing	9	708.8	0.622	-315.2

An effort to measure relative output of existing versus the new units was done by means of steady state analysis. In a steady state analysis the kWh per degree hour sustained during compressor operation is calculated. It was found by inspection of the data that a steady state measurement could be made during hours when the compressor was operating almost the full hour. The data showed the peculiar characteristic that the compressor would operate at full capacity regardless of the outdoor temperature so that any sort of a steady state performance measurement was best made when the difference between the outdoor and indoor temperatures was at least 20 degrees (it was at least 90 degrees outside).

These steady state measurements are presented in Table 10-7. This table presents both the relative performance efficiency (kWh per room degree hour) and peak power of the unit. The kWh per delta T refers to the power consumption of the unit per degree of temperature difference (inside to outside temperature). The lower kWh pre delta T in the new units at Site 1 demonstrates the units use less energy for each degree of cooling; therefore, they operate at higher efficiency.

Note in the next table that at Site 1, the peak power of the new units is greater than the peak power of the existing units, yet the efficiency of the new units (kWh/degree hour) is better than the old units. This provides a physical basis for the significant savings shown by the new units at Site 1.

By contrast, the maximum power for the new units at Site 2 is almost identical to the existing units at Site 2 and the relative steady state efficiency is also almost identical between the new and existing units at this site. This suggests there is no physical basis for savings at this site and the apparent increase in usage is due to an occupancy aberration.

Table 10-7: Steady State Measurement

Site	Climate Zone	Unit Condition	Number of Qualifying sites	Average Peak Power	kWh/ΔT
Site 1	7	New	9	1.55	0.0273
	7	Existing	10	1.43	0.0447
Site 2	10	New	7	1.12	0.0295
	10	Existing	6	1.13	0.0287

Site 1 shows clear savings from the replacement. Site 2 does not show clear savings, and probably actually shows a loss because of the resistance heat element. At Site 2, there was no difference in the steady state measurement; it suggests the old and new units would perform identically. In addition, there were too little data to draw conclusive observations from Site 2, and, 70 percent of the PTAC/PTHP measures were installed in climate zone 7. Operating procedures varied greatly between sites. Therefore, there is not enough compelling evidence to reject the ex-ante estimates.

10.1.10 NTG Survey Analysis

A modified version of the Joint Simple NTG survey was conducted for the SDG&E 3029 PTAC/PTHP program. Results of the survey were used to assess free-ridership in the program and to determine whether the NTGR of 0.8 used in program planning assumptions should be adjusted for actual free-ridership.

Although there were 768 PTAC/PTHP units for which savings were claimed under the 2006-2008 program period, there were only 12 actual participants, or hotel decision makers. The Specialized Commercial CG Evaluation Team successfully contacted all twelve decision makers and completed interviews.

A net-to-gross ratio was calculated from survey responses as per the proscribed free-ridership algorithm for the Joint Simple NTG survey. The NTG ratio calculated was then weighed by the ex-ante savings associated with the survey respondents. The evaluated savings-weighted net-to-gross ratio calculated for the SDGE 3029 PTAC/PTHP Program is 0.25, which indicates high free ridership in the program.

The evaluation team reviewed the individual responses and found the algorithm produced 100% free ridership scores for six respondents. There were inconsistencies within responses that were not resolved by other survey questions. Therefore, the evaluation team passes through the ex-ante NTGR of 0.80.

10.1.11 Program Specific Results

While experimental work confirmed the general magnitude of the ex-ante estimate, evaluators believe the ex-ante should be used for the class as a whole rather than base the savings found from two very different sites. Therefore, evaluators chose to pass through the ex-ante annual energy and demand savings. However, we retained the 95% installation rate observed in field verifications.

Table 10-8. PTAC/PTHP Energy Savings Summary

Program Name	Measure Ex-ante Gross kWh Savings	Measure Ex-post Gross kWh Savings	Install Rate	Measure Installed Ex-post Gross kWh Savings	Measure NTG	Measure Ex-post Net kWh Savings
SDG&E 3029 PTAC/PTHP	592,399	592,399	95%	569,437	.80	450,223

Table 10-9. PTAC/PTHP Demand Savings Summary

Program Name	Measure Ex-ante Gross kW Savings	Measure Ex-post Gross kW Savings	Install Rate	Measure Installed Ex-post Gross kW Savings	Measure NTG	Measure Ex-post Net kW Savings
SDG&E 3029 PTAC/PTHP	250	250	95%	237.50	.80	190.0

10.1.12 Findings and Recommendations

1. The replacement of packaged terminal heat pump units with packaged terminal AC units will lead to an increased heating energy usage and should not be allowed.

2. The two hotels metered exhibited very different occupancy patterns and operations policies. Ideally, hotels would turn off the AC or minimize usage when the room is unoccupied. There is high variability in operating practices with this industry.

Report Abbreviations

Abbreviation	Definition
A/C (AC)	Air Conditioning
ACCA	Air Conditioning Contractors of America
ACM	Alternative Calculation Method
ACP	Air Care Plus
ADM	ADM Associates
AEC	Architectural Energy Cooperation
AERS	Automated Energy Review for Schools
AHP	Analytic Hierarchy Process
ARI	Air Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEA	Building Efficiency Analysis
Bldg	Building
C&I	Commercial
C&S	Codes & Standards
CASE	Codes and Standards Enhancement Initiative
CATI	Computer Assisted Telephone Interviewing
CBEE	California Board of Energy Efficiency
CEC	California Energy Commission
CFL	Compact Fluorescent Lamp
CG	Contract Group
CHEERS	California Home Energy Efficiency Rating Services
CIEE	California Institute for Energy Efficiency
CMFNH	California Multifamily New Homes Program
CMMHP	Comprehensive Manufactured-Mobile Home Program
CPUC	California Public Utilities Commission
CRCA	Computerized Refrigerant Charge & Airflow
CTZ	Climate Thermal Zone
CV	Coefficient of Variation
CZ	Climate Zone
DEER	Database for Energy Efficiency Resources
DFC	Designed for Comfort
DHW	Domestic Hot Water
DRET	Demand Response Emerging Technologies
DSA	Division of the State Architect
ECM	Energy Conservation Measure
ED	Energy Division
EE	Energy Efficiency
EEGA	Energy Efficiency Groupware Application
EER	Energy Efficiency Rating
EUL	Economic Useful Life
FLA	Full Load Amps
GWh	Gigawatt
HERS	Home Energy Rating System

Abbreviation	Definition
HIM	High Impact Measure
HMG	Heschong Mahone Group
HUD	Housing & Urban Development
HVAC	Heating, Ventilation & Air Conditioning
ICF	ICF International
IDEEA	Innovative Designs for Energy Efficiency Applications
InDEE	Innovative Design for Energy Efficiency
IOU	Investor Owned Utility
IPMVP	International Performance Measurement and Verification Protocol
ITD	Installed To Date
kW	Kilowatt
kWh	Kilowatt Hour
LADWP	Los Angeles Department of Water & Power
LEED	Leadership in Energy and Environmental Design
LPD	Lighting Power Density
LTO	Leakage to Outside
M&V	Measurement & Verification
MECT	Master Evaluation Contractor Team
MF	Multifamily
MHRA	Manufactured Housing Research Alliance
Mil	Million
MS	Microsoft
n	Sample Size
NAC	Normalized Annual Consumption
NC	New Construction
NCCS	New Construction/Codes & Standards
NOMAD	Naturally Occurring Market Adoption
NOSAD	Normally Occurring Standards Adoption
NP	Non Participant
NRNC	Non Residential New Construction
NTG	Net-to-gross
NTGR	Net-to-gross Ratio
NTP	Notice to Proceed
P	Participant
Pa	Pascal
PG&E	Pacific Gas & Electric
PIER	Public Interest Energy Research
PTAC	Packaged Terminal Air Conditioner
PTHP	Packaged Terminal Heat Pump
PY	Project Year
Q2	Second Quarter
Q3	Third Quarter
Q4	Fourth Quarter
QA	Quality Assurance
QC	Quality Control
QII	Quality Insulation Installation
RCA	Refrigerant Charge and Airflow

Abbreviation	Definition
Res	Residential
RFP	Request for Proposal
RH	Relative Humidity
RLA	Rated Load Amps
RMSE	Root Mean Square Error
RNC	Residential New Construction
ROB	Replace on Burnout
RP	Relative Precision
RTU	Roof Top Unit
SAS	Statistical Analysis Software
SBD	Savings By Design
SCE	Southern California Edison
SCG	Southern California Gas
SCP	Sustainable Communities Program
SDG&E	San Diego Gas & Electric
SEER	Seasonal Energy Efficiency Rating
SF	Single Family
SFA	Single Family Attached
SHGC	Solar Heat Gain Coefficient
SOW	Statement of Work
sqft	Square Foot
T24	Title 24 Building Energy Efficiency Standards
TBD	To Be Determined
TXV	Thermostatic Expansion Value
UES	Unit Energy Savings
VFD	Variable Frequency Drive
VSD	Variable Speed Drive
VSP	Verification Service Providers
W/SF	Watts per square foot
WH	Water Heater