DNV·GL

Impact Evaluation of 2015 Commercial Quality Maintenance Programs (HVAC3)

California Public Utilities Commission

Date: April 7, 2017

CALMAC Study ID CPU0117.04

LEGAL NOTICE

Table of contents

List of figures

List of tables

1 EXECUTIVE SUMMARY

This report presents DNV GL's impact evaluation of heating, ventilation, and air conditioning (HVAC) quality maintenance (QM) measures and programs administered by the California investor-owned utilities in 2015. We performed this work under contract with the California Public Utilities Commission (CPUC) Energy Division (ED). Consistent with study numbering used for the 2013-15 evaluation studies, this QM study is referred to as HVAC3.

This work is a continuation of ongoing evaluation research on the California QM and related HVAC tune-up programs. In April 2016, DNV GL completed an evaluation of the 2013-14 programs[1] (referred to in this document as our previous HVAC3 evaluation). In addition to new field work, the current study relies on data and findings from the previous evaluation, laboratory research[2], and ex ante program data to develop gross energy and demand savings for the 2015 programs. We also rely on our recently published QM net-to-gross (NTG) study[3] to develop net savings estimates for these programs.

The primary goals of the previous 2013-14 and this 2015 evaluation was

- To assess the efficacy of the key measures installed and the subsequent savings achieved from QM programs, and
- To provide insight on how effective these programs are and what improvements can be made to move towards the strategic energy efficiency goals.

1.1 Study focus

HVAC system maintenance involves many specific activities that address unit deficiencies such as cleaning dirty condenser coils or adjusting levels of refrigerant. The QM programs in California have historically reported bundled savings made up of multiple measures installed on one HVAC unit. However, several programs moved away from that structure in this program cycle, and reported measure-level savings. Hence to provide more relevant information on program performance, to the extent possible we selected a measure-level evaluation structure prioritized by measures with the most energy-savings in program claims. For the 2015 study, DNV GL evaluated the following measure groups implemented through investor-owned utility (IOU) QM and tune-up programs:

- Five key commercial measure groups: economizer (replacement, repair, or adjustment), thermostat (replacement or adjustment), coil-cleaning, supply fan (control adjustment), and refrigerant charge adjustment (RCA)
- One bundled commercial QM measure group
- Three residential measure groups implemented through the IOU's QM programs: coil cleaning, supply fan (airflow adjustment or blower motor replacement), and refrigerant charge adjustment (RCA)

Figure 1 shows a schematic drawing of a common HVAC unit, such as is found on many commercial building rooftops, and identifies the five measure groups (three that pertain to both residential and commercial

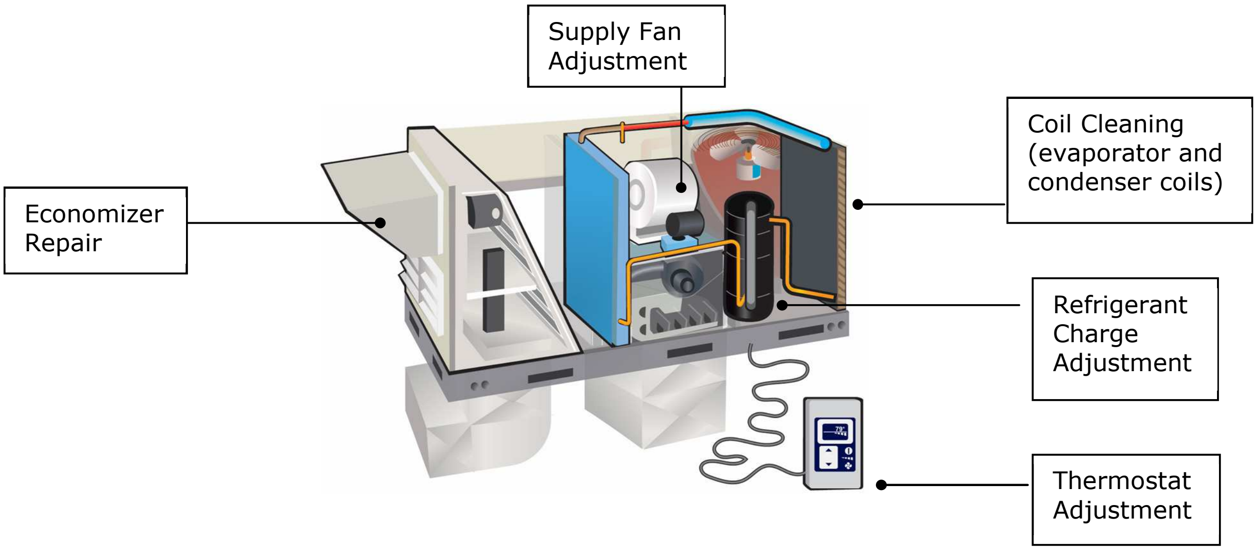
[1] CPUC 2016. Impact Evaluation of 2013-14 Commercial Quality Maintenance Programs (HVAC3). www.calmac.org/publications/HVAC3ImpactReport_0401ES.pdf

[2] CPUC, 2017 (in press). Laboratory HVAC Testing Research for 2013-14 (HVAC5): An Introduction and Data Dictionary.

[3] CPUC 2016. Net-to-gross Evaluation of 2013-14 Commercial Quality Maintenance Programs (HVAC3). http://www.calmac.org/publications/HVAC3_NTG_Final_Report_2016-12-07.pdf

programs and two that pertain only to commercial programs) targeted in the evaluation. The measure groups address different components of the unit, with the goal to improve overall performance by addressing the most important aspects that affect energy consumption. Energy savings accrue when units are adjusted for their best performance.

Figure 1. Schematic of a rooftop unit and location of evaluated QM measure groups



- The economizer-repair measure group, which includes economizer repairs and an economizer controller replacement, saves energy by increasing the use of outside air for cooling (during cooler periods) and decreasing the compressor run time.
- The thermostat-adjustment measure group saves energy by adjusting the occupied and unoccupied thermostat set point schedules to reduce the required cooling and heating energy.
- Coil cleaning saves energy by removing dirt, which reduces pressure drop, increases airflow, and improves the heat transfer rate across the condenser or evaporator coil.
- The supply-fan controls measure group saves energy by not running the fan and/or bringing in outdoor ventilation air to the building during unoccupied hours.
- The RCA measure saves energy by adding or removing refrigerant charge from the refrigeration circuits to achieve optimal levels and improve system performance.

1.2 Evaluation approach

For the commercial QM measures, DNV GL used an engineering approach for assessing savings. Field measurements were taken and combined with data collected in the previous HVAC3 evaluation to develop a dataset of ex post values for key QM parameters. Examples of key parameters include economizer changeover set points, thermostat set points, and level of refrigerant charge. These data were used to update the ex ante parameter assumptions used to develop program savings claims. The updated parameters where then run through the same DEER eQuest models that were used to develop the ex ante program savings estimates. The runs with the updated parameters translate changes in the key parameters into changes in estimated energy and peak demand savings.

The engineering analysis provided estimates of gross program impacts, which were then adjusted by NTG ratios to provide net program impacts. The NTG ratios were developed through interviews of participating program contractors in the separately reported NTG study.

The residential programs were evaluated using billing analysis that was developed by Itron as a subcontractor to DNV GL on this study. Gross program impacts were developed using participant models, while the net program impacts were developed using models estimated on both the participant and matched non-participant sample. The development of both gross and net savings estimates satisfies the need to report gross savings estimates while also providing an estimate of the net-to-gross ratio and savings attributable to the program. The final models utilized hourly AMI data.

1.3 Gross program savings results

This evaluation estimated the achieved savings and compared them with the expected savings as a ratio called gross realization rate (GRR). This ratio includes the evaluated (ex post) installation rate and evaluated adjustments to the unit energy savings. Table 1 provides a summary of the gross realization rates for the IOU programs and measure groups evaluated in this study. Empty table cells are those program measure groups that had no implementation (ex ante) claims in a specific program.

Table 1. Gross kWh realization rates of evaluated QM programs and measure groups

	Economizer 	Thermostat 	Coil Cleaning 	Supply Fan 	Refrigerant Charge 
Pacific Gas and Electric Company (PG&E)					
Commercial QM	**77%**	**103%**		**47%**	**36%**
AirCare Plus	**100%**	**115%**	**426%**	**47%**	**37%**
Residential QM				**37%**	**123%**
San Diego Gas and Electric Company (SDG&E)					
Deemed Incentives–Commercial HVAC			**160%**		**81%**
Commercial Direct Install	**100%**	**40%**	**53%**		**32%**
Residential QM	**48%**				
Southern California Edison (SCE) and Southern California Gas Company (SoCalGas)					
Commercial QM	**135%**				

The SDG&E residential QM program could not be evaluated on a measure level basis. SCE Commercial Quality Maintenance program did not report claims on a measure level so a program-wide realization rate is given. The coil cleaning realization rates are a weighted average of condenser and evaporator coil cleaning realization rates.

As with our previous HVAC3 evaluation, the 2015 GRRs were mixed, with some GRRs greater than 100% and others falling below 100%.

- The economizer gross realization rates range between 77% and 100%, and they were noticeably higher than in previous HVAC3 evaluation, where the GRRs ranged from 43% to 56%. The primary factor driving a lower GRR for this measure was the observation during field visits that a number of "repaired" economizers were not operating. We saw an installation rate improvement of about 10% compared to our previous HVAC3 evaluation.
- The thermostat GRRs were 103% for PG&E's Commercial QM program, 115% for PG&E's AirCare Plus program, and 40% for SDG&E's Direct Install program, reflecting findings that most of PG&E's thermostats met or exceeded the program setback requirement while half of SDG&E's thermostats did not meet program setback requirements during unoccupied periods.
- The coil cleaning measure GRRs ranged from 53% to 426%. The AirCare Plus program's large GRR is at least partly due to PG&E's reduction of their claimed savings by approximately 90% as directed by the CPUC Energy Division Disposition of the 2013-14 workpapers issued June 2013. The AirCare Plus program also achieved a high GRR in the previous HVAC3 evaluation (353%).
- The commercial supply fan adjustment GRR of 47% is based on verification surveys that indicated the program baseline requirements (fan being on continuously in the pre-retrofit case) were only met 47% of the time. The residential GRR of 37% for this measures was determined through a billing analysis that doesn't provide additional insight into measure performance.
- The commercial refrigerant charge adjustment GRRs range from 32% to 81%. The RCA analysis relied on previously collected data and the GRRs are similar to the previous HVAC3 results. The higher GRR for the SDG&E Deemed Incentive program reflects the fact that SDG&E lowered their claimed savings for 2015. The residential GRR of 123% for this measures was determined through a billing analysis that doesn't provide additional insight into measure performance.
- The bundled commercial QM program for SCE achieved a GRR of 135%. This GRR reflects the fact that the program installed measures more often than was assumed in the workpapers.
- The bundled SDG&E residential QM program was found to have a GRR 48%, based on the billing analysis. This is driven by the fact that the program claimed high savings for fan controls, but SDG&E reduced their per unit ex ante claims for measures installed in the last quarter of 2015.[4]

Gross program savings estimates are derived by applying the GRRs to ex ante tracking data. First year electric savings are reported in Table 2 for all evaluated programs and gas savings are reported in Table 3 for those programs that reported therm savings.

We discuss demand savings very little in this report because they are low for most of the measures installed through HVAC QM and tune up programs. The most significant demand savings come from RCA and coil cleaning measures that increase the efficiency of the HVAC unit, hence reducing the kW draw when it is running. Economizer measures have slight kW savings caused by climates where the economizer operates during peak demand periods. Similarly, thermostat measures produce very small demand savings, and supply fan measures have no demand savings. Some of the reported demand realization rates are large or

[4] The residential HVAC fan control measure group is a fan controller device using built-in logic to delay the evaporator fan cycle off time.

small, and that is caused by the difficulty of calculating and reporting a small number. Small modeling changes have a relatively large effect on the demand savings.

Table 2. First year gross electric impacts of evaluated QM programs

Program Name	Claimed kWh Savings	Claimed kW Savings	Evaluated Reali-zation Rate kWh	Evaluated Reali-zation Rate kW	Evaluated kWh Savings	Evaluated kW Savings
PG&E Commercial Quality Maintenance	6,640,718	316	74%	159%	4,908,834	502
PG&E AirCare Plus	3,218,761	176	108%	112%	3,491,595	197
PG&E Residential Quality Maintenance	5,627,449	4,578	49%	-	2,739,757	-
SCE Quality Maintenance	3,517,807	1,242	135%	41%	4,737,119	505
SDG&E Deemed	2,653,960	1,508	105%	116%	2,783,819	1,753
SDG&E Direct Install	2,926,735	358	46%	104%	1,354,573	371
SDG&E Residential Quality Maintenance	310,167	148	48%	-	149,769	-
Total	**24,895,598**	**8,326**	**81%**	**40%**	**20,165,466**	**3,328**

The residential programs were not evaluated for kW savings.

Table 3. First year gross gas impacts of evaluated QM programs

Program Name	Claimed therm Savings	Evaluated Reali-zation Rate therms	Evaluated therm Savings
PG&E Commercial Quality Maintenance	515,788	35%	182,229
PG&E AirCare Plus	284,449	12%	34,660
SCE Quality Maintenance	14,496	-	0
SoCalGas Quality Maintenance	7,146	40%	2,877
SDG&E Deemed	-245	-	0
SDG&E Direct Install	271,646	-1%	-3,009
Total	**1,093,279**	**21%**	**216,756**

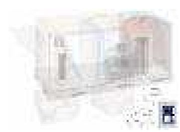
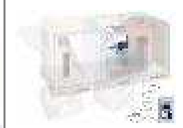
The residential programs were not evaluated for them savings.

1.4 Net program savings results

As stated above, commercial QM program NTG ratios were developed from a separate NTG study and are applied here to provide net commercial program savings results. Net residential QM program savings were developed directly from a billing analysis, and the implied NTG ratios are calculated by dividing net savings by gross savings.

Despite these low NTG ratios, however, there were a few encouraging results. The NTG ratios for the RCA measure were much higher than those for other maintenance measures. Furthermore, these NTG ratios were also higher across all three programs with this offering. These results suggest that the programs are influencing the adoption of this measure group. Combining the NTG ratios with the GRRs provide net program realization rates, which are shown in Table 4 for kWh.

Table 4. Net kWh realization rates of evaluated QM programs and measure groups

	Economizer 	Thermostat 	Coil Cleaning 	Supply Fan 	Refrigerant Charge 
PG&E					
Commercial QM	28%	37%		17%	13%
AirCare Plus	36%	41%	153%	17%	13%
Residential QM				23%	51%
SDG&E					
Deemed Incentives– Commercial HVAC			57%		29%
Commercial Direct Install	73%	29%	39%		23%
Residential QM	0%				
SCE and SoCalGas					
Commercial QM	48%				

The SDG&E residential QM program was not evaluated on a measure level basis. SDG&E's Direct Install program was not evaluated in the NTG effort so we have assigned the claimed NTG ratio of 0.73 for that program. SCE Commercial Quality Maintenance program did not report claims on a measure level so a program-wide realization rate is given. The coil cleaning realization rates are a weighted average of condenser and evaporator coil cleaning realization rates. SDG&E's residential program had measured net savings less than zero, but a value of zero has been assigned.

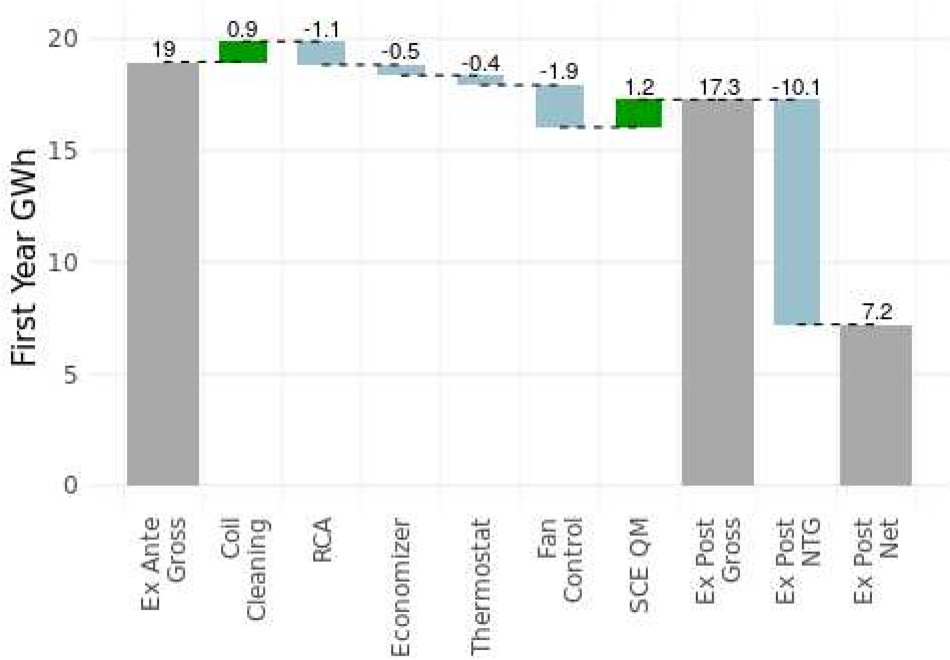
NTG ratios and net impacts are shown in Table 5, and a graphical presentation of the results is shown in Figure 2. Key measures contributing to evaluated gross results being lower than claimed savings are RCA and fan control measures. The bundled SCE QM measure contributed to an increase in evaluated savings compared to claimed savings. The biggest adjustment came when going from evaluated gross savings to evaluated net savings. The evaluation NTG ratio of 42% is lower than the average claimed NTG ratio of 76%.

Table 5. QM program net-to-gross ratios and net impacts

Program Name	Evaluated kWh Savings	Evaluated NTG ratio kWh	Net Evaluated kWh Savings	Evaluated therm Savings	Evaluated NTG Ratio therm	Net Evaluated therm Savings
PG&E Commercial Quality Maintenance	4,908,834	36%	1,767,180	182,229	25%	45,557
PG&E AirCare Plus	3,491,595	36%	1,256,974	34,660	25%	8,665
PG&E Residential Quality Maintenance	2,739,757	54%	1,476,287	-	-	-
SCE Quality Maintenance	4,737,119	36%	1,705,363	-	-	-
SoCalGas Quality Maintenance	-	-	-	2,877	25%	719
SDG&E Deemed	2,783,819	36%	1,002,175	-	-	-
SDG&E Residential Quality Maintenance	149,769	0%	0	-	-	-
Total	**18,810,893**	**42%**	**7,207,979**	**219,756**	**25%**	**54,941**

The SDG&E Direct Install program was not evaluated for NTG ratio. Evaluated gross savings from Table 2 were applied to the claimed NTG which varied by measure.

Figure 2. Commercial QM savings breakout by key measure group



1.5 Conclusions and recommendations

The implementation and evaluation of QM and related HVAC tune-up measures have evolved over the last decade. The changes to programs, measures, and the evaluation of impacts present challenges to assessing and tracking performance. Overall, the achieved savings were lower than expected relative to the workpapers and ex ante dispositions, but in the context of past measure performance, there are some clear improvements, particularly for economizers.

We observed large variation in HVAC system pre-treatment baseline performance when we visited sites that had not yet participated in the program. Some rooftops displayed new, clean equipment and others had dirty, rusted, poorly functioning HVAC equipment. We also observed equipment economizers that were not functioning after program repair and discrepancies in assumed thermostat settings and program adjustments.

Given the overall HVAC unit performance gains found in this evaluation, we conclude that QM provides uncertain energy impacts. Therefore, addressing other larger system issues, such as distribution losses, and improving the operation of advanced digital economizer controls may provide greater energy savings opportunities than the other individual measures addressed in this evaluation. We recommend continuation of pilots and development of holistic measures including improvement of previously installed non-functioning advanced digital economizer controls and increased incentives to replace the dirty, rusty, poorly functioning units as opposed to maintaining them.

We also note that improvement is necessary in the data that support tracking system claims. Implementers collect data on the installed measures, but these data are not part of the standardized savings claims database submitted to the CPUC by the IOUs. The link between the tracking data claims and the implementer data is not well established. We found it difficult to use the large volume of data collected by the programs, without this link, but we believe there is great value in this site- and unit-specific data for truing up workpaper assumptions and improving the accuracy of program claims.

Lack of integrated implementer data may have contributed to low gross realization rates, as the IOUs may have claimed savings that were either ineligible or not actually fully implemented. We also view the implementer data as providing the supporting documentation behind the tracking system savings claims, and the inability to link the implementer data with the tracking data raises verification concerns about the validity of the tracking savings estimates.

Despite some mixed results for 2015, we note improvements over the past two program years. The HVAC industry seems to have momentum toward improvement with the Western HVAC Performance Alliance work[5] and energy code[6] (referred to as The Standards) requiring onboard fault detection for new units.

1.5.1 Commercial program recommendations

Measure-specific program recommendations based on field observations, include:

- *Economizers*: We found overall that the newer advanced digital economizer controllers (referred to as ADEC) were functioning more often than the older analog type. The industry is moving toward

[5] http://www.performancealliance.org/WHPAWorkProducts/tabid/440/Default.aspx

[6] California Title 24, Part 6 Building Energy Standards (http://www.energy.ca.gov/title24/2016standards/index.html)

ADEC, and we recommend that the programs increase training on how to install and program the units, as they are more complicated and we found setup errors such as incorrectly wired sensors and incorrectly programmed controllers. The Standards require that economizers be integrated with cooling operation and we recommend that the programs include this aspect of economizer control set-up in their training courses.

- *Thermostat adjustment*: We recommend that program-adjusted thermostats be periodically checked to maintain energy savings throughout the claimed measure life.
- *Coil cleaning*: We recommend continuing this measure as a low-cost, low-savings item. We found a high degree of variation in energy savings from units tested and suspect that the savings vary depending not only on the potential for savings given the degree and type of fouling, but also on the cleaning technique. Although our study did not find large energy savings from coil cleaning, it still has a very important role from a hygiene perspective, and we do not recommend that the practice be abandoned.
- *Supply fan controls*: We recommend better targeting of the measure to units that do not already have the supply fan in automatic mode or switched off during unoccupied building periods. A baseline study could help determine the potential for savings from this measure.
- *RCA*: We recommend continuing this measure only in cases where the refrigerant circuit is low or devoid of refrigerant because savings are small for the observed adjustments. Although it is important to detect circuits with extremely low refrigerant charge, we caution against over-use of refrigerant pressure measurement devices since the process of attaching and detaching them can release refrigerant, harming the atmosphere, and slightly reducing refrigerant in the circuit each time it is checked.

Despite the overall mixed program savings results, we believe that the programs are providing valuable services to at least a portion of the participating contractors, and helping to move the HVAC industry in the right direction.

We recommend exploring additional measures that could better address system performance issues followed by ongoing maintenance. A potential change in strategy to improve gross savings may be to identify the high-quality practices and contractors and focus on getting those contractors to sites most in need of performance improvements. The program would then not seek to improve the quality of all contractors, but focus on getting the top-quality contractors to the poorest performing sites. As discussed in the NTG report, the baseline for both the gross and the net savings estimates was the absence of the measure rather than a poorly installed measure. Contractor responses in the NTG survey indicated that in many instances they installed the same measures outside of the program as within the program which lead to a low NTG ratio.

To address measure quality in the future, we recommend updating the workpapers so the gross baseline is a poor maintenance-level rather than no maintenance at all. This will require a baseline study of measures installed in the absence of utility QM or tune-up programs.

1.5.2 Residential program recommendations

The savings derived from the residential QM programs has been uncertain. The 2013 Workpaper Disposition for these programs revised the QM measure group ex ante savings down substantially due to concerns about the use of incorrect maintenance techniques that could lead to either an improvement in efficiency or an increase in energy usage. The findings from the billing analysis implemented on 2013 and 2014 program participants in PG&E's and SDG&E's service territories reinforce the CPUC's concerns. SDG&E's residential QM program had no net energy savings and PG&E's had a net realization rate of 26% in 2015.

Given these findings, the evaluation team recommends the residential QM programs apply the workpaper disposition savings per ton for RCA and fan repair. The ex ante estimate of blower motor and fan control savings appears to exceed the realized values and may need to be adjusted downward.

1.5.3 Ongoing evaluation activities

This evaluation developed savings estimates by using repeatable field measurements that correlate to laboratory performance data for coil cleaning and RCA measures. It also provided an evaluation methodology that accounted for variability across building types and climate zones through modeling, including measuring parameters on-site that have less variability than the overall HVAC end-use, leading to more cost-effective data collection efforts. Going forward, this approach can be scaled to add sample points and implementer data can be used to support more accurate savings estimates. There are remaining and new evaluation challenges to overcome. Additional improvements for future evaluations objectives could include:

- Collecting additional data on why economizers are not functioning. Specifically, if we collect more information to characterize failure modes it should lead to more focused repairs in the future.
- Collecting economizer airflow data to further quantify outside airflow rates, particularly at low flow conditions. And continue with more investigation of baseline economizer outside air flows.
- Further study on "smart" thermostats which are now entering the program and can serve as a demand control vehicle. These thermostats could possibly improve the persistence of the thermostat measure.
- Continuing to develop in-field performance measurement. The 2015 evaluation added promising new field instrumentation to determine refrigerant cycle performance.[7] [8] The equipment was used for the evaluation of the coil cleaning measure in this evaluation but it could be applied to all measures either individually, or the comprehensive QM measure. Humidity sensors could be added to improve estimation of the coil bypass factor. IOU programs and pilots are concurrently developing system performance measurement approaches[9] that could also be used for evaluation.
- Continuing the comprehensive measure-specific measurement approaches that provide the opportunity for better quantification of the interactive effects and measuring the difference between the savings from the sum of individual measures.
- Perform a baseline study to characterize market driven HVAC system maintenance practices.

There will remain significant uncertainties in measuring QM impacts, but there appears to be general acceptance that relative changes in key parameters can be detected. New measure strategies can be tested and piloted in the field if there are consistent measurement approaches to assess the performance changes.

---

[7] http://www.climacheck.com/dl.php?did=76

[8] http://media.home.climacheck.com/2015/01/8_18410_BerglofIEAJune2005.pdf

[9] https://www.nationalcomfortinstitute.com/pro/index.cfm?pid=4030

2 INTRODUCTION

This report presents DNV GL's impact evaluation of commercial and residential quality maintenance (QM) and related heating, ventilation, and air conditioning (HVAC) tune-up programs that are part of the California Public Utilities Commission (CPUC) HVAC Research Roadmap. The primary results of this evaluation are ex post gross and net energy impacts (in kWh, kW, and therms) achieved by the 2015 HVAC QM programs offered by four California investor-owned utilities (IOUs): San Diego Gas and Electric Company (SDG&E), Southern California Edison (SCE), Southern California Gas Company (SoCalGas), and Pacific Gas and Electric Company (PG&E).

"Quality maintenance" in general refers to multiple HVAC energy efficiency improvement measures and specific procedures for their implementation based on ANSI/ASHRAE/ACCA[10] Standard 180, Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems. In the 2013-15 period, PG&E, SCE, SoCalGas, and SDG&E implemented commercial and residential HVAC QM activities through a variety of different administrative channels and program structures. Although residential QM programs contributed less than 10% of the overall ex ante savings and were not evaluated in our previous HVAC3 study, they were considered an important aspect of the portfolio, and therefore we added to the current evaluation.

In the 2013-15 program cycle, PG&E phased out reporting an overarching QM measure in their tracking system and phased in individual measures such as "coil cleaning" and "supply fan control" for its Commercial QM HVAC program. SDG&E discontinued its Commercial QM program all together (leaving only tune-up programs), and SCE retained its bundled QM program status quo from the previous cycle. Although SCE's QM program volume was considerably lower than any of the other QM or HVAC tune-up programs in 2013, they finished the cycle in 2015 with volumes similar to the other programs.

2.1 Objectives

The primary objective of this evaluation is to assess the kWh, kW and therm savings achieved from QM programs. The focus is on the selected five highest-impact measures in 2013-15 commercial HVAC QM programs offered by SDG&E, SCE, SoCalGas, and PG&E and two residential HVAC QM programs offered by SDG&E and PG&E.

The secondary objectives of this impact evaluation are to:

1. Determine reasons for differences between ex post and ex ante savings
2. Provide results and data that will assist with updating ex ante workpapers and the California Database for Energy Efficiency Resources (DEER) values
3. Provide timely feedback to the CPUC, IOUs, and other stakeholders on the evaluation research study to facilitate timely program improvements and support future program design efforts and ex ante impact estimates

Two independent subcontractors, Balance Point Home Performance and Itron, assisted DNV GL to achieve these objectives by collecting new primary data on-site and completing residential billing analyses that support defensible ex post savings estimates.

[10] American National Standards Institute/ American Society of Heating, Refrigerating and Air-Conditioning Engineers/ Air Conditioning Contractors of America

2.2 Evaluated measure groups

DNV GL selected five high-impact HVAC measure groups for evaluation under the IOU QM programs: coil cleaning, refrigerant charge adjustment, economizer repair or adjustment, thermostat adjustment, and supply fan repair or adjustment. The measure groups were selected based on commercial program activity, and the residential activity happened to fall into the same categories. Each of the five groups includes several specific measures related to a particular category of treatment. For example, coil cleaning would include evaporator coil cleaning as well as condenser coil cleaning. High-impact measures are those that provided the greatest program savings, but they are not necessarily the measure groups with the highest savings per unit installed. Also, some measures within measure groups are installed much more frequently than others.

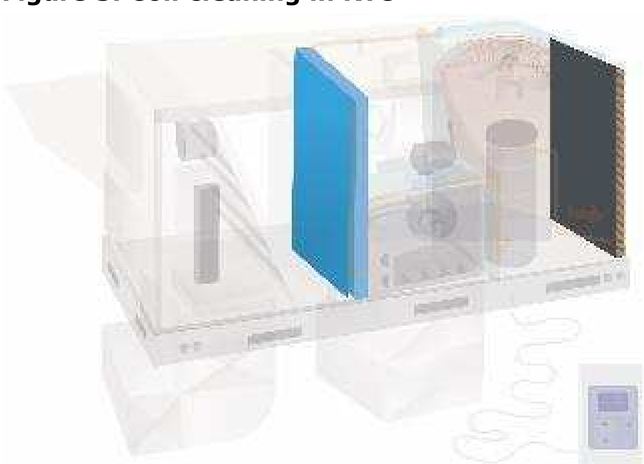
2.2.1 Measure group descriptions

The measure groups' processes and locations in a schematic HVAC rooftop unit (RTU) are shown in this section.

2.2.1.1 Coil Cleaning

Coil cleaning includes condenser or evaporator coil cleaning in the blue and brown areas shown in the RTU in Figure 3. The coil cleaning process involves spraying the coil with either water or chemical solution to remove the built-up grime that accumulates on the coil. Local conditions determine the rate at which particulates deposit on the coil, accumulating faster in areas with a lot of dust or kitchen grease near the HVAC unit. This measure was performed in both the commercial and the residential QM programs.

Figure 3. Coil cleaning in RTU



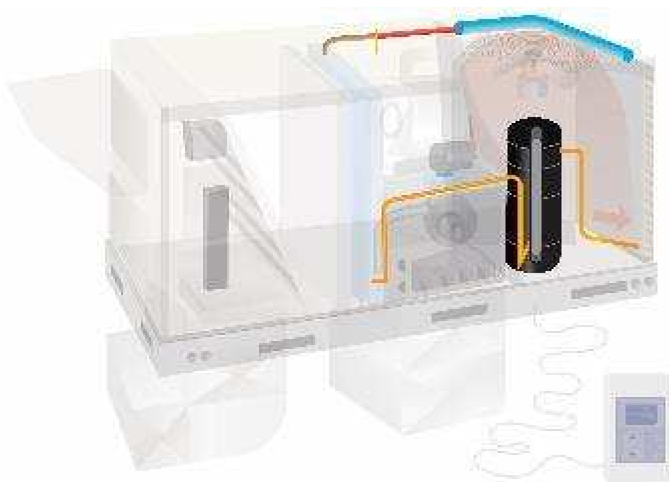
Coil cleaning saves energy by decreasing static pressure and increasing airflow and heat transfer rate across the condenser or evaporator coil. The heat transfer rate is determined by the mass flow rate of air and the coil's thermal resistance from air to the refrigerant. Dirt and debris build-up on the coil increases the thermal resistance across the coil, and reduces airflow thus reducing heat transfer rates. This increases the refrigerant pressure differential across the compressor, increasing compressor work/power.

2.2.1.2 Refrigerant charge adjustment

Another measure that was performed in both the commercial and residential QM programs, the RCA measure seeks to improve air conditioning unit performance by adding or removing refrigerant charge from air conditioning refrigeration circuits. An improved refrigerant charge level is assumed to produce energy savings compared to both an under or over charged system. The QM programs use system diagnostic tests and adjust charge amounts to achieve fault detection diagnostic targets.

Laboratory tests show that even in non-ideal system configurations, such as low system airflow, HVAC system efficiency is maximized at or near the factory refrigerant charge. In Figure 4, the compressor is represented as a black cylinder with refrigerant lines represented in yellow and line insulation in blue.

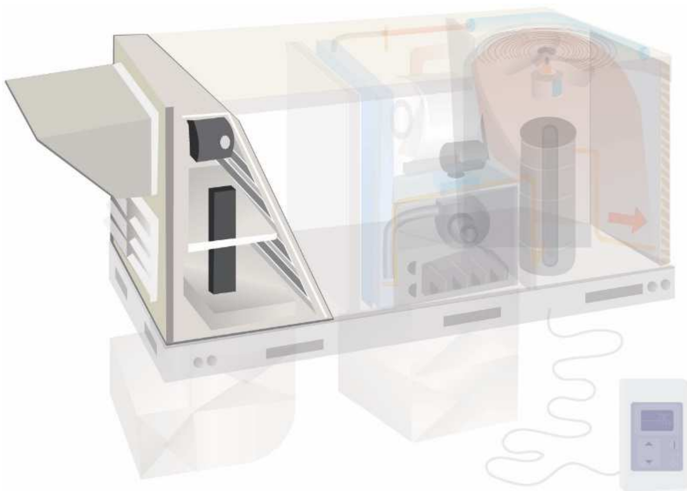
Figure 4. RCA in RTU



2.2.1.3 Economizer repair

This measure includes economizer repairs and economizer controller replacement with an advanced digital economizer controller. The measure saves energy by increasing the use of outside air for cooling (during cooler periods) and decreasing the compressor run-time. Energy savings are dependent on the volume of outdoor air entering the supply air stream at different economizer positions. This includes repair or replacement of the economizer or controls, located in left side of Figure 5. In California, economizers are required on HVAC package units larger than five tons that serve commercial building spaces. They are not required on residential units so this measure group is not installed through the residential QM programs.

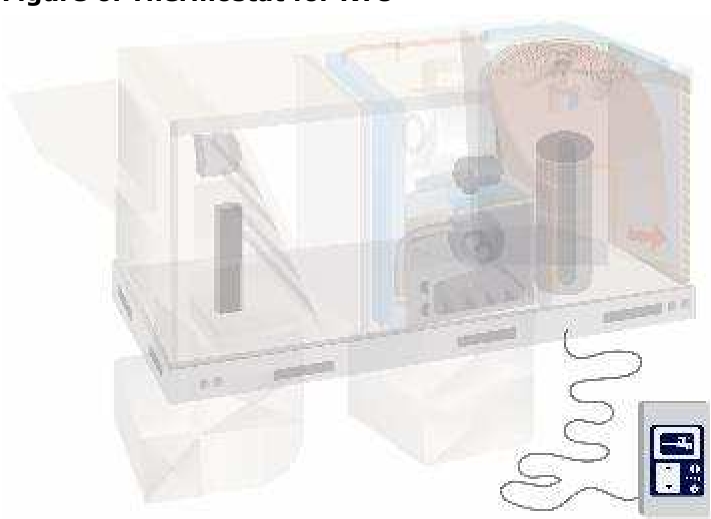
Figure 5. Economizer in RTU



2.2.1.4 Thermostat adjustment

These measures save energy by adjusting the unoccupied thermostat set point schedules to reduce the required cooling and heating load. The measure sometimes includes replacement of a non-programmable thermostat, but it can also simply be reprogramming of an already-installed programmable thermostat. The thermostat is shown connected to the HVAC unit in Figure 6. This measure group was commonly installed in the commercial QM programs, and not installed in any of the residential QM programs in 2015.

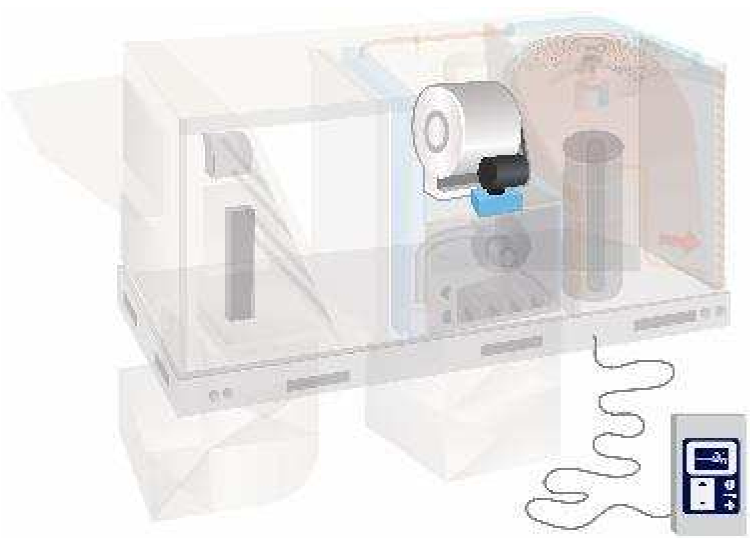
Figure 6. Thermostat for RTU



2.2.1.5 **Supply fan**

In the commercial QM programs the only supply fan measure implemented with any significant frequency was the supply fan control measure. It entails adjusting the unit controls, from "always on" to "cycle on with load" or "off" during unoccupied hours. The control is typically a thermostat although it could also be an energy management system. This measure saves energy by controlling the fan not to run thus reducing outdoor ventilation air to the building when there are no occupants. Though this measure group was selected based on commercial QM program supply fan control activity, two other supply fan measures were implemented in the residential QM programs: fan adjustment and blower motor replacement. Fan adjustment saves energy by optimizing the system airflow for peak air conditioner performance. And replacing a permanent split capacitor (PSC) blower motor with an electrically commutated motor (ECM) saves energy because the ECM maintains better fan performance efficiency at the lower operating speeds often seen in HVAC applications. Figure 7 illustrates the supply fan and associated thermostat control system.

Figure 7. Supply fan and thermostat in RTU



2.2.2 Claimed gross savings

Though the commercial QM and related tune-up programs are similar with many overlapping measures, they also have distinct measures. To decide where to focus evaluation efforts, we identified the commercial measure groups with the greatest claimed (ex ante) savings across IOU commercial QM and tune-up programs (Table 6). The first five highlighted rows show measure groups with the greatest savings that were chosen for our previous HVAC3 evaluation covering program years 2013 and 2014, and persist as the measure groups with the greatest savings for the full 2013-15 period. The 2015 program year claims shifted slightly away from coil cleaning and towards thermostat and supply fan controls. The SCE and SoCalGas general QM measure was also evaluated because it comprises the first five evaluated measures and amounts to a large share of claimed savings.

Table 6. Measure group total ex ante program savings (2013-15)

Measure Group	Savings kWh/Year	% of Total QM kWh Savings	Cumulative % of Total QM kWh Savings	Savings therm/ Year	% of Total QM therm Savings	Measure Evaluated in this Study?
Coil Cleaning	16,874,370	27%	27%	(23)	0%	Yes
Economizer	10,759,860	17%	43%	8,629	0%	Yes
Thermostat	9,873,954	16%	59%	1,474,126	61%	Yes
RCA	9,090,354	14%	73%	(1,074)	0%	Yes
Supply Fan	8,355,050	13%	86%	1,027,242	39%	Yes
QM	7,482,097	12%	98%	47,947	1%	Yes
Air Filter Replacement	772,882	1%	99%	-	0%	No
Fan Repair	289,301	0%	100%	-	0%	No
Duct Sealing	100,324	0%	100%	(1,686)	0%	No
Economizer Addition	33,108	0%	100%	(1)	0%	No
Total	**63,631,299**	**100%**		**2,555,160**	**100%**	

The top five measures comprise 89% of total QM program kWh claimed savings. By focusing on these five measure groups, DNV GL addresses at least 86% and up to 98% of the total savings because the QM group likely contains some measures in the five measure groups.

Looking at this from an individual program perspective, for program year 2015, Table 7 lists each commercial QM program, total program savings claimed, savings claims from the five highest impact measures defined above, and the percent of total program savings associated with the high-impact measures. As the table shows, the high impact measures account for the vast majority of claimed savings.

Table 7. Evaluated high-impact measures and savings by commercial program (2015)

Program	High-Impact Measures	Program kWh Savings	High-Impact kWh Savings	High-Impact kWh % of Total Program
SDG&E Deemed Incentives–Commercial HVAC	Coil Cleaning, RCA	2,653,960	2,653,960	100%
SDG&E Commercial Direct Install	Coil Cleaning, Thermostat, Economizer, RCA	3,308,825	3,108,144	94%
PG&E Commercial QM	Economizer, Supply Fan Control, Thermostat, RCA	6,689,503	6,640,718	99%
PG&E AirCare Plus	Economizer, Supply Fan Control, Thermostat, RCA	3,272,583	3,218,762	98%
SCE Commercial QM	QM, Economizer	3,594,693	3,517,807	98%
SoCalGas Commercial QM	QM, Economizer	7,146 (therm)	7,147 (therm)	100%

A description of evaluated QM programs, 2013-14 program activity, and their claimed savings are provided in the 2013-14 QM evaluation report.[11]

Residential QM programs are operated by PG&E and SDG&E. The four residential measure groups implemented through these programs are supply fan repair or adjustment, RCA, coil cleaning, and fan controls. Claimed savings by IOU and measure are shown in Table 8.

Table 8. Residential QM measure group ex ante kWh savings (2015)

Measure Group	2015 kWh Savings/Year	% of Total Residential QM kWh Savings*
PG&E		
Supply fan repair or adjustment	4,820,219	81.2%
RCA	807,230	13.6%
SDG&E		
Supply fan repair or adjustment	394	0.0%
RCA	1,971	0.0%
Coil cleaning	8,488	0.2%
Fan Control	299,315	5.0%

* Note: percentages are relative to the combined PG&E and SDG&E programs. PG&E accounts for approximately 95% of the combined ex ante savings.

[11] CPUC 2016. Impact Evaluation of 2013-14 HVAC3 Commercial Quality Maintenance Programs. www.calmac.org/publications/HVAC3ImpactReport_0401ES.pdf

2.3 Research history and issues

This evaluation builds on previous California research on QM concepts and programs. Initial laboratory studies from PG&E in 2000-01 showed savings potential for the RCA measure.[12] Subsequent field studies in 2001 and 2004 confirmed the savings potential.[13] Consequently, RCA became a measure with deemed savings in 2005 and had massive implementation in 2006-09 residential programs. Meanwhile, on the commercial side, a CPUC-sponsored Public Interest Energy Research (PIER) buildings program study showed economizer functionality and airflow issues that, if addressed, could lead to significant energy savings.

The CPUC evaluation of the 2006-08 residential programs found installation and realization rates less than 50% based on field studies that measured pre-to-post energy efficiency ratio (EER) changes and performed diagnostic refrigerant charge verification. These findings, and the high variability of impacts from charge adjustments in isolation, raised concerns with the California IOUs, who then revised the programs to a more holistic QM approach. Additionally, the residential HVAC market experienced a major shift toward thermostatic expansion valve (TXV) metering devices where the RCA impact is much smaller.

IOUs also responded by shifting program focus from residential to commercial HVAC systems. Residential QM programs had low program uptake and were plagued by problems ranging from excessive data collection requirements to negative savings resulting from opening economizers. The programs started with one universal refrigerant diagnostic protocol, which was the one adopted by the California Energy Commission (CEC), later shown to be flawed, and moved to any diagnostic method available.

The subsequent 2010-12 QM program evaluation showed all the refrigerant charge diagnostic methods to be at least somewhat flawed according to HVAC5 laboratory measurements. It also revealed issues related to economizer functionality and the difficulty of performing commercial HVAC rooftop unit field measurements due to several complicating factors.

Evaluating deemed savings for QM measures is challenging. A commercial QM "package" is much more like a custom retrofit than a deemed measure because each HVAC unit varies in operational efficiency when entering and exiting a program. For example, a new unit entering in a program may have never had its condenser coils cleaned, but an older unit entering a program would likely have had them cleaned at least once, though at some unknown point in time.

However, unlike custom retrofit programs, each unit in QM and tune-up programs provides small kWh savings, and thousands of units currently participate. Further, the variation in savings across units is great. The traditional evaluation approach would be to draw a sample based on the tracking data and perform energy monitoring to develop savings. Given the large number of units and the variation in savings, a large number of sample points would be needed to meet acceptable precision targets. Because the cost per sample point is high, the traditional approach can be cost prohibitive.

Other notable research challenges in QM measures were discovered in our final impact evaluation of 2010-12 QM programs under Work Order 32 (WO32).[14] Key issues included:

---

[12] Davis, R., and E. D'Albora. 2001. *Influence of Expansion Device and Refrigerant Charge on the Performance of a Residential Split-System Air Conditioner using R-410a Refrigerant*. Report No.: 491-01.7. San Francisco, Calif.: Pacific Gas and Electric.

[13] Mowris, R., A. Blankenship and E. Jones. 2004. *Field Measurements of Air Conditioners with and without TXVs.* ACEEE Proceedings http://aceee.org/files/proceedings/2004/data/papers/SS04_Panel1_Paper19.pdf

[14] DNV GL, HVAC Impact Evaluation FINAL Report WO32 HVAC – Volume 1: Report, Jan. 28, 2015 (Commercial Quality Maintenance). http://www.calmac.org/publications/FINAL_HVAC_Impact_Evaluation_WO32_Report_28Jan2015_Volume1_ReportES.pdf

- Long-term, time-series measurements of system efficiency were problematic given the variations in outdoor air quantities with economizer operation that are difficult to measure in real time. Incomplete mixing of outdoor and return air requires extensive instrumentation to obtain accurate measurements of mixed-air temperatures and hence outdoor air fractions and cooling coil entering conditions.
- Pre-program sampling and long-term system monitoring were very difficult to achieve because only service providers know which sites and units receive maintenance within a given program cycle. Furthermore, it is unknown which measures will be applied to the pre-maintenance unit when monitoring equipment was installed. These issues led to a lower-than-anticipated sample size and some sampling bias.
- Insufficiently long monitoring periods or periods without significant air conditioner operation can cause high levels of uncertainty when projected to represent annual energy consumption.
- Pre/post monitoring of individual HVAC units did not distinguish measure-level savings for each unit due to the completion of multiple measures during the same implementation visit.
- It was challenging to re-create baseline for testing because of poor documentation of HVAC systems pre-maintenance for some programs. Programs without adequate documentation for an (measurement and verification) M&V evaluation were at risk and subject to true-up based on available data from other programs and IOUs.

The WO32 evaluation measured total energy savings for a sampled unit, and then developed average QM measure savings, but the average savings were found to be far off from program ex ante savings claims. The variation in HVAC unit energy consumption was high because the wide range of weather, building type, and climate all affected the results. The coefficient of variation found among HVAC measure savings was so large that the traditional M&V approach of sampling program-treated HVAC units required an infeasible sample size.

Our previous HVAC3 evaluation used a combination field testing and laboratory test data that avoided many of the problems we experienced in the WO32 study. We were able to identify improvement in economizer repair savings, but found only small changes and hence small energy savings from coil cleaning and RCA.

2.4 Evaluation approach

The commercial portion of this evaluation follows the same approach as our previous HVAC3 evaluation. Since the 2015 program year exhibited no significant changes in program structure, we could leverage the previous study, increasing precision by collecting additional data using similar methods, and applying the combined 2013-15 data set to the 2015 tracking claims.

As with the previous evaluation, to address the large variation in HVAC-unit energy consumption and associated program-induced savings, this evaluation used field component testing and verification to estimate energy savings for individual measures rather than savings for the entire HVAC unit. Thus, we collected data on observed operational parameters and conditions such as refrigerant pressures and temperatures, airflows, control set points, and other parameters that go into savings calculations. This allowed us to use engineering models to develop inputs to prototypical building simulation models to generate total savings.

This disaggregated approach avoided the need for a very large sample across multiple climate zones and building types, which would have been much costlier. Instead of measuring overall energy consumed by an HVAC unit, which has large variation across the program population, we measured parameters that can characterize how the units operate with a smaller sample because they have less variation across the program population.

The building simulation models used to generate measure savings were the same DEER prototype models used to develop ex ante impacts for program workpapers. Therefore, our evaluation results reflect only differences in observed versus assumed values for operational parameters and not in modeling differences.

A net-to-gross (NTG) analysis, documented in separate report[15] relied on contractor self-report data to develop self-reported NTG ratios. These NTG ratios were applied to gross impacts to provide estimates of net impacts.

The residential programs and measures were evaluated using a billing analysis approach. This work was conducted by Itron. Regression models were developed using tracking information on the QM measures installed, the timing of the measure installation, weather data, and advanced metering infrastructure (AMI) billing data. Participant-only models were developed to estimate gross impacts. The development of gross impacts fulfills the gross evaluation reporting requirements. A matched comparison group was added to provide estimates of net impacts. A propensity-score matching approach was used to select the comparison group. The net model adds insight into the net savings attributable to the program while providing an estimate of the NTG ratio.

The billing analyses requires extensive pre- and post-installation consumption data, which limited the regression analysis to residential QM measures installed during 2013 and 2014. The estimated savings per ton of HVAC measure (PG&E) or per HVAC unit (SDG&E) from the 2013-14 measures were applied to the 2015 residential QM measures.

[15] CPUC 2016. Net-to-gross Evaluation of 2013-14 Commercial Quality Maintenance Programs (HVAC3) Impact Evaluation of 2013-14 Commercial Quality Maintenance Programs (HVAC3). http://www.calmac.org/publications/HVAC3_NTG_Final_Report_2016-12-07.pdfwww.calmac.org/publications/HVAC3ImpactReport_0401ES.pdf

3 COMPLETED EVALUATION ACTIVITIES

This section presents the results of completed evaluation activities.

3.1 Participation records review

DNV GL reviewed the program tracking data and the detailed implementer data received from each electric IOU. Records were not requested from SoCalGas because their QM program is administrated through SCE, and energy savings are credited to SoCalGas through a therm exchange program. After multiple phone calls with program implementers to identify a unique identifier to link tracking claims to implementer database claims, the best option we identified was “ServiceAccountID.”

This is not a unique record identifier in either the tracking data or the implementer data, as there are multiple HVAC units and therefore multiple claims at each site. Sometimes there were more than 100 claims at a site because each HVAC unit can receive multiple claimed measures. Unique identifiers such as “SiteID” in the tracking database did not exist in the implementer databases, and unique claim identifiers in the implementer databases such as sticker number did not exist in the tracking database. Therefore, we used the ServiceAccountID field to link the tracking and implementer databases at the site level. A summary of the two databases is shown in the Table 9 below. The poor match between the last two columns of the table leads to serious concerns regarding the verifiability of the tracking system data.

Table 9. Summary of tracking data matching to implementer-provided data by program

Program ID	Records in 2015 Tracking Data	Unique "SiteID" in 2015 Tracking Data	Unique "ServiceAccountID" in 2015 Tracking Data	Matching “ServiceAccountID” in Implementer Data
PG&E Commercial QM	5,426	369	165	119
PG&E AirCare Plus	7,869	1,698	262	234
SCE QM	9,777	1,210	1,219	995
SDG&E Deemed Savings	20,158	863	693	607
SDG&E Direct Install	9,908	2,057	1,890	1,440

3.1.1 Tracking data findings

The tracking data contain the official energy savings claims, referred to as ex ante claims, that form the basis for the impact evaluation. Unfortunately, there are several issues with the tracking data that resulted in challenges for the evaluation:

- Contact information was partially populated or erroneously populated, often requiring a link to the customer database to pull in customer contact information. In PG&E’s Commercial HVAC program one erroneous name appeared 4,468 times in the “ContactName_1” field and 259 times in the “ContactName_2” field.
- Program sticker number is not in the tracking database making it difficult to link a tracking claim to an individual HVAC unit on a rooftop. (The program sticker is affixed to the HVAC unit when it is

serviced through the program, and is used in the implementer databases to identify the measures performed through the program.)

- In other places, key information is missing. For instance, QM measures require the HVAC system type, climate zone, and building type to determine ex ante savings. Sometimes the climate zone variable is populated with a term indicating an average across all climate zones, the HVAC system type variable is populated with "Any" and the building type variable is populated with codes that don't exist in the DEER building prototypes.

We also recommend that the tracking databases could be improved by including individual measure M&V information in a standardized way. Currently, we need to merge on implementer data, which is currently not a good match, to associated M&V information with the appropriate tracking records. For example, a critical piece of information for the RCA measure group was the amount of charge added or removed from the units by the program for sampled units with savings claims. Each IOU stored this critical piece of information in a variety of ways and it required multiple data requests to obtain this information.

3.1.2 Implementer data findings

Implementer data are critical to understanding actual site activities perform through the QM programs. Although some programs sent us the implementer data promptly and without errors, we had to make several requests and take additional steps to get the correct data from other programs. In general, some programs' data included more detail than others, there was variation in completeness, and some data fields were populated for one program but not another. Consequently, where we used implementer data in the RCA analysis, we applied results from IOU programs with data to those in the same IOU that did not provide data. PG&E's Commercial QM program sent an extensive database that required transposition into a new format before it was useful. It was an extremely tedious but it was a straightforward process to re-organize the data. SDG&E's Direct Install program contained no measure-level data at all, only customer contact information. While we did not eliminate savings from programs with incomplete data, we note that lack of sufficient supporting implementer data for tracking system claims could lead to lower verification rates in future evaluations, due to insufficient evidence that the claims are based on valid data.

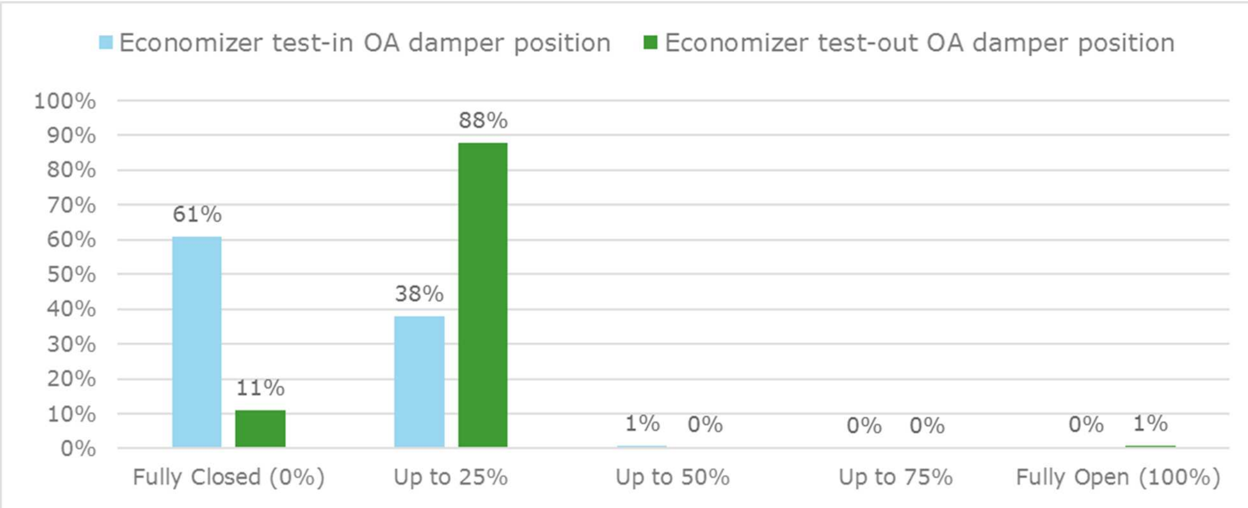
3.1.2.1 **Economizer**

Measure-specific economizer measure records were provided by SCE and PG&E. Each program implementer recorded different information. The provided information was not used directly in the development of ex-post savings, but was used to review program activity and ex-ante assumptions. In this section, we provide information specific to the types of economizer controls and the test-in and test-out set points for dry-bulb economizers recorded in the data sets. Data are presented as provided by the program, and no actions were completed by the evaluation team to test the validity of the information within each database.

SCE

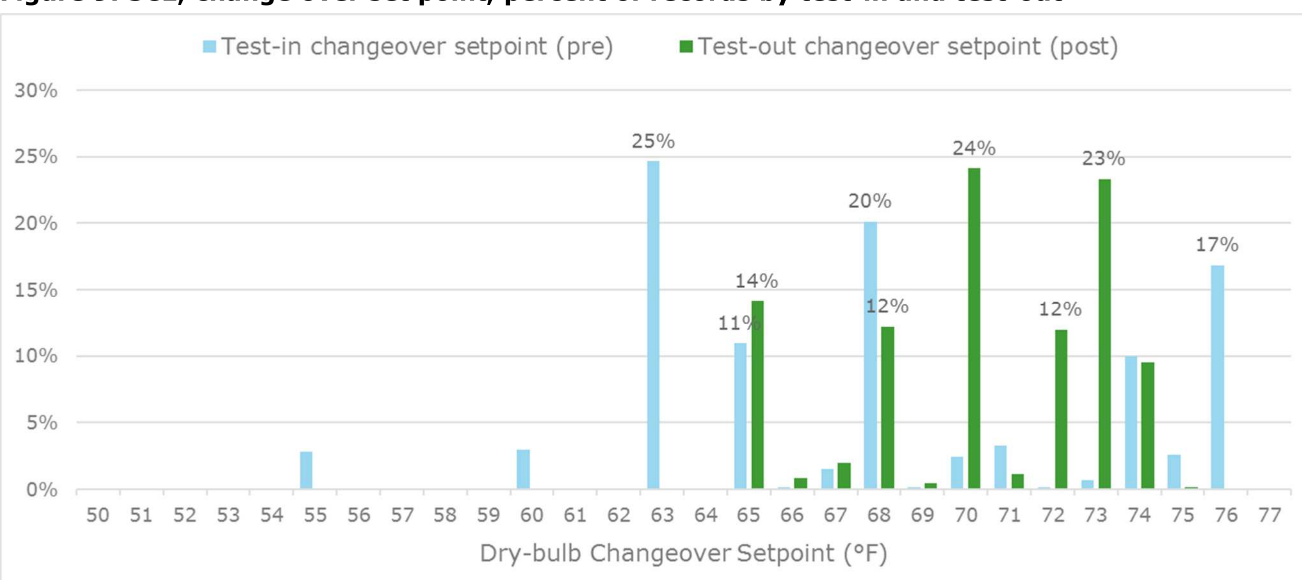
The SCE program data contained the most information for each measure. We reviewed the pre- and post-retrofit condition information for damper position, control type, and dry-bulb set point. There were 4,039 records showing both the pre- treatment (test-in) and post-treatment (test-out) damper position. Figure 8 shows the distribution of recorded outside air (OA) damper positions. The graph shows that 61% of OA dampers were closed at test-in and only 11% were closed at test-out indicating that at least half of units were adjusted from fully closed (reduction from to up to 25% open, which showed an increase of 38% to 88% test-out). This change will result in increased energy use, but is not part of the impact evaluation reported in this study.

Figure 8. SCE, minimum OA damper position, percent of records by test-in and test-out



We reviewed the 1,589 test-in recordings of dry-bulb set points and the 1,701 test-out recordings of dry-bulb changeover set point. The average test-in value recorded was 68.0°F and the average test-out value was 70.3°F. Figure 9 shows the percent of setting value recorded.

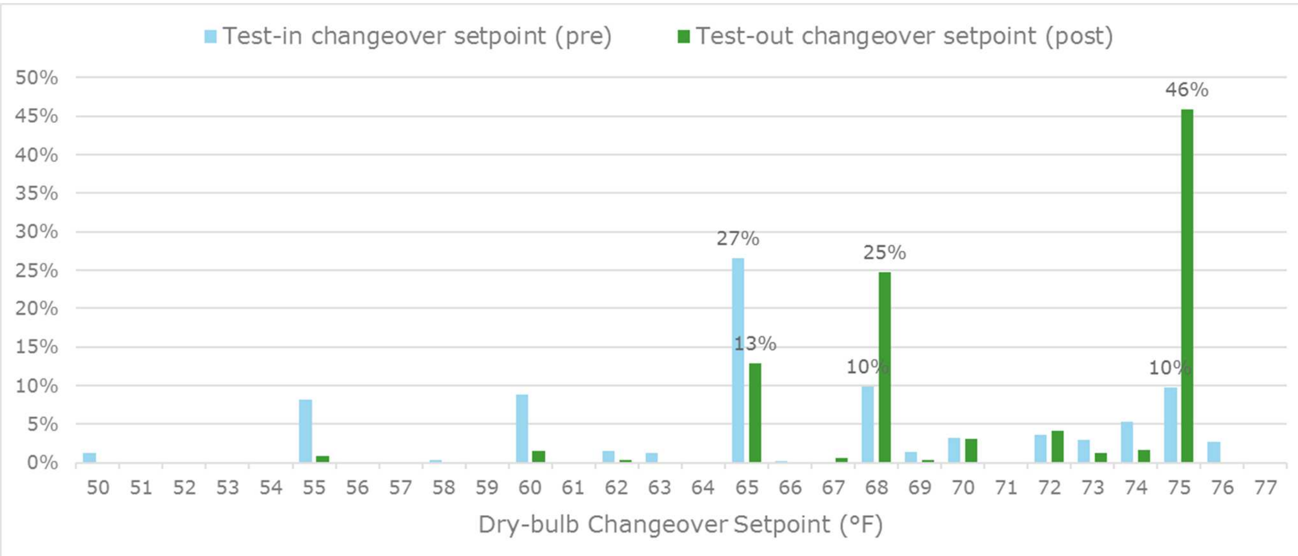
Figure 9. SCE, change over set point, percent of records by test-in and test-out



PG&E Commercial QM

The dataset for this program provided information on the functionality of the economizer and the changeover set points, but not the position of the damper nor the actions taken by the program. We isolated 743 unique test-in values and 778 unique test-out values that are believed to be the set points for repaired units. The average test-in set point was 65.9°F and the average test-out value was 71.0°F. Figure 10 shows the percent of setting values recorded in the isolated data within the same range as the SCE program.

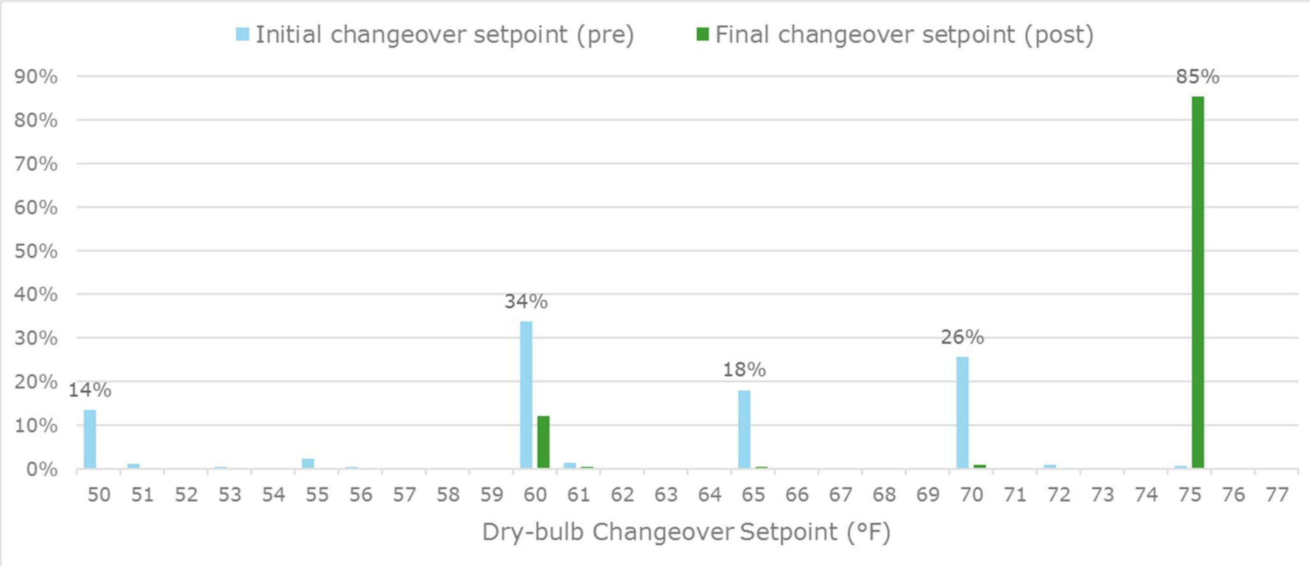
Figure 10. PG&E Commercial QM, change over set point, percent of records by test-in and test-out



PG&E AirCare Plus

We also analyzed the PG&E AirCare Plus program records. These records also indicate the pre- and post-set points. From the 19,495 unique lines of data, we isolated 1,532 unique test-in values and 3,954 unique test-out values that are believed to be the set points for repaired units. The average test-in set point was 62.3°F and the average test-out value was 73.0°F. Figure 11 shows the percent of setting value recorded in the isolated data within the same range as the SCE program.

Figure 11. PG&E AirCare Plus, change over set point, percent of records by test-in and test-out



Economizer changeover set point summary

While the distribution of set point values around the means varies from program to program, there was consistency in the mean values from each program. Table 10 shows the mean values.

Table 10. All programs, average test-in and test-out set points recorded

Program	Average Test-in Set Point (°F)	Average Test-out Set Point (°F)
SCE	68.0	70.3
PG&E CQM	65.9	71.0
PG&E ACP	62.3	73.0

3.1.2.2 Thermostat

The PG&E Commercial QM, SCE Commercial QM and SDG&E Direct Install program implementers recorded pre- and post-implementation thermostat set point temperatures. For these three programs, the heating and cooling set points were recorded for occupied and unoccupied building periods. Recording these set points allows for verification of the workpaper set point assumptions, and would be useful if they were recorded across all programs. We reviewed implementer data for thermostat measures extensively in our previous HVAC3 report so we don't go into depth here since the same issues are present in 2015.

3.1.2.3 Supply fan

Two programs had extensive fan control data—SCE QM and PG&E Commercial QM. Similar to the thermostat measures, we reviewed the supply fan data extensively in 2013-14, and there have been no significant changes in 2015. In both programs, the implementer recorded the fan setting during unoccupied building periods when they initially arrived on site. However, the fan setting was very different between the programs, with 78% of fans on during unoccupied periods in buildings in the SCE QM program while only

13% of fans were on in the PG&E Commercial QM program. The tracking data does show a real difference between the types of buildings participating in the two programs, and the difference was also observed in our field data collection where the baseline supply fan operation was "on" close to 100% of the time for SCE sites surveyed.

3.1.2.4 **Coil cleaning**

Condenser and evaporator coil cleaning data was non-existent for the 2013-15 QM programs, but coil cleaning data were available for the tune up programs: PG&E's AirCare Plus and SDG&E's Deemed and Direct Install. These programs provided the date of evaporator and condenser coil cleaning in their implementer data. Implementers provided no other coil cleaning data, such as HVAC system airflow before and after evaporator coil cleaning, and discharge pressure before and after condenser coil cleaning. In addition, for the discharge pressure to be useful, outdoor temperature must be collected at the same time as the discharge pressure measurements so the temperature correction can be made as described in the coil cleaning methods, section 4.1.3.1

3.1.2.5 **RCA**

The data for the RCA measure were thoroughly studied in 2013-14 and the 2015 data has the same missing data issues identified in the 2013-14 evaluation. Implementer data from four of the programs contained critical information for the refrigerant charge parameters we needed for analysis, namely, the weight of charge added or removed by the implementer through the program. This is an improvement as PG&E's AirCare Plus program did not contain this data previously. The SDG&E Direct Install program implementer data contained no RCA data at all.

3.2 QM Sample design

This study is made up of multiple components, each requiring different sample design methods: Stratified random sampling methods were used in the commercial program impact evaluation for the post-participant site visit and phone survey samples, and in the residential program impact evaluation for the non-participant sample used in the billing analysis. The commercial program impact evaluation also employed stratified non-random methods for the ride-along site visit sample, and a census approach for the phone interview sample results used to determine NTG ratios. The residential program impact evaluation also employed a census approach for the participant sample in the billing analysis. The following is a brief description of the sample design approach used in the impact evaluation: first the methods used in the commercial gross impact estimation and then those used in the NTG ratio estimation followed by the residential program evaluation sampling methods.

3.2.1 Commercial gross-impact sampling methodology

The commercial program gross-impact evaluation involved multiple data collection efforts relating to the parameters used in energy savings estimation for each measure group. The first step was to prioritize the various data collection efforts to make most effective use of the available evaluation funds. This is described in the first section below, followed by a description of the non-random methods used for ride-along visit site selection, and finally a description of the stratified random sampling methods used for post-participation site visit and phone survey selection. The final section describes the achieved sample for each measure group and the associated relative precision.

3.2.1.1 Prioritization of data collection activities within the commercial program gross-impact assessment

Our previous HVAC3 evaluation results achieved lower-than-expected precision due to higher than expected coefficient of variation (CV) across several measures. The 2015 program year was essentially a continuation of 2013-14 program practices. Therefore, we were comfortable creating a combined sample across program years for 2015 evaluation. The combined data set was expected to yield higher precision than if the results were based on 2015 data alone. We recognize that major program changes were implemented for 2016, so the results are only projected to the 2015 program population. No adjustment to the 2013-14 savings was performed or expected since these reported ex post savings are final. We performed an assessment of M&V uncertainty reduction per dollars of M&V spent in each of the measure groups, and for that comparison, we defined the sample to be the number of HVAC units surveyed within each measure group. Although collecting data on multiple HVAC units at a site significantly reduces the cost per sample point, it can also reduce the diversity of units inspected. To mitigate this risk, we placed an emphasis on recruiting a variety of sites and participating contractors and limited the number of units that we surveyed at each site, based on type of site visit as follows:

- One to two units at each coil cleaning ride along visit
- Four units at each economizer ex-post site visit
- An average of two units per telephone survey

Finally, rather than treat the data from each unit as an independent sample point in the final analysis, we used the cluster sampling formula to calculate the standard error and resulting coefficient of variation. Cluster sampling is described in more detail in section 3.2.1.4.

Table 11 shows the sample sizes by measure group in the 2013-14 evaluation cycle and the proposed and achieved additional 2015 sample. It also provides the resulting relative precision for each measure group. Although we would have liked to collect more coil cleaning data points, logistical difficulties of scheduling the sites with implementation contractors prohibited a larger sample.

Table 11. Sample size and precision by evaluation cycle and measure group

Field/Measure	Coil Cleaning (Ride-along)	Economizer (Ex-post)	T-stat and Supply Fan Control (Survey)	Refrigerant Charge Adjustment
2013-14 sample size, units	12	88	59	48
CV	0.28*	0.72	1.55	1.26
Relative precision of 2013-14 sample	15%	13%	33%	30%
2013-14 measure savings, kWh	14,499,585	8,282,806	10,654,248	6,947,131
2015 sample size, units	30	100	220	0
Proposed total of 2013-14 and 2015 samples, units	42	188	279	48

Field/Measure	Coil Cleaning (Ride-along)	Economizer (Ex-post)	T-stat and Supply Fan Control (Survey)	Refrigerant Charge Adjustment
Proposed combined relative precision	13%	9%	15%	30%
Achieved combined number of units	29	163	148	48
Achieved combined relative precision	15%	9%	21%	30%
Achieved change in relative precision	0%	4%	12%	0%
2015 measure savings, kWh	2,039,038	5,494,920	7,301,693	2,133,834

*We assumed a CV of 0.5 in the combined sample since the 2013-14 sample came from just two sites, which likely reduced the CV.

3.2.1.2 Non-random stratified sampling methods

Ride-along visit sites for the coil cleaning measure were not chosen from the tracking data, but instead program implementation contractors were sampled based on their volume of 2015 program claims. The tracking data did not contain contractor names, so we used the implementer-supplied data to sort the program contractors by number of claims submitted to stratify them in the sample. We then contacted program implementers to put us in touch with the implementation contractors. Sites were chosen by coordination with implementation contractors performing coil cleaning on initial visits to a site entering the program, and because we had to accept what sites were available for coordinated ride along visits during the data collection period the sample was non-random. The ride-along site visits are described in detail in section 3.3.1. That section also provides the number of site visits targeted and achieved.

3.2.1.3 Stratified random sampling methods

Ex post visit sites and phone survey sites were chosen using stratified random sampling methods. The sampling methodology employed a stratified estimation model that first places participants into segments of interest (IOU) and then into strata by size, measured in claimed kWh savings. Samples were then selected based on the segment of interest or control variables like program implementer, program name, measure group, and various kWh strata within the combination of control variables. ex-

After drawing each stratified random sample, we verified it was indeed distributed across characteristics of interest such as building type, climate zone, and installation contractor to make sure that it represented the population across these indices. Each program implementer coordinates multiple installation contractors that participate in the program. A backup sample was drawn, similarly, per the priority assigned by the sample design model for instances when a primary sample site could not be completed. A more detailed description of the stratified random methods used for the ex-post site visit and phone survey samples is provided in APPENDIX B.

3.2.1.4 Sampling results

The recruiting process resulted in a total of 39 completed site visits consisting of 17 ride-along sites and 22 post-participation sites. Table 12 shows the number of sample points planned and achieved for each measure. It also shows the planned and achieved precision for the individual measure characteristics collected on site visits and used in the measure level analyses. We collected data on multiple HVAC units within one site.

Rather than treat the data from each unit as an independent sample point, we used the cluster sampling technique to calculate the standard error and resulting coefficient of variation.

$$se(\bar{y}) = \sqrt{\frac{\sum_{i=1}^{n}(\mathrm{y}_i - \bar{\mathrm{y}}\mathrm{m}_i)^2}{n(n-1)\bar{m}^2}}$$

Where:

$$n = number\ of\ sampled\ clusters$$
$$m = number\ per\ cluster$$
$$y = variable\ of\ interest$$

For most of the measures, we came close to meeting or surpassed the sample target, but did not achieve the planned precision. This is because of the large differences between the estimated variation of the parameter within the population and the actual variation within the measured parameter. The estimated coefficient of variation was based on our previous HVAC3 evaluation and the actual coefficients of variation are listed in the table.

Table 12. Data set size for measure parameters with corresponding sampling precision

Measure	Model Parameter	Achieved Model Parameter Data Set Size	Achieved Precision at 90% Confidence	2013-14 CV	2013-15 CV
Economizer	Minimum outside air	28	± 24%	N/A	0.572
Economizer	Dry-bulb set point	11	± 5%	N/A	0.104
Thermostat	Set point temperature	85	± 3%	1.5	0.06
Cond Coil Cleaning	Efficiency (EIR)	27	± 27%	0.37	0.84
Cond Coil Cleaning	Cooling Sizing Ratio	27	± 18%	0.66	0.57
Evap Coil Cleaning	Efficiency (EIR)	25	± 24%	0.28	0.73
Evap Coil Cleaning	Coil Bypass Factor	25	± 12%	0.10	0.38
Evap Coil Cleaning	Cooling Sizing Ratio	25	± 23%	0.25	0.69
RCA	Efficiency (EIR)	48	± 47%	1.26	1.26
RCA	Cooling Sizing Ratio	48	± 47%	1.26	1.26

The supply fan control measure was not modeled, precisions for the installation rate at 36 sites was ±40%. The RCA modeling was based on data from each refrigerant circuit measured in 2013-14.

3.2.2 Commercial NTG ratio estimation sampling methods

The tracking data files included energy efficiency measures completed during the 2013 and 2014 program years. For the four programs evaluated, 39% of records in the tracking data were missing the contractor name. However, implementer files allowed us to reduce this number to 7%. In the process of looking up contact information for the contractors, we discovered that a subset of the listed contractors in the remaining programs were dedicated program implementation contractors. We removed records of such contractors from the sample frame as they are entirely program dependent, and therefore would be very limited in their ability to describe maintenance activities outside the program as a baseline or comparison to program maintenance activities. After removing these program implementation contractors, we arrived at a sample frame of 93 "valid" contractors, which represented about 80% of the original population.

Because we based our stratification on kWh savings per contractor, we could not expand our results back to the portion of the population where we did not have contractor information. In the NTG report we discuss how the difference between the sample frame and the population affects the applicable sampling error in our discussion of the results.

Table 13 presents the percentage of records matched with a contractor name by program. It shows that our overall contractor match rate was high (93%) with only the PG&E Commercial HVAC program having a match rate of less than 90% of its records. Overall, the electric energy savings represented by the matched records is 94% in PG&E, 87% in SCE and 99% in SDG&E territories.

Table 13. Tracking data records with contractor name merged

PA	Program Name	Contractor Name	Records	Percent
PG&E	AirCare Plus	Not Matched	330	2%
		Matched	15,693	98%
			16,023	**100%**
PG&E	Commercial HVAC	Not Matched	3,449	23%
		Matched	11,487	77%
			14,936	**100%**
SCE	Non-residential HVAC	Not Matched	647	3%
		Matched	24,098	97%
			24,745	**100%**
SDG&E	Commercial Deemed Incentives	Not Matched	1,928	7%
		Matched	27,375	93%
			29,303	**100%**
Overall		Not Matched	6,354	7%
		Matched	78,653	93%
			85,007	**100%**

Note: Some records were originally matched, but the name listed as a contractor was an implementer.

The number of contractors varied substantially across the three IOUs, with fewer contractors achieving a larger share of savings for SDG&E. Table 14 presents the number of contractors and achieved savings broken out by program. Although savings are somewhat equally distributed across the programs, the number of contractors achieving those savings is not. Both the Commercial HVAC and Non-residential HVAC programs use many more contractors than the other two programs.

Table 14. Number of contractors and total savings by IOU and program

IOU	Program	Number of Contractors in Program	Percent of Contractors	Ex Post kWh	Percent of Ex Post kWh
PG&E	AirCare Plus	10	11%	4,651,418	21%
PG&E	Commercial HVAC	44	48%	6,775,257	31%
SCE	Nonresidential HVAC	29	31%	5,086,757	23%
SDG&E	Commercial Deemed Incentives	10	11%	5,605,988	25%
Total		**95**	**100%**	**22,119,419**	**100%**

DNV GL attempted to complete surveys with a census of HVAC3 contractors. Weights for expansion were developed with a post-stratification of the resulting sample based on estimated ex post kWh savings per contractor.[16]

The number of contractors and savings per strata are reported in Table 15.

Table 15. Contractor strata

IOU	Program	Strata Number	Number of Contractors	Percent of Contractors	Ex Post kWh	Percent of Ex Post kWh
PG&E	AirCare Plus	1	5	50%	448,315	10%
		2	5	50%	4,203,103	90%
			10	**100%**	**4,651,418**	**100%**
PG&E	Commercial HVAC	1	20	45%	272,435	4%
		2	6	14%	343,768	5%
		3	5	11%	444,837	7%
		4	3	7%	462,585	7%
		5	10	23%	5,251,632	78%
			44	**100%**	**6,775,257**	**100%**
SCE	Nonresidential HVAC	1	19	66%	467,470	9%
		2	6	21%	716,210	14%
		3	4	14%	3,903,077	77%
			29	**100%**	**5,086,757**	**100%**
SDG&E	Commercial Deemed Incentives	1	7	70%	559,629	10%
		2	3	30%	5,046,359	90%
			10	**100%**	**5,605,988**	**100%**

Note: Two contractors were counted with other contractors because they were determined to be the same company through the surveys.

[16] We limited the population to the records with contractor information as we do not know the distribution of contractor sizes for the records without a contractor matched.

3.2.3 Residential non-participant selection

The gross billing analysis is implemented on all residential QM participants that meet the data requirements (see section 4.4.2). The net billing analysis model requires both participants and a sample of non-participant or control households. The control households provide a baseline for energy consumption in the absence of the program while controlling for economic, weather, environmental and average behavioral changes that occurred during the pre- and post-installation period that may influence energy consumption independent of QM participation. This non-participant group also controls for the fact that some households will choose to maintain their air conditioners without participating in the QM program. Having the control group allows for the development or isolation of energy savings that would not have occurred without the program or the development of savings attributable to the program (net savings).

Ideally, when trying to determine the net savings from a program, a controlled experimental design would be used to develop the control group. Households would be randomly assigned to participant (treatment) and non-participant (control) groups. Pre-assignment into control and treatment groups would likely ensure that the pre-program average usage and average unobservable characteristics were approximately equivalent across the participant and non-participant households.[17] If the treatment and control groups are similar prior to program implementation, measurable difference following the program implementation would be reasonably attributable to the program.

Participation in residential QM is voluntary. Given that participants choose to participate, participant and non-participant groups are likely to differ systematically. The voluntary, self-selection of participants into the residential QM program makes the estimation of unbiased savings attributable to the program (net savings) more difficult.[18] To estimate the QM net savings, Itron used a quasi-experimental design. Itron developed a matched control group using Stratified Propensity Score Matching (SPSM). The SPSM method is used to develop a nonparticipant sample of households that are observationally equivalent to participant households to help control for the potential selection bias that may result from voluntary participation.

The quasi-experimental design approach cannot ensure that the nonparticipant sample of households is equivalent to the participant households, but the approach implemented for this research undertakes several steps to develop a best match possible given the available data. The development of the nonparticipant sample uses stratification, two rounds of logistic model matching, explores the use of Census tract data and incorporates participation in other downstream energy efficiency programs. The extreme care undertaken to develop the matched sample helps to improve the validity of the match and the development of net savings impact.

Prior to implementing the propensity scoring method the utility Customer Information System and monthly billing data were allocated into residential QM participants and non-participant households. The PG&E participant and non-participant data was also sub-set to only include participants and non-participants in climate zone 11, 12, and 13 as over 99.8% of PG&E’s QM participants lived in these three climate zones. The SDG&E participant and non-participant matching process began with all SDG&E residential customers that passed the data attrition requirements (see section 4.4.2 for information on data attrition).

The average yearly load shape of participant and non-participant customers is illustrated in the first-stage matching graphs of Figure 12 and Figure 13 and **Error! Reference source not found.**the average monthly

[17] Experimental design does not ensure that the participant and non-participant households are, on average, equivalent.

[18] It is not clear that the non-participant households were aware of the residential QM program. The likelihood of sample selection bias is lower if the non-participant households are not aware of the program. If the non-participants are aware of the program and they have voluntarily opted out of the program, the non-participants would have clearly signaled that they are different from participants.

usage is presented in Table 16 and Table 17. In the first-stage matching graphs, the average monthly consumption of participants is represented by the solid red line while the average monthly consumption of all non-participants prior to matching is the green dotted line. These graphs clearly illustrate that the average participant in QM is observationally different from the average non-participant: The average electricity consumption for a QM household is substantially higher than the average electricity consumption for all non-participant households. As provided in Table 16, the average monthly consumption of SDG&E participants is 712 kWh while the average consumption of non-participants is 514 kWh. Table 17 lists the average monthly consumption of PG&E participants as 796 kWh and the average consumption of non-participants as 715 kWh.[19] The objective of the SPSM method is to match the participant households with non-participant households that are observationally similar.

The first step of the stratified propensity score method approach is to stratify the participant and non-participant population. The stratification helps to enable better matches by stratifying customers into similar buckets while the propensity score matching chooses the match within the strata with the most similar likelihood of participating in the QM program. PG&E's large participant residential QM program participant population allowed for the development of 16 strata. The PG&E participant and non-participant data was stratified by annual kWh usage (large and small users), CARE participation,[20] and half-yearly participation timing.[21] The smaller SDG&E participant population was allowed for just two strata: customers who participated from January–June 2013 and those participating after June of 2013.

SPSM uses a logistic regression (logit) model to estimate the probability or score of participation in the residential QM program within each stratum. The matching ultimately pairs each participant with a non-participant that has the most similar estimate of the probability of program participation. The SPSM logistic regressions matched participant and non-participant households using several independent variables including participation in the CARE rate, usage, the seasonal distribution and weather sensitivity of usage, and participation in other energy efficiency programs. [22] Matching on these observable characteristics will likely reduce the potential bias in the estimation of the program impacts.[23] Matching on pre-installation period participation in other non-upstream, non-QM, energy efficiency program participation likely helps to control for unobservable differences in households that influence a household's likelihood of participating in utility programs including the QM program.

One of the key methods of assessing the effectiveness of the SPSM is to conduct t-tests on the differences in the means of the participant and non-participant independent variables used in the logistic regressions for the groups both before and after the matching. If the matching is successful, the participant and control groups should not be statistically different for the variables included in the match models. The mean differences across the participant and non-participant households for all independent variables, across all

[19] The summer temperature in PG&E climate zones 11, 12, and 13 are hotter than the summer temperature in most of SDG&E's service territory, helping to explain the higher average usage for PG&E participant and nonparticipant households.

[20] CARE is the California Alternative Rate for Energy, a low-income energy assistance rate.

[21] The size, CARE participation, and participation timing strata are designed to help develop a better pre-installation match. The participation timing strata limits the time from participation to the date of the pre-installation data pull for matching. For example, a customer participating in January through June 2013 relies on consumption data from the period January-December 2012 for their pre-installation matching. This same period is used for the non-participant data. Using half-yearly participation strata limits the time from installation for the pre-installation matching data while not leading to excessive numbers of strata.

[22] The analysis team also tried SPSM models incorporating Census tract estimates of neighborhood income and home ownership percentage. Including Census tract variables in the models did not improve the match, using t-tests of matched variables to determine match quality. The failure of Census tract variables to lead to improvements in the match may be due to combining neighborhood averages into a model where all other variables are household specific. The household specific variables likely lead to a better household specific match while the neighborhood variables lead to matches in the neighborhood that are not as good as the household specific matches.

[23] Following the matching process, it is not possible to determine if the matching procedure has controlled for the potential selection bias. It is possible to determine if the matched participant and non-participant households are similar on observable characteristics, but not along non-observable characteristics.

strata, used in the matching process are presented in APPENDIX J. The mean value of participant and non-participant average monthly electricity consumption are presented in Table 16 and Table 17 for SDG&E and PG&E respectively. The quality of the match can also be observed by graphing the electricity usage information for the unmatched non-participant population, the matched non-participant sample, and the participant population. T-tests were undertaken to determine the quality of the match and graphing of non-participant and participant populations following both the first and the second stage matching (see APPENDIX J).

The non-participant matching was undertaken in a two-stage approach. The first-round SPSM used monthly billing data to identify an initial set of 10 to 15 non-participant candidates for each participating customer. Itron then requested hourly AMI data for the first-round matches to determine the best non-participant match in a second-round SPSM process.

The first-round logit model used monthly data from the pre-installation period to estimate the probability of QM program participation. The first-stage matching included 16 strata for PG&E and two for SDG&E with nine independent variables in the PSM models. Across these many different strata and independent variables, following the first-stage match, only two t-test were statistically different (presented in APPENDIX I).[24]

The data presented in the left-most illustrations in Figure 12 and Figure 13 present the average monthly participant and non-participant (control) usage during the first-round match while Table 16 and Table 17 list the average monthly usage and statistics to determine if the average usage differs statistically. Prior to matching, the non-participant population had much lower usage per month than the participant population. The statistics presented in Table 16 and Table 17 indicate that the hypothesis that the usage of participants and non-participants was statistically the same prior to matching can be rejected. Following the first stage matching, the participant and non-participant or control group, after-match 1 appear very similar in Figure 12 and Figure 13 (the red and the blue dotted lines). In Table 16 and Table 17 the stage one matching average monthly usage are very similar for participants and stage one matched non-participants and the test statistics indicate that the hypothesis that the usage of participants and non-participants was statistically the same following the first round of matching cannot be rejected. The similarity of the participant and the first-round non-participant monthly consumption supports the validity of the first-round matching process.

[24] The first-round matching analyzed the differences in nine independent variables across 18 models. The t-tests found that 2 of the 162 differences in means analyzed were statistically different. These results are presented in APPENDIX I.

Table 16. Average monthly kWh of SDG&E participants and non-participants

SDG&E	Participants	Non-participants	t test value	P value
Prior to matching				
Usage	710	514	-9.43	<0.0001
N	339	1,787,850		
After stage one matching				
Usage	710	707	-0.13	0.90
N	339	6,292		
After stage two matching				
Usage	689	689	0.13	0.90
N	299	286		

Table 17. Average monthly kWh of PG&E participants and non-participants

PG&E	Participants	Non-participants	t test value	P value
Prior to matching				
Usage	796	715	-24.56	<0.0001
N	8,955	3,461,695		
After stage one matching				
Usage	796	796	-0.21	0.84
N	8,955	119,275		
After stage two matching				
Usage	790	791	0.13	0.90
N	8,374	7,766		

Following the first-round matching process, Itron requested hourly AMI data for the participants and the matched first-round non-participants. The second-round logit matching model used hourly data from the pre-installation period to develop a better match between the participant and non-participant hourly load shapes.[25] Requesting and receiving AMI data led to the loss of some participants and non-participants from the potential analysis population as the IOUs were not able to provide the requested data for all customers.

[25] The two-staged approach to matching limits the quantity of AMI data that needs to be requested, processed and modeled. This reduces the burden on the utilities and the analysis.

The second stage matching starts with the monthly matched population with AMI data. For each participant, the second-round logit model finds the non-participant with the most similar probability of QM participation using the hourly usage data. In the second-stage match, which was based on a logistic model with 18 independent variables implemented on 12 strata, only four t-tests of differences across the independent variables (4 out of 216 independent variables) were statistically different for the part and non-part sample (presented in APPENDIX J). The t-test results support the quality and validity of the second-round matching process.

Graphing of hourly load shapes was used to ensure that the second-round propensity score matching led to the development of a matched non-participant sample whose hourly loads were similar to those of participants prior to participation. Figure 12 and Figure 13 illustrate the participant and matched non-participant average hourly usage shapes for the stage 2 match. The right-most graphs in Figure 12 and Figure 13 include both the first-round control group match in green and the second-round match in blue along with the average load shape for participants in red.[26] The figures illustrate that the first-round non-participant match hourly load shape closely matches the participant load shape. The second-round non-participant match (matched nonparticipants), improves on the first-round match and is nearly exact with the average participant load shape. These figures illustrate the high quality of the non-participant match.

Table 16 and Table 17 also present information on the average monthly usage of the participants and the matched nonparticipants following the stage 2 matching. The use of AMI data in the second-round matches led to a reduction in the participant population size. The second-round matching process improves the matching of households based on hourly usage. In Table 16 and Table 17 the stage two matching average monthly usage are very similar for participants and matched non-participants and the test statistics indicate that the hypothesis that the usage of participants and non-participants was statistically the same following the second round of matching cannot be rejected.

[26] The stage 2 control after stage 1 match appears less closely matched to the participant load shape than the stage 1 control after stage 1 to the participant load shape for two reasons. First, the stage 1 matching was undertaken and illustrated at the monthly usage level while the stage 2 matching was at the hourly level. The change in scale contributes to the impression that the control after match 1 are substantially different from the participants when viewed in the hourly graph. Second, the matching was done with replacement, allowing a non-participant to be matched with multiple participants. The control after match 1 are weighted for multiple matching in the stage 1 matching graph but not in the stage 2 matching graph due to fact that prior to matching in stage 2, we don’t know the stage 2 weights.

Figure 12. SDG&E participant and non-participant at first and second-round matching

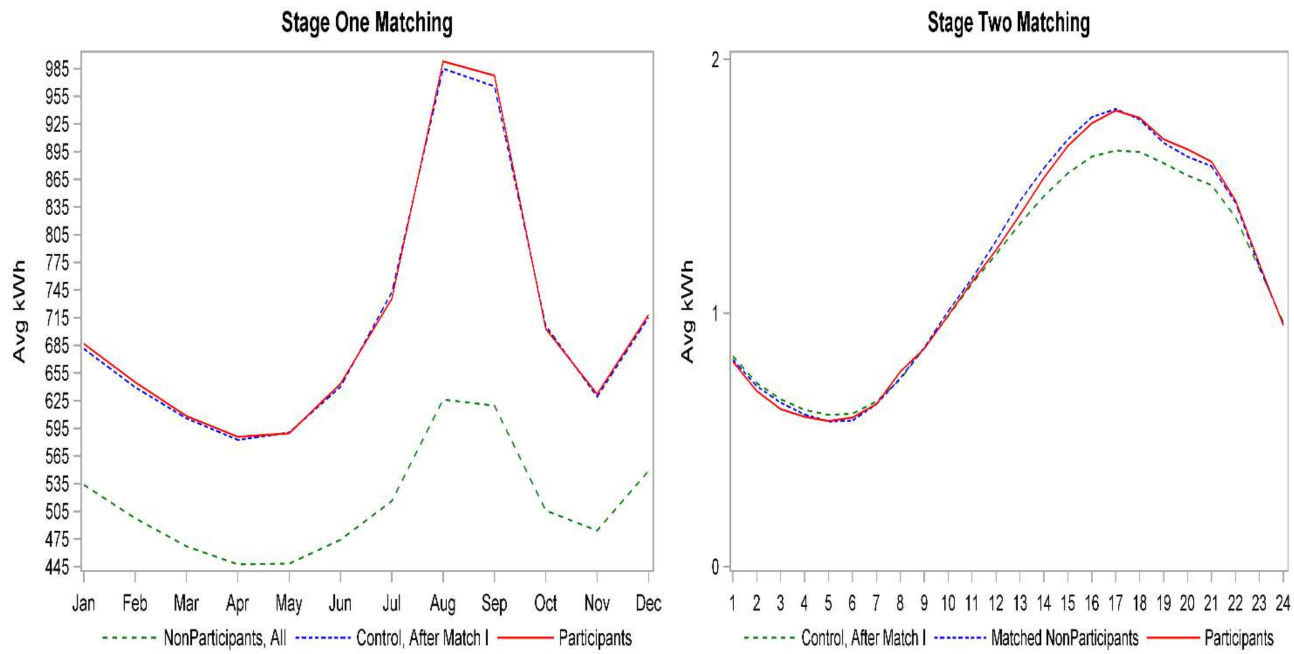
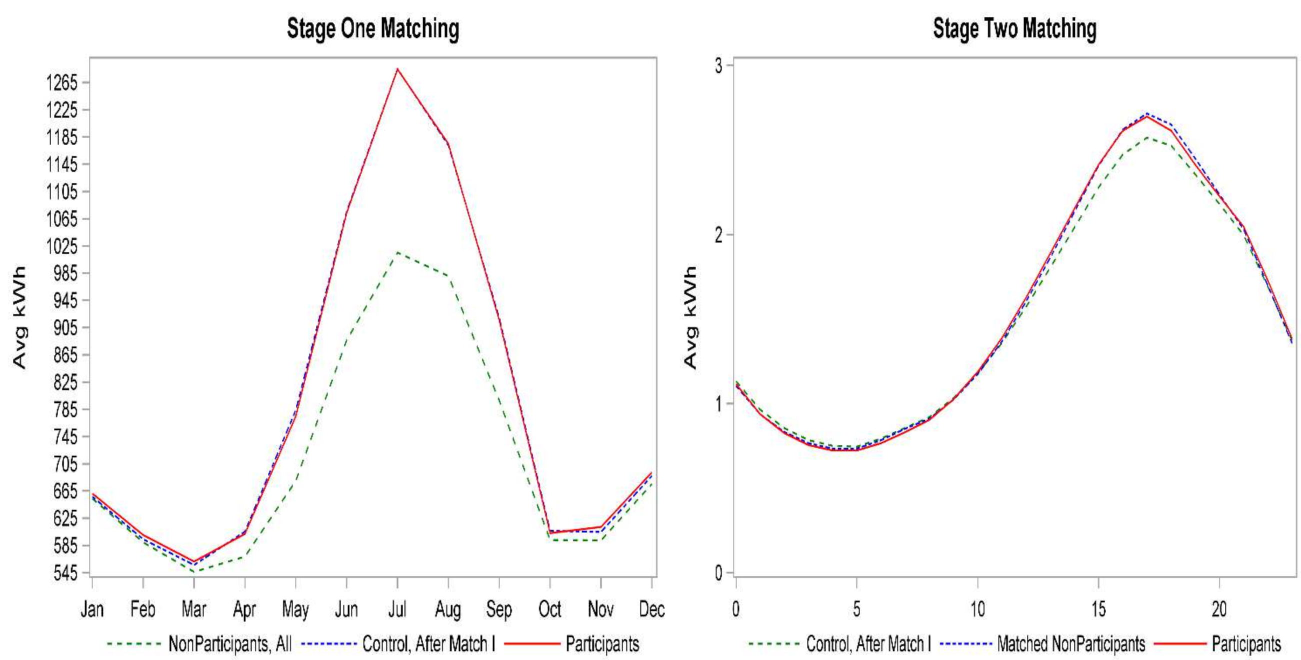


Figure 13. PG&E participant and non-participant at first and second-round matching



While the quasi-experimental design matching process undertaken to develop a matched set of non-participant households can never prove that the participant population and non-participant sample are the same across unobservable characteristics, extreme care was taken to ensure that these groups were observationally similar.[27] Statistical tests were run to determine that the quality of the match was high and that observable characteristics did not differ across the two groups. Lastly, the inclusion of information on prior participation in energy efficiency programs other than QM for both the participant and non-participant households in the matching process may help to control for unobservable characteristics that increase the likelihood of participation for these households.

3.3 Commercial program data collection

The M&V effort included three distinct data collection activities: Implementer ride-along visits at current program sites to evaluate the coil cleaning measures, traditional ex post site visits for a sample of the 2013-14 QM population primarily to evaluate economizer measures, and phone surveys to evaluate thermostat and supply fan measures. The phone survey was supplemented with thermostat and supply fan data collected onsite at the ex post visits.

3.3.1 Implementation ride-along visits

In our previous HVAC3 evaluation, we completed ride-along visits with implementation technicians at five sites that resulted in coil cleaning measure data collection on 28 units. Unfortunately, due to a temporary freeze on coil cleaning rebates and internal communication issues, units from three of those five sites had their coils cleaned less than three years prior to the ride-along visit, thus some sites did not necessarily represent the condition of coils at sites entering the program. For that reason, we only used the results from a subset of 12 units across two sites to revise simulation input parameters for our previous HVAC3 evaluation report.

The previous evaluation results showed greater variation in coil cleaning impacts between units at different sites than between units at the same site. For this reason, we targeted the unit inspections across a greater number of sites relative to the prior evaluation, testing one to two units per site visit. While we expanded the sample over the previous evaluation, final sample size was limited by difficulties scheduling ride-along visits with contractors. We completed inspections of 17 units across 10 sites for the coil cleaning measures.

We planned to execute the ride-along visits during the warmer months as often as possible to allow us to record the change in refrigerant discharge or static air pressure before and after coil cleaning when units are operating in cooling mode during representative operating conditions. While we achieved a successful pilot of measurement methods on a demonstration HVAC unit at PG&E’s Energy Training Center in Stockton, CA, the first ride-along site visit in June produced results that showed virtually no observable changes in key measurements. These initial results indicated that a more comprehensive measurement and analysis approach was necessary to detect changes to system performance produced from coil cleaning. Our revised approach used an integrated multi-point refrigeration performance analyzing system, ClimaCheck, to record refrigerant system pressures and temperatures, as well as compressor power and air side temperatures and produce real-time analysis of system performance. These changes in methodology and equipment resulted in a delay in returning to the field while the new approach was developed by the evaluation staff and CPUC advisor. The remaining nine sample site visits were performed between October–December 2016, so testing was at lower outdoor temperatures and lower internal loads than planned.

Table 18 shows the number of sites planned and completed. Findings from the ride-along visits are discussed in section 4.1.1.2.

[27] Randomized control studies can also have situations where the treatment and control households are not the same on average.

Table 18. Implementation ride-along sample by IOU

IOU	Sample Target	Sample Complete	% Complete
SDG&E	5	3	60%
PG&E	5	3	60%
SCE	5	4	80%
Total	**15**	**10**	**67%**

The overall condition of the inspected units was fair, but this varied from site to site and some of the systems inspected were judged to be in poor condition. Of the 17 units inspected at the 10 sites, two were in very good condition (both were at the same site and were less than two years old), 10 units were judged to be in fair condition (average age of 14 years old), and five units were judged to be in poor condition (average of 12 years old). Sites with units found to be in poor condition either had units exhibiting faults that had to be corrected prior to testing (e.g., an empty refrigerant circuit) or had so many improperly functioning units at a single site that it was difficult or impossible to identify two units without system faults to test.

HVAC units inspected during the coil cleaning ride-along visits varied in age and condition. Units at five of the 17 sites were in poor condition and required corrections to faults before performance testing could be performed.

3.3.2 Post-performance site visits

We visited 22 participant sites to collect data for evaluation of economizer, supply fan control, and programmable thermostat measures. The fundamental activities included:

Determining the economizer functionality, control sequence, changeover set point, and outside airflows
Recording of thermostat settings for supply fan control and thermostat reprogramming measures

The accurate measurement of outside airflow is inherently challenging, and we investigated multiple methods in our pilot. We used two methods for the ensuing field measurements, one using a hot wire anemometer traverse and the second using a TrueFlow from Energy Conservatory. The visits occurred in the late fall and winter when building cooling was not required. Table 19 shows the sites planned and completed.

Table 19. Post-performance site visit sample by IOU

IOU	Sample Target	Sample Complete	% Complete
SDG&E	3	2	66%
PG&E	17	16	94%
SCE	5	5	100%
Total	**25**	**23**	**92%**

3.3.3 Phone survey activities

Phone surveys were used to collect data on thermostat set points and supply fan operation in facilities where those measures were installed. Our previous HVAC3 evaluation efforts did not collect data from a large enough sample to confidently assess savings for these measures. Therefore, for the 2015 evaluation, we piloted phone surveys to cost effectively collect a larger sample, which allowed us to produce unit energy savings estimates (UEC) for programmable thermostat and supply fan measures across climate zones and building types.

Both measures only involve changing the settings during unoccupied periods. Therefore, this was the focus of our survey, though we also collected data on occupied schedule and settings, which could be used to determine whether the building ventilation complies with Title 24 Building Energy Standards (Standards) ventilation requirements, although these calculations were not performed as part of this evaluation.

Survey questions were developed using a thermostat survey DNV GL conducted as part of a Massachusetts study as a guideline.[28] That survey asks customers questions they can easily answer (e.g., baseline thermostat type and degree of occupant intervention) and avoids asking detailed questions about exact baseline set points and schedules. The survey used for this evaluation can be found in APPENDIX E.

To reduce survey respondent inconvenience, we asked customers with multiple thermostats to read us the settings of no more than three thermostats. We asked the customer to cycle through the current thermostat settings, reading us current set points and schedules. Our survey showed a 28% response rate which seemed to be slightly biased towards customers with a fewer number of thermostats at their site. Because of this bias we supplemented the phone survey with ex-post data collected from sites with a higher than average number of thermostats.

We surveyed at total of 72 sites out of a target sample of 100. Factors contributing to the lower achieved sample size, despite working both a primary and backup sample, included refusals, inability to reach the appropriate site contact, and limitations tied to incomplete contact information in the program tracking data. Table 20 shows the percentage of completed phone surveys by IOU.

Table 20. Phone survey sample by IOU

IOU	Sample Target	Number with Thermostat Measure	Number with Supply Fan Measure	Sample Complete	% Complete
SDG&E	14	39	41	11	79%
PG&E	71	15		54	76%
SCE	15	14	1	7	47%
Total	**100**	68	42	**72**	**72%**

[28] DNV GL (in publication), MA45 Phase 2 Programmable Thermostat Memo, part of a study underway for Massachusetts Program Administrators: Massachusetts Commercial Industrial Evaluation Contract (CIEC) Project 45: 2013 Prescriptive Gas Evaluation.

3.4 Residential QM program data sources

This section describes the key data sources incorporated into the impact analysis of the PG&E and SDG&E residential QM programs, including a description of the ex ante program tracking claims. It also provides a high-level overview of the methods used to develop ex post savings estimates.

The data sources include:

- Program tracking data from SDG&E and PG&E with information on measure group-level installations, installation dates, and savings. The program tracking data also included information on the site-level installation of other rebated energy efficiency measures.[29]
- Weather data for the major weather stations in SDG&E's and PG&E's service territories
- Electric consumption data from monthly utility billing records and interval or AMI billing data

For each data source, a description of its contents and uses are described below. This section also provides a high-level description of the development of the analysis population and the methods used to develop the analysis population and evaluate residential QM program savings.

3.4.1 Program tracking data

The billing analysis sites are participants in the 2013-14 SDG&E and PG&E residential QM programs.[30] The residential QM program tracking data include ex ante measure group-level savings and installation dates that were used in the analysis. The evaluation team also incorporated information on participation in other IOU energy-efficiency programs from 2012 to 2015. The tracking information for other IOU energy efficiency programs included data on site-level participation, ex ante savings, and timing of participation. The program tracking data listing the installation of energy efficiency measures other than residential QM were used in the analysis to ensure that the billing analysis' estimated impacts were not biased by the energy efficiency savings attributable to other energy efficiency measures installed during the pre- and post-installation periods.

The ex ante measure group savings from the residential program 2013-15 tracking data are summarized by year and measure group in Table 21. The first three rows of data highlight the measure groups and ex ante energy savings associated with PG&E's program while the final five rows present similar information for SDG&E's program. These data indicate that PG&E's ex ante savings claims are substantially larger than SDG&E's. The final column in the table lists the share of total program kWh savings associated with the different utility measure groups. The share information reinforces PG&E's greater ex ante claims relative to SDG&E's.

[29] The program tracking data does not include information on the installation of upstream measures, such as light bulbs, that are not tracked at the site level.

[30] The program IDs for SDG&E and PG&E are SDGE3212 and PGE21006, respectively. The billing analysis was based on 2013-14 participants of residential QM program due to the need for extensive pre- and post-installation billing data. The measure level savings from this analysis will be applied to the 2015 residential participants. The same measures were installed in 2013-15. The ex ante savings per ton (PG&E) or per unit (SDG&E) changed over time, but the savings estimates derived from the 2013-14 models will be applied to the 2015 participants.

Table 21. Residential QM measure group ex ante kWh savings (2013-15)

Measure Group	2013 kWh Savings/Year	2014 kWh Savings/Year	2015 kWh Savings/Year	% of Total Residential QM kWh Savings*
PG&E				
Fan repair	774,479	47,410	239,964	4%
Motor replacement	44,085	3,440,854	4,580,255	77%
RCA	-	1,364,995	807,230	14%
SDG&E				
Fan repair	83	80	49	0.0%
Motor replacement	1,227	970	345	0.0%
RCA	1,718	1,403	1,971	0.0%
Coil cleaning	4,950	1,043	8,488	0.1%
Fan control	301,256	119,974	299,315	5.0%

* Note: percentages are relative to the combined PG&E and SDG&E 2015 programs. PG&E accounts for approximately 95% of the combined ex ante savings.

PG&E's higher share of program savings is due to a larger number of claims relative to SDG&E. The average ex ante claims for PG&E were 479 kWh per household and 673 kWh per household for SDG&E.[31] Nearly all SDG&E's participant customers installed the fan control measure group.

For the 2013-14 program, PG&E included tracking savings for over 16,500 different records while SDG&E only included slightly more than 1,600 claims.[32] PG&E's program participation is dominated by claims within the inland climate zones 11, 12, and 13. Less than 30 claims originated from climate zones 2, 3, and 4. The small size of participation from coastal climate zones (zones 2, 3, and 4), and the substantially different weather relative to climate zones 11, 12, and 13, led us to focus on the inland climate zones.

The evaluation team compared the per measure-group ex ante claims for PG&E and SDG&E with the values prescribed in the Workpaper Disposition for Residential HVAC Quality Maintenance California Public Utilities Commission, Energy Division May 2, 2013. PG&E's ex ante claims per installed QM measure group are larger than the values prescribed in the Workpaper Disposition. Over the three-year period, PG&E reduced its per-unit ex ante claims, but the reductions generally still resulted in PG&E's 2015 ex ante savings values exceeding those from the 2013 Workpaper Disposition.

SDG&E's ex ante claims generally are consistent with the prescribed values in the 2013 Workpaper Disposition. SDG&E, however, appears to have claimed savings based on a prescribed number of tons rather than the HVAC tonnage observed on site. SDG&E also claimed residential QM savings for efficient fan controllers. The efficient fan controller workpaper (WPSDGEREHC0024, RV0) stipulates that ex ante savings for single family households are substantially less than SDG&E's ex ante claims. SDG&E appears to have claimed the savings associated with a double wide mobile home instead of single family residence.[33] APPENDIX G provides a disposition of the utility specific average ex ante claims by measure group, climate

[31] The ex ante average fraction savings for PG&E was 479/9,480 or 5.1% of average household usage and SDG&E was 673/8,268 or 8.1% of average household usage.

[32] Tracking data claims represent a single record of measure level installations. If a home had multiple measures installed there will be multiple records.

[33] The climate zone weighted ex ante savings for fan controls in SDG&E's service territory in work paper WPSDGEREHC0024 for single family homes is 211.69 kWh while the climate zone weighted ex ante savings for double wide mobile homes are 528.52 kWh.

zone, and period relative to the values prescribed in the Workpaper Disposition from May 2, 2013. The HVAC fan control measure was not included in the 2013 Residential QM Workpaper Disposition.

3.4.2 Weather data

The billing analysts used weather data provided from Schneider Electric, formerly known as Telvent. The weather data consisted of hourly temperature reads that we used as inputs to the calculation of hourly and daily heating- and cooling-degree hours and days. The cooling and heating degree data were developed from January 2012 through December 2015. The cooling and heating degree data were developed for each climate zone included in the analysis. For PG&E, the analysis, and degree day development was limited to participants in climate zones 11, 12, and 13. For the SDG&E analysis, degree days were developed for climate zones 6, 7, 8, 10, and 14. A zip code-to-climate zone mapping system was used to assign weather stations to each site in the analysis. The degree day data were then associated with a site-level consumption based on the site's weather station and dates and hours from the usage data. The actual weather data, used in the estimation of the billing analysis indicates that the post-installation weather was slightly warmer than the pre-installation weather.[34] The number of cooling degree days increased slightly while the number of heating degree days declined slightly as shown in Table 22. Given the similarity between the pre- and post-installation period, it is unlikely that the slightly warmer weather led to a substantial change in energy consumption.

Typical weather was used to develop weather normalized estimates of savings. Typical weather data were drawn from CZ2010 weather files developed for the California Energy Commission for locations in California using actual 1989-2009 weather data.

Table 22: Pre- and post-participation average cooling and heating degree days

	Pre-Participation Period	Post-Participation Period
Average Cooling Degree Days	5.91	6.04
Average Heating Degree Days	4.62	4.3

3.4.3 Consumption data

Analysts used both monthly billing data and hourly AMI data. The monthly billing data were used in the first round of non-participant matching while the AMI data were used for the second round of non-participant matching and in the impact evaluation. Itron received electric monthly billing data from the CPUC evaluation residential data manager, DNV-GL, and received electric AMI data at the hourly interval from both SDG&E and PG&E.

Monthly billing data for the pre-installation period for the SDG&E and PG&E residential populations were made available to Itron for the matching process. The potential pre-installation period ranged from January 2012 to November 2014, depending on the timing of residential QM participation. Monthly bills contain records with customer-level consumption ending on a given meter read date. The number of days is typically almost 30, but this number and the day of the month of the read date vary substantially from customer-to-customer and month-to-month.

[34] For both the cooling and heating degree days 65 was used as the basis.

Analysts used the monthly data to create a panel data structure of calendarized usage that was used in the development of the first-round, non-participant matched samples for PG&E and SDG&E. For the first-round non-participant matching, participants and non-participants were required to have at least 12 months of pre-installation monthly data. Non-participant matches were also required to be in the same climate zone as the participant match.[35]

Following the development of the first-round, non-participant matched samples, Itron requested and received AMI data for the participants and the matched non-participant sample.[36] The AMI data were requested for the pre- and post-installation period, from January 2012 to December 2015. To be included in the second-round of the matched participant sample, the participants and the matched non-participant sample were required to have 12-month pre-installation interval data.

For the second-round matching and the evaluation process, the program tracking and weather data were merged with the AMI data by account and calendar. These data were used in the second round PSM to develop a one-to-one match of participants and non-participants.[37] Following the development of a matched participant and non-participant sample, these data are used in the billing regression model to develop gross and net ex post estimates of residential program savings.

35 Participant and non-participant customers were also removed from the analysis if they were on an electric vehicle rate or a net energy metering rate. Given the relatively small size of the anticipated residential program impact, large changes in measured consumption associated with electric vehicles or solar energy production would make the task of observing savings impact more difficult. In SDG&E programs, these criteria led to the elimination of 91 participants and 513 participants in PG&E territory. A small number of households were also eliminated for gaps or overlaps in the consumption data.

36 The first-round matching led to the development of approximately 13 non-participants for each PG&E participant and 19 non-participants for each SDG&E participant. This sample was then used in a second round of matching using hourly data to develop a one-to-one match of participants and non-participants. SDG&E's ratio of first-round non-participants to participants was higher than PG&E's because SDG&E's participant population was smaller. The smaller size of SDG&E's participant population could lead to increased difficulty finding a good non-participant match, leading the evaluation team to increase the ratio of non-participants in the first-round match.

37 The matching was done with replacement so that a non-participant may be a match for more than one participant. The match process provides each participant with their best match. The post-installation period for the non-participant is defined by the date of participation for their matched participant. For non-participants matched to multiple participants, multiple records are included with a different participation data for each match.

4 GROSS SAVINGS METHODS AND RESULTS

In this section, we describe the commercial and residential program evaluations separately in detail and then present program-specific results at the end.

4.1 Commercial program gross savings evaluation methods and results

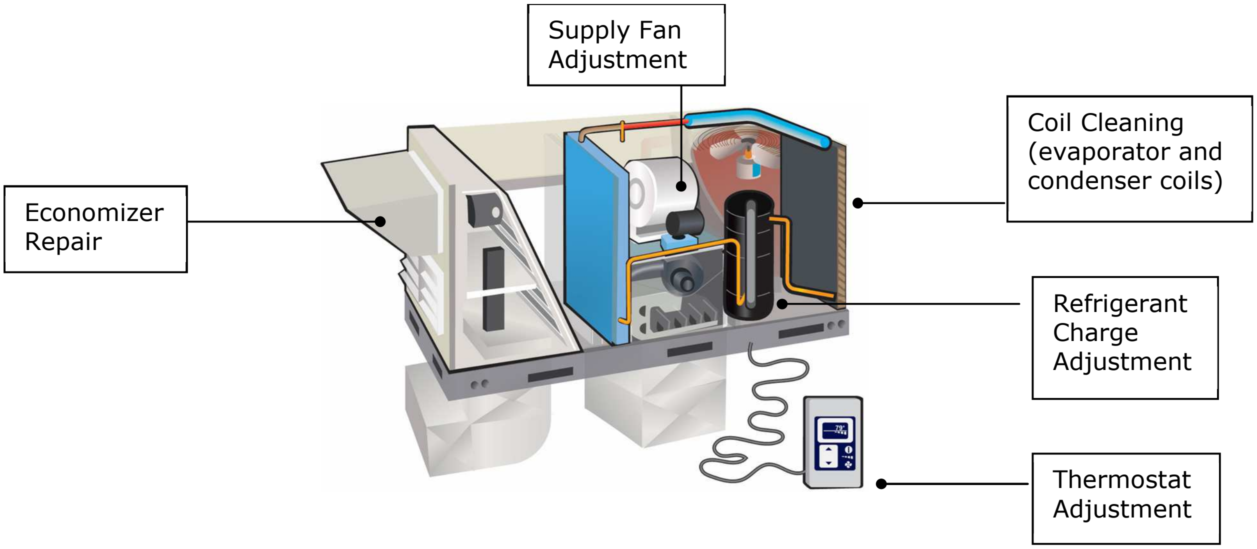
The commercial programs were evaluated at a measure level, placing each of the evaluated measures into related measure groups. In this section, we describe each measure group's methods and results separately. Each measure-specific section begins with a review of the 2013-14 ex post methodology and a description of any changes to the methodology in the 2015 evaluation. All the workpapers for the evaluated measures included energy savings estimated from simulations using eQuest, which is a front-end interface for DOE-2.2. eQuest and DOE-2.2 form the basis of the ex-ante savings estimates developed for the workpaper developers California Database for Energy Efficiency Resources (DEER). The workpapers and this evaluation used the 20 DEER commercial building prototypes that were modeled in seven vintages for all 16 California climate zones. This set of models, referred in this report as DEER eQuest models, were utilized in this evaluation to translate changes in measured unit performance into changes in energy use. No additional research was conducted in the evaluation to update the baseline heating energy or cooling energy or demand consumption estimated by the DEER eQuest models.

The following measure groups are included in this report:

- Economizer repair and adjustment
- Thermostat adjustment
- Supply fan control
- Coil cleaning
- Refrigerant charge adjustment (RCA)
- Quality Maintenance (a measure group made up of the previous five measure groups)

Figure 14 shows the location of the equipment served by each measure group in a basic rooftop package unit.

Figure 14. Schematic of a RTU and location of evaluated measure groups



4.1.1 Economizer measure group

DNV GL's 2015 approach to evaluate gross savings of the economizer measure group builds on our prior HVAC3 evaluation approach. We collected data on an additional sample of 2015 participant and combined with the 2013-14 participant data. The combined dataset was then analyzed to develop adjustments to ex ante estimates. The adjustment factors were applied to 2015 tracking claim values to estimate the ex post impact of the measure. The larger sample provides a more robust data set for future revision of ex ante workpapers.

Like for the 2013-14 program cycle, the following three categories of economizer measures were implemented in QM programs for 2015:

Economizer retrofit/repair. The retrofit/repair measure activity was either an addition of an economizer to a fixed outside air unit, the repair of a non-functional economizer, or the complete replacement of non-functioning economizer with a new economizer and control system. For the economizer retrofit/repair measures, the program assumed no economizer functionality, which resulted in a fixed outside-air fraction (OAF) in the pre-treatment case and a functioning economizer in the post-treatment case. The economizer retrofit/repair measure for PG&E's and SCE's QM programs also adjusted the minimum airflow setting

Economizer control/adjustment. The economizer control/adjustment measure categories included making settings changes to existing control hardware or replacing the controller or sensors if the existing controls were not capable of implementing the control setting changes. To establish a baseline for this measure for the ex ante savings calculations, systems were modeled with an economizer installed with a low changeover set point (55°F). The effect of this modeling change is that the economizer only in the unlikely condition where the OA temperature is below 55°F and the building is in cooling mode. The ex ante savings methodology measure involved raising the changeover set point in the post-treatment models, described further in the methodology section 4.1.3.2.

Air damper re-positioning. This measure involved checking and re-positioning outside air dampers and was implemented in the SDG&E Direct Install program only. The goal of the measure was to set the damper position to achieve optimal minimum OAF. We did not evaluate this measure because we were not able to attain baseline damper position for this measure during this evaluation.

4.1.1.1 Economizer characteristics

We surveyed 75 participant HVAC units with economizers for the 2015 data collection effort to determine predominate control types and set points. We combined these data with the 2013-14 data from 117 HVAC units for a total of 192 HVAC units in this evaluation. Table 23 shows the counts of single-sensor, set point controlled economizers versus economizers controlled by dual-sensor differential controls. There were very few differential controlled economizers (3%) in our survey during the 2013-14 program cycle, but they were much more prevalent (53%) in the 2015 program year.

Table 23. Number of evaluated economizer-control types

Control Type	2013-14 Units		2015 Units		Combined Units	
Set Point	96	82%	35	47%	131	68%
Differential	4	3%	40	53%	44	23%
Don’t know	17	15%			17	9%
Total	**117**		**75**		**192**	

Table 24 shows the proportions of participant units using dry-bulb temperature sensors versus enthalpy sensors, which measure temperature and humidity, for economizer controls. In the 2013-14 sample, there were more enthalpy sensors installed in the surveyed units than dry-bulb sensors, but in the 2015 sample there were more dry-bulb sensor equipped units.

Table 24. Number of evaluated economizer-sensor types

Sensor Type	2013-14 Units		2015 Units		Combined Units	
Enthalpy	59	50%	19	25%	78	41%
Dry-Bulb	44	38%	56	75%	100	52%
Don't know	14	12%			14	7%
Total	**117**		**75**		**192**	

Economizers are controlled by energy management systems (EMS), advanced digital economizer controllers (ADEC), or analog economizer controllers. Table 25 shows the controller types found at the 24 sites investigated for this component of our previous HVAC3 study and the 22 sites in the 2015 study. Analog controllers were the dominant control method among the sample. Two sites in the 2015 sample had both analog and ADEC economizer controllers at the same site.

Table 25. Number of evaluated economizer-controller types

Economizer Control	2013-14 Sites		2015 Sites		Combined Sites	
EMS	5	21%	2	9%	7	15%
Analog Controller	11	46%	12	55%	23	50%
ADEC	3	13%	6	27%	9	20%
Analog/ADEC			2	9%	2	4%
Unknown	5	21%			5	11%
Total	**24**		**22**		**46**	

4.1.1.2 Ex post methodology

In our previous HVAC3 evaluation, we attempted to collect data to verify the model inputs used in the ex-ante calculation, principally changeover set points and minimum and maximum outside air fractions (OAFs), but had limited success collecting economizer airflow rates, low limit lockout, or changeover set points. Therefore, the ex post impact was not based on changes to the simulation models, but was based on field observations of economizer functionality informing an installation rate. In this 2015 evaluation, we were successful at collecting economizer functionality and economizer characteristics such as changeover set point and sensor type information (enthalpy or temperature, and single or differential) at 22 sites. In addition, the system airflow and economizer airflow were measured to determine OAFs. These measurements were taken at both at maximum outside air condition (economizing mode, outside air dampers completely open) and minimum outside air conditions. These data were used to inform an installation rate and verify or adjust simulation inputs for the ex post models. The OAFs were held constant between pre- and post- models.

In the research plan we stated our intent to collect field data on the specific parameters, compare them with ex ante assumptions, and adjust these parameters in the ex post model where necessary. The parameters were as follows:

Minimum outside air, MIN-OA-AIR
Maximum outside air, MAX-OA-AIR
Economizer lockout temperature. LOW-LIMIT-T
Changeover set point, ENTHALPY-LIMIT or DRY-BULB-LIMIT
Outside air control type, OA CONTROL

The changeover set point and economizer lockout temperature are relevant to the economizer controls repair/replace measure, and the minimum and maximum outside air settings are relevant to the air damper reposition measure and the economizer repair/replace measure. However, the most important aspect of the economizer repair/replace measure is whether the economizer functions properly after the retrofit. The methodology focuses first on installation rate for that reason, and then investigates the changeover set points, followed by an investigation of outside air fraction.

Installation rate

When functioning properly, economizer dampers will open when the outside conditions are favorable and the system is calling for cooling. The dampers of a properly functioning economizer should return to the minimum outside air position when the system is operational and not calling for cooling or when conditions become unfavorable. If the cooling loads are not met by the economizer, the compressor(s) will engage to meet the cooling needs, and the dampers may adjust to a minimum or an intermediate position depending on the control strategy. The dampers should return to the fully closed position when the unit is not in operation. Typically, when economizers fail, the outside air damper will remain stuck in one position, and will not move under any circumstances.

The economizer functional testing in this evaluation was performed per manufacturer protocols, where available. Many HVAC units had a "test mode" where the unit can be overridden into economizer mode (dampers open) even when conditions are not favorable. Units from one specific manufacturer, for example, were cycled through all operational modes: fan only, economizer mode, one compressor cooling, two compressor cooling, and heating mode by using a "jumper wire" between the test terminals. Other units were equipped with ADEC that have an integrated test mode to perform this actuator test. If the economizer dampers did not open during test mode, it is likely a problem with linkage, actuators or damper motor and is considered a non-functioning economizer for the study. Likewise, there are cases where the economizer dampers are stuck and in a fully or partially open position which also constitutes actuator functionality failure.

However, if the economizer opened during test mode, it does not necessarily mean that the economizer was fully functional, because there may be problems with the outside air sensor or other components of the economizer control system.

Several methods were used to test the sensors and control system functionality. These included:

- Cooling the outside air sensor with either cold spray or a cold pack until it reached a temperature below the changeover set point.
- Manipulating the set point of the economizer controller such that the outside air temperature or enthalpy was below the set point.
- Emulating a temperature or enthalpy sensor signal with specialized equipment (a decade box for resistance signals or a loop calibrator for 4 mA–20 mA signals). During this testing, the unit needed to be calling for cooling. If the conditions were such that the unit was not calling for cooling, then the unit thermostat was manipulated until a call for cooling was made, or we sent a signal to the unit to get it into cooling mode.

We tested the control system for functionality by disconnecting the outside air sensor or control system signal and using a decade box or loop calibrator to simulate conditions that were favorable for economizing even when outside conditions were not. Conversely, if outside air conditions were suitable for economizer mode, we used a decade box or loop calibrator to emulate non-favorable conditions to force the unit out of economizing mode if the control system is working correctly. The most obvious drawback in the emulation approach is the outside air sensor functionality is not specifically tested because the sensor has been disconnected from the system for the test. Therefore, the sensors were tested separately under this approach.

In some cases, the units were controlled by a CO2 sensor. Usually these were set to a low limit of 700 parts-per-million (PPM) and high limit of 1,100 PPM. In these cases, the CO2 input to the unit was removed and replaced with a Fluke 707 loop calibrator to recreate the electrical signal of the applicable CO2 range to test the functionality.

The results of the functionality tests in the 2015 field data collection are shown in Table 26 and Table 27.

Table 26. Economizer functionality results

Site ID	IOU	Number of Units Tested	Number of Units Verified to be Functional	Site Installation Rate
1	SCE	4	0	0
2	PGE	4	2	0.5
3	PGE	3	0	0
4	SCE	2	2	1
5	PGE	2	0	0
6	PGE	3	3	1
7	SCE	4	4	1
8	PGE	4	4	1
9	PGE	4	3	0.75
10	SCE	1	0	0
11	SCE	4	4	1
12	PGE	4	0	0
13	PGE	4	4	1
14	PGE	3	3	1
15	PGE	4	2	0.5
16	PGE	3	3	1
17	PGE	4	3	0.75
18	PGE	3	0	0
19	PGE	4	4	1
20	PGE	4	2	0.5
21	PGE	2	2	1
22	SDGE	3	0	0
Combined				0.59

Table 27. Economizer installation rate results summary

Program Year	Sites	Installation Rate
2013-14	24	0.63
2015	22	0.59
Combined	46	0.61

Changeover set point

Economizer changeover set points, also known as high-limit set points, were gathered where available. In some cases, the set points could not be determined because the set point indicators on the controllers were not discernable. Others could not be determined because they were globally controlled with an energy management system that we did not have access to. Reliable set point information was collected at 12 sites;

seven sites had enthalpy set points and five sites had dry-bulb set points. These were combined with set points collected from the 2013-14 survey to produce combined average set points. Table 28 shows the changeover average dry-bulb and enthalpy set points, and their precision estimates for both controller types by program cycle.

Table 28. Economizer set point averages by controller type

Controller Type	Dry-bulb	Enthalpy
2013-14		
Set Point Average	67.2 F	24.4 Btu/lbm
# of sites	6	8
90% Error Bound	5.7	1.3 Btu/lbm
90% Relative Precision	8.5%	5.3%
2015		
Set Point Average	67.6 F	22.7 Btu/lbm
# of sites	5	7
90% Error Bound	4.1 F	1.3 Btu/lbm
90% Relative Precision	6.0%	5.6%
Combined		
Combined Set Point Average	67.4 F	23.6 Btu/lbm
# of sites	11	15
90% Error Bound	3.5 F	1.0 Btu/lbm
90% Relative Precision	5.1%	4.1%

As described above, the changeover set points, enthalpy, or dry-bulb limits, are the set points that when exceeded by temperature or enthalpy, returns the economizer damper to the minimum position. According to the workpapers, SCE modeled the post-treatment case with a 68°F-changeover set point. The 68°F changeover set point agrees with the average of 67.4°F average dry-bulb set point from the field data, considering the error bounds. Since the 67.4°F sample average agrees with the 68°F, no adjustments to the SCE models were made. In addition, analysis of implementer data for 1301 participants in SCE's program shows an average changeover temperature of 70.5°F, which supports that the ex ante 68°F-changeover set point is conservative if not accurate.

Conversely, PG&E modeled the post-treatment case with a 73°F changeover set point. Although this is a higher set point than we found statewide, we are not confident in the field data results to adjust this parameter in the ex post models. The field data sample contains only four sites within PG&E territory. In addition, since Title 24 dictates varying economizer changeover set points across California climate zones, it would not be appropriate to character the PG&E participant population using SCE participant changeover set points. However, we note that this a somewhat aggressive assumption and PG&E may want to revisit this assumption for future program years.

Similarly, no adjustments were made to the ex post models for the economizer low-limit setting. Low-limit or economizer-lockout set points were only used and recorded in the data collection at six sites. Four sites had 45°F low-limit set points and two had 32°F set points. The ex ante assumption was that there was no lockout temperature. Since the set points found during field activities were so low, it is unlikely they would come into play during the modeling analysis.

OAF measurements

In the 2013-14 survey, minimum OAF was not measured during field data collection with any degree of confidence, and we were not able to relate damper position field observations. For to the HVAC5 laboratory results for the 2015 survey, so we estimated OAF by measuring the system flow rate through the units and then measuring airflow through the economizer opening.

We performed system flow measurement by using the Trueflow[38] orifice plate and differential pressure gauge as the equipment was designed. That is, we removed unit air filters from the unit and we placed the orifice plates in the filter slots for the measurement. We made system airflow measurement with the maximum outside air (OA dampers completely open) and minimum outside air operational states. After the system airflows were measured, we measured the outside air with a more unique approach by taping a Trueflow plate in front of the economizer openings as shown below in Figure 15. Similar to system airflow, outside airflow on the tested units was measured at maximum and minimum outside air operational states. In addition to the Trueflow measurements, outside airflow was measured using the “traverse” method with a hot wire anemometer.[39]

---

38 The TrueFlow method was used to measure economizer flows by Robert Davis (Ecotope) in his 2002 study: 2002. Davis, Robert, David Baylon, Reid Hart. Identifying Energy Savings Potential on Rooftop Commercial Units, ACEEE Conference Proceedings.

39 The anemometer traverse method is endorsed and practiced by a CASE initiative that studied methods for conducting acceptance testing of outdoor air ventilation rates, see Codes and Standards Enhancement Initiative Outside Air recommendation from the California Utilities Statewide Codes and Standards Team, October 2011.

Figure 15. Trueflow outside air measurement set-up

The traverse measurements did not appear to be reliable since the outside air measurement at the maximum OA state were often much higher than the total system airflow. Similarly, the traverse measurement for minimum outside air were also considerably higher than expected and much higher than the Trueflow OA measurements.

We believe that Trueflow measurements were reliable since all the Trueflow outside air measurements were less than the system air flow measurementsa and the two measurements were made with the same instrument, thereby reducing measurement bias. The measurements were not feasible in all cases due to the outside air intake geometry. Some of the outside airflow rates at the minimum condition were below the minimum threshold for the smallest Trueflow plate of about 300 cfm. For that reason, there are fewer minimum outside airflow rate measurements than maximum outside airflow rates for this study.

There are 22 units with maximum OA airflow rate measurements and the average OAF is 70%. This is the same fraction as included in the ex ante assumptions. There were 16 measurement of the OA flow rate for the minimum position. The average OAF was 25.2%. This is a considerably less than the ex ante assumption of 37.5%.

The ex ante pre-treatment OAF of 24.5% assumed that 40% of the units' pre-treatment had failed in the stuck closed position with an OAF of 5% and the remaining 60% had failed in the minimum OA position, assumed at 37.5% OAF. For the 2015 economizer assessment, we analyzed 28 units with failed economizers to test this assumption. For each unit with a failed economizer, we characterized the OA damper position as either closed, at the minimum OA position, partially open, or completely open. In addition, there was a OAF associated with each position. We assumed the closed position to be an OAF of 5% due to leakage; we assumed the minimum position to be 0.25; we assumed partially open to be 0.40; and we assumed open to be 0.70. The minimum and open OAF assumptions were based on our field testing. The results are summarized in Table 29. Although the proportion of failed damper positions was very different than the ex ante assumptions, the overall estimate of 0.229 OA is very close to the ex ante assumption of 0.245.%. Note that we are using post-treatment failed economizer OA damper positions to characterize pre-treatment damper positions. This is less than ideal, but the best data available since failed economizer damper positions were not included in the implementer data.

Table 29. Failed economizer OA analysis

OA Damper Failed Position	n	Percentage	Estimated OA Fraction
Closed	15	54%	0.05
Minimum	3	11%	0.25
Partial	7	25%	0.40
Open	3	11%	0.70
Weighted Average	28		0.229

The minimum OA post-treatment ex ante assumed OAF of 37.5%was is high compared with the measured OAF of 25.2%. The minimum OAF in the ex post models was adjusted to 25%.

Conversely, the ex-ante maximum OAF of 70% was confirmed by the field measurements, where the average OA percentage of the 22 units measured was 70%. Therefore, no adjustment of the maximum OA percentage in the ex post models was necessary.

4.1.1.3 Program-specific results

Table 30 shows the resulting energy and demand savings on a program level. As mentioned above, SDG&E's direct install economizer measure consisting of adjusting outside air dampers was not evaluated because we did not know the baseline condition. SDG&E's deemed program did not install economizer measures. SCE's QM program has no savings because they reported savings on an aggregated level. Results for this program are explained in more detail in section 4.1.6.

Therm savings are not reported here because the economizer measure, as modeled, produces a heating penalty rather than savings. This is because the minimum ventilation rate as a fraction of HVAC system flow increased slightly between the baseline case at 0.229 and the installed case at 0.252.

Table 30. Economizer savings by program

Program	Number of Claims	Ex Ante kWh Savings	Ex Ante kW Savings	Ex Post Instal-lation Rate	Ex Post Reali-zation Rate kWh	Ex Post Reali-zation Rate kW[40]	Ex Post kWh Savings	Ex Post kW Savings
PG&E Commercial QM	1,155	2,037,921	-72	61%	77%	*	1,568,155	34
PG&E AirCare Plus	1,081	712,567	-87	61%	100%	*	714,945	3
SDG&E Deemed								
SDG&E Direct Install	370	213,220	2	100%	100%	100%	213,220	2

4.1.2 Thermostat measure group

The thermostat measure group involves replacing a non-programmable thermostat with a programmable thermostat, or reprogramming an existing programmable thermostat. The savings derive from reduced heating and cooling set points during unoccupied building periods. Thermostat measures were claimed in all the programs except SDG&E's Deemed Incentives program.

4.1.2.1 **Ex post methodology**

The 2013-14 approach involved recording thermostat settings for temperature setback during ex post site visits. These data points were used to determine an installation rate based on whether the installed settings met the measure requirements. We also calculated the installed setback temperature, however, the variation of the collected data was higher and the sample size slightly smaller than anticipated, leading to lower precision than we found acceptable for our estimate. Hence, we did not use the data as inputs to eQuest to calculate a revised unit energy savings (UES) for our previous HVAC3 evaluation report.

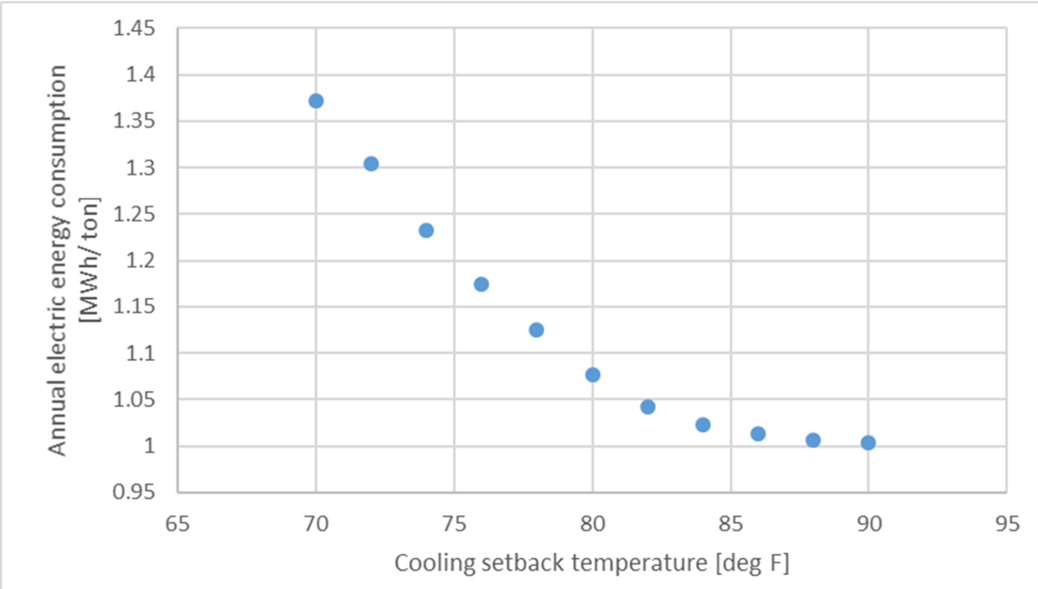
For the 2015 evaluation, we increased the sample size significantly by collecting data at nine site visits and by performing a telephone survey to collect thermostat settings at 64 additional sites. The analysis described in the sections below uses a combined 2013-15 data set (i.e., from both evaluations) containing 85 sites. The combined data set provided sufficient data inputs for eQuest to produce updated (i.e., ex post) programmable thermostat UES estimates across climate zones and building types that we then applied to 2015 claims.

The modeled effect of changing the unoccupied set point temperature on total building annualized energy consumption is non-linear, shown in Figure 16 for cooling a prototypical small office building in California climate zone 13, averaged across all vintages. The figure shows an obvious change in the effect of thermostat setback temperature between 80°F and 85°F, which is the temperature range of interest for this evaluation. According to the workpapers, the installed measure has a cooling setback temperature of 85°F across all programs. Those thermostats that are set better than the threshold save more energy than assumed, but the effect per degree above the threshold is not as pronounced as the effect per degree of thermostats that do not meet the threshold. If the relationship was linear then a one-degree thermostat

[40] The ex ante kW savings claims for these measures were negative, while the ex post values we found to be positive therefore the usual calculation of realization rate was withheld as it would produce an inaccurate representation of measure savings when applied to the ex ante claims in the usual manner.

change at 90°F would have equal energy savings to a one-degree thermostat change at 80°F, but because it is non-linear this is not true. For this reason, we decided to model two distinct post-treatment cases. The first case is a thermostat that meets the unoccupied set point temperature and the second case is a thermostat that does not meet it.

Figure 16. Effect of changing setback temperature on annual electricity consumption



The workpaper assumptions for cooling and heating set point temperatures are provided in Table 31. We compared our collected data to the workpaper assumptions as presented in the following section. Note that SCE's CQM program instructed contractors with the unoccupied cooling set point temperature of 80°F instead of 85°F stated in the workpaper. The evaluation maintains the required setback temperature at 85°F, but we describe the savings difference if the setback temperature of 85°F is used.

Table 31. Programmable thermostat workpaper assumptions

Utility	Installed thermostat Measure Specifications for unoccupied Building Periods	
	Cooling Set Point Temperature	Heating Set Point Temperature
SCE[41]	85°F	60°F
SDG&E[42]	85°F	55°F
PG&E[43]	85°F	60°F

Field data results

A total of 85 sites including 161 thermostat units were evaluated for this measure. At each site, all surveyed thermostat set points were averaged to estimate a site-level thermostat set point for heating and cooling

[41] Workpaper SCE13HC037 Comprehensive Commercial HVAC RTU QM.

[42] Workpaper WPSDGENRHC0026 Programmable Thermostat.

[43] Workpaper Unoccupied Building Controls Measure.

during unoccupied periods. We were not able to determine if a specific thermostat at a site was claimed through the program since the tracking data did not contain enough detail nor were there program stickers on most of the thermostats. Therefore, we excluded server-room thermostats from the data set since none of them met the program setback requirements, and included all other thermostats in the data set. At most sites, most the thermostats were set at the same set points.

The site-level thermostat settings were averaged by program and shown with their corresponding 90% confidence interval error bounds in Table 32 for cooling and Table 33 for heating. The complete data set showing average set point temperatures at all 85 sites is shown in APPENDIX E.

Table 32. Cooling thermostat unoccupied set point field results

Program	Number of Ex Post Sites in Data Set	Weekday Average Set Point [°F]		Weekday Percent Meeting Threshold	Weekend Average Set Point [°F]		Weekend Percent Meeting Threshold
		Threshold Met	Threshold Not Met		Threshold Met	Threshold Not Met	
PGE, combined programs	57	87.4 ± 0.8	76.9 ± 6.5	68%	87.2 ± 0.8	75.9 ± 6.4	67%
SCE Quality Maintenance	18	88.3 ± 2.7	75.6 ± 1.7	58%[44]	88.0 ± 3.3	76.4 ± 2.0	56%[45]
SDG&E Direct Install	11	89.4 ± 1.9	81.0 ± 1.4	50%	90.5 ± 0.8	81.0 ± 1.4	47%

When the 80°F threshold is substituted for the 85°F threshold, the average set point temperature changes less than two degrees in each category. Hence the models were unchanged, and we only changed the fraction meeting the threshold when we calculated the ex post savings (shown in section 4.1.6) for the 80°F set point case.

Table 33. Heating thermostat unoccupied set point field results

Program	Number of Ex Post Sites in Data Set	Weekday Average Set Point [°F]		Weekday Percent Meeting Threshold	Weekend Average Set Point [°F]		Weekend Percent Meeting Threshold
		Threshold Met	Threshold Not Met		Threshold Met	Threshold Not Met	
PGE, combined programs	57	53.8 ± 1.1	64.5 ± 8.3	78%	54.2 ± 0.8	64.5 ± 4.1	77%
SCE Quality Maintenance	18	51.1 ± 5.1	69.6 ± 2.2	71%	53.5 ± 4.8	69.6 ± 2.2	72%
SDG&E Direct Install	11	52.0 ± 2.0	61.0 ± 9.0	40%	52.0 ± 2.0	61.6 ± 4.4	42%

DNV GL performed two sets of pre-treatment/post-treatment models for each IOU, the first including unoccupied heating and cooling setback temperatures for the case where the program setback temperature was met, and another for the case where it was not met. The heating and cooling savings were weighted by the respective percent meeting the threshold. School summer periods were assumed to be already setback

[44] The weekday percent meeting threshold changes to 71% if an 80°F threshold is used.
[45] The weekend percent meeting threshold changes to 68% if an 80°F threshold is used.

in the baseline condition because we believed schools were already setting the temperature back during unoccupied summer periods. The school maintenance staff that we interviewed during ex post site visits were conscientious about changing their thermostat settings with changes in school schedule. The complete set of UES results for each case in each IOU are shown in APPENDIX F.

Although we collected information on hours of operation, we did not expect or achieve sufficient sample within each building type to change the occupied hours for any of the modeled prototypes.

4.1.2.2 Program-specific results

Table 34 shows the resulting electric energy and demand savings on a program level and Table 35 shows the resulting gas savings. SCE's Quality Maintenance program has no ex ante savings because they reported savings on an aggregated level. Results for this program are explained in more detail in section 4.1.6.

Table 34. Thermostat savings by program

Program	Number of Claims	Ex Ante kWh Savings	Ex Ante kW Savings	Ex Post Instal-lation Rate	Ex Post Reali-zation Rate kWh	Ex Post Reali-zation Rate kW	Ex Post kWh Savings	Ex Post kW Savings
PG&E Commercial QM	678	908,381	0	100%	103%	-	933,979	24
PG&E AirCare Plus	1,334	1,896,751	0	100%	115%	-	2,180,896	35
SDG&E Deemed Incentives								
SDG&E Direct Install	695	1,247,512	-193	100%	40%	23%	501,773	-44

The gas savings realization rates are quite low. Although we were not able to determine why the ex ante gas savings claims were relatively high since the workpapers did not include enough detail, we did scrutinize our results, and discovered that gas savings were low because the deep night setback cooled the thermal mass of the building, and resulted in an energy penalty to re-heat the building during occupied hours. Additionally, the potential for night-time savings was low because the baseline heating load was low in most climate zones. Much of the day time heating load was due to the fresh air ventilation load which is not present at night because there were no occupants in the building hence no required ventilation.

Table 35: Thermostat gas savings by program

Program	Number of Claims	Ex Ante therm Savings	Ex Post Reali-zation Rate therm	Ex Post therm Savings
PGE Commercial QM	678	131,876	7%	9,730
PGE AirCare Plus	1,334	249,607	10%	24,620
SDGE Deemed Incentives				
SDGE Direct Install	695	275,839	0%	1,126

4.1.3 Coil cleaning measure group

Cleaning the condenser and evaporator heat exchange coils save energy by removing buildup that reduces airflow and heat transfer across the coil. This section begins with a description of the ex post impact analysis methodology, followed by a discussion of the ride-along data gathered in the 2015 evaluation, and concludes with the analysis results. A thorough discussion of our previous HVAC3 evaluation methodology including HVAC5 laboratory data is described in that report[46] and reproduced in APPENDIX D. The workpaper ex ante methodology is also described in our previous HVAC3 evaluation and is included in APPENDIX C for reference.

4.1.3.1 **Ex post methodology**

As in our 2013-14 evaluation, this evaluation of the coil cleaning measure group focused on revising key input parameters for the DEER eQuest models used to estimate ex ante savings and re-running the simulations to produce ex post savings estimates. The revised adjustment factors were used to modify ex ante savings without significantly modifying the calculation methodology (eQuest simulation).

Our previous HVAC3 approach for condenser coil cleaning was to first measure discharge pressure before and after the coil was cleaned. Next, we correlated the change in discharge pressure to a change in system performance metrics (EER, EIR, cooling capacities, etc.) using lab data gathered through our parallel HVAC5 study.[47] This provided a basis for the changes to eQuest model performance metric inputs.

However, because the laboratory data correlations were developed from units with correct charge levels, we deemed it prudent to first correct the charge, then gather discharge pressure. Thus, the field units required a lengthy charge removal and weigh-in procedure prior to coil cleaning measurement so that the measurements would be comparable to our lab data.[48] Collecting the ambient temperature data enabled us to use the HVAC5 laboratory data relationships to correct for changes in discharge pressures due to ambient

[46] CPUC 2016. Impact Evaluation of 2013-14 Commercial Quality Maintenance Programs (HVAC3). www.calmac.org/publications/HVAC3ImpactReport_0401ES.pdf

[47] Laboratory HVAC Testing Research Plan, prepared for the CPUC by KEMA, Inc. 11/17/2014 (HVAC5 research plan and results).

[48] Due to schedule constraints we were not able to correct RCA on all units in the 2015 field effort. We verified that there was at least some subcooling for each of the units tested, that there were reasonable refrigerant pressures, and that delivered cooling was on the order of nameplate capacity.

temperature changes between pre- and post-cleaning observations and to correct the values to AHRI Standard test conditions. Further details on the previous evaluations approach for coil cleaning measures can be found in APPENDIX D. One correction that we performed relative to the previous methodology is that we eliminated small errors in the biquadratic laboratory data derived relationships between change in discharge pressure and system performance (EIR and cooling capacities). This modification vertically shifted the biquadratic equations, so that the equations correctly produced an output of 1.00 for a discharge pressure change of 0.0 when evaluating these changes at 95 °F OAT.

Our previous HVAC3 approach for evaporator coil cleaning was to measure the change in airflow due to coil cleaning and correlate that to a change in EER using HVAC5 laboratory data. The shortcomings of this approach are first, that the measured changes in airflow are very small and are at the limit of our measurement capability; and second, that the change in airflow likely only accounts for the convective portion of the evaporator coil cleaning effect. Reduction in airflow reduces the heat transfer across the coil, and the heat transfer is further reduced by the change in surface conductance caused by the residue on the coil.

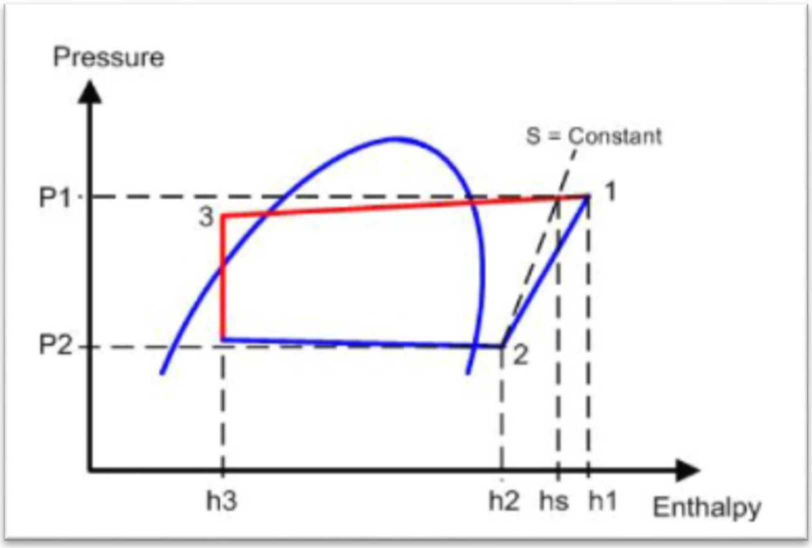
The 2015 evaluation sought to improve the measure evaluation approach for both evaporator and condenser coil cleaning by collecting a suite of additional HVAC system measurements using equipment purchased from ClimaCheck, which provided a more comprehensive data set from which to detect subtle changes in cooling system performance. To capture changes in system performance without first adjusting refrigerant charge for condenser coil cleaning and to better capture both evaporator coil cleaning effects (conductive and convective heat transfer), we used an approach whereby we monitored refrigerant circuit pressure, temperature, and compressor power data points sufficient for calculating a refrigerant-side cooling capacity and coefficient of performance (COP) during the ride along visit, thus before and after coil cleaning. This approach allowed us to more directly capture the effect of coil cleaning on cooling performance with COP uncertainty estimated at ±5%.[49]

This 2015 approach entailed measurements of refrigerant suction (P2) and discharge (P1) pressures, refrigerant suction, discharge, and liquid (leaving condenser) temperatures[50] as well as refrigerant compressor power. From these measurements, the ClimaCheck system software determined the enthalpy of the refrigerant entering the compressor (h_2), leaving the compressor (h_1), and leaving the condenser (h_3) as shown in Figure 17.

49 http://effsysplus.se/wp-content/uploads/2012/02/EP18-Slutrapport-20140630rev0704.pdf

50 Coil entering and exiting air dry-bulb temperatures were also measured and recorded.

Figure 17: Refrigerant system pressure-enthalpy diagram[51]



With this information, the system calculates the COP of the system using the following equation:

$$COP_{cooling} = \frac{(h_2 - h_3)}{(h_1 - h_2)}(1 - f)$$

Where:

h_1 is the compressor discharge enthalpy

h_2 is the compressor suction enthalpy

h_3 is the enthalpy after condenser,[52] and

f is the compressor heat losses (as a percent of electrical input)

The compressor heat-loss factor (f) is a constant; however, there is debate about the magnitude of the loss. Because our evaluation utilized a constant compressor loss factor over the series of tests for each unit and only looked at relative changes to efficiency and capacities, the value chosen for the compressor loss factor has no impact on the calculated measure results. We did, however, set the value of the compressor heat-loss factor at 12% based on HVAC5 lab data. Note that the compressor loss factor, if it is assumed to be constant before and after coil cleaning, drops out of the analysis when the ratio of pre- and post-coil cleaning COP is calculated. Additional discussion of that investigation can be found in the 2015 planning memo in APPENDIX A.

Following this approach outlined above, we installed the following ClimaCheck measurement equipment during the ride-along visits for coil cleaning measure observations:

---

[51] http://media.home.climacheck.com/2015/01/8_18410_BerglofIEAJune2005.pdf

[52] h_3 is evaluated using the pressure reading from point one and the temperature reading at point three (after the condenser but prior to the expansion device). The actual refrigerant pressure at point three is slightly lower than the pressure measured at point one, but the difference in enthalpy is small as the refrigerant is in a liquid state and so the constant temperature line near point three is steep.

- Pressure transducers installed on the refrigerant suction and discharge service ports to measure high and low-side refrigerant pressures
- Pipe surface temperature probes to measure refrigerant suction, discharge, and liquid line temperatures
- Current transformers and voltage leads to measure compressor power demand
- Air-side temperature probes on the coils to measure condenser and evaporator coil entering and exiting dry-bulb temperatures.

All the above instrumentation equipment data were processed through a single data logging unit, the ClimaCheck Performance Analyzer. The instrument readings and calculated system performance metrics such as cooling capacity and COP were displayed in real-time. We also installed static air-pressure probes across the unit to separately record external static pressure reading over the course of the coil cleaning test periods. These static air pressure changes served as a proxy for changes in system airflow so that we could compare the results from the ClimaCheck system against the 2013-14 method.

Once the HVAC unit was instrumented, the unit was put into full cooling mode and the data readings verified. Once readings were determined correct, an "as-found" or "test-in" data recording period was observed to establish a baseline of performance prior to any coil cleaning. With a sufficient observational period of data recorded (5 minutes or more after the software indicates steady state unit operation), a total spot power measurement was taken from a handheld power meter to calculate a nameplate comparable EER efficiency value.

Once the measurements were complete, the HVAC unit was shut off and the maintenance technician performed their condenser coil cleaning procedure while the evaluation engineer observed the cleaning process. Another period of unit performance data was then recorded after allowing a reasonable amount of time for the cleaned coil to dry and then for the HVAC system to reach a steady state of cooling mode operation. The HVAC unit was then turned off and the maintenance technician performed their evaporator coil cleaning procedure, while the evaluation engineer again observing the cleaning. After allowing time for the coil to dry and with both condenser and evaporator coils clean, a final "test-out" data recording-period was observed and total unit spot-power was measured with both the coils cleaned.

The results from the COP-based ClimaCheck approach were compared to the results produced by applying the discharge pressure (condenser coil) or airflow based (evaporator coil) analysis methods on the same data set to see if the COP method would be a viable alternative measurement approach going forward. The comparisons of method results are presented in section 4.1.1.3. After determining changes in efficiency and capacity from the coil cleaning activity, we simulated the change in energy use using eQuest to produce savings across building types and climate zones.

4.1.3.2 **Ride-along data**

The evaluation collected ride-along data on 17 systems at 10 sites from the 2015 sample. Of these, two systems at the initial ride-along site were inspected using the compressor discharge/ static pressure methods prior to the adoption of the alternative COP-derived ClimaCheck method. The remaining 15 systems were inspected using the updated approach. Two inspected units using this COP-derived approach were excluded from this data set: one HVAC unit that was inspected had its condenser coil cleaned by the program maintenance contractor the day prior to the ride-along inspection as so was incomplete, another exhibited non-steady state operation during our observation.

The ClimaCheck system produced COPs and total cooling-capacity output values directly from the raw data inputs: the pressure, temperature, and power sensors. The evaluation team applied temperature correction factors to these output values using DEER-based performance curve coefficients to correct the efficiency and capacity values from their observed temperature conditions to those of AHRI Standard 210/240 rating conditions (95°F entering outdoor dry-bulb and 67°F entering indoor wet-bulb temperatures). Table 36 shows the temperature-corrected EIR[53] and total capacity values for each of the three tests performed on an individual unit basis.

Table 36. Temperature-corrected ClimaCheck test data

	Input	EIR			Total Capacity (tons)		
Unit ID	Tons	Pre-Coil Cleaning	Condenser Coil Cleaned	Both Coils Cleaned	Pre-Coil Cleaning	Condenser Coil Cleaned	Both Coils Cleaned
2015_2_1	4	0.251	0.255	0.253	3.654	3.500	3.613
2015_2_2	4	0.240	0.244	0.257	3.912	3.691	3.534
2015_3_1	5	0.229	0.231	0.226	4.675	4.707	4.882
2015_3_2	5	0.223	0.240	0.220	5.105	4.774	5.098
2015_4_1	4	0.253	0.249	0.253	1.985	1.983	1.953
2015_4_2	4	0.279	0.273	0.272	1.890	1.839	1.920
2015_5_1	7.5	0.203	0.209	0.209	8.386	8.151	8.151
2015_5_2	7.5	0.233	0.226	0.246	7.127	7.176	6.732
2015_7_1	6	0.266	0.262	0.264	5.469	5.628	5.599
2015_8_1	7.5	0.325	0.315	0.323	6.254	6.388	6.551
2015_8_2	10	0.180	0.161	0.181	16.238	17.685	16.423
2015_9_1	15	0.287	0.264	0.240	11.905	12.785	13.892
2015_10_1	3	0.237	0.200	0.175	3.290	3.804	3.630

The sample test values show that for condenser coil cleaning, the ClimaCheck system produces an improvement in average EIR and total capacity of 2.0% and 2.8%, respectively, relative to the pre-coil cleaning condition. However, looking at the results of the evaporator coil cleaning, the average impact on EIR and total capacity is quite small, 0.3% and 0.2% respectively, when comparing test values with both coils cleaned relative to the test taken with only the condenser coil cleaned. The respective magnitudes of the observed impacts from the condenser and evaporator coil cleaning testing obtained using the ClimaCheck-based method agrees with the results from our previous HVAC3 evaluation's methods and findings.

Because of this finding, and to develop the most robust data set possible from which to derive measure impacts, the evaluation utilized the refrigerant compressor-discharge pressure and unit external static pressure data gathered in the 2015 evaluation with the analysis methods from the previous evaluation to produce results that could be combined with the previous sample data set. Therefore, we calculated

[53] EIR is the inverse of COP and is equivalent to 3.412/ EER. EIR is presented in the report because it is the unit efficiency value used by the eQuest software.

adjustment factors for condenser coil cleaning using 27 ride-along data points[54] and HVAC5 lab research results correlating the change in discharge pressure to relative changes HVAC system efficiency.

For evaporator coil cleaning, we calculated adjustment factors using 25 ride-along data points[55] in addition to the lab research results that correlated the changes in airflow (2013-14 sample) or static pressure (2015 sample) and relative HVAC system efficiency change. This pre/post coil cleaning data was then processed using DEER performance curves and the laboratory correlations described in our previous HVAC3 impact evaluation report to develop adjustment factors for eQuest modeling simulation inputs from which gross savings impact estimates are ultimately derived.

Key unit characteristics and pre/post performance metrics, such as outdoor air temperature (OAT), used to estimate relative efficiency impacts from coil cleaning are shown in Table 37. For condenser coil cleaning, this metric is compressor discharge pressure, and Table 37 shows the discharge pressures recorded for both pre-condenser coil cleaning (pre-CCC) and post-condenser coil cleaning (post-CCC). For evaporator coil cleaning, this metric was either airflow (2013-14 sample) or static pressure (2015 sample), and Table 37 shows the airflow or static pressure recorded for both pre-evaporator coil cleaning (pre-ECC) and post-evaporator cleaning (post-ECC). A cell in Table 37 with grey fill and contains a "-" in place of a numerical value represents a data point that was not captured or was discarded for reasons described in the footnote below.

Table 37. Test ride-along pre and post coil-cleaning unit characteristics

Unit ID	IOU	Tons	Discharge Pressure (lb./in^2)		OAT (°F)		Airflow (ft^3/min)	
			Pre-CCC	Post-CCC	Pre-CCC	Post-CCC	Pre-ECC	Post-ECC
2013-14_1_1	SDG&E	4	229.8	210.3	93.9	93.6	1,156	1,162
2013-14_1_2	SDG&E	4	247.5	236.7	91.4	92.4	1,376	1,382
2013-14_1_3	SDG&E	4	207.4	195.8	80.3	80.5	1,367	1,378
2013-14_1_4	SDG&E	4	205.3	187.5	79.3	79.7	1,365	1,379
2013-14_1_5	SDG&E	4	207.6	189.7	80.2	79.9	1,094	1,112
2013-14_1_6	SDG&E	4	201.4	186.4	79.5	79.2	1,379	1,386
2013-14_1_7	SDG&E	4	202.9	189.5	79.7	79.8	1,242	1,254
2013-14_2_1	SDG&E	4	219.9	212.0	88.3	88.2	1,314	1,323
2013-14_2_2	SDG&E	4	204.6	188.7	89.5	89.2	1,232	1,246
2013-14_2_3	SDG&E	4	214.9	201.4	88.5	88.5	1,304	1,315
2013-14_2_4	SDG&E	4	210.4	201.2	86.6	86.6	1,131	1,143
2013-14_2_5	SDG&E	4	226.2	219.1	86.2	86.4	1,275	1,282
2015_1_1	PG&E	7	226.5	214.2	74.1	69.2	81.3	83.5
2015_1_2	PG&E	40	271.0	256.6	72.5	69.9	-	-
2015_2_1	PG&E	4	188.7	187.3	75.9	76.1	140.8	143.1
2015_2_2	PG&E	4	192.8	182.5	79.6	76.4	145.0	148.2
2015_3_1	SCE	5	284.4	308.8	71.0	73.6	300.3	293.5

[54] A total of 12 points from the 2013-14 sample and 15 from the 2015 sample. Two inspected units were excluded from the dataset: one HVAC unit that was inspected had its condenser coil cleaned by the program maintenance contractor the day prior to the ride-along inspection, another exhibited non-steady state operation during our observation.

[55] A total of 12 points from the 2013-14 sample and 13 from the 2015 sample. Four inspected units were excluded from the dataset: two HVAC unit that was inspected received a fan belt adjustment between observations that produced a large static pressure change, another unit that was inspected likely had inconsistent placement of the return air static pressure probe that lead to erroneous readings, and a third unit that was inspected likely had inconsistent placement of the air filter that also impacted static pressure readings that lead to erroneous readings.

Unit ID	IOU	Tons	Discharge Pressure (lb./in²)		OAT (°F)		Airflow (ft³/min)	
			Pre-CCC	Post-CCC	Pre-CCC	Post-CCC	Pre-ECC	Post-ECC
2015_3_2	SCE	5	326.4	326.8	79.8	77.3	223.7	229.6
2015_4_1	SCE	4	183.4	199.1	69.1	73.1	64.5	62.6
2015_4_2	SCE	4	211.6	224.6	76.6	81.6	68.5	72.5
2015_5_1	PG&E	7.5	179.6	178.2	70.2	70.5	281.0	278.6
2015_5_2	PG&E	7.5	171.0	176.7	65.9	66.2	221.1	222.2
2015_6_1	SDG&E	4.8	-	-	-	-	115.6	118.3
2015_7_1	SDG&E	6	203.9	210.8	77.9	79.5	111.9	-
2015_8_1	SCE	7.5	246.4	267.6	89.6	91.0	46.7	-
2015_8_2	SCE	10	262.9	247.5	92.4	90.7	180.8	193.1
2015_9_1	SCE	15	172.4	164.5	65.8	64.9	101.1	112.0
2015_9_2	SCE	15	-	-	-	-	299.9	302.2
2015_10_1	SDG&E	3	165.9	167.1	65.5	66.1	233.7	-

4.1.3.3 Results: Ex post analysis using HVAC5 data

In this section, we describe the analysis and findings first for the condenser coil and then for the evaporator coil. As noted earlier, to develop the most robust data set possible, we utilized the refrigerant compressor-discharge pressure and static airflow pressure data gathered in the 2015 evaluation with the analysis methods from the previous evaluation to produce results that could be combined with the previous sample data set.

Condenser coil analysis and results

For consistency, we used only the biquadratic regression results from HVAC5 lab data for 3-ton, non-thermostatic expansion valve (TXV) units. The relative change in efficiency was estimated using the corresponding relative change (%) in discharge pressure from the ride-along data and the regression described in our previous HVAC3 evaluation. The individual unit results and the straight average are listed below in Table 38.

Table 38. Ride-along condenser coil-cleaning results

Unit ID	IOU	Tons	Relative Discharge Pressure Change (%)	OAT Change (%)	Cooling EIR Change (%)	Total Cooling Capacity Change (%)	Sensible Cooling Capacity Change (%)
2013-14_1_1	SDG&E	4	8.12%	-0.30%	-10.02%	2.42%	1.23%
2013-14_1_2	SDG&E	4	5.66%	1.10%	-6.77%	1.59%	0.79%
2013-14_1_3	SDG&E	4	5.89%	0.20%	-7.07%	1.66%	0.83%
2013-14_1_4	SDG&E	4	9.24%	0.50%	-11.56%	2.82%	1.44%
2013-14_1_5	SDG&E	4	8.19%	-0.40%	-10.12%	2.44%	1.24%
2013-14_1_6	SDG&E	4	7.01%	-0.40%	-8.53%	2.03%	1.03%
2013-14_1_7	SDG&E	4	6.75%	0.10%	-8.19%	1.94%	0.98%
2013-14_2_1	SDG&E	4	3.46%	-0.10%	-4.02%	0.92%	0.45%
2013-14_2_2	SDG&E	4	7.38%	-0.30%	-9.03%	2.16%	1.09%
2013-14_2_3	SDG&E	4	6.28%	0.00%	-7.58%	1.79%	0.90%

Unit ID	IOU	Tons	Relative Discharge Pressure Change (%)	OAT Change (%)	Cooling EIR Change (%)	Total Cooling Capacity Change (%)	Sensible Cooling Capacity Change (%)
2013-14_2_4	SDG&E	4	4.37%	0.00%	-5.15%	1.19%	0.59%
2013-14_2_5	SDG&E	4	3.42%	0.20%	-3.98%	0.90%	0.45%
2015_1_1	PG&E	7	-2.94%	-7.08%	3.14%	-0.65%	-0.30%
2015_1_2	PG&E	40	0.98%	-3.65%	-1.10%	0.24%	0.12%
2015_2_1	PG&E	4	2.95%	0.30%	-3.41%	0.77%	0.38%
2015_2_2	PG&E	4	-0.53%	-4.26%	0.59%	-0.13%	-0.06%
2015_3_1	SCE	5	1.15%	3.53%	-1.30%	0.29%	0.14%
2015_3_2	SCE	5	1.00%	-3.23%	-1.13%	0.25%	0.12%
2015_4_1	SCE	4	6.91%	5.56%	-8.41%	2.00%	1.01%
2015_4_2	SCE	4	7.96%	6.14%	-9.80%	2.36%	1.20%
2015_5_1	PG&E	7.5	1.28%	0.39%	-1.45%	0.32%	0.16%
2015_5_2	PG&E	7.5	1.69%	0.48%	-1.92%	0.43%	0.21%
2015_7_1	SDG&E	6	0.56%	2.07%	-0.63%	0.14%	0.07%
2015_8_1	SCE	7.5	1.19%	1.46%	-1.34%	0.30%	0.14%
2015_8_2	SCE	10	3.30%	-1.94%	-3.83%	0.87%	0.43%
2015_9_1	SCE	15	1.74%	-1.33%	-1.98%	0.44%	0.21%
2015_10_1	SDG&E	3	0.47%	0.84%	-0.53%	0.12%	0.06%
Average		**6.6**	**3.83%**	**0.00%**	**-4.63%**	**1.10%**	**0.55%**

The ride-along data on cooling EIR percent change have a standard deviation of 4.0% with a maximum value of 3.1% and a minimum of -11.6%. There was very little change in either total or sensible capacity. The variation in relative changes could have come from many conditions that could not be practically controlled or accounted for in the analysis and data collection. The individual units experience different operating schedules (and therefore vary in total run hours), environmental conditions affecting coil fouling (e.g., airborne pollutant type and density, wind, and rain), and manufacturer coil geometry and airflow dynamics. These variables influence the dirt loading on the coil and therefore the change in discharge pressure due to the cleaning and the subsequent effect on efficiency and capacity change when the coil is cleaned.

To determine ex post savings for both condenser and evaporator coil cleaning measures, we performed simulations using inputs informed by the HVAC5 laboratory data applied to the field-collected sample. The adjustment factors for the condenser coil eQuest simulations were cooling EIR and cooling-sizing ratio.[56] The condenser coil individual unit results are listed below in Table 39.

[56] Cool-sizing ratio was chosen instead of cooling capacity (total cooling capacity in btuh) and sensible cooling capacity (btuh) because of the convenience of adjusting a capacity sizing ratio (whose value is 1 in the DEER prototypes) rather than adjusting individual system cooling capacities for each building type-weather zone-vintage combination. Making those individual adjustments to cooling capacity and sensible cooling capacity would have made the simulation approach impractical.

Table 39. Condenser coil cleaning unit level eQuest adjustment factors

Unit ID	IOU	Tons	Cooling-EIR Adjustment Factor	Cooling-Sizing Ratio Adjustment Factor
2013-14_1_1	SDG&E	4	1.1002	0.9818
2013-14_1_2	SDG&E	4	1.0677	0.9881
2013-14_1_3	SDG&E	4	1.0707	0.9875
2013-14_1_4	SDG&E	4	1.1156	0.9787
2013-14_1_5	SDG&E	4	1.1012	0.9816
2013-14_1_6	SDG&E	4	1.0853	0.9847
2013-14_1_7	SDG&E	4	1.0819	0.9854
2013-14_2_1	SDG&E	4	1.0402	0.9932
2013-14_2_2	SDG&E	4	1.0903	0.9837
2013-14_2_3	SDG&E	4	1.0758	0.9866
2013-14_2_4	SDG&E	4	1.0515	0.9911
2013-14_2_5	SDG&E	4	1.0398	0.9932
2015_1_1	PG&E	7	0.9686	1.0047
2015_1_2	PG&E	40	1.0110	0.9982
2015_2_1	PG&E	4	1.0341	0.9943
2015_2_2	PG&E	4	0.9941	1.0009
2015_3_1	SCE	5	1.0130	0.9979
2015_3_2	SCE	5	1.0113	0.9982
2015_4_1	SCE	4	1.0841	0.9850
2015_4_2	SCE	4	1.0980	0.9822
2015_5_1	PG&E	7.5	1.0145	0.9976
2015_5_2	PG&E	7.5	1.0192	0.9968
2015_7_1	SDG&E	6	1.0063	0.9990
2015_8_1	SCE	7.5	1.0134	0.9978
2015_8_2	SCE	10	1.0383	0.9935
2015_9_1	SCE	15	1.0198	0.9967
2015_10_1	SDG&E	3	1.0053	0.9991

The average values for the cooling EIR and cool-sizing-ratio adjustment factors are 1.046 and 0.992, respectively, and are presented in Table 40 with their 90% confidence interval relative precision values.

Table 40. Condenser coil-cleaning average eQuest adjustment-factors and relative precisions

	Cooling-EIR	Cooling-Sizing Ratio
Average Adjustment Factor	1.046	0.992
Relative Precision at 90% Confidence Interval; +/-	23.25%	24.29%

These adjustment factors are applied to the "optimal" eQuest model factors to simulate impacts due to dirty condenser coils. The cooling EIR adjustment factor decreases the optimal system efficiency (i.e., EIR has inverse units of COP, so larger a value is less efficient) by approximately 4.6% and the cool-sizing-ratio adjustment factor reduces both total and sensible capacity by approximately 0.8%.

For the purposes of comparing results from the two analysis methods, the evaluation also developed eQuest input adjustment factors for the ClimaCheck-derived results. Scatter plots comparing the EIR and cooling sizing ratio adjustment factors derived from the two methods are presented below in Figure 18 and Figure 19.

Figure 18. Comparison of condenser coil cleaning EIR adjustment factors

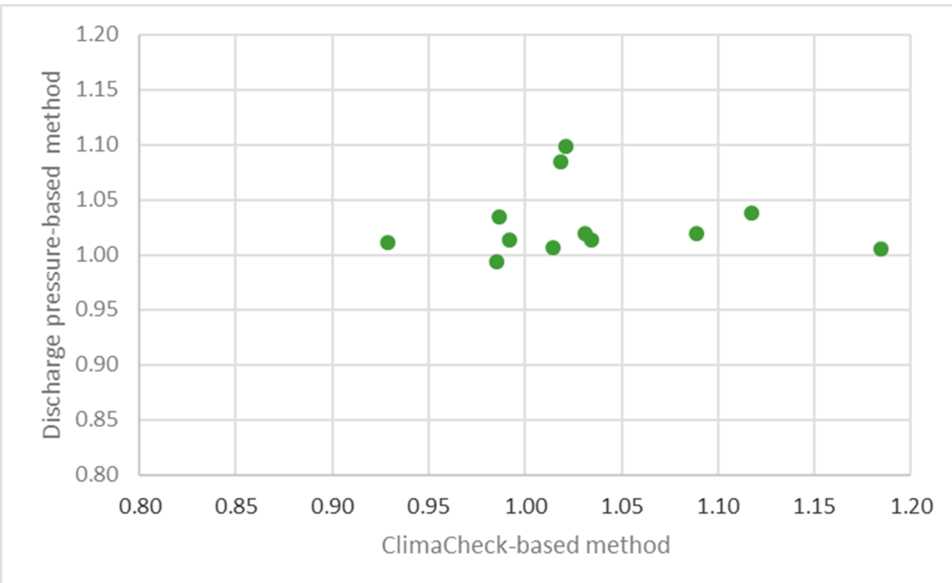
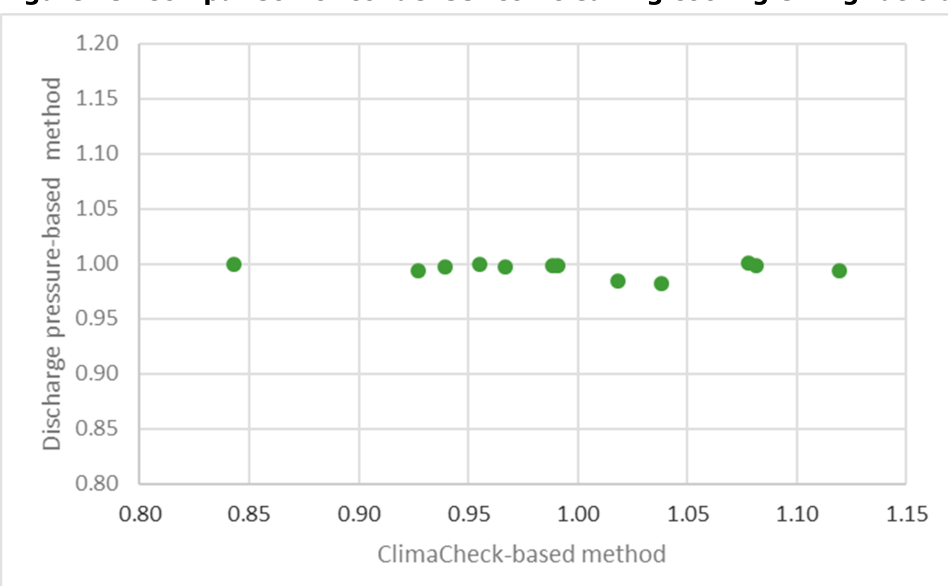


Figure 19. Comparison of condenser coil cleaning cooling-sizing ratio adjustment-factors



A comparison of average sample adjustment factors and relative precision (RP) values for each method are presented below in Table 41. For a comparison of adjustment factors at the individual unit level, see Table 87 in APPENDIX D.

Table 41. Comparison of average condenser coil cleaning input-adjustment factors across methods and samples

		Sample					
		2013-14		2015		2013-15	
Input Adjustment Factor	Method	Value	90% RP; +/-	Value	90% RP; +/-	Value	90% RP; +/-
EIR	Discharge Pressure	1.077	14.94%	1.022	44.00%	1.046	23.25%
	ClimaCheck	-	-	1.034	50.17%	-	-
Sizing Ratio	Discharge Pressure	0.9863	16.00%	0.996	46.82%	0.992	24.29%
	ClimaCheck	-	-	0.995	35.22%	-	-

Looking at the column for the 2015 sample allows for a direct comparison of average input adjustment factors produced by the two different methods using the same primary data. The ClimaCheck method produced results showing slightly greater EIR impact due to condenser coil cleaning than the discharge pressure method produced from the 2015 sample. Both methods show lower EIR impact for the 2015 sample compared to our previous HVAC3 sample discharge pressure-based finding. Both methods also have poorer relative precisions for the 2015 sample than observed in the 2013-14 sample. The finding of smaller impacts and poorer relative precision values could be a result of the greater diversity of sites in the 2015 sample (10 sites) relative to the 2013-14 sample (two sites).

Both methods produced very small adjustments to the cooling sizing ratio input for the 2015 sample, with the discharge pressure methods showing a slight decrease in capacity due to coil cleaning compared to slight increase in capacity measured using the ClimaCheck method. The slight decreases in sizing ratio for the 2015 sample contrast with the impacts found in the 2013-14 sample, which found slight increases in the sizing ratio due to coil cleaning, although all the data set suggest insignificant change to capacity. The table does clearly show the improvement in relative precision gained by combining the 2015 sample with the 2013-14 sample instead of relying on the 2015 sample alone.

Evaporator coil analysis and results

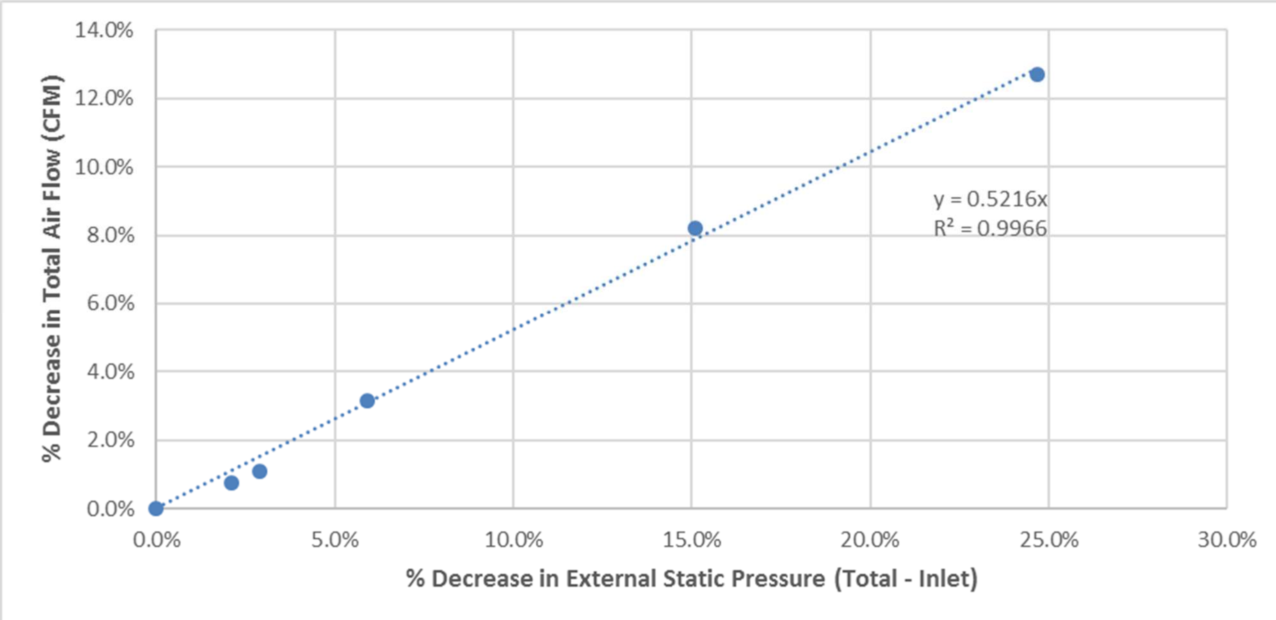
For the evaporator coil cleaning measure, a relationship between a static pressure decrease and the correlated relative airflow decrease was developed using HVAC5 lab data on evaporator blockage. A plot of static pressure decrease versus relative airflow decreased was developed from five data of points with differing amounts of evaporator coil blockage and a linear equation relationship derived as the following:

$$\Delta Relative\ Airflow = f(\Delta Static\ Pressure) = a(\Delta Static\ Pressure)$$

$$where\ a = 0.5216$$

The plot of static pressure decrease versus relative airflow decreased is presented below in Figure 20.

Figure 20. Percent decrease in external static pressure vs. percent decrease in total airflow



The individual unit results of applying HVAC5 laboratory data relationships to the evaporator coil cleaning field measurements made on 24 units during ride-along visits are shown below in Table 42.

Table 42. Ride-along evaporator coil cleaning results

Unit ID	IOU	Tons	Relative Airflow Change (%)	Cooling EIR Change (%)	Coil Bypass Factor[57] Change (%)	Total Cooling Capacity Change (%)	Sensible Cooling Capacity Change (%)
2013-14_1_1	SDG&E	4	0.52%	0.33%	3.85%	0.42%	0.88%
2013-14_1_2	SDG&E	4	0.44%	0.30%	3.74%	0.38%	0.81%
2013-14_1_3	SDG&E	4	0.80%	0.43%	4.21%	0.55%	1.10%
2013-14_1_4	SDG&E	4	1.03%	0.50%	4.48%	0.64%	1.27%
2013-14_1_5	SDG&E	4	1.65%	0.72%	5.25%	0.91%	1.75%
2013-14_1_6	SDG&E	4	0.51%	0.32%	3.83%	0.42%	0.87%
2013-14_1_7	SDG&E	4	0.97%	0.48%	4.41%	0.62%	1.23%
2013-14_2_1	SDG&E	4	0.68%	0.38%	4.06%	0.49%	1.01%
2013-14_2_2	SDG&E	4	1.14%	0.54%	4.62%	0.69%	1.36%
2013-14_2_3	SDG&E	4	0.84%	0.44%	4.25%	0.56%	1.13%
2013-14_2_4	SDG&E	4	1.06%	0.52%	4.53%	0.66%	1.30%
2013-14_2_5	SDG&E	4	0.55%	0.34%	3.88%	0.43%	0.90%
2015_1_1	PG&E	7	1.40%	0.64%	4.97%	0.82%	1.58%
2015_2_1	PG&E	4	0.86%	0.45%	4.28%	0.57%	1.15%

[57] The coil bypass factor is an eQuest modeling input related to cooling coil performance. The DOE-2 dictionary describes the coil bypass factor is the following way: "Using the bypass model, the exit air stream from a coil is characterized as being composed of two components: one component leaves the coil at the coil surface temperature and at, or below, the corresponding saturation humidity ratio above or below this saturation value); the other component leaves at the same temperature and humidity ratio as the entering air stream (thus the bypass name). The fraction of the total air flow in the bypassed component is the bypass factor."

Unit ID	IOU	Tons	Relative Airflow Change (%)	Cooling EIR Change (%)	Coil Bypass Factor[57] Change (%)	Total Cooling Capacity Change (%)	Sensible Cooling Capacity Change (%)
2015_2_2	PG&E	4	1.15%	0.55%	4.65%	0.70%	1.38%
2015_3_1	SCE	5	-1.21%	-0.30%	1.65%	-0.35%	-0.49%
2015_3_2	SCE	5	1.34%	0.62%	4.89%	0.79%	1.53%
2015_4_1	SCE	4	-1.57%	-0.42%	1.20%	-0.51%	-0.77%
2015_4_2	SCE	4	2.86%	1.17%	6.83%	1.47%	2.74%
2015_5_1	PG&E	7.5	-0.43%	-0.02%	2.64%	0.00%	0.13%
2015_5_2	PG&E	7.5	0.26%	0.23%	3.52%	0.31%	0.67%
2015_6_1	SDG&E	4.8	1.16%	0.56%	4.67%	0.71%	1.39%
2015_8_2	SCE	10	3.32%	1.33%	7.42%	1.68%	3.11%
2015_9_1	SCE	15	5.08%	1.96%	9.65%	2.46%	4.50%
2015_9_2	SCE	15	0.39%	0.28%	3.69%	0.37%	0.78%
Average		**5.6**	**0.99%**	**0.49%**	**4.45%**	**0.63%**	**1.25%**

The ride-along data on cooling EIR percent change have a standard deviation of 0.5% with a maximum value of 1.96% and a minimum of -0.42%. The ride-along data on coil bypass factor (CBF) have a standard deviation of 1.7% with a maximum value of 9.7% and a minimum of 1.2%. Cleaning the evaporator coil seems to have slightly more impact on the capacity than cleaning the condenser coil. The very small change in airflow (<1%) in the 2013-14 sample is within the measurement error of the TrueFlow equipment (7%) used to make the field measurements. Likewise, the small changes in static pressure (2%), and correlated airflow change (~1%), is near the measurement error of the DG-700 manometer equipment (1%) used to make the field measurements for the 2015 sample. Finding these minimal changes to airflow are not unexpected since evaporator coils are not exposed to the elements, and are generally protected by a filter so they often do not foul as quickly as condenser coils.

The adjustment factors for the evaporator coil eQuest simulations were cooling EIR, coil bypass factor (CBF), and cooling-sizing ratio. The adjustment of multiple inputs is an improvement over our prior HVAC3 evaluation that, due to technical modeling limitation that have since been resolved, was only able to implement adjustment of the coil bypass factor input. The evaporator coil individual unit results are listed below in Table 43.

Table 43. Evaporator coil-cleaning DOE-2 adjustment factors

Unit ID	IOU	Tons	Cooling-EIR Adj. Factor	CBF Adj. Factor	Cooling-Sizing Ratio Adj. Factor
2013-14_1_1	SDG&E	4	1.0033	1.0385	0.9935
2013-14_1_2	SDG&E	4	1.0030	1.0374	0.9940
2013-14_1_3	SDG&E	4	1.0043	1.0421	0.9918
2013-14_1_4	SDG&E	4	1.0050	1.0448	0.9904
2013-14_1_5	SDG&E	4	1.0072	1.0525	0.9867
2013-14_1_6	SDG&E	4	1.0032	1.0383	0.9936
2013-14_1_7	SDG&E	4	1.0048	1.0441	0.9908
2013-14_2_1	SDG&E	4	1.0038	1.0406	0.9925

Unit ID	IOU	Tons	Cooling-EIR Adj. Factor	CBF Adj. Factor	Cooling-Sizing Ratio Adj. Factor
2013-14_2_2	SDG&E	4	1.0054	1.0462	0.9897
2013-14_2_3	SDG&E	4	1.0044	1.0425	0.9915
2013-14_2_4	SDG&E	4	1.0052	1.0453	0.9902
2013-14_2_5	SDG&E	4	1.0034	1.0388	0.9933
2015_1_1	PG&E	7	1.0064	1.0497	0.9880
2015_2_1	PG&E	4	1.0045	1.0428	0.9914
2015_2_2	PG&E	4	1.0055	1.0465	0.9896
2015_3_1	SCE	5	0.9970	1.0165	1.0042
2015_3_2	SCE	5	1.0062	1.0489	0.9884
2015_4_1	SCE	4	0.9958	1.0120	1.0064
2015_4_2	SCE	4	1.0117	1.0683	0.9789
2015_5_1	PG&E	7.5	0.9998	1.0264	0.9994
2015_5_2	PG&E	7.5	1.0023	1.0352	0.9951
2015_6_1	SDG&E	4.8	1.0056	1.0467	0.9895
2015_8_2	SCE	10	1.0133	1.0742	0.9761
2015_9_1	SCE	15	1.0196	1.0965	0.9652
2015_9_2	SCE	15	1.0028	1.0369	0.9943

The average EIR, coil bypass factor, and cooling-sizing ratio input adjustment values were 1.005, 1.044, and 0.991 respectively, and are presented in Table 44 with their 90% confidence interval relative precision values.

Table 44. Evaporator coil-cleaning average eQuest adjustment factors and relative precisions

	Cooling-EIR	CBF	Cooling-Sizing Ratio
Average Adjustment Factor	1.005	1.044	0.991
Relative Precision at 90% CI; +/-	23.85%	12.43%	22.56%

These adjustment factors are applied to the "optimal" eQuest model factors to simulate impacts due to dirty evaporator coils. Cooling EIR and CBF adjustment factors greater than one indicate an improvement to the optimal system efficiency due to coil cleaning, while a cooling sizing ratio less than one indicates an improvement due to coil cleaning. The coil bypass factor had the largest percent change since it is a function of the evaporator coil cooling performance.

As with the condenser coil cleaning measure, for the purposes of comparing results from the two analysis methods, the evaluation also developed eQuest input adjustment factors for the ClimaCheck derived results. Scatter plots comparing the EIR and cooling sizing ratio adjustment factors derived from the two methods are presented below in Figure 21 and Figure 22.

Figure 21. Comparison of evaporator coil cleaning EIR adjustment factors

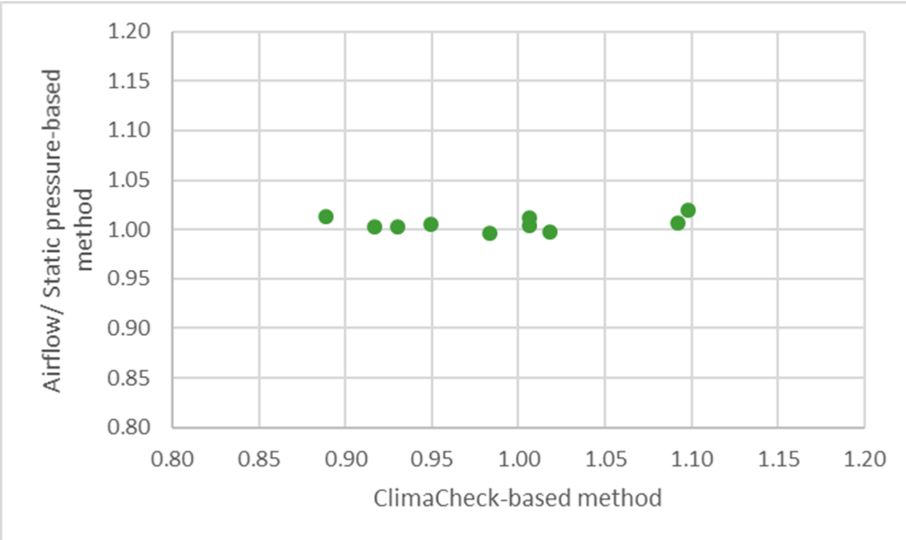
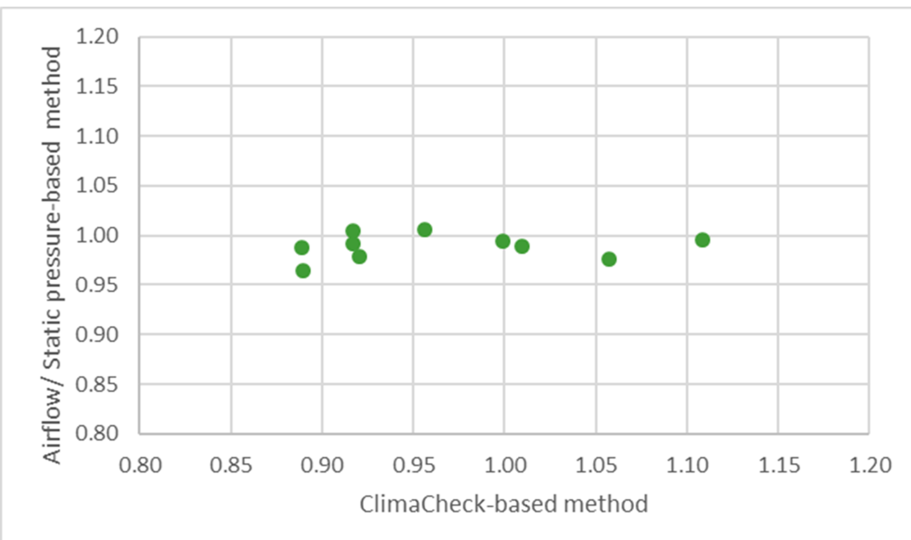


Figure 22. Comparison of evaporator coil cleaning cooling-sizing-ratio adjustment factors



A comparison of average sample adjustment factors for each method are presented below in Table 45. For a comparison of adjustment factors at the individual unit level, see Table 88 in APPENDIX D.

Table 45. Comparison of average evaporator-coil-cleaning input adjustment-factors across methods and samples

		Sample					
		2013-14		2015		2013-15	
Input Adjustment Factor	Method	Value	90% RP; +/-	Value	90% RP; +/-	Value	90% RP; +/-
EIR	Airflow/ Static Pressure	1.004	13.12%	1.005	39.71%	1.005	23.85%
	ClimaCheck	-	-	0.991	36.74%	-	-
Coil Bypass Factor	Airflow/ Static Pressure	1.043	4.82%	1.046	24.99%	1.044	12.43%
	ClimaCheck	-	-	-	-	-	-
Sizing Ratio	Airflow/ Static Pressure	0.991	11.76%	0.990	38.91%	0.991	22.56%
	ClimaCheck	-	-	0.966	28.88%	-	-

Again, looking at the column for the 2015 sample allows for a direct comparison of average input adjustment factors produced by the two different methods using the same primary data. One disadvantage of the ClimaCheck method is that it does not easily allow for calculation of a coil-bypass factor, which is why there is no CBF adjustment factor value for the ClimaCheck method. The coil bypass factor, however, demonstrates the largest change due to coil cleaning at 4.6% while EIR and sizing ratio, show changes of half a percent and one percent respectively. Future research using the ClimaCheck equipment should include a humidity sensor to calculate coil bypass factor directly and verify lab-based results. Once again the table shows that combining the data sets improves the relative precision compared to the 2015 dataset alone.

4.1.3.4 Program-specific results

The results are shown by program in Table 46 and Table 47. The PG&E Commercial QM program did not report any ex ante savings for this measure in 2015, as in 2013-14. However, they performed the measure 71% of the time according to implementer data. We credited the program for the measure by assigning savings to their "signing contract" claim that had ex ante savings equal to zero. The SCE Quality Maintenance program reported savings on an aggregated level and has no specific claims for this measure. Results for the SCE QM program are explained in more detail in section 4.1.6.

Table 46 and Table 47 present the evaporator and condenser coil cleaning results for each climate zone and building type. The realization rates for the SDG&E programs in Table 46 are as expected since lab data showed savings that were about half of what was in the workpaper. The PG&E AirCare Plus program has extremely high realization rates because their ex ante savings claims followed the disposition that reduced savings to less than 10% of the workpaper saving. The workpaper applied 13% savings to HVAC end-use energy whereas the disposition applied the 13% savings to the predicted refrigerant charge adjustment savings for an HVAC unit. The realization rate results for evaporator coil cleaning are shown in Table 47.

Table 46. Condenser coil cleaning results by program

Program	Number of Claims	Ex Ante kWh Savings	Ex Ante kW Savings	Ex Post Instal-lation Rate	Ex Post Reali-zation Rate kWh	Ex Post Reali-zation Rate kW	Ex Post kWh Savings	Ex Post kW Savings
PG&E Commercial QM	1,724	0	0	100%	N/A	N/A	492,388	247
PG&E AirCare Plus	2,054	71,205	57	100%	467%	210%	332,192	121
SDG&E Deemed	6,615	814,855	200	100%	160%	413%	1,301,171	825
SDG&E Direct Install	1,456	713,086	215	100%	37%	76%	261,922	164

Table 47. Evaporator coil cleaning results by program

Program	Number of Claims	Ex Ante kWh Savings	Ex Ante kW Savings	Ex Post Instal-lation Rate	Ex Post Reali-zation Rate kWh	Ex Post Reali-zation Rate kW	Ex Post kWh Savings	Ex Post kW Savings
PG&E Commercial QM	1,724	0	0	100%	N/A	N/A	113,643	63
PG&E AirCare Plus	1,660	33,146	27	100%	147%	41%	48,603	11
SDG&E Deemed Incentives								
SDG&E Direct Install	1,188	364,550	96	100%	70%	183%	254,672	176

4.1.4 Supply fan control measure group

The unoccupied supply fan control measure is implemented by adjusting the HVAC unit controls from "always on" to "cycle on with load" or "off" during unoccupied hours. Typically, the adjustment is to a thermostat though it could also be to an energy management system. The adjustment saves energy by not running the fan and/or bringing in outdoor ventilation air to the building when there are no occupants. This measure only applies to the PG&E and SCE programs and is not included in the scope of the SDG&E programs since neither SDG&E's Direct Install program nor their Deemed program report it as a measure. The SCE QM program did not explicitly claim the fan control measure, but it is implicitly claimed because the Quality Maintenance workpaper includes savings from fan controls as part of the thermostat savings. Section 4.1.6 provides more detail about QM measure savings. Within PG&E, the sample is weighted towards the Commercial HVAC program since they installed the measure more often, though the AirCare Plus program installed this measure more often in 2015 than they did in 2013-14.

4.1.4.1 Ex post methodology

As in our previous HVAC3 evaluation, the 2015 evaluation found the energy savings outlined in the workpaper, summarized in APPENDIX C, to be fundamentally sound. The DOE-2 modeling software and DEER building prototypes are expected to give reasonable savings if the baseline and installed fan conditions are consistent with the model assumptions, and hence it was not necessary to run any eQuest simulations as part of the ex post impact analysis. DNV GL focused efforts on determining whether the baseline and installed measure conditions were met at locations where tracking claims were made for the supply fan measure. We used a combined sample of field data and phone survey data collected during the 2013-14 and 2015 program years.

The installation rate determined through field and phone survey efforts was applied to the ex ante savings to determine ex post savings.

4.1.4.2 Field data results

The sample contained 36 sites overall, shown in Table 48 by program year and whether the data was collected during an onsite visit or during a phone call. Recall from the sample described in section 3.3.3 that there were only 42 sites in the phone survey sample, and all but one were in PG&E programs. As mentioned, the contact information for customers in the PG&E CQM tracking data was poor, leading to extremely low response rate in those strata. During the planning stage, we mistakenly thought that we would be able to sample sites that had both measures (thermostat and supply fan control) installed. Instead, there were very few sites where both measures were installed and we were forced to sample sites that had one or the other measure installed.

Table 48. Supply-fan measure sample by program, program cycle, and data collection method

Program Name	2013-14 All On-Site	2015 On-Site	2015 Phone Survey	Total
PG&E Commercial QM	7	10	5	22
PG&E AirCare Plus	1	0	5	6
SCE Quality Maintenance	6	1	1	8
All Programs	**14**	**11**	**11**	**36**

Field data utilized in the analysis came from 25 on-site and 11 phone surveys. At each site visit or phone survey we asked the site contact what the pre-treatment condition was for the HVAC supply fan during periods when the building was unoccupied. Most of the respondents could tell us the condition, though four didn’t know. As mentioned earlier, the pre-treatment supply fan condition had to be “on” for the measure to meet the baseline requirement in the ex ante workpapers. If the respondent told us the supply fan was set to “off” or “auto” then it did not meet the baseline requirement. The installation rate excludes all sites where the respondent didn’t know the pre-treatment condition of the supply fan. As shown in Table 49, the supply fan measure installation rate for PG&E’s Commercial QM program was 47%, for PG&E’s AirCare Plus program it was 0% and for SCE’s Quality Maintenance program it was 100%.

Table 49. Field results for supply fan control measure baseline by program

Program Name	Number Meeting Baseline	Number not Meeting Baseline	Don't Know	Total	Installation Rate	Precision at 90% Confidence
PG&E Commercial QM	9	10	3	22	0.47	±0.19
PG&E AirCare Plus	0	5	1	6	0.00	±0.0
SCE Quality Maintenance	8	0	0	8	1.00	±0.0

4.1.4.3 Program-specific results

Our field results point to a realization rate of 47%, the precision of the field-collected data is low: ± 40% at 90% confidence. The low precision is due to the high survey dropout rate in the programs that installed the supply fan measure. The savings are based on the product of the installation rate and the workpaper and disposition deemed savings applied to the ex ante claims. Table 50 shows the resulting electric energy and demand savings on a program level. PG&E programs did not report any gas savings for the supply fan control measure. SCE's Quality Maintenance program has no ex ante savings because they reported savings on an aggregated level. Results for this program are explained in more detail in section 4.1.6. Neither of the SDG&E programs claimed ex ante electric or gas savings for the supply fan control measure.

Table 50. Supply fan control results by program

Program	Number of Claims	Ex Ante kWh Savings	Ex Ante kW Savings	Ex Post Instal-lation Rate	Ex Post Reali-zation Rate kWh	Ex Post Reali-zation Rate kW	Ex Post kWh Savings	Ex Post kW Savings
PG&E Commercial QM	796	3,259,691	0	47%	47%	N/A	1,532,055	0
PG&E AirCare Plus	213	274,646	0	47%	47%	N/A	129,084	0
SDG&E Deemed Incentives								
SDG&E Direct Install								

4.1.5 Refrigerant charge adjustment measure group

We did not allocate additional sample points to the RCA measure group for the 2015 evaluation cycle. RCA has been studied[58] more often than the other measures investigated here, so evaluation funds were focused elsewhere. The results of the 2013-14 field data collection are applied to the distributions of charge adjustment types found in the 2015 claims as described in the sections below. A discussion of our workpaper review for this measure is provided in APPENDIX C.

[58] http://calmac.org/publications/FINAL%5FHVAC%5FImpact%5FEvaluation%5FWO32%5FReport%5F28Jan2015%5FVolume1%5FReportES.pdf

4.1.5.1 Ex Post Methodology

During our evaluation of the refrigerant charge adjustment (RCA) measure group in the 2013-14 program cycle, we made ex-post measurements of the mass of refrigerant at each system in the sample by pumping it out and weighing it on a scale. Using data provided by the implementer, we were able to calculate the pre-treatment mass of refrigerant and determine the percent change due to the program intervention. Finally, using lab data gathered through the parallel HVAC5 study,[59] we translated the calculated relative refrigerant change to the relative efficiency change.

Many of the sampled units were found to have been undercharged at the initial point of service. Significant charge was added to those units and the resulting recovery by the master technician field team indicated that the initially undercharged units ended up being both undercharged and overcharged after the initial point of service. The implementer data corroborated this finding that most units were initially undercharged. Recovery and weigh-out of these units indicated cases of both over- and undercharge after service. Units that were still undercharged after the program-added charge realized benefits, but additional potential remained. Units that had charge added and ended up overcharged had multiple potential outcomes, including positive, zero, or slightly negative benefits.

Because the charge state before and after the retrofit and the type of pressure-metering device in the system significantly affect the results, the analysis was broken down into groups along those lines. The average pre- and post-treatment charge offsets categorized by system type and pre-treatment condition are listed in Table 51 below. Because of the limited number of overcharged pre-treatment circuits (only 16 of the 110 field-observed were overcharged) it was decided to average these circuits together regardless of system types shown in the table.

These data are used to develop pre- and post-treatment adjustment factors for EIR, capacity, and sensible capacity that impact measure savings. We applied the regression results to each field-collected sample point, and then we developed average impacts for each group that could be applied back to the savings claims.

Table 51. 2013-14 field data pre- and post-charge offset by system type and pre-condition[60]

Pre-condition and System Type	# of Circuits	Pre Charge Offset Used for Regression	Post Charge Offset Used for Regression
Non-TXV, Overcharge, Single (NT1 Over)	*10*	*9%*	*9%*
Non-TXV, Overcharge, Multiple (NT2 Over)	*5*	*9%*	*9%*
Non-TXV, Undercharge, Single (NT1 Under)	73	-17%	-8%
Non-TXV, Undercharge, Multiple (NT2 Under)	15	-15%	-2%
TXV, Undercharge (TXV Under)	6	-10%	0%
TXV, Overcharge (TXV Over)	*1*	*9%*	*9%*

Implementer data were examined to determine the distribution of measure group implementations (retrofits) among the system types and pre-conditions described earlier. The SDG&E Direct Install program

59 Laboratory HVAC Testing Research Plan, prepared for the CPUC by KEMA, Inc., Nov. 17, 2014 (HVAC5 research plan and results).

60 Note that the circuits that had an overcharged pre-condition were averaged together regardless of system type because there were very few sample points for that pre-condition. Those lines are italicized in the table and can be noticed by identical pre- and post- charge offsets of 9%.

did not have sufficient data for this effort, so the SDG&E Deemed program data were applied to that program. Across all programs with data, undercharged circuits were the dominant pre-treatment condition. Table 52 lists the distribution of the program circuits by system type and pre-treatment condition.

Table 52. HVAC circuit distribution by program

	PG&E AirCare Plus and Commercial QM	SCE Quality Maintenance	SDGE3224 Deemed Incentives
Total Number of Circuits	**9,482**	**3,134**	**22,389**
Non-TXV, Overcharge, Single	6%	0%	8%
Non-TXV, Overcharge, Multiple	2%	0%	2%
Non-TXV, Undercharge, Single	61%	50%	58%
Non-TXV, Undercharge, Multiple	9%	19%	12%
TXV, Undercharge	17%	29%	9%
TXV, Overcharge	5%	0%	11%

The EIR, total capacity, and sensible capacity adjustment factors that were calculated based on the pre- and post-treatment offsets listed in Table 51 were then weighted by the distributions of each of the representative program groups listed in Table 52. The results of this weighting process are listed in by IOU in Table 53. The values provided in Table 53 represent the adjustment factors applied to the system performance (cooling EIRs), capacities (total and sensible) and cooling sizing ratio of the DEER prototype HVAC building models.

Table 53. Ex post DOE-2 adjustment factors

IOU	Run	Cooling EIR	Cooling Capacity	Cooling Sensible Heat Capacity	Cooling to Sizing Ratio[61]
SDG&E	Pre-condition	1.0455	0.9397	0.9510	0.9453
	Post-condition	1.0127	0.9822	0.9883	0.9852
SCE	Pre-condition	1.0518	0.9233	0.9375	0.9304
	Post-condition	1.0099	0.9793	0.9857	0.9825
PG&E	Pre-condition	1.0450	0.9363	0.9488	0.9426
	Post-condition	1.0121	0.9804	0.9871	0.9837

The modeled savings per ton in the ex post were applied to the tonnage claimed by each program within in combination of building type and climate zone. The savings per ton results by climate zone and building type are available in APPENDIX E and in an Excel workbook of tables.

4.1.5.2 Program-specific results

Table 54 shows the results of the modeled savings applied to each claim in the ex ante tracking data and propagated to the program level. The large realization rate for SDG&E's Deemed Incentive program is because they used a lower UES value in their ex ante claim than the other programs. SCE's Quality

[61] Note that the cooling to sizing ratio was calculated by averaging the cooling capacity and the cooling sensible heat capacity. This decision was made to practically process the large volume of DEER prototype models with differing absolute capacities.

Maintenance program is not included in this table because they reported savings on an aggregated measure level. Results for the SCE QM program are explained in more detail in section 4.1.6.

Table 54. RCA results by program

Program	Number of Claims	Ex Ante kWh Savings	Ex Ante kW Savings	Ex Post Instal-lation Rate	Ex Post Reali-zation Rate kWh	Ex Post Reali-zation Rate kW	Ex Post kWh Savings	Ex Post kW Savings
PG&E Commercial QM	791	434,726	388	100%	36%	19%	154,972	72
PG&E AirCare Plus	802	230,446	178	100%	37%	15%	85,875	27
SDG&E Deemed Incentives	5,452	1,839,105	1,308	100%	81%	71%	1,482,648	928
SDG&E Direct Install	1,969	388,367	238	100%	32%	31%	122,985	73

4.1.6 Quality maintenance measure group

This section addresses the QM measures under the SCE and SoCalGas QM program. As previously mentioned, this program was primarily administered through SCE, and gas savings were transferred to SoCalGas through the therm exchange program. SCE and SoCalGas program administrators used a single line item to claim savings for a package of HVAC maintenance activities or measures, which is consistent with the QM program strategy.

4.1.6.1 QM program activity

The tracking data shown in Table 55 reflects the number of units enrolled in the program and the associated ex ante savings. As described above, the QM component measure incidence from the CPUC disposition was embedded in the savings calculation. However, the actual program activity deviated from the disposition forecast. Table 55 shows both the disposition-reported measure incidence distribution and the actual measure incidence derived from implementer data.

Table 55. Assumed and implemented QM component measure incidence in 2015

Individual Treatment (both DXGF[62] and PKHP[63])	Disposition Incidence	Implementer Tracking Data Incidence, 2013-14	Implementer Tracking Data Incidence, 2015
Refrigerant Charge Adjustment	40%	38%	37%
Condenser Coil Cleaning	40%	86%	98%
Evaporator Coil Cleaning	20%	97%	88%
Airflow Adjustment	20%	32%	29%
Thermostat Replacement	20%	18%	25%
Thermostat Reprogramming	10%	29%	23%
Economizer Repair	10%	26%	33%
Economizer Reprogramming	10%	17%	35%

DXGF is a direct expansion gas fired system and PKHP is a packaged heat pump.

4.1.6.2 Ex post methodology

The ex post savings were built up by using the actual quantity of component measures performed, as documented by implementer data. The implemented component measure quantities were then multiplied by the individual measure savings values to produce savings at the component measure-level. Disposition-approved unit energy savings (UES) were used as a basis for all the component measure savings except for RCA, condenser coil cleaning and evaporator coil cleaning which were replaced with the simulation results developed in this evaluation. Where the disposition-approved UES was used, it was multiplied by the installation rate found in this evaluation: 61% for economizer measures from the statewide analysis described in the economizer section 4.1.1.2 and 64% for thermostat measures (calculated from SCE-specific site data using the methodology described in the thermostat section 4.1.2.1). The component measure-level savings were summed to produce ex post savings values at the measure package level. The realization rate for the program is the ex post savings divided by the sum of the ex ante claims.

The overall realization rate for the QM package was 137% primarily due to relatively high realization rates for condenser coil cleaning, economizer repair and thermostat measures as well as a higher than expected frequency of repair for coil cleaning, economizer repair and thermostat reprogramming.

Table 56 shows the results of the measure level savings applied to each SCE claim in the ex ante tracking data and propagated to the program level. Similarly, Table 57 shows the results of the measure level gas savings applied to each SoCalGas claim in the ex ante tracking data and propagated to the program level.

62 DXGF refers to a package air conditioning unit with a gas furnace.

63 PKHP refers to a package heat pump unit that provides cooling and heating using only electricity as fuel.

Table 56. SCE QM program savings by measure

Measure Group	Number of Claims	Ex Ante kWh Savings	Ex Ante kW Savings	Ex Post Reali-zation Rate kWh	Ex Post Reali-zation Rate kW	Ex Post kWh Savings	Ex Post kW Savings
Quality Maintenance	608	448,268	193	99%	42%	441,686	81
Heat Pump Quality Maintenance	952	528,743	218	100%	53%	529,895	116
QM with Economizer	1,240	1,804,351	549	156%	35%	2,812,785	193
QM Heat Pump with Economizer	728	736,445	281	129%	41%	952,754	115
Total	**3,528**	**3,517,807**	**1,242**	**135%**	**41%**	**4,737,119**	**505**

Table 57. SoCalGas QM program savings by measure

Measure Group	Number of Claims	Ex Ante therm Savings	Ex Post Realization Rate therms	Ex Post therm Savings
Quality Maintenance	193	927	150%	1387
QM w/Economizer	443	6,219	26%	1636
Total	**636**	**7,146**	**42%**	**3,023**

Substituting an 80°F cooling unoccupied set point temperature causes a noticeable change in ex post kWh savings, but very little change in ex post kW savings. The ex post kWh savings calculated using the 80°F cooling unoccupied set point temperature are shown in Table 58.

Table 58. SCE QM program savings by measure using 80°F cooling unoccupied set point

Measure Group	Number of Claims	Ex Ante kWh Savings	Ex Ante kW Savings	Ex Post Reali-zation Rate kWh	Ex Post Reali-zation Rate kW	Ex Post kWh Savings	Ex Post kW Savings
Quality Maintenance	608	448,268	193	110%	41%	494,599	79
Heat Pump Quality Maintenance	952	528,743	218	110%	52%	584,165	114
QM with Economizer	1,240	1,804,351	549	167%	35%	3,020,396	190
QM Heat Pump with Economizer	728	736,445	281	139%	40%	1,020,427	113
Total	**3,528**	**3,517,807**	**1,242**	**146%**	**40%**	**5,119,586**	**496**

4.2 Commercial program-level gross savings

The following tables provide a summary of the extrapolation of the sample to the population and program-level realization rate. The totals reported are for the measures evaluated under the HVAC3 section of the CPUC HVAC Roadmap. In each program, there may be additional measures that were assigned to a different part of the CPUC HVAC Roadmap, or were assigned as pass-through. A full accounting by program and measure group is available in APPENDIX K.

Table 59. PG&E commercial QM program-level electric first-year savings

Measure Group	Number of Claims	Ex Ante kWh Savings	Ex Ante kW Savings	Ex Post Reali-zation Rate kWh	Ex Post Reali-zation Rate kW[64]	Ex Post kWh Savings	Ex Post kW Savings
Coil Cleaning - Condenser	1,724	0	0	N/A	N/A	606,031	310
Coil Cleaning - Evaporator	1,724	0	0	N/A	N/A	113,643	63
RCA	791	434,726	388	36%	19%	154,972	72
Economizer	1,155	2,037,921	-73	77%	*	1,568,155	34
Thermostat	678	908,381	0	103%	N/A	933,979	24
Fan Control	796	3,259,691	0	47%	N/A	1,532,055	0
Total	**6,868**	**6,640,718**	**316**	**74%**	**159%**	**4,908,834**	**502**

64 * The ex ante kW savings claims for these measures were negative, while the ex post values we found to be positive therefore the usual calculation of realization rate was withheld as it would produce an inaccurate representation of measure savings when applied to the ex ante claims in the usual manner.

Table 60. PG&E commercial QM program-level gas first-year savings

Measure Group	Number of Claims	Ex Ante therm Savings	Ex Post Reali-zation Rate therms	Ex Post therm Savings
Thermostat	678	131,876	7%	9,730

Table 61. PG&E AirCare Plus program-level electric first-year savings

Measure Group	Number of Claims	Ex Ante kWh Savings	Ex Ante kW Savings	Ex Post Reali-zation Rate kWh	Ex Post Reali-zation Rate kW[65]	Ex Post kWh Savings	Ex Post kW Savings
Coil Cleaning - Condenser	2,054	71,205	57	467%	210%	332,192	121
Coil Cleaning - Evaporator	1,660	33,146	27	147%	41%	48,603	11
RCA	802	230,446	178	37%	15%	85,875	27
Economizer	1,081	712,568	-87	100%	*	714,945	3
Thermostat	1,334	1,896,751	0	115%	N/A	2,180,896	35
Fan Control	213	274,646	0	47%	N/A	129,084	0
Total	**7,144**	**3,218,762**	**176**	**108%**	**112%**	**3,491,595**	**197**

Table 62. PG&E AirCare Plus program-level gas first-year savings

Measure Group	Number of Claims	Ex Ante therm Savings	Ex Post Reali-zation Rate therms	Ex Post therm Savings
Thermostat	1,334	249,607	10%	24,620

65 Ibid.

Table 63. SCE program-level electric first-year savings

Measure Group	Number of Claims	Ex Ante kWh Savings	Ex Ante kW Savings	Ex Post Reali-zation Rate kWh	Ex Post Reali-zation Rate kW	Ex Post kWh Savings	Ex Post kW Savings
Quality Maintenance	608	448,268	193	99%	42%	441,686	81
Heat Pump Quality Maintenance	952	528,743	218	100%	53%	529,895	116
QM with Economizer	1,240	1,804,351	549	156%	35%	2,812,785	193
QM Heat Pump with Economizer	728	736,445	281	129%	41%	952,754	115
Total	**3,528**	**3,517,807**	**1,242**	**135%**	**41%**	**4,737,119**	**505**

Table 64. SoCalGas program-level gas first-year savings

Measure Group	Number of Claims	Ex Ante therm Savings	Ex Post Realization Rate therms	Ex Post therm Savings
Quality Maintenance	193	927	143%	1,329
QM w/Economizer	443	6,219	25%	1,548
Total	**636**	**7,146**	**40%**	**2,877**

Table 65. SDG&E deemed program-level electric first-year savings

Measure Group	Number of Claims	Ex Ante kWh Savings	Ex Ante kW Savings	Ex Post Reali-zation Rate kWh	Ex Post Reali-zation Rate kW	Ex Post kWh Savings	Ex Post kW Savings
Coil Cleaning - Condenser	6,615	814,855	200	160%	413%	1,301,171	825
Coil Cleaning - Evaporator							
RCA	5,452	1,839,105	1,308	81%	71%	1,482,648	928
Economizer							
Thermostat							
Fan Control							
Total	**12,067**	**2,653,960**	**1,508**	**105%**	**116%**	**2,783,819**	**1,753**

Table 66. SDG&E Direct Install program-level electric first-year savings

Measure Group	Number of Claims	Ex Ante kWh Savings	Ex Ante kW Savings	Ex Post Reali-zation Rate kWh	Ex Post Reali-zation Rate kW	Ex Post kWh Savings	Ex Post kW Savings
Coil Cleaning - Condenser	1,456	713,086	215	37%	76%	261,922	164
Coil Cleaning - Evaporator	1,188	364,550	96	70%	183%	254,672	176
RCA	1,969	388,367	238	32%	31%	122,985	73
Economizer	370	213,220	2	100%	100%	213,220	2
Thermostat	695	1,247,512	-193	40%	23%	501,773	-44
Fan Control							
Total	**5,678**	**2,926,735**	**358**	**46%**	**104%**	**1,354,573**	**371**

Table 67. SDG&E Direct Install program-level gas first-year savings

Measure Group	Number of Claims	Ex Ante therm Savings	Ex Post Realization Rate therms	Ex Post therm Savings
Economizer	370	-4,135	100%	-4,135
Thermostat	695	275,839	0%	1,126
Total	**4,897**	**271,646**	**-1%**	**-3,009**

4.3 Commercial program NTG savings ratio methods and results

The NTG evaluation answers the question "to what extent did the programs cause an increase in maintenance actions deemed to save energy?" In short, net savings are about program attribution for taking maintenance actions and gross savings are about how much energy the actions saved, regardless of why they were taken. NTG evaluations determine the proportion of gross evaluated savings that are attributable to the program under study. Additional detail about the NTG ratios per program is provided in the HVAC3 NTG report.[66]

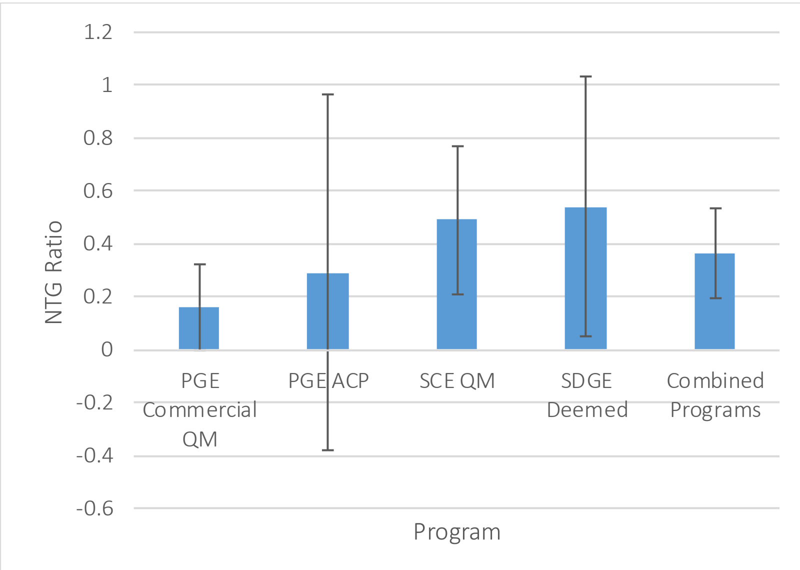
DNV GL estimated NTG savings ratios for both electric and gas using the contractor survey responses to the evaluation's NTG questions that we described in the HVAC3 NTG report. We then applied the ex post NTG ratio to the ex post gross energy and demand savings to arrive at ex post net program energy and demand savings.

The NTG ratios are the same for all programs because they were computed using all the data combined; the individual program NTG ratios have high uncertainty, which is illustrated in the HVAC3 NTG report.

[66] CPUC 2016. Net-to-gross Evaluation of 2013-14 Commercial Quality Maintenance Programs (HVAC3). http://www.calmac.org/publications/HVAC3_NTG_Final_Report_2016-12-07.pdf

Contractor responses indicated that 64% of verified program kWh savings would have occurred without the programs. Figure 23 shows that the average NTR ratio across all programs (0.36 ±0.17) falls within the 90% confidence interval error band for each evaluated program.

Figure 23. NTG ratios with 90% confidence interval error bars for each evaluated program



Generally, we found that the individual measure level NTG ratios, shown in Table 68, were low across most programs and measure groups. The exceptions were the RCA measure group that scored a high NTG ratio across two programs, and the QM measure group, only performed in the SCE QM program. The QM measure group is the only measure in the SCE QM program (it is comprehensive and includes all the other measures), resulting in a high NTG ratio for that program. The fan control and thermostat measures had the lowest NTG ratios among the measure groups.

Table 68 also shows that three of the four programs had overall NTG ratios in a similar range. The one exception was PG&E's Commercial QM program which had a much lower overall NTG ratio. This result surprised us somewhat because this PG&E program had a similar design to SCE's QM program, which had a much higher ratio. A closer examination of these results revealed that the differences in NTG ratios between the PG&E and SCE programs were mostly driven by different assessments of program attribution by a small number of contractors who accounted for a very large volume of program savings in each of the programs. With these contractors removed the program results were very similar.

Table 68. Measure-level kWh NTG ratios across programs, PY 2013-14

Measure Group	PG&E Commercial QM	PG&E AirCare Plus	SCE QM	SDG&E Deemed Incentives
Coil Cleaning		0.00 ±0.00		0.48 ±0.63
Economizer	0.21 ±0.30	0.55 ±1.19		
Fan Control	0.05 ±0.08	0.00 ±0.00		
QM			0.49 ±0.28	
RCA	1.00 ±0.00	0.37 ±1.06		0.84 ±0.37
Thermostat	0.21 ±0.19	0.31 ±1.00		
Overall	**0.16 ±0.16**	**0.29 ±0.67**	**0.49 ±0.28**	**0.54 ±0.49**

Another contributing factor for the very different NTG ratios between the PG&E and SCE QM programs may have been methodological. Because the SCE program did not track individual measures separately, we could not evaluate the effectiveness of the program in promoting different measures.

4.4 Residential program gross and net-savings evaluation methods and results

To estimate ex post impacts for the residential QM program and program measures, Itron used regression based models. Gross program impacts were developed using participant models while the net program impacts were developed using models estimated on both the participant and matched non-participant sample as described in section 3.2.3.

4.4.1 Estimating ex post impacts

Following the development of the non-participant control group, regression models were developed to estimate ex post gross and net residential program impacts based on hourly residential loads for both PG&E and SDG&E. Gross impacts were estimated using a model with only the participant customers while the net impacts are derived from a model with both participant and non-participant customers.

Several different specifications were tested in developing the final ex post models. The models were run as hourly models, estimating a separate model for each hour of the day.[67] The final model specification differed slightly for SDG&E and PG&E. For SDG&E, the impact of the residential program was included in the model as a binary variable equaling one following the customer's participation and zero prior to participation. For the PG&E models, the program impact was estimated by measure group. For PG&E participants, the model estimates the impact of fan repair, blower motor replacement, and RCA using the quantity (in tons of cooling) of residential QM measures installed at each customer's site.[68] It was possible to estimate the measure group specific impacts for PG&E participants due to the large number of participants and the

[67] Models were also estimated at the monthly and daily level. The daily level results are presented in the results section. The daily and hourly results are similar.

[68] The ton quantity measure is the tonnage of the air conditioner serviced. The ex ante savings are proportional to the tonnage of the air conditioner measure. The estimate of measure group impacts using ton quantity is similar to using a binary variable to indicate when the treatment occurred. Using quantities, however, allows for additional variability in the independent variable that should be site and measure specific.

distribution of measure installation across participants.[69] For SDG&E the impact modeling was limited to a single program impact due to the small number of participants and extensive overlap in measure group participation.

The final specification included a customer-specific fixed effect with independent variables for the day of the week, the month of the year, heating- and cooling-degree hour, participation in other IOU-sponsored energy efficiency programs, residential QM measures and an interactive term for residential QM measures interacted with heating and cooling degree hours. [70] A separate model was run for weekday and weekends.[71] The following specification is the gross impact model estimated for PG&E.[72] The specifications of the PG&E net impact model and the SDG&E gross and net impact models are presented in APPENDIX I. The model was estimated on an hourly basis with 48 different models, one for each hour of the day and separately for weekdays and weekends.

$$\begin{aligned} kWh_{it} = \gamma_i &+ \sum_d \beta_1^d \times DOW_d + \sum_m \beta_2^m \times Month_m + \beta_3 \times CDH65_{it} + \beta_4 \times HDH65_{it} + EEkWh_{it} \\ &+ \beta_5 \times QFan_{it} \times Post_{it} + \beta_6 \times QBlowerMotor_{it} \times Post_{it} + \beta_7 \times QRCA_{it} \times Post_{it} \\ &+ \beta_8 \times QFan_{it} \times CDH65_{it} \times Post_{it} + \beta_9 \times QBlowerMotor_{it} \times CDH65_{it} \times Post_{it} \\ &+ \beta_{10} \times QRCA_{it} \times CDH65_{it} \times Post_{it} + \beta_{11} \times QFan_{it} \times HDH65_{it} \times Post_{it} \\ &+ \beta_{12} \times QBlowerMotor_{it} \times HDH65_{it} \times Post_{it} + \beta_{13} \times QRCA_{it} \times HDH65_{it} \times Post_{it} + \varepsilon_t \end{aligned}$$

Where:

kWh_{it}	Is the hourly kWh for individual i on time t
γ_i	Is the customer specific fixed effect
β_1^d	Is the set coefficient for day of week (DOW) d
β_2^m	Is the set of coefficient for month m
β_3	Is the estimated impact of a one-degree increase in cooling degree hours (CDH) on hourly consumption
β_4	Is the estimated impact of a one-degree increase in heating degree hours (HDH) on hourly consumption
β_5	Is the estimated impact of participation in other energy efficiency programs on hourly consumption
β_6	Is the estimated direct effect of fan repair on post-installation hourly consumption
β_7	Is the estimated direct of effect a new blower motor on post-installation hourly consumption
β_8	Is the estimated direct estimate of RCA on post-installation hourly consumption
β_9	Is the estimated effect of fan repair interacted with CDH on post-installation hourly consumption
β_{10}	Is the estimated effect of a new blower motor interacted with CDH on post-installation hourly consumption

69 For PG&E the gross and net models were estimated separately for 2013 participants and 2014 participants. In 2013, PG&E's QM participants largely only installed fan repairs. In 2014, PG&E's QM participants largely only installed blower motors and RCA, with approximately 1/3 of customers installing blower motors, 1/3 RCA and 1/3 both RCA and blower motors.

70 The model is estimated using actual weather. The weather normalized savings estimates use the parameter estimates from the model and simulate savings using normal weather.

71 The impact of many of the independent variables, including the residential QM program variables, on hourly energy consumption depend on weekend and weekdays due to the number of people home during different hours of the day during these two periods. Running separate models allows the models to estimate the unique impact of the independent variables over these two different time periods.

72 Specifications including a one to three hour lag in HDH and CDH were also implemented. These alternative specifications did not change the general results or estimated savings for the QM measures.

β_{11}	Is the estimated effect of RCA interacted with CDH on post-installation hourly consumption
β_{12}	Is the estimated effect of fan repair interacted with HDH on post-installation hourly consumption
β_{13}	Is the estimated effect of a new blower motor interacted with HDH on post-installation hourly consumption
β_{14}	Is the estimated effect of RCA interacted with HDH on post-installation hourly consumption
ε_t	Is the error

The estimated gross program impacts are based on the interaction of the program measures and their interaction with heating- and cooling-degree hours. Interacting the residential QM measures with heating and cooling degree hours allows the estimate of savings to differ with temperature and season. Participants in the QM program, and their matched non-participants, may have participated in other energy efficiency programs, during the pre- and/or post-QM periods. To ensure that the estimates of residential QM measure savings are not biased by savings associated with other energy efficiency measures in the IOU program tracking data, the regression model controls for participation in other energy efficiency programs. The $EEkWh_{it}$ independent variable in the regression model is the ex ante savings estimate of other, non-residential QM, energy efficiency measures installed at the customer's home.

The net impact model is like the gross impact model except for the analysis population and the addition of one new independent variable.[73] The net model is estimated using both the participant and the non-participant sample. For the net model specification, a post-period binary variable is also added to the gross model specification. The post-period binary variable is equal to zero prior to participation and one post-installation. For the non-participant sample, the post-period binary variable moves from zero to one based on the matched participant's participation. The post-period binary variable estimates the change in consumption in the post-installation period across all households. For example, if all households become more energy conscious during the post period, the post-period binary will be negative, showing a reduction in consumption across all households.

In the net impact model, the estimated net program impacts are based on the interaction of residential QM program measures and their interaction with heating- and cooling-degree hours. The estimated coefficients, and therefore the net impacts are likely to differ between the net and gross specification due to the net model's ability to control for population wide changes in electricity consumption during the post period. If the program is leading to a reduction in consumption unique to and above changes in consumption seen in the matched non-participant population, the program coefficients will be negative and statistically significant within the net model specification.

4.4.2 Data attrition

Underlying all the analysis are many steps that are necessary to integrate the multiple data sources into the structure required for the analysis. These steps include preparing the monthly billing data for the first-stage

[73] The estimated gross impact of the QM program may include other changes in energy consumption that occurred during the post installation period. For example, if the post period coincided with a time of robust macroeconomic growth, and if economic growth is correlated with an increase in electricity consumption, the gross estimate of QM savings could underestimate the impact of QM on the electric grid. Alternatively, if the post period coincided with a time of increased concern about climate change, and this concern had led households in the post period to change their behavior such that they consumed less electricity, the gross estimate of QM savings could overestimate the impact of QM on the electric grid. Many household specific changes can also impact a households' consumption, for example children being born and children leaving for college.
It is generally assumed that household specific changes in consumption will tend to cancel, with some households having changes that lead to an increase in consumption (having children) and some experiencing changes that lead to a decrease in consumption (children leaving for college).

participant matching, preparing the hourly load data for the second-stage matching, and preparing the data for the impact analysis. Table 69 lists the number of participant and non-participant households with monthly kWh data pulled from the billing database. The tracking data row illustrates the number of unique customers in the SDG&E and PG&E 2012-14 residential program tracking data.[74] The received billing data row indicates the large number of households originally included in the non-participant monthly billing data request. The billing data for participants and non-participants were reviewed for anomalies that would limit the ability of these data to be of used in the matching and analysis process.

A first step in this analysis eliminated households with electric vehicles (EV) or net energy metering (NEM) associated with solar energy production. EV consumption and solar energy production are likely to lead to increased variance in utility energy consumption, making observation of the program impact more difficult. Within SDG&E's participant population with billing data, elimination of EV and NEM customer reduced the participant analysis population by close to 20%.

Table 69. Number of participant and non-participant customers following first-round matching

	PG&E		SDG&E	
	Participant	Non-Participant	Participant	Non-Participant
Tracking Data	11,841		542	
Received Billing Data	11,834	8,228,299	493	2,419,352
Exclude NEM and EV	11,321	7,992,996	402	2,346,037
At Least 1 Year of Pre-Billing Data in Analysis Climate Zone	8,955	1,626,820	339	1,189,153
After First-Round Matching	8,955	113,614	339	6,276

The billing data review also included an analysis of consumption gaps and overlaps and periods of zero usage. A substantial number of customers in the participant and non-participant population were eliminated due to less than one year of pre-installation billing data. For the PG&E non-participant sample, however, the largest decline in the number of eligible customers was due to the requirement that the non-participant sample be drawn from the same climate zones as the participant analysis population. PG&E's program participation in 2013 and 2014 included over 16,500 claims, dominated by claims within climate zones 11, 12, and 13. Fewer than 30 claims originated from PG&E climate zones 2, 3, and 4, so data from these climate zones were eliminated from the billing analysis.[75]

Table 70 lists the number of participant and the non-participant households following the second-round propensity score matching process. The first-stage matching led to the selection of between 10 and 15 non-

[74] The number of unique customers is less than the number of tracking data records listed in the Tracking Data section above. The number of tracking data records counts the number of measure group installations. A unique customer may have installed multiple measures.

[75] The realization rate from ex post savings estimated developed for climate zones 11, 12, and 13 will be applied to ex ante claims in climate zones 2, 3, and 4.

participant households for every participant household. AMI load data were requested for all the participant and non-participant customers listed in the final row. Table 70 lists the data attrition associated with the second-round matching of program participants. As with the first-round attrition, households were lost due to missing AMI data, NEM and EV customers, gaps in the data, and the requirement that households have at least one year of pre-installation AMI data.

The final row in Table 70 lists the number of participant and non-participant households following the second-stage propensity score matching. The number of participant households exceeded the number of non-participant households because the matching was done with replacement, some non-participant households were designated as the best match for more than one participant household.

Table 70. Number of participant and non-participant customers following second-round matching

	PG&E		SDG&E	
	Participant	Non-Participant	Participant	Non-Participant
AMI Data Requested	8,955	113,614	339	6,276
AMI Data Received	8,940	113,303	339	6,276
Exclude New NEM and EV	8,630	111,050	317	6,040
Exclude Gaps and Too Much Estimated Data	8,549	109,772	310	5,895
At Least 1 Year Per Installation Data	8,499	93,878	309	5,142
After Second-Round Matching	8,374	7,733	299	286

The first row of Table 71 lists the number of participant and non-participant households following the second-stage propensity score matching. Two additional data reviews were undertaken prior to implementation of the impact modeling. Participant sites and their non-participant matches were excluded from the analysis if their annual ex ante estimates or program savings exceeded 35% of their pre-installation consumption. The program is anticipated to have a modest impact on electricity usage, household reporting an ex ante impact exceeding 35% of their pre-installation consumption likely represent customers with incomplete pre-installation usage. Customers were also removed from the analysis data set if they did not have at least one year of post-installation AMI data.

Table 71. Number of participant and non-participant customers for the regression analysis

	PG&E		SDG&E	
	Participant	Non-Participant	Participant	Non-Participant
After Second-Round Matching	8,374	7,733	299	286
Excludes Sites with Too High Savings	8,023	7,675	286	281
At Least 1 Year Post-Installation Data	7,424	7,507	276	280
Matched Participant/Non-participant	7,192	6,705	271	260

4.4.3 Results

The goal of this analysis was to determine the gross and net impacts from residential QM programs. Review of the SDG&E and PG&E tracking data led to the conclusion that there were sufficient observations and diversity of measure installation within the PG&E participant population to separately estimate the impact of PG&E's program measures. The PG&E analysis, therefore, leads to the development of savings estimates for fan repair, blower motor replacement, and RCA measure groups. The SDG&E analysis estimates the gross and net impacts for the programs.

Given the different approaches taken for PG&E and SDG&E's analyses, the results will be presented separately.

4.4.3.1 **PG&E analysis and results**

This section presents the ex post gross and net savings estimates for PG&E's residential QM program. The saving estimates will be presented separately for each of the three program measure groups. Review of the timing of PG&E's measure group installation (Table 74) indicates that airflow adjustment was the dominant measure group installed in 2013 with a very limited number of blower motor repairs and no RCA. In 2014, the dominant measure groups installed were blower motor replacement and RCA with a very limited number of airflow adjustments.[76] Given the distribution of program participation, the PG&E analysis was implemented separately for 2013 and 2014 participants. The 2013 analysis focused on developing ex post savings estimates for fan repair while the 2014 model developed savings estimates for blower motor replacement and RCA.[77]

Table 72 lists the estimated gross and net savings estimates for program measure groups in PG&E's service territory. The savings estimates are presented for both hourly and daily model specifications. The hourly models were estimated using 48 individual hourly models, 24 for weekdays and 24 for weekends, while there were two daily models, one for weekdays and one for weekends. The gross models were estimated using only the participant population and the estimated gross ex ante impact is the total change in the

[76] In 2015, the PG&E program installations were dominated by blower motor replacements and RCA. There were 11,606 blower motor records, 8,871 RCA, and only 493 airflow adjustments. All but one of the aifrlow adjustment records occurred in the fourth quarter of 2015.

[77] The 2013 analysis developed a savings estimate for the 2013 blower motor participants and the 2014 analysis develop a savings estimate for the airflow adjustment participants. Given the limited number of blower motor 2013 participants and the airflow adjustment 2014 participants, the analysis team has chosen to focus on fans in 2013 and blower motors and RCA in 2014.

participant population electricity consumption including the average change in post period consumption attributable to non-program effects.[78] The net models used both the participant and matched non-participant sample. The gross and the net models are estimated as fixed effects models, controlling for the customers' average consumption (site level fixed effects), the time of year and day of the week (time fixed effects), the influence of heating and cooling degree days on electricity consumption, the impact of participation in energy efficiency programs other than QM on consumption and the impact of residential QM measure group installations on participant consumption.[79] The net models include a post-participation binary variable for QM participants and their matched non-participants. The coefficient on the post-participation binary variable is an estimate changes in energy consumption in the post period that are common across both participants and non-participants. Within the net models, the coefficients on the residential QM measure groups is an estimate of changes in consumption following the installation of these measures, that is net of the observed change in consumption for both the participant and non-participant populations.

All impact parameters for the daily gross models are statistically significant and the motor blower replacement and RCA impacts for the net daily models are statistically significant. The hourly models include 144 impact parameters,[80] most of which are statistically significant. In the hourly net models, the fan repair coefficients are generally not statistically significant. The coefficient estimates for the program variables are presented in APPENDIX I

Using actual weather data, the gross ex post estimates of first year savings from program measures range from 33.0 kWh for motor replacement to 39.7 kWh for fan repair in the hourly specification and 36.2 kWh for RCA to 45.1 kWh for fan repair in the daily specification.[81] The net results, using a model incorporating both participants and a sample of matched non-participants leads to statistically insignificant savings for the fan repair measure. For the blower motor and RCA, the net savings estimates are statistically significant, but substantially lower than the gross savings, indicating that the matched non-participants also reduced their electricity consumption during the post period.

[78] The model controls for participation in other downstream EE programs. Typically, it is assumed that the average non-program related change in consumption is zero as some households will increase their non-program related consumption and some households will decrease their non-program related consumption.

[79] The matching of participants and non-participants was undertaken using a propensity score model that controlled for household consumption, the relationship between consumption and weather, and participation in other programs. Participant and non-participant households were not matched based on the non-participant households undergoing non-incented HVAC maintenance. Information on non-incented HVAC maintenance is not available for the participant or non-participant households.

[80] 48 models times three impact parameters per model

[81] The savings estimates are presented on a per ton basis to facilitate comparison to the tracking data below. The average capacity (tons) of systems getting an airflow adjustment is 3.49, blower motor ton average is 3.14, and RCA is 3.27. Multiplying the savings per ton by the average number of tons leads to the per household savings.

Table 72. PG&E residential program average savings per ton – actual weather

Measure	Gross kWh Savings/Year Hourly Model	Net kWh Savings/Year Hourly Model	Gross kWh Savings/Year Daily Model	Net kWh Savings/Year Daily Model
Airflow Adjustment[82]	39.7	Not Statistically Different From Zero	45.1	Not Statistically Different From Zero
Motor Replacement[83]	33.0	17.7	44.0	18.0
RCA[84]	38.2	18.9	36.2	11.1

Table 73 presents the ex post gross and net kWh savings per year using normal weather and the coefficient estimates from the hourly model.

Table 73. PG&E residential program average savings per ton – normal weather

Measure	Gross kWh Savings/Year Hourly Model	Net kWh Savings/Year Hourly Model
Airflow Adjustment	41.35	Not Statistically Different From Zero
Motor Replacement	47.95	30.37
RCA	36.80	15.33

PG&E ex post savings estimates

The gross and net weather normalized savings from the hourly model were compared to the 2013, 2014, and 2015 claimed savings to develop realization rates. Table 74 lists the gross and net ex post savings estimates and the ex ante tracking data claims for 2013 through 2015 for PG&E's program. The savings estimates, both ex ante and ex post, are listed on an average savings per ton basis. The ex ante savings were weighted by tons installed by climate zone to develop an average across climate zone for the tracking data values.

[82] The PG&E HVAC airflow adjustment savings are estimate for 2013 participants.
[83] The PG&E HVAC blower motor savings are estimate for 2014 participants.
[84] The PG&E HVAC RCA savings are estimated for 2014 participants.

Table 74. PG&E residential program gross and net realization rates 2013-15

Measure	Ex Post Gross Normalized Savings	Ex Post Net Normalized Savings	Tracking Data 2013	Tracking Data 2014	Tracking Data 2015
Airflow Adjustment kWh Savings per Ton	41.35		182.03	175.27	148.58
Airflow Gross Realization Rate			23%	24%	28%
Airflow Net Realization Rate					
Blower Motor Replacement	47.95	30.37	158.58	147.87	130.97
Blower Motor Gross Realization Rate			30%	32%	37%
Blower Motor Net Realization Rate			19%	21%	23%
RCA	36.80	15.33		55.97	29.82
RCA Gross Realization Rate				66%	123%
RCA Net Realization Rate				27%	51%

For the fan repair measure group, PG&E's ex ante claimed savings per ton declined slightly over the three-year period (2013-15). Due to the relative consistency of the ex ante claims, the fan repair gross realization rate varied from 23% to 28% while the net realization rate was not statistically different from zero.

PG&E's ex ante claimed savings per ton for blower motor replacement declined over the three-year period. The estimated gross ex post savings, however, were substantially smaller than the claimed savings. The blower motor gross realization rate increased from 30% to 37% as PG&E's ex ante claims decreased over time. The net realization rate from blower motor replacement increased from 19% to 23%.

The RCA realization rates were calculated for 2014 and 2015 as there were no installations of RCA in 2014. PG&E's ex ante claims for RCA declined between 2014 and 2015, leading to an increase in the gross and net realization rates. The RCA gross realization rate for 2014 was 66% and 123% for 2015. The net realization rate for RCA was 27% in 2014 and 51% in 2015.

Table 75 applies the gross and net realization rates to PG&E's ex ante claimed savings by year and measure group to develop gross and net ex post savings values.[85] The gross and net savings increased over the three-year period but was substantially less than claimed. The program level gross realization rate is 49%,

[85] The realization rates are applied to all savings for a measure group in a given year, including the savings for measures installed in climate zones that were not analyzed as part of the billing regression model. This application is similar to applying the savings estimated using 2013 and 2014 data to the claims in 2015.

for gross first year ex post savings of 2,739,757 kWh in 2015. The program level net realization rate is 26%, for net first year ex post savings of 1,476,287 kWh in 2015.

Table 75. PG&E residential QM program gross and net first-year savings for 2013-15

Residential QM Measure	2013	2014	2015
Quantity of Airflow (tons)	4,255	271	1,615
Airflow Total Ex Ante Savings (kWh)	774,479	47,410	239,964
Airflow Gross Ex Post Savings (kWh)	175,914	11,184	66,774
Airflow Net Ex Post Savings (kWh)			
Quantity of Blower Motor (tons)	278	23,270	34,972
Blower Motor Replacement Total Ex Ante Savings (kWh)	44,085	3,440,854	4,580,255
Blower Motor Gross Ex Post Saving (kWh)	13,329	1,115,683	1,676,749
Blower Motor Net Ex Post Savings (kWh)	8,443	706,745	1,062,160
Quantity of RCA (tons)		24,387	27,071
RCA Total Ex Ante Savings (kWh)		1,364,995	807,230
RCA Gross Ex Post Savings (kWh)		897,461	996,235
RCA Net Ex Post Savings (kWh)		373,783	414,921
Total Ex Ante Savings (kWh)	818,564	4,853,258	5,627,449
Total Gross Ex Post Savings	189,243	2,024,328	2,739,757
Total Net Ex Post Savings	6,350	1,080,395	1,476,287

When analyzing the ex post savings values and the gross and net realization rates for PG&E residential QM measure groups it is important to recall that PG&E's ex ante claims across the three measure groups were not consistent with the ex ante values listed in the Workpaper Disposition for Residential HVAC Quality Maintenance (May 2013), referred to as the workpaper disposition. The workpaper disposition includes adjustments to reduce ex ante savings values that were not entirely incorporated into PG&E's ex ante claims. If PG&E had used the values in the workpaper disposition, the average ex ante claims per ton for the fan repair measure group would have been 1.27 kWh per ton given the 2015 installations in climate zone 11, 12, and 13. This value is substantially less than the 176.95 kWh per ton in the PG&E ex ante claims and less than the gross ex post estimate of 41.35 kWh per ton. For Blower Motors, the workpaper disposition implies an average ex ante claim of 110.79 per ton in 2015 compared to the 137.03 PG&E claimed and the ex post gross savings estimate of 47.95 per ton. For RCA, the workpaper disposition leads to an average ex ante claim of 22.79 per ton in 2015 given the installations in climate zones 11, 12, and 13. PG&E's tracking data distribution leads to an average of 33.2 kWh per ton while the ex post gross estimate of savings was 36.8 kWh per ton.

The substantial decline in estimated savings going from gross to net implies that both the average participants and non-participants are reducing their electricity consumption in the post period.[86] The reduction in savings estimates from the gross to the net model may imply that both participants and non-participants are reducing their HVAC energy usage associated with improvement in HVAC maintenance or/and that both participants and non-participants are reducing their general electricity usage in the post-installation period. The pre- and post-installation average hourly consumption of participants and non-participants are illustrated in Figure 24 and Figure 25, respectively. Both figures illustrate that the average electricity consumption fell slightly during the post-installation period. The fall in consumption appears slightly larger for participants than non-participants supporting the positive estimates of net ex post savings.

[86] While the average participant and non-participant reduced their consumption in the post period, the participants and non-participants include households that reduced their consumption and households that increased their consumption.

Figure 24. PG&E Residential QM participants average hourly consumption pre- and post-installation

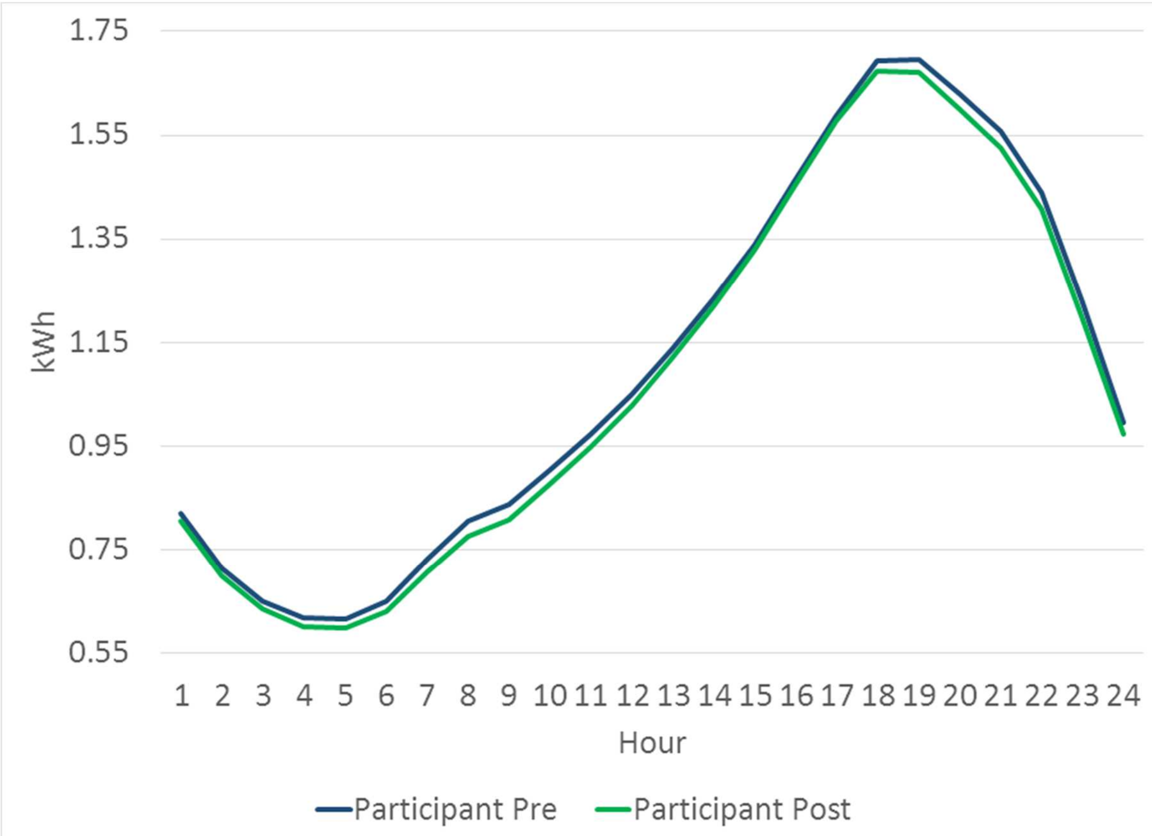
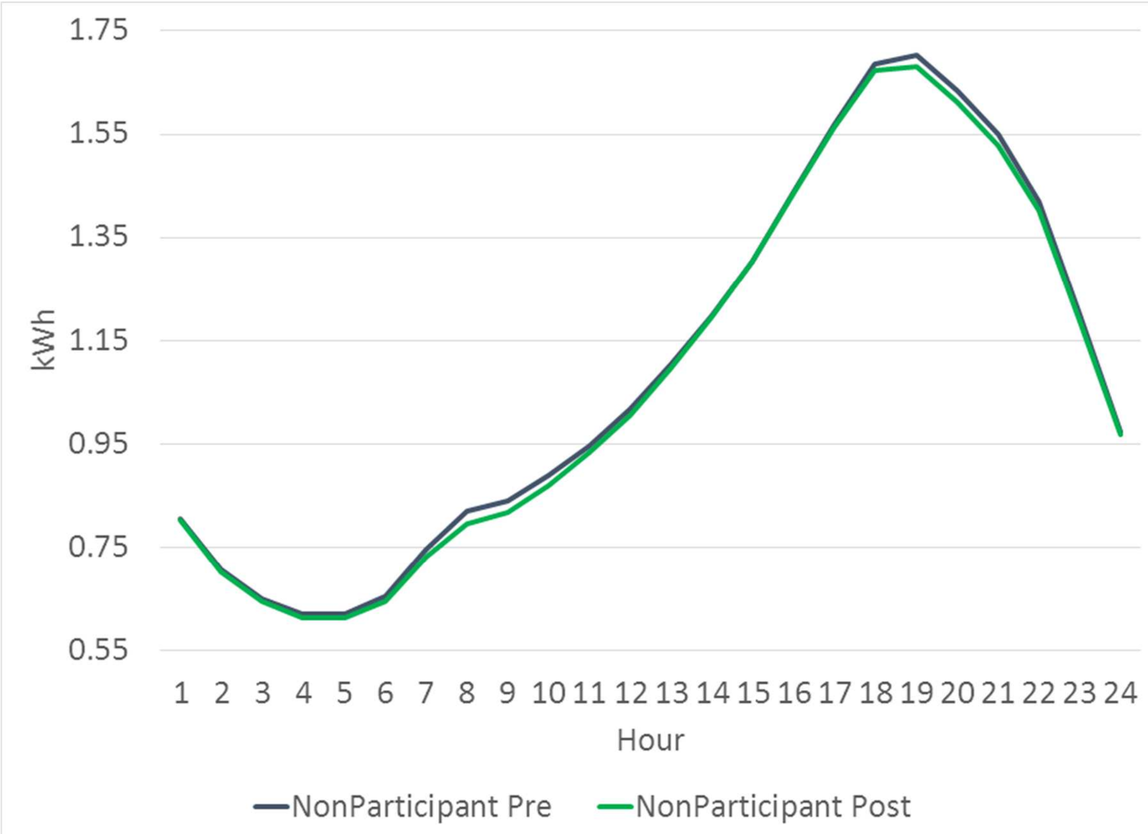


Figure 25. PG&E match non-participants average hourly consumption per and post installation



4.4.3.2 **SDG&E analysis and results**

Table 76 lists the estimated gross and net savings estimates for the residential QM program in SDG&E's service territory. The savings estimates are presented for both hourly and daily model specifications. The model specifications are similar to PG&E's, except in the SDG&E model, the independent variable representing the program is a binary variable. The coefficient estimates for the program variables for SDG&E models are presented in APPENDIX I.

Using actual weather data, the gross ex post estimate of first year savings for the SDG&E residential QM program is 197 kWh per household for the hourly model and 148 kWh for the daily model.[87] The net results, however, estimate a slight, statistically insignificant increase in usage for program participants. Given that the net results are not statistically significant, Table 76 does not include a numerical estimate of net savings. The combined gross and net results imply that the participants and matched non-participants are consuming less energy in the post period, but the decline in usage is not attributable to the program. Given the statistically insignificant estimate of net residential QM savings within SDG&E's service territory, participants and their matched non-participants reduced their consumption by a statistically similar amount in the post installation period.

[87] The SDG&E model results are presented on a per household basis because SDG&E claimed savings in the tracking data on a per household basis.

Table 76. SDG&E residential program gross and net results (per household) – actual weather

Gross kWh Savings/Year Hourly Model	Net kWh Savings/Year Hourly Model	Gross kWh Savings/Year Daily Model	Net kWh Savings/Year Daily Model
197	-24	153	-25

Table 77 presents the ex post gross and net kWh savings per year for SDG&E's program using normal weather. The normal weather savings are slighting lower than the savings estimated using actual weather.

Table 77. SDG&E residential program gross and net results – normal weather

Gross kWh Savings/year Hourly Model	Net kWh Savings/year Hourly Model
189	-25

SDG&E ex post savings estimates

The gross and net weather normalized savings from the hourly model were applied to the 2013, 2014, and 2015 claimed savings to develop estimates of realization rates. Program savings from SDG&E were developed at the program level for 2013, 2014, and 2015 and compared to the ex ante claims for the same time period (Table 78). In 2015, SDG&E substantially reduced their per unit claims for HVAC fan controls, contributing to the substantial drop in SDG&E's ex ante claims per household. The SDG&E gross realization rate was 27% of the claimed savings in 2013, 28% in 2014 and 48% in 2015. The net realization rate was zero for all years given that the residential QM parameter estimate were not statistically different from zero.

Table 78. SDG&E residential program gross and net realization rates

	Gross Normalized kWh Savings per Participant	Tracking Data 2013	Tracking Data 2014	Tracking Data 2013
Residential QM Savings (kWh)	178	654	627	368
Gross Realization Rate		27%	28%	48%
Net Realization Rate		Not significantly different from zero	Not significantly different from zero	Not significantly different from zero

Table 79 lists SDG&E's ex ante, gross ex post, and net ex post savings from its residential QM program. Note that the net results are not statistically different from zero. This analysis implies that SDG&E's program is not producing net energy savings.

Table 79. SDG&E residential program gross and net savings

	2013 kWh	2014 kWh	2015 kWh
Ex Ante Savings (kWh)	309,234	123,469	310,167
Gross Ex Post Savings (kWh)	84,134	35,041	149,769
Net Ex Post (kWh)	Not significantly different from zero	Not significantly different from zero	Not significantly different from zero

5 CONCLUSIONS AND RECOMMENDATIONS

The implementation and evaluation of QM and related HVAC tune-up measures have evolved over the last decade. The changes to programs, measures, and the evaluation of impacts present challenges to assessing and tracking performance. Overall, the achieved savings were lower than expected relative to the workpapers and ex ante dispositions, but in the context of past measure performance, there are some clear improvements, particularly for economizer measures.

We observed a large variation in HVAC system pre-treatment baseline performance when we visited sites that had not yet participated in the program. Some rooftops displayed new, clean equipment and others had dirty, rusted, poorly functioning HVAC equipment. We also observed equipment economizers that were not functioning after program repair and discrepancies in assumed thermostat settings and program adjustments.

Given the overall HVAC unit performance gains found in this evaluation, we conclude that QM provides marginal energy impacts on HVAC energy use. Therefore, addressing other large system issues, such as distribution losses, and improving the operation of advanced digital economizer controls may provide greater energy savings opportunities than the other individual measures addressed in this evaluation. We recommend continuation of pilots and development of holistic measures including improvement of previously installed non-functioning advanced digital economizer controls and increased incentives to replace the dirty, rusty, poorly functioning units as opposed to maintaining them.

We also note that improvement is necessary in the data that support tracking system claims. Implementers collect data on the installed measures, but these data are not part of the standardized savings claims database submitted to the CPUC by the IOUs. The link between the tracking data claims and the implementer data is not well established. We found it difficult to use the large volume of data collected by the programs without this link, but we believe there is great value in this site- and unit-specific data for truing up initial workpaper assumptions and improving the accuracy of program claims. Lack of integrated implementer data may have contributed to low gross realization rates, as the IOUs claimed savings that were either ineligible or not actually fully implemented. We also view the implementer data as providing the supporting documentation behind the tracking system savings claims, and the inability to link the implementer data with the tracking data raises verification concerns about the validity of the tracking savings estimates.

Despite some discouraging results in the report regarding both gross and net savings, the HVAC industry seems to have momentum toward improvement with the Western HVAC Performance Alliance efforts work[88] and energy code[89] requiring onboard fault detection for new units.

5.1 Commercial measure-group conclusions and recommendations

The following sections describe the measure group results.

5.1.1 Economizer measure group

We found a number of economizers categorized as "repaired" via the QM programs that were not operating. The reasons for failure varied, but we found overall that the newer advanced digital economizer controllers (referred to as ADEC) failed due to incorrectly wired sensors and incorrectly programmed controllers, and

88 http://www.performancealliance.org/WHPAWorkProducts/tabid/440/Default.aspx

89 California Title 24, Part 6 Building Energy Standards (http://www.energy.ca.gov/title24/2016standards/index.html)

were easily repairable while the older analog type had un-identifiable or un-repairable failures. We also found mixed air sensors installed downstream of the evaporator cooling coil set to close and lock out the economizer when the temperature drops below 55°F. This turned the economizer control system into a non-integrated system where the economizer closes when the mechanical cooling initiates. We do not know if this setup is intentional on the part of the technicians to reduce potential revisits resulting from customer complaints, or if it is in error.

The industry is moving toward ADEC, and we recommend that the programs increase training on how to install and program the units, as they are more complicated and we found setup errors such as incorrectly wired sensors and incorrectly programmed controllers. The California Title 24 Standards require that economizers be integrated and we recommend that the programs include this aspect of economizer control set-up in their training courses.

5.1.2 Thermostat measure group results

We found a number of thermostats replaced or reprogrammed that did not meet the program requirements for heating and cooling setback temperatures during unoccupied building periods. It could be that the thermostats are being occupant-adjusted after the contractor adjusted the thermostat to program required setbacks leading to lower than expected persistence rate for this measure. One of the programs has installed thermostats that can be remotely checked and adjusted not only as an energy savings measure, but also as a demand control method.

For programs that do not check thermostats quarterly, we recommend that programs move toward remotely adjustable thermostats so that they can be periodically checked to maintain energy savings throughout the claimed measure life.

5.1.3 Coil-cleaning measure group

We observed a wide variety of cleaning techniques from washing only the air-entering surface with water to washing both surfaces of the coil with cleaning agents. We suspect that some cleaning techniques may force small and perhaps greasy particles further into the coil, potentially degrading rather than improving the heat exchange of the coil. Further variation in observed HVAC efficiency and capacity is expected due to variation in the extent of pre-existing coil fouling, refrigerant under-charge, non-condensibles in the refrigerant, and ducting configuration affecting airflow across the coil.

We recommend continuing this measure as a low-cost, low-savings item. We found a high degree of variation in energy savings from units tested, even some units indicating worse performance after evaporator coil cleaning and suspect that the savings vary depending not only on the potential for savings given the degree and type of fouling, but also on the cleaning technique. Although our study did not find large energy savings from coil cleaning, it still has a very important role from a hygiene perspective, and we do not recommend that the practice be abandoned.

5.1.4 Supply-fan measure group

The only programs that claimed this measure were PG&E's commercial QM program and PG&E's AirCare Plus program. PG&E's installation rate of the supply fan control adjustment was 47%. This is higher than we anticipated based on the implementer-supplied data where only 20% of the claims were eligible for the program; most the fans were described with the controls set at auto or intermittent baseline-states, rather than always on during unoccupied periods. The measure was implicitly claimed by SCE and SoCalGas since it was one of the bundled measures within the Quality Maintenance measures claimed. Our evaluation survey results found a 100% realization rate for the supply fan measure in these programs.

We recommend better targeting of the measure to units that do not already have the supply fan in automatic mode or switched off during unoccupied building periods. A baseline study could help determine the potential for savings from this measure.

5.1.5 RCA measure group results

Direct expansion HVAC systems with thermostatic expansion valve (TXV) metering devices are widely in use and have much less sensitivity[90] to non-optimal charge than the older devices.

The statewide gross realization rates were 64% for electric energy (kWh) savings and 52% for electric demand reduction (kW). Although most of the programs remained at realization rates close to our previous HVAC3 evaluation energy savings realization rate of 34% (averaged across all programs), the SDG&E Deemed program realization rate was higher at 81% for this measure.

We recommend continuing this measure only in cases where the refrigerant circuit is low or devoid of refrigerant because savings are small for the observed adjustments. Although it is important to detect circuits with extremely low refrigerant charge, we caution against over-use of refrigerant pressure measurement devices since the process of attaching and detaching them can release refrigerant, harming the atmosphere and slightly reducing refrigerant in the circuit each time it is checked.

5.1.6 QM measure group

This measure group represents unitary HVAC maintenance initiatives under the SCE's Commercial Quality Maintenance program.

Consistent with the QM program philosophy, SCE program administrators submitted a single savings claim representing a package of HVAC maintenance activities or component measures. Their savings claims reflect the number of units enrolled in the program by four unit types: package HVAC units with natural gas heat (with and without economizers) and package heat pumps (with and without economizers). The ex ante claim assumed a component-measure mix across the program.

The overall realization rate for the QM measure group was 90% primarily due to high realization rates for coil cleaning, economizer retrofits, and supply fan control measures, as well as a higher than expected frequency of repair for coil cleaning, economizer repair, and thermostat reprogramming.

5.2 Residential program conclusions and recommendations

The goal of this work was to develop gross and net electricity ex post savings estimates for the PG&E and SDG&E residential QM programs. The analysis was implemented separately for PG&E and SDG&E. The PG&E analysis was implemented at the measure-group level due to the larger size of the PG&E program and the diversity of installations, while the SDG&E analysis was implemented at the program level.

The study began with a review of the ex ante claims for each utility. PG&E's ex ante claims were found to exceed the workpaper disposition values for the three program measures implemented in PG&E's service territory. Over the 2013-15 period, PG&E's ex ante claims declined on a per ton basis, but they continued to exceed the workpaper values in 2015. SDG&E's ex ante claims appear to follow the workpaper dispositions

---

90 HVAC5 lab data showed 7.5-ton TXV systems to have much less sensitivity to over-charged conditions than non-TXV systems. The finding was less pronounced in the 3-ton systems tested, but 7.5-ton better represents the average system participating in QM and tune-up programs.

for all measures other than HVAC fan controls where their ex ante claims exceed workpaper values. SDG&E, however, does not include the installed tonnage in their tracking data, making it difficult to verify that SDG&E's ex ante claims are consistent with the workpaper values.

Hourly billing analysis models were implemented to estimate gross and net electricity savings. The model estimates for the PG&E program imply a 2015 gross realization rate of 49% and a net realization rate of 54%. Within the PG&E program, the 2015 RCA measure gross realization rate was 123% and the net realization rate was 51%. RCA had the highest gross and net realization rates across the three PG&E residential QM measure groups. PG&E's gross and net realization rates were influenced by their use of ex ante values that substantially exceeded specified savings values in the workpaper disposition for Residential HVAC Quality Maintenance.

The billing analysis model estimates for SDG&E residential QM program imply a 2015 gross realization rate of 48% and a net realization rate that is not statistically different from zero. Within SDG&E's service territory the program does not appear to be saving energy for participants more than the reduction in energy usage found for non-participants.

The savings derived from the residential QM programs has been uncertain. The 2013 workpaper disposition for these programs revised the QM measure group ex ante savings down substantially due to concerns about the use of incorrect maintenance techniques that could lead to either an improvement in efficiency or an increase in energy usage. The findings from the billing analysis implemented by 2013 and 2014 program participants in PG&E's and SDG&E's service territories reinforce the CPUC's concerns. SDG&E's residential QM program had no net energy savings and PG&E's had a net realization rate of 26%. A graphical review of the pre- and post-installation average hourly consumption of program participants and matched non-participants illustrates that both participants and non-participants reduced their energy usage in the post installation period even though the post period included slightly warmer weather.

The energy savings impact analysis of residential QM programs found low net realization rates for PG&E's program and no discernable net savings for SDG&E's program. Given these findings, the evaluation team recommends the residential QM programs either review implementation issues that have the potential to adversely impact savings or consider major program design changes and new measures. Because a billing analysis was utilized to estimate residential savings, there are no field-based findings to provide more detailed, measure-level recommendations. We recommend that the IOU's consider more exploratory research to understand how best to improve program savings. Subsequent evaluation work may also want to devote resources to a more field-based engineering assessment that would provide more insight into factors driving measure performance that is possible with a billing analysis.

5.3 Future evaluation activities

This evaluation developed savings estimates by using repeatable field measurements that correlate to laboratory performance data for coil cleaning and RCA measures. It also provided an evaluation methodology that accounted for variability across building types and climate zones through modeling, thus measuring parameters on-site with less variability than HVAC end-use, which made data collection efforts more cost-effective. Going forward, this approach can be scaled to add sample points and implementer data can be used to support more accurate savings estimates. There are remaining and new evaluation challenges to overcome. Additional improvements for future evaluations objectives may include:

- Collecting additional data on why economizers are not functioning. Specifically, if we collect more information to characterize failure modes it should lead to more focused repairs in the future. Collect economizer airflow data to further quantify outside airflow rates, particularly at low flow conditions. And continue with more investigation of baseline economizer outside air flows.
- Utilizing smart thermostats to improve persistence. We started to see "smart" thermostats entering the program to serve as a demand control vehicle. These thermostats could improve the persistence of the thermostat measure, but will require additional study.
- Continuing to develop in-field performance measurement. The 2015 evaluation added promising new field instrumentation to determine refrigerant cycle performance.[91] [92] The equipment was used for the evaluation of the coil cleaning measure in this evaluation but it could be applied to all measures either individually, or the comprehensive QM measure. Humidity sensors could be added to improve estimation of the coil bypass factor. IOU programs and pilots are concurrently developing system performance measurement approaches.[93]
- Improving our understanding of interactive effects of different measures on unit/system performance. The comprehensive measurement approaches provide the opportunity for better quantification of the interactive effects and measuring the difference between the savings from the sum of individual measures versus the comprehensive QM suite of measures.
- Perform a baseline study to characterize market driven HVAC system maintenance practices.

There will remain significant uncertainties, but there appears to be general acceptance that relative changes can be detected. New measure strategies can be tested and piloted in the field if there are consistent measurement approaches to assess the performance changes.

5.4 Commercial program recommendations

Based on the findings in this evaluation (including the net-to-gross analyses that is reported in a separate document), the net energy savings of the commercial QM and related tune up programs is less than one third of the anticipated net program savings. The commercial program net-to-gross analysis also found a large reported variation across contractors in how they've changed practices because of the programs. This variation was substantiated by the gross impact field observations when our team accompanied technicians and when we visited sites after QM treatment through the programs. As mentioned, we think program training would raise the level of HVAC technician understanding of HVAC system operation and maintenance effects. The conclusion that we arrive at is that some QM contractors are taking advantage of the program training resources and improving the services that they offer while others are not. Still other contractors may have had high-quality maintenance practices before joining the programs, hence little influence from the program.

Despite the overall low program savings, we believe that the programs are providing valuable services to at least a portion of the participating contractors, and helping to move the HVAC industry in the right direction. We recommend exploring additional measures that could better address system performance issues followed by ongoing maintenance. A potential change in strategy may be to identify the high-quality practices and contractors and focus on getting those contractors to sites most in need of performance improvements. The

---

[91] http://www.climacheck.com/dl.php?did=76

[92] http://media.home.climacheck.com/2015/01/8_18410_BerglofIEAJune2005.pdf

[93] https://www.nationalcomfortinstitute.com/pro/index.cfm?pid=4030

program would then not seek to improve the quality of all contractors, but focus on getting the top-quality contractors to the poorest performing sites.

APPENDIX A. 2015 PLANNING MEMO

2015 Quality maintenance impact evaluation research plan update

Introduction

This memo outlines the research plan updates for the 2015 impact evaluation for the Quality Maintenance and related HVAC tune-up programs. This evaluation follows on the 2013-14 evaluation of the same programs, using a similar evaluation methodology. The 2013-14 evaluation results suffered from low precision due to higher than expected coefficient of variation (CV) across several measures. In the areas with low precision we propose to collect additional sample for the 2015 program year to combine with the previously collected data to increase the precision of the findings.[94] Major program changes have now occurred in 2016, but the 2015 program is essentially an extension of 2013-14. The 2015 results will be based on the combined dataset with higher precision than if the results were based on 2015 data alone. Results will only be projected to 2015 participants since savings for 2014-14 are now final. The sample is based on the number of HVAC units surveyed, not the number of sites visited. An emphasis will still be placed on variety of sites and participating contractors so many units at a single site are not permissible to reach the sample targets. We plan to survey the following quantity of HVAC units per type of site:

- Two units, on average, at each coil cleaning ride along visit[95]
- Four units at each economizer ex-post site visit
- And an average of two units per telephone survey.

Table 80 shows the sample sizes by measure group in the 2013-14 evaluation cycle and the proposed additional 2015 sample. It also provides the resulting relative precision for each measure group after including the proposed 2015 sample.

Table 80. Sample size and precision by evaluation cycle and measure group

Field/ Measure	Coil Cleaning (Ride-along)	Economizer (Ex-post)	T-stat and Supply Fan Ctrl. (Survey)	Refrigerant Charge Adjustment
2013-14 Sample Size, units	10	88	59	48
Coefficient of Variation	0.28*	0.72	1.55	1.26
Relative Precision of 2013-14 Sample	15%	13%	33%	30%
2013-14 Measure Savings, kWh	14,499,585	8,282,806	10,654,248	6,947,131
Proposed 2015 Sample Size, units	60	40	220	0
Total of 2013-14 & 2015 Samples, units	70	128	279	48
Combined Relative Precision	10%	10%	15%	30%
Relative Precision Δ	5%	2%	18%	0%
2015 Measure Savings, kWh	2,039,038	5,494,920	7,301,693	2,133,834

*We assumed a CV of 0.5 in the combined sample since the 2013-14 sample came from just two sites and we think that likely reduced the CV.

[94] Excepted is the refrigerant charge measure which has low precision, but we don't propose further study because this measure has been extensively studied elsewhere as we describe in later sections of this memo.

[95] In the execution of this approach we will evaluate the necessity of the initial weight-in/ weigh-out process in observing efficiency changes due to coil cleaning, and if possible will drop the weigh-in/out method in favor of verifying charge with superheat or subcool tests. This could provide enough time on site to perform testing on more than two units, where appropriate.

Methodology by measure

The sections below briefly summarize the 2013-14 methodology and note any changes that will be made in the 2015 evaluation. Refer to the research plan[96] and the final report[97] for more details about the data collection and analysis methodology. We developed data collection forms and protocols for the 2013-14 effort, and will modify the forms slightly to meet the needs of this effort.

Condenser and evaporator coil cleaning measures

The 2013-14 approach for condenser coil cleaning measure impact was to measure discharge pressure before and after the coil was cleaned, and then to correlate the change in discharge pressure to a change in EER using lab data developed in support of this evaluation. This method required the refrigerant charge to be corrected before making measurements, and required an outdoor air temperature correction. The 2015 approach will use the same methodology.

The 2013-14 approach for evaporator coil cleaning measure impact was to measure the change in airflow due to coil cleaning and correlate that to a change in EER using lab data. The shortcomings of this approach are first, that the measured changes in airflow are very small and are at the limit of our measurement capability; and second, that the change in airflow only accounts for a portion of the evaporator coil cleaning effect. Reduction in airflow reduces the heat transfer across the coil, and the heat transfer is further reduced by the change in heat transfer coefficient caused by the residue on the coil. To better capture both effects we propose monitoring refrigerant circuit pressure and temperature data points sufficient for calculating an enthalpy based cooling coefficient of performance (COP) throughout the ride along visit, thus capturing the evaporator cleaning effect on COP.[98] We will additionally monitor the static pressure changes as a proxy for changes in system airflow so that we can compare the results from the two methods.

The refrigerant pressure and temperature measurements required for the evaporator coil cleaning impact assessment will be monitored continuously during the ride along visit. The intent is to install the monitoring equipment prior to any maintenance service on the unit, thus providing the evaluators with the opportunity to apply this COP analysis approach to the condenser cleaning measure as well, and in parallel with the discharge pressure and lab data EER correlation approach for condenser coil cleaning described earlier. We plan to compare the impact calculated through measured change in COP to the impact calculated using the discharge pressure correlation to lab-collected EERs to see if the COP method would be a viable one going forward. It may eliminate the need to correct the charge before making measurements, and could reduce the cost of future impact evaluation work.

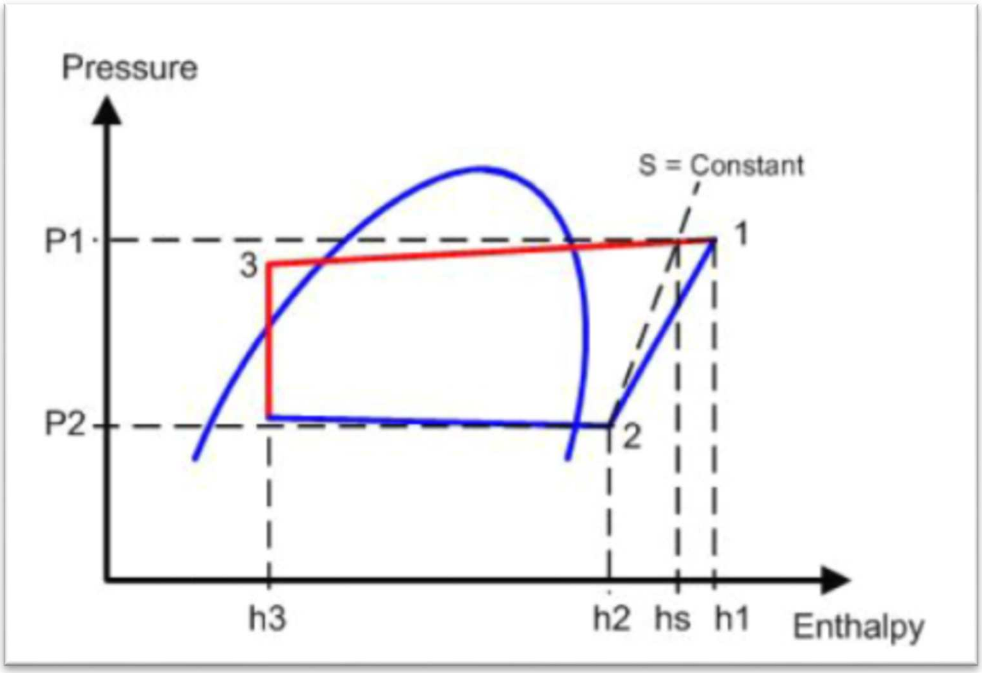
The 2015 COP approach will entail measurements of refrigerant suction and discharge pressures, refrigerant suction, discharge, and liquid (leaving condenser) temperatures, and outdoor air temperature and relative humidity. From these measurements, we can determine the enthalpy of the refrigerant entering the compressor (h_2) leaving the compressor (h_1) and leaving the condenser (h_3). These data points are visually presented below in Figure 26.

96 http://www.energydataweb.com/cpucFiles/pdaDocs/1285/HVAC201314QMResearchPlan_2.pdf

97 http://calmac.org/publications/HVAC3ImpactReport%5F0401ES.pdf

98 While we don't anticipate encountering ambient temperature limitations stemming from the monitoring equipment, the expected timing of the fieldwork presents some risk of work stoppage due to inclement weather impacting equipment and staff safety as well as issues around occupant comfort while running the HVAC units in cooling mode during cooler ambient temperatures. We will make efforts to limit occupant discomfort through unit sampling, as well as pre-heating the conditioned space prior to engaging cooling or even simultaneously heating and cooling where possible and necessary.

Figure 26. Refrigerant system pressure-enthalpy diagram[99]



With this information, it is possible to calculate the COP of the system using the following equation

$$COP_{cooling} = \frac{(h_2 - h_3)}{(h_1 - h_2)}(1 - f)$$

where:

h1	compressor discharge enthalpy
h2	compressor suction enthalpy
h3	enthalpy after condenser
f	compressor heat losses (as a percent of electrical input)

The compressor heat loss factor is a constant; however, there is debate about the magnitude of the loss. A literature review found a theoretical value of 7%[100], and HVAC5 lab data (CPUC publication pending) bears out losses of 6.0 to 18% for R-22 refrigerant circuits smaller than five tons, absent any refrigerant faults (flow, non-condensables[101] or charge), and outdoor dry bulb temperatures equal to or less than 82 °F. Figure 27 below shows the calculated compressor loss values relative to outdoor dry-bulb temperature for systems without refrigerant faults but with various evaporator airflow rates and economizer positioning. The subset of values for tests performed at or below 82° F, the data points within the red box on the chart, range from 6.0 to 18%, and represent the conditions under which we would be testing these systems. Based on field testing of one initial HVAC unit, varying the compressor loss factor appears to have a linearly proportional impact on the calculation of cooling capacity of the HVAC system. Because the evaluation utilized a constant compressor loss factor over the series of tests for each unit and only looked at relative

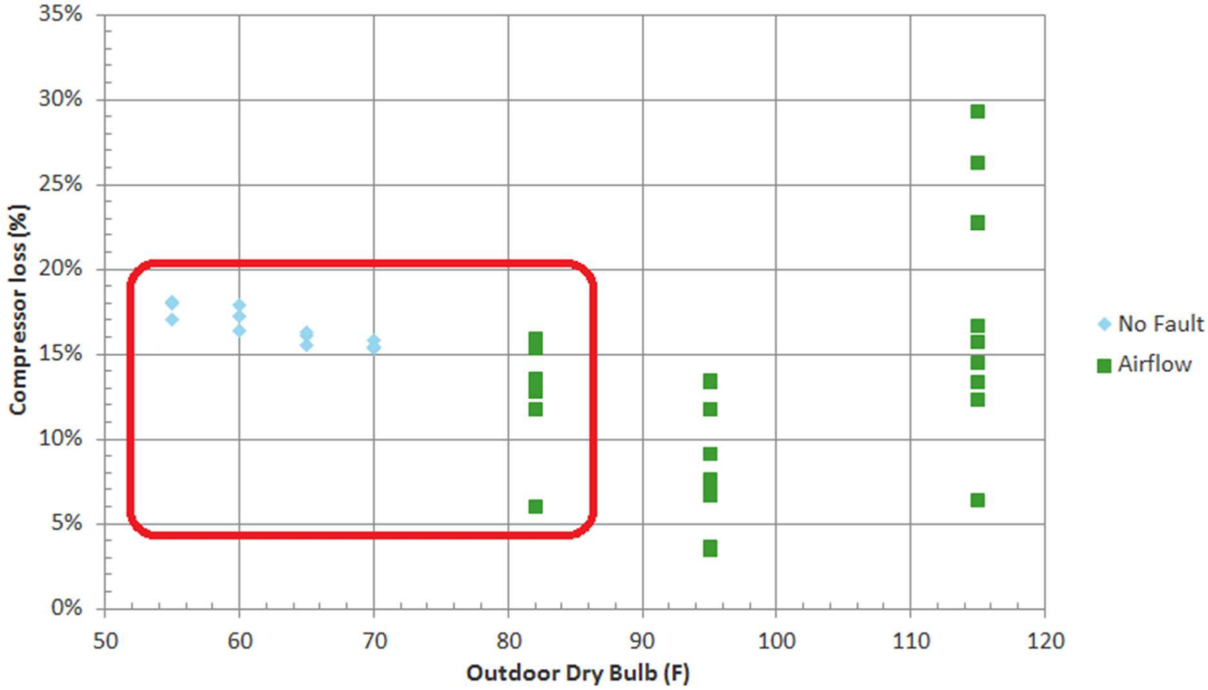
99 http://media.home.climacheck.com/2015/01/8_18410_BerglofIEAJune2005.pdf

100 http://media.home.climacheck.com/2015/01/8_18410_BerglofIEAJune2005.pdf

101 Air, nitrogen, hydrogen, and other foreign gasses present in a refrigerant system are referred to as non-condensables since they will not condense into a liquid at pressures encountered in a refrigeration system.

changes to efficiency and capacities, the value chosen for the compressor loss factor has no impact on the calculated measure results. This evaluation will use a compressor loss factor of 12%,

Figure 27. HVAC 5 lab data, compressor loss (%) vs. outdoor dry-bulb temperature



There is no lab data for R-410a systems. Due to this we will start data collection on smaller R-22 units (5-10 tons), and will work towards larger units, and possibly some R-410a systems.

Refrigerant charge adjustment measure

We decided not to add additional sample to the refrigerant charge adjustment (RCA) measure group in the 2015 evaluation cycle. This measure has been studied[102] more often than the other measures investigated here so we decided to focus limited evaluation funds elsewhere. The 2013-14 approach was to make an ex-post measurement of the mass of refrigerant in the system by pumping it out and weighing it on a scale. From data provided by the implementer, we were able to back-calculate the pre-retrofit mass of refrigerant and determine the percent change due to the program intervention. We correlated the refrigerant change to an EER change using lab data. In the 2015 evaluation, we will not collect ex-post refrigerant charge data, but will collect baseline refrigerant charge data as a by-product of the condenser coil cleaning procedure at ride along visits.

Economizer repair/replacement measure

The 2013-14 approach to determine energy impact from economizer repairs and replacement was based on field observations of economizer functionality informing an installation rate. We attempted to collect data to verify the model inputs used in the ex-ante calculation, principally minimum and maximum outside air fractions (OAF), but had limited success collecting economizer air flow rates, low limit lockout or changeover set points. In the 2015 approach, we will collect economizer functionality, and economizer characteristics

[102] http://calmac.org/publications/FINAL%5FHVAC%5FImpact%5FEvaluation%5FWO32%5FReport%5F28Jan2015%5FVolume1%5FReportES.pdf

such as changeover set point, low limit lockout and sensor type (enthalpy or temperature, and single or differential) information at 10 sites, and believe we will have higher success because of our increased experience in this and other projects.

Measurement of minimum outside air rate deserves additional discussion because it is more complicated. The 2013-14 approach to quantifying these outside air rates involved on-site, short term logging of temperature and relative humidity of the outside, return, and mixed air streams at minimum and maximum economizer damper positons. This requires a naturally present enthalpy differential between the outside and return air large enough to reliably calculate OAF. It also assumes equal airflow through each of the section of the logger matrix. Unfortunately, this approach did not produce results with a degree of certainty sufficient to supplant the ex-ante assumptions on minimum and maximum OAF used in the workpaper.

Both PG&E & SCE's QM programs adjust the minimum airflow setting as part of the economizer repair measure so we will again attempt to measure the minimum and maximum outside air settings. After much research on airflow measurement techniques for this situation, we have decided to use two methods in parallel: TrueFlow plates installed at the bottom of the eyebrow so that the flow relatively perpendicular to the plates and a hot wire anemometer traverse of the outside air intake. The TrueFlow method was used by Robert Davis (Ecotope) in his 2002 study[103], while the anemometer traverse method is endorsed and practiced by the CASE initiative study[104]. The results of the OA measurements will not be used to adjust 2015 savings claims, but this information, future data collected in the same manner, and data from the Quality Renovation Pilot measurements may form more field evidence on which to base future ex ante calculation.

Thermostat and supply fan control measures

The 2013-14 approach involved recording thermostat settings for temperature setback and supply fan controls while onsite to assess other QM measures. These data points were then used to determine an installation rate based on whether the installed settings met the measure requirements. The CV of the collected data was higher than anticipated and the sample was slightly smaller leading to lower precision than we found acceptable for our estimate. For this reason, we did not use the data to calculate a revised unit energy savings (UES) for the 2013-14 report. In 2015, we plan to increase the sample size significantly by performing a telephone survey to collect thermostat and supply fan control settings. We think it only realistic to ask customers to read us settings for, at most, three thermostats. The questions in our survey were crafted based on DNV GL's preliminary results from a thermostat survey as part of a Massachusetts CIEC study to focus on things customers can easily answer like baseline thermostat type and degree of occupant intervention and to avoid asking detailed questions about exact baseline set points and schedules. We plan to ask the customer to cycle through the current thermostat settings, reading us current set points and schedules[105]. Our pilot survey showed a 28% response rate which seemed to be slightly biased towards customers with a fewer number of thermostats at their site. Because of this bias we plan to supplement the phone survey with ex-post site collected data from sites with more than 10 thermostats that we will piggy back with the economizer data collection.

---

[103] 2002. Davis, Robert, David Baylon, Reid Hart. Identifying Energy Savings Potential on Rooftop Commercial Units, ECEEE Conference Proceedings.

[104] Codes and Standards Enhancement Initiative Outside Air recommendation from the California Utilities Statewide Codes and Standards Team, October 2011.

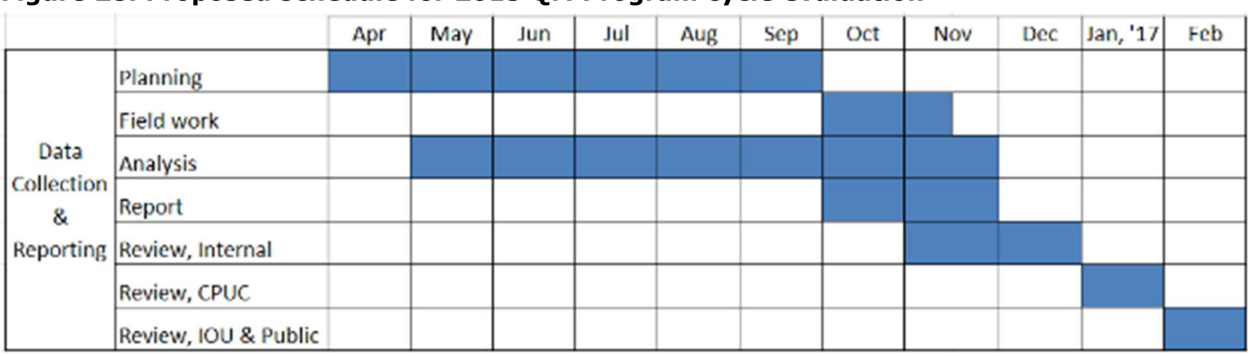
[105] DNV GL will attempt to perform a very limited sampling of Bay Area sites for which we will verify phone survey responses against thermostat setting found on-site.

The 2013-14 evaluation DNV GL did not collect data from a large enough sample to confidently adjust inputs to the eQuest model which was used to calculate ex-ante savings estimates. DNV GL has planned a significantly larger sample for the 2015 evaluation so that we can use the model to produce updated (i.e. ex post) programmable thermostat and supply fan measure unit energy savings (UES) across climate zones and building types. For both measures the installed measure case only involves changing the unoccupied setting. DNV GL will use the average unoccupied set points across all building types, building sizes, climate zones, and IOUs to update the eQuest model prototypes. The number of occupied building hours collected in the survey will be compared to the number in the building prototypes, but due to anticipated variation we don’t think the sample will provide sufficient precision to justify changing the number of hours in the model. The occupied supply fan control setting is not important to energy savings, but is important to whether the building ventilation complies with Title-24 requirements, and we may investigate this using the collected data.

Schedule

We are currently in planning phase, but getting ready to begin field work in early October. Ongoing analysis has been done using tracking and implementer supplied data. We expect to begin analysis on field-collected data as soon as the first batch of data becomes available, continuing through to the end of November. The report writing will begin as soon as the planning phase is complete, and will continue until all the review cycles are complete as shown in Figure 28.

Figure 28. Proposed schedule for 2015 QM Program cycle evaluation



APPENDIX B. SAMPLE DESIGN MEMO

This appendix describes the sample design used to determine the number of visits to 2015 participant sites necessary to verify gross savings from thermostat, supply fan controls, and economizer measures in the Quality Maintenance programs as shown in Table 81.

Participant data and aggregation

The tracking data file had 37,562 records from the programs of interest: PGE's Air Care Plus and Commercial HVAC program, SCE's Non-residential HVAC program, and SDGE's Commercial Direct Install and Deemed Incentive HVAC programs (Table 81). This population was divided into two sample frames: one for ex post site visits focusing on economizer, thermostat and supply fan control measures and a phone survey sample to focus only on thermostat and supply fan control measures.

Table 81. Number of tracking data records by program

Program Name	Number of Records	Proportion of Records
PG&E Commercial HVAC	3,702	10%
PG&E AirCare Plus	7,869	21%
SCE Nonresidential HVAC Program	4,017	11%
SDG&E Deemed Incentives	12,067	32%
SDG&E Direct Install	9,907	26%
Total	**37,562**	**100%**

The ex post site visit sample frame included 7,263 records comprised of economizer-related measures and all other measures of interest including thermostats and supply fan control measures. The phone survey sample frame included 7,244 records comprised of thermostats and supply fan controls. Once the record-level data were summarized at the site level, using site identification numbers, the resulting sample frames consisted of 1,038 phone survey sample sites and 455 ex post sample sites.

Our goal was to collect data at 25 ex post sample sites and 100 phone survey sample sites. The ex post site visit sample frame included the economizer savings at each site and the phone survey sample frame included the thermostat and supply fan control savings at each site. Furthermore, in hopes of gathering on-site thermostat and supply fan control data for larger sites, we prioritized those ex post sites with combined thermostat and supply fan control savings greater than the median savings of the sites in the sample frame. For the SCE measure group, where measure savings were bundled in the tracking data, we applied a proportion factor from the May 2013 Disposition ex ante savings calculation workbook to disaggregate thermostat/supply fan control and economizer savings. Table 82 provides the initial sample targets for economizer and thermostat /supply fan control measures within each program and overall.

Table 82. Initial ex post site visit sample plan

Program	Thermostat / Supply Fan Control Savings Above Median	Number of Sites in Sample Frame	Number of Sites in Sample
PGE_Commercial_HVAC	No	82	18
SCE_NonRes_HVAC	No	157	0
SCE_NonRes_HVAC	Yes	72	5
SDGE_SW_Comm_DI	No	144	2
Total		**455**	**25**

Table 83 shows the initial sample plan for the survey sample.

Table 83. Initial phone survey sample plan

Program	Number of Sites in Sample Frame	Number of Sites in Sample
PGE_Commercial_HVAC	149	47
PGE_AirCare_Plus	190	24
SCE_NonRes_HVAC	443	15
SDGE_SW_Comm_DI	256	14
Total	**1,038**	**100**

Sample design methodology

The sampling methodology employs a stratified estimation model that first places participants into segments of interest (program names based on IOU) and then into strata by annual electric savings, measured in kWh (economizer savings for the ex post site visit sample frame and combined thermostat and supply fan control savings for the phone survey sample frame). The methodology then selects samples randomly within each segment of interest using control variables including program name (and for ex post sites, whether sites had thermostat/supply fan control savings greater than median savings) and savings strata within each combination of control variables.

We then specified primary sample and backup samples in each of the strata (combination of control variables and size stratum) based on priority number given to each site by our algorithm. Primary samples were given the highest priority for data collection. If data could not be collected for primary sample, the backup sample of the next highest priority are used. Also—as can be seen in Table 84 and Table 85—the sample size for each program was proportional to the overall savings from that program.

To estimate the precisions, we assume an error ratio of 1 for both samples. This is based on the error ratios found in our previous HVAC3 evaluation. The error ratio is a summary statistic of variability between tracking savings and the ex post savings. After data collection, the actual error ratio precisions were determined. Based on our sample frame sizes, target sample sizes, number of units per site, and estimated error ratios, we estimated the precisions as shown in both tables. For the economizer measure, we treated each HVAC unit at a site as an independent data point in the analysis of the economizer measures.

Table 84. Economizer measure sample precision estimates

Program	Number of Sites in Sample Frame	Proportion of Economizer Savings	Number of Units in Sample	Precision using 90% Confidence Interval
PGE_Commercial_HVAC	82	76%	72	19%
SCE_NonRes_HVAC	229	16%	20	37%
SDGE_SW_Comm_DI	144	8%	8	58%
Total	**455**	**100%**	**100**	**16%**

Table 85. Thermostat and supply fan control sample precision estimates

Program	Number of Sites in Sample Frame	Proportion of Thermostat Savings	Number of Sites in Sample	Precision using 90% Confidence Interval
PGE_Commercial_HVAC	149	47%	54	16%
PGE_AirCare_Plus	190	24%	24	34%
SCE_NonRes_HVAC	443	15%	17	51%
SDGE_SW_Comm_DI	256	14%	15	42%
Total	**1,038**	**100%**	**110**	**15%**

Using a confidence interval of 90%, the expected statewide precision is ±16% for economizer parameters and ±15% for thermostat/supply fan control parameters. The parameters determined through data collection activities will be used as inputs to DEER building prototype models for ex post savings calculations.

APPENDIX C. WORKPAPER REVIEWS

The following are the workpaper reviews for each measure group.

Coil cleaning workpaper review: ex ante methodology

The workpaper disposition released by CPUC Energy Division May 2, 2013 covered a comprehensive list of workpapers including all commercial HVAC maintenance measures. The workpapers covered in the disposition also included measures that are part of the suite of treatments in the QM programs. The notable affected workpapers are listed in Table 86.

Table 86. Relevant workpapers affected by QM disposition

Service Description	Related Workpapers
Condenser Coil Cleaning (statewide)	SCE13HC037
Evaporator Coil Cleaning	PGE3PHVC158
Condenser Coil Cleaning	PGE3PHVC156
Coil Cleaning	WPSDGENRHC1010 and WPSDGENRHC1020

QM workpapers that estimate RCA savings using DEER measures include a mix of non-charge related services, notably, coil cleaning. The disposition affected these non-charge related services by reducing the UES values to 25% of the DEER RCA UES values and distributing that reduction using the following allocation:

Condenser coil cleaning – 50% of total (DEER RCA UES values * 0.125)
Evaporator coil cleaning – 25% of total (DEER RCA UES values * 0.0625)
Airflow adjustment – 25% of total (DEER RCA UES values * 0.0625)

We assessed the claimed savings from the coil cleaning measure group and measure names reported in the tracking data to determine how ex ante savings were generated. It appears that PG&E ex ante savings reported in the tracking data are in line with the disposition-defined savings; however, SDG&E ex ante savings are significantly different from the disposition savings for coil cleaning. It appears that SDG&E did not update their UES values for coil cleaning measures according to the disposition.

Refrigerant charge adjustment workpaper review

The IOUs established a range of methods for the RCA measure group across four applicable workpapers. The approach to defining the base case and the savings calculation methods we reviewed are summarized in Table 87.

Table 87. Commercial HVAC workpaper summary for RCA

Workpaper	Base Case	Savings Calculations
PGE3PHVC160	AC/Heat Pump unit not correctly charged based on manufacturer's recommendations. Base case consumption varies based on climate zone (CZ) and building type	Refrigerant charge correction for the residential and nonresidential sector is included in the 2011 DEER for residential and nonresidential buildings. All measurements are adopted from the 2011 DEER with ED dispositions de-rating install rate.
DEER (SDG&E claims DEER directly)	AC/Heat Pump unit not correctly charged based on manufacturer's recommendations. Base case consumption varies based on CZ and building type	Refrigerant charge correction for the residential and nonresidential sector is included in the 2011 DEER for homes and buildings. All measurements are adopted from the 2011 DEER with ED dispositions de-rating install rate.
SCE13HCO37	RTU with economizer receiving typical maintenance without the QM+ treatments ("as-found")	Program savings are based on methods developed in the AirCare Plus program. When possible, DEER information and approaches are used as assumptions for savings calculations. Expected Value analysis is the basis for estimating savings for QM service that includes RCA. Four DEER eQUEST prototypes were used to determine a multiplier for converting gas heating savings into equivalent heat pump electric heating savings. All savings have been de-rated by 25% per option two of the workpaper disposition issued by ED on 3/8/2012.
PGE3COHVC138	An existing RTU in as-found condition	Base case consumption determined using eQUEST modeling of common equipment. Faults modeled by CZ, building type, and system type (package variable air volume (VAV), gas package. heat pump). The latest ED disposition de-rated install rate for this measure's UES.

The 2013-14 ex ante disposition for QM and related measures determined that IOUs should use the DEER measure for refrigerant charge and provided guidance where refrigerant charge was bundled with other measures.

Economizer repair workpaper summary

This measure was applicable to any customer who has an existing rooftop unit with a nonfunctional economizer. Technicians repaired common economizer problems and adjusted set points so that the economizer operated as designed to optimize the performance of the unit. According to the workpaper, the energy savings for this measure result from repairing the mechanical functionality of an existing economizer. SDG&E and SCE workpapers are based on the PG&E study, all of which are included in this summary.

According to the workpapers, the base case for this measure used DEER models for a retrofit of a new economizer rather than repair of an existing, non-functional economizer. However, the energy savings were assumed to be essentially the same since the performance of a broken economizer is similar to a fixed outside air unit with no economizer. The baseline assumptions for failed economizers were a weighted average assuming that 60% of units failed at the minimum outdoor air setting and 40% of units were failed with outside air dampers in the closed position. A failed-close damper leakage rate of 5% outside air was assumed along with a minimum outside air percentage of 37.5 %. The minimum outside air assumption was derived from minimum outside air ventilation requirement for "Other" building types per Title 24, Part 6, which is 0.15 CFM per square foot and the DEER assumption for HVAC total system airflow, which is 0.4 cfm/sf.

The base case usage for all included building types was determined by degrading the performance of a modified DEER prototype reference model. There was a total of 348 reference models created that represented the measure end state of a functioning economizer with 70% maximum outside air and 73°F economizer dry bulb temperature high limit. The default DEER prototypes used as the reference models for the measure case buildings were based on the "2005DEERNonresidentialPrototypeCharacteristics-051206modified.xls" [7] spreadsheet. The models for packaged VAV, gas packs, and packaged heat pumps with economizers were modified in the following ways:

Weather file updated from CZ 2 to CZ 2010
System dry-bulb limit set to 73°F for PG&E, 68°F for SCE
System maximum outside air fraction set to 0.70 instead of 1
Unit efficiency for vintages v75 and v85 were set equal to v96 as it was assumed that the older vintage units would have been replaced with a v96 efficiency unit.

Economizer control workpaper summary

This measure involves the repair and adjustment of economizers on existing rooftop units. Economizer controls and/or sensors are adjusted or replaced to enable it to be used when the outside ambient dry-bulb temperature is below the set point temperature activating the economizer. This triggers the outside air dampers to modulate between minimum and maximum position, bringing in cool outside air. The ex ante energy savings for this measure were calculated by modifying DEER prototypes of various building categories across the applicable climate zones. Table 88 below summarizes the energy savings parameters for each workpaper.

Table 88. Workpaper base-case and measure-case economizer parameter definitions

Base Case	Measure Case
Dry-bulb Limit: 55°F Maximum Outdoor Air Fraction: 70% Minimum Outdoor Air Fraction: 24.5%	Dry-bulb Limit: PG&E: 73°F, SCE: 68°F Maximum Outdoor Air Fraction: 70% Minimum Outdoor Air Fraction: 37.5%

The base case dry bulb limit was simulated to 55°F to represent a degraded rooftop unit, which corresponds with the DEER measure D03-060, Economizer Maintenance. The maximum outside air percentage was modeled as 70% in both the base case and measure case such that all savings are related to controls repair or replacement of the economizer only. The base case minimum outside air (OA) fraction is set to 24.5% and is based on the assumed failure position occurrences as described in the repair measure above.

According to the workpapers, PG&E set their measure case economizer limits are set to a dry-bulb temperature of 73°F and SCE used 68°F. The maximum outdoor air fraction that the economizer can achieve was reduced from 1 to 0.7 because field data suggests that within the current stock of buildings 70% outside air is the average maximum outdoor air fraction that is achieved.

Simulations in eQuest were used to determine the energy savings for economizer controls. Savings are greater in coastal climate zones where air temperatures are cooler year around and favorable conditions for economizer occur on a more frequent basis than inland climate zones.

Thermostat workpaper review: ex ante methodology

Across all IOU workpapers, the baseline assumption for thermostat replacement is a non-programmable thermostat and the baseline for thermostat reprogramming is a thermostat with constant heating and cooling set points. The installed measure in both cases is a thermostat with heating setback and cooling set-up during building non-occupied times. The workpaper temperature set points are listed in Table 89 by utility.

Table 89. Programmable thermostat workpaper assumptions

Utility	Installed Thermostat Measure Specifications for Unoccupied Building Periods	
	Cooling Set Point Temperature	Heating Set Point Temperature
SCE[106]	85°F	60°F
SDG&E[107]	85°F	55°F
PG&E[108]	85°F	60°F

The workpaper methodology calculates energy savings by modeling the energy consumption of the DEER commercial building types in each California climate zone using the eQuest software. We expect the modeling software and prototypes to provide reasonable savings if the baseline and installed thermostat conditions are consistent with the model assumptions. The Disposition published by Energy Division in May 2013 reduces thermostat reprogramming savings using a 0.5 multiplier and thermostat replacement savings by a 0.25 multiplier. The tracking data claims were consistent with the disposition-adjusted thermostat savings across all programs that claimed this measure. This evaluation focuses on verifying that thermostats installed or reprogrammed through the utility rebate programs conform to the assumptions in the thermostat workpapers.

Supply fan workpaper review: ex ante methodology

The PG&E unoccupied supply fan control workpaper (PGE3PHVC157) has a savings methodology based on simulating fan schedule changes in DEER prototype buildings using DOE-2. The workpaper describes the deemed saving methodology for the measure using a baseline assumption that the supply fan runs continuously at Title-24 minimum outdoor airflow and the installed measure assumption is that the fan operation matches occupied building schedule, running for ventilation purposes only when the building is occupied.

Savings are derived from the DEER2011 measure for time clock controls. These include: demand, electric, and gas energy savings. While the DEER measure is for a retrofit of a time clock to schedule the supply fan

106 Workpaper SCE13HC037 Comprehensive Commercial HVAC RTU QM.
107 Workpaper WPSDGENRHC0026 Programmable Thermostat.
108 Workpaper Unoccupied Building Controls Measure.

in Auto mode the energy savings are assumed to be the same as adjusting an existing programmable thermostat. The base case is existing rooftop equipment with direct expansion (DX) cooling, gas heating and fan on during unoccupied periods where the economizer is at the minimum outside air setting.

The SCE supply fan savings are contained within the "thermostat reprogramming" component of the QM measure, and the ex ante savings are defined by the SCE13HC037 workpaper "Comprehensive Commercial HVAC Rooftop Unit Quality Maintenance" and the associated Energy Division Disposition. The basis of the savings calculation is also fan schedule changes in DEER prototype buildings using DOE-2.

The Energy Division Disposition[109] that applies to both the PG&E workpaper and SCE QM ex ante savings combines supply fan savings with thermostat reprogramming and modifies the workpaper savings with a 50% multiplier. It states, "The 0.50 gross savings multiplier for thermostat reprogramming accounts for potential negative impacts associated with sites that currently operate with occupied fans at their intermittent, rather than continuous, settings. It also accounts for inappropriate thermostat set point changes like those noted for unoccupied buildings."

Quality maintenance workpaper review: ex ante methodology

SCE's workpaper SCE13HC037, titled "Comprehensive Commercial HVAC Rooftop Unit Quality Maintenance" details the assumptions made for calculating the savings for these measure packages. It has four categories of measure savings: heat pumps with and without an economizer and natural gas HVAC package systems with and without an economizer.

The following is a list of measures that may be included in the Quality Maintenance measure packages:

Airflow and coil cleaning
Evaporator and condenser coil cleaning
Refrigeration charge adjustment – single and multiple compressors
Schedule management
Schedule adjustment
Thermostat replacement and adjustment
Economizer service (only for measure types with economizers)
Economizer temperature high limit control
Economizer controls commissioning
Integrate economizer: wiring
Integrate economizer: wiring + thermostat
Economizer linkage renovation
Economizer renovation: damper motor
Economizer renovation: damper motor and controller/sensor

The assumed incidence of any given treatment being performed on a unit was taken from the ED Disposition for Non-Residential HVAC Rooftop Quality Maintenance, dated 5/2/13, and is shown side by side with the implementer distribution in Table 46. Of course, the economizer measures apply only to the economizer-equipped units. Essentially, the ex-ante claims for every unit enrolled in program assumes this measure mix.

[109] Energy Division Disposition (Disposition) titled "2013_2014-ComHVACQMWorkpaperDisposition_2May2013.docx"

APPENDIX D. COIL CLEANING DATA

Table 90. Condenser coil cleaning unit level input adjustment factor comparison

Input	EIR		Sizing Ratio	
Tons	ClimaCheck	Discharge Pressure	ClimaCheck	Discharge Pressure
7	-	0.9686	-	1.0047
40	-	1.0110	-	0.9982
4	0.9868	1.0341	1.1193	0.9943
4	0.9850	0.9941	1.0781	1.0009
5	0.9916	1.0130	0.9882	0.9979
5	0.9288	1.0113	1.0812	0.9982
4	1.0187	1.0841	1.0180	0.9850
4	1.0210	1.0980	1.0379	0.9822
7.5	-	1.0145	-	0.9976
7.5	1.0311	1.0063	0.9668	0.9990
6	1.0143	1.0134	0.9554	0.9978
7.5	1.0345	1.0383	0.9908	0.9935
10	1.1173	1.0198	0.9271	0.9967
15	1.0890	1.0063	0.9396	0.9990
3	1.1845	1.0053	0.8428	0.9991

Table 91. Evaporator coil cleaning unit level input adjustment factor comparison

Input	EIR		Coil Bypass Factor		Sizing Ratio	
Tons	ClimaCheck	Static Pressure	ClimaCheck	Static Pressure	ClimaCheck	Static Pressure
7	-	1.0064	-	1.0497	-	0.9880
4	1.0065	1.0045	-	1.0428	0.9171	0.9914
4	0.9496	1.0055	-	1.0465	1.0094	0.9896
5	1.0181	0.9970	-	1.0165	0.9171	1.0042
5	1.0920	1.0062	-	1.0489	0.8888	0.9884
4	0.9832	0.9958	-	1.0120	0.9564	1.0064
4	1.0065	1.0117	-	1.0683	0.9206	0.9789
7.5	-	0.9998	-	1.0264	-	0.9994
7.5	0.9168	1.0023	-	1.0352	1.1086	0.9951
4.8	1.0229	-	-	-	0.9539	-
7.5	0.9739	-	-	-	0.9717	-
10	0.8886	1.0133	-	1.0742	1.0572	0.9761
15	1.0983	1.0196	-	1.0965	0.8894	0.9652
15	0.9304	1.0028	-	1.0369	0.9992	0.9943

2013-14 Ex post methodology

Evaluation of the coil cleaning measure group focused on revising key input parameters for the DEER models used to estimate ex ante savings and re-running the simulations to produce ex post savings estimates. No research was conducted to update the baseline cooling energy and demand consumption estimated by the DEER prototype models. The evaluation calculated adjustment factors for condenser coil cleaning using 28 ride-along data points and laboratory research results (HVAC5) correlating the change in discharge pressure and relative HVAC system efficiency change.[110] The revised adjustment factors true up ex ante savings without significantly modifying the calculation methodology (DOE-2 simulation).

Laboratory data

The lab research data are results from a two-year testing period at Intertek, an Air-conditioning Heating and Refrigeration Institute (AHRI) certified laboratory. This work was part of the 2013-14 Laboratory HVAC Testing Research Plan (HVAC5) developed to support CPUC evaluation efforts. The laboratory data consists of measurements taken on packaged RTUs in controlled environment conditions with the following air property controls:

- Ambient temperature (dry-bulb and wet-bulb)
- Return air temperature (dry-bulb and wet-bulb)
- Economizer damper position

Accurate sensors were permanently installed in the laboratory setup to measure:

- Total system power (W)
- Supply air fan power – added by test personnel (W)
- Compressor discharge and suction pressure (psig)
- Supply and return air temperatures (dry-bulb and wet-bulb °F)
- Supply air flows (cfm)
- Outdoor airflows for repeatable economizer damper positions were measured in separate fan-only tests. Numerous tests indicated this to be a repeatable outdoor air setting.

These allow the researchers to calculate performance metrics such as:

- Total and sensible gross and net capacity (Btuh)
- Coil bypass factor (CBF) – a simulation input
- Efficiency metrics: sensible and total EER

The laboratory results relating specifically to the coil cleaning measure analysis are described below; those used in the RCA analysis are described in that section. The laboratory test procedure recreated the overall impact of a dirty coil using cardboard to block the surface of the evaporator or condenser coil. Measurements were made by varying the condenser coil blockage from zero to as much as 80%. Evaporator coil blockage was from 0% to 50%. Tests were performed on three HVAC systems that included two HVAC unit compressor sizes and units with fixed geometry and thermostatic expansion valves (TXV). The distinct data sets' properties are listed below in Table 92.

[110] Laboratory HVAC Testing Research Plan, prepared for the CPUC by KEMA, Inc 11/17/2014 (HVAC5 research plan and results).

Table 92. Laboratory research: Properties of evaluated units

Unit Capacity	TXV or non-TXV	Economizer Damper Position	Ambient Dry-Bulb Temperature °F	Mixed Air Wet-Bulb Temperature °F
7.5-ton	Non-TXV	Closed	82°F	63.0°F
7.5-ton	Non-TXV	Closed	95°F	64.2°F
7.5-ton	Non-TXV	Closed	115°F	65.2°F
3- ton	Non-TXV	Closed	82°F	63.5°F
3- ton	Non-TXV	Closed	95°F	65.4°F
3-ton	Non-TXV	Closed	115°F	65.2°F
7.5-ton	TXV	Closed	95°F	63.6°F

Condenser coil laboratory results

Holding ambient temperature fixed while changing coil blockage affected unit performance approximately linearly. Figure 29 and Figure 30 illustrate how the relative[111] change in discharge pressure correlates to a relative change in unit efficiency (EER [%]) and total cooling capacity, respectively. The relationship makes sense because discharge pressure (and temperature) increase as less heat is removed from the condenser due to coil fouling.

[111] A relative change in a quantity is one that is expressed as a percentage of the total quantity. Hence, all relative quantities are expressed as a percentage and are unitless.

Figure 29. Relative efficiency impact due to condenser coil blockage

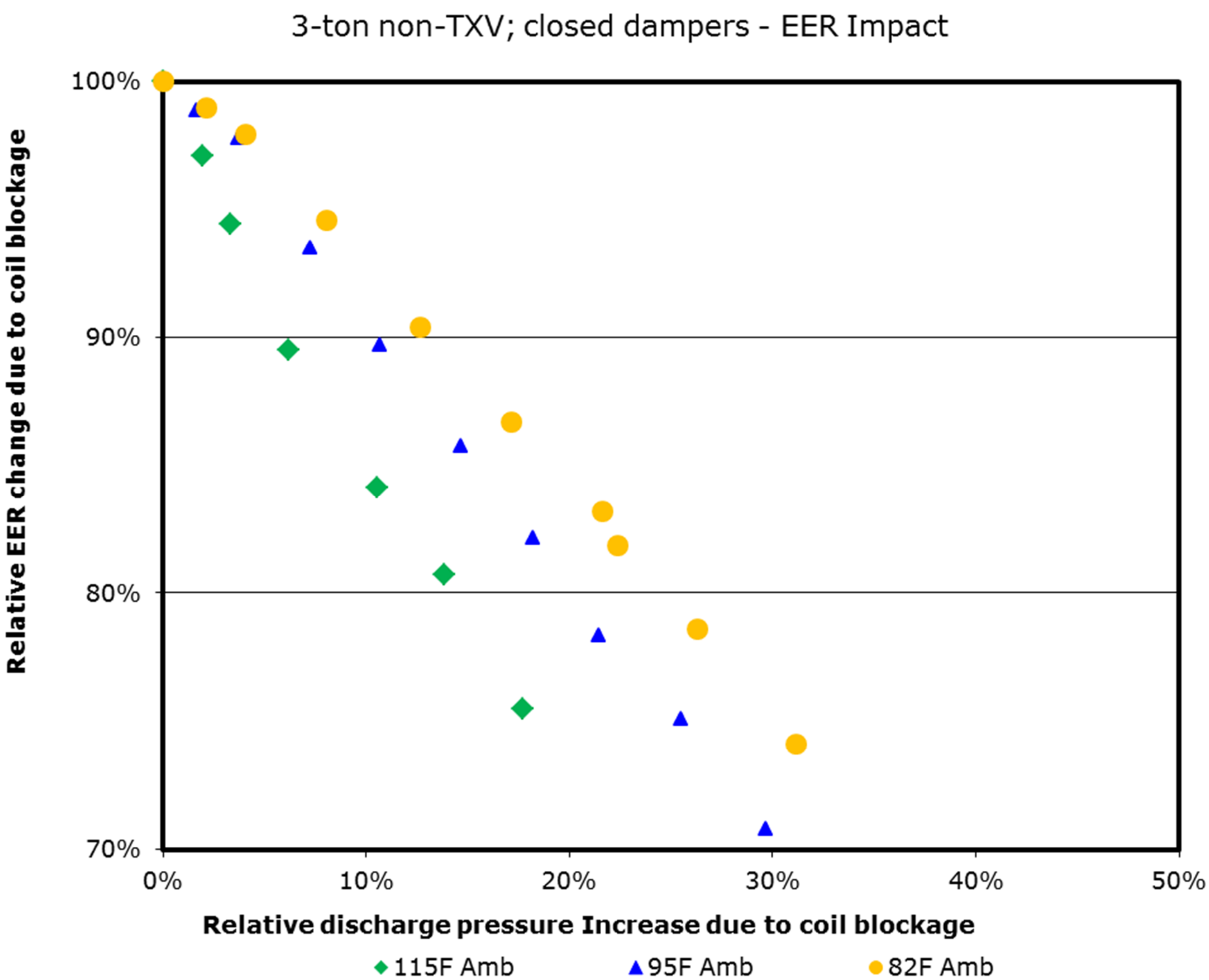
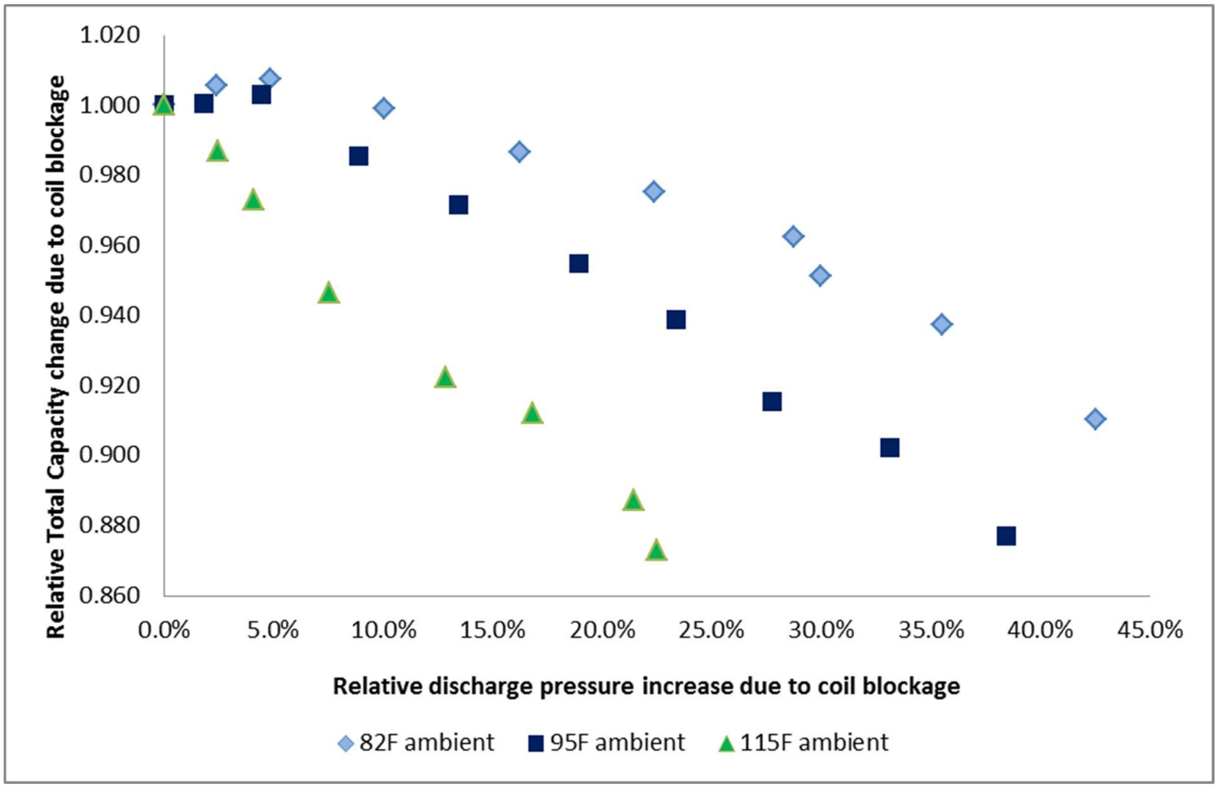


Figure 30. Relative total capacity impact due to condenser coil blockage



Having multiple laboratory data sets at different fixed ambient temperatures (82°F, 95°F, and 115°F for the 3-ton and 7.5-ton non-TXV units) allowed the opportunity to correlate the parameters of interest - relative energy efficiency ratio (EER [%]) and relative capacity (CAP [%]) - using two independent variables: outdoor air temperature (OAT [˚F]) and relative discharge pressure (ΔDP [%]). This allowed us to correct for ambient temperature changes between the pre- and post-cleaning discharge pressure measurements in the field. The following multivariable biquadratic regressions were developed using the non-TXV 3-ton unit data:

$$\Delta EER = f(OAT, \Delta DP) = a_1 + a_2(OAT) + a_3(\Delta DP) + a_4(OAT)^2 + a_5(\Delta DP)^2 + a_6(OAT)(\Delta DP)$$

Where:

a_1	a_2	a_3	a_4	a_5	a_6
0.734358	0.006044	0.465252	-3.3250E-05	- 0.06085	- 0.01559

The EER biquadratic function fit well across the OAT ranges with a relative error of less than 1.4% compared to the original non-TXV 3-ton system’s lab data.

And

$$\Delta CAP = f(OAT, \Delta DP) = a_1 + a_2(OAT) + a_3(\Delta DP) + a_4(OAT)^2 + a_5(\Delta DP)^2 + a_6(OAT)(\Delta DP)$$

Where:

a_1	a_2	a_3	a_4	a_5	a_6
0.854799	0.003515	0.960154	- 2.024E-05	- 0.703957	38

Similarly, the total capacity change biquadratic fit very well across all three ambient temperature ranges with a relative error of less than 1.2% compared to the original lab data.

For the purposes of DOE-2 simulations, the relative change in system electric input ratio (EIR), a DOE-2 keyword used to define system efficiency sans air handler fan power, was also analyzed using the lab data. The EIR biquadratic function is described below.

$$\Delta EIR = f(OAT, \Delta DP) = a_1 + a_2(OAT) + a_3(\Delta DP) + a_4(OAT)^2 + a_5(\Delta DP)^2 + a_6(OAT)(\Delta DP)$$

Where:

a_1	a_2	a_3	a_4	a_5	a_6
1.416554	-0.008871	0.000046	-1.435104	1.503211	0.026811

While the difference in ambient temperature between pre and post coil cleaning measurement was likely insignificantly small, the post-coil cleaning discharge pressure was first normalized to the pre-ambient temperature using a function developed from coil lab test data at a constant coil blockage state.[112] Data points for the clean coil instances at the three different ambient temperatures were used to correlate the change in ambient temperature to the relative change in discharge pressure using the linear equation is shown below:

$$\Delta DP = f(\Delta OAT) = a(\Delta OAT)$$
$$where\ a = 1.2496$$

The evaluation team decided to use only the biquadratic regression results from the 3-ton non-TXV lab data because that unit's capacity and compressor configuration most closely represented the units that were measured in the field. The relative change in efficiency and total cooling capacity was estimated using the corresponding relative change (%) in discharge pressure from the ride-along data and the regression described above.

To determine ex post savings for both condenser and evaporator coil cleaning measures simulations were performed using inputs informed by the laboratory data applied to the field-collected sample. The adjustment factors chosen for the condenser coil DOE-2 simulations were cooling EIR and cooling-sizing

[112] The zero blockage state was chosen, and the three temperature testing configurations defined three data point pairs of ambient temperature and discharge pressure for clean coils at 82°F, 95°F, and 115°F ambient temperature. These were used to create the linear correlation.

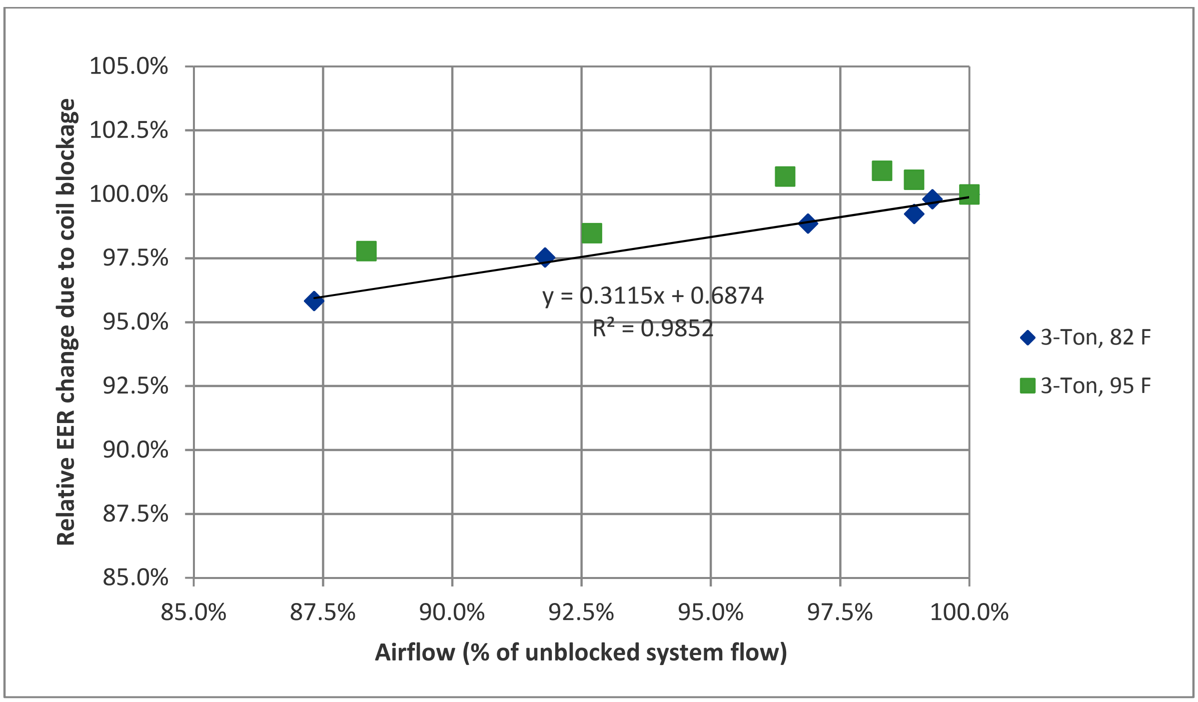
ratio.[113] Using the biquadratic equations developed from the lab data, DOE-2 adjustment factors were estimated using the ride along data.

Evaporator coil laboratory results

The laboratory testing also included simulations of evaporator coil (cooling coil) blockage to analyze the effects of cleaning those coils. As evaporator blockage increases, there is a reduction in supply air flow rate as well as heat transfer across the coil which changes the sensible heat ratio (latent capacity increases while sensible capacity decreases), EER and total cooling capacity. These relationships are evident in the laboratory data.

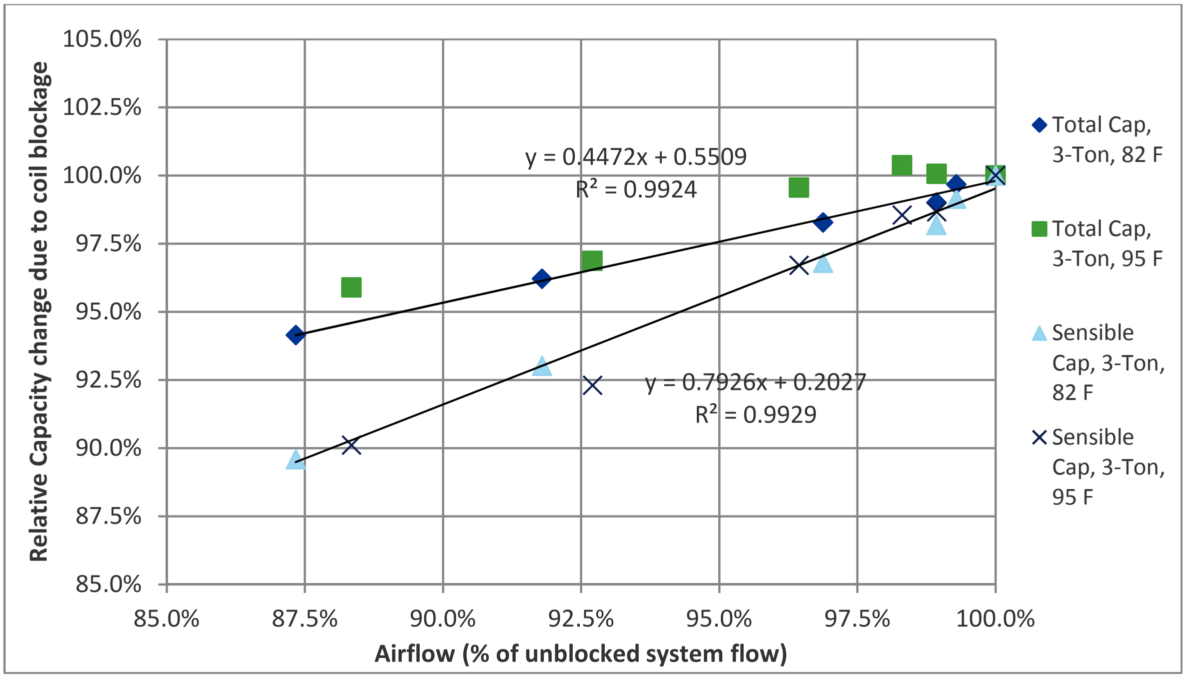
Figure 31 shows the laboratory results of the relative change in efficiency as a function of HVAC system airflow. Airflow is shown on the x-axis because the relationships between it and EER and capacity degradation are closer to linear than those of coil blockage. We applied the airflow relationship to field-gathered data to determine system improvement due to coil cleaning. The accuracy of the laboratory testing instrumentation is 1%. Only the data at 82°F ambient temperature were used for the linear fit and analysis, though the 95°F data is also shown to illustrate that the ambient temperature does not have a large effect on the results. In future workpaper development we suggest combining the data we have used here with additional data available in the literature to create a more robust relationship for evaporator coil cleaning.

Figure 31. Impact of evaporator coil blockage on relative efficiency



113 Cool-sizing ratio was chosen instead of cooling capacity (total cooling capacity in btuh) and sensible cooling capacity (btuh) because of the convenience of adjusting a capacity sizing ratio (whose value is 1 in the DEER prototypes) rather than adjusting individual system cooling capacities for each building type-weather zone-vintage combination. Making those individual adjustments to cooling capacity and sensible cooling capacity would have made the simulation approach impractical.

Figure 32. Impact of evaporator coil blockage on total and sensible cooling capacity



APPENDIX E. THERMOSTAT / SUPPLY FAN VERIFICATION SURVEY

Background

The primary objective of the programmable thermostat and supply fan portion of the HVAC3 evaluation is to verify the IOU's energy savings claims for these measures under their Quality Maintenance and HVAC Tune-up programs. The largest uncertainties affecting the ex ante energy savings estimates of the programmable thermostat measure are:

- If participants are even using the programmable thermostat
- Whether or not thermostat set points adhere to the program requirements for periods when the building is unoccupied
- The baseline set points during unoccupied periods
- And the hours that the building is occupied.

The baseline set points are very hard to collect reliably and we don't attempt to collect them in this survey. However, DNV GL will attempt to characterize baseline operation (i.e. whether or not the thermostat was setback) during unoccupied hours in this survey. Previous evaluation efforts for 2013-14 were limited to field collected data at 11 sites and only verified whether or not the thermostats observed at those sites met the conditions outlined in IOU workpapers for unoccupied periods. The results from that evaluation exhibited a high degree of uncertainty but indicated only 30 percent of the verified thermostats meet the program's specifications.

The largest uncertainty affecting the ex ante energy savings estimates of the supply fan control measure is the baseline operation of the supply fan, especially for periods when the building is unoccupied. The previous evaluation had difficulty verifying the baseline condition and also had a large degree of uncertainty due to a small sample size (14 sites).

Survey Goals

The goal of the T-STAT and Supply Fan Verification Survey is to determine operating characteristics of rebated programmable thermostat and supply fan controls. The survey will attempt to document the schedule and set points of a sample of installed programmable thermostats as well as the baseline and current operation (on/off/auto) of supply fans during occupied and unoccupied times. The findings from the survey will be used to verify program tracking savings claims and ultimately update gross savings estimates for both measures.

Key Research Questions.

The T-STAT and Supply Fan Verification Survey will address the following key research questions in support of updating gross savings estimates:

- Are participants using their programmable thermostat?
- What is the average thermostat set point during unoccupied hours (across all building types)?
- What was the baseline operation of the supply fan during unoccupied hours (across all building types)?

Survey Scope

Our pilot survey showed a 28% response rate (4 completes and 3 refusals out of 14 attempted sites) and participants who agreed to the survey had no problem providing the required information. The respondents seemed to be slightly biased towards customers with fewer thermostats at their site although the sample size was too small to draw any conclusions. To address this potential bias, we plan to supplement the phone survey with ex-post on-site data collection at ten randomly selected sites with more than ten thermostats that we will piggy back with the economizer data collection. DNV GL will collect thermostat and supply fan data through a phone survey of 100 participants and an on-site survey of 10 participants to build on the findings of the 2013-14 evaluation. The sample of participants will be stratified by IOU, building type, and size (i.e. quantity of rebated measures or energy savings).

Analysis

The 2013-14 evaluation DNV GL did not have a large enough sample to confidently adjust inputs to the eQuest model which was used to calculate ex-ante savings estimates. DNV GL has planned a significantly larger sample for the 2015 evaluation so that we can use the model to produce updated (i.e. ex post) programmable thermostat and supply fan measure unit energy savings (UES) across climate zones and building types. For both of these measures the installed measure case only involves changing the unoccupied setting. DNV GL will use the average unoccupied set points across all building types, building sizes, climate zones, and IOUs to update the eQuest model prototypes. The number of occupied building hours collected in the survey will be compared to the number in the building prototypes, but due to anticipated variation we don't think the sample will provide sufficient precision to justify changing the number of hours in the model. The occupied supply fan control setting is not important to energy savings, but is important to whether the building ventilation complies with Title-24 requirements, and we may investigate this using the collected data.

Database Variables

Variable	Description
<CONTACT NAME>	Program participant's full name
<ADDRESS>	Program participant address
<COMPANY NAME>	Program participant's company name
<DATE>	Month and year tstat and/or supply fan control was installed
<PHONE>	Telephone number
<PROGRAM NAME>	Multiple program names depending on the IOU
<MEASURE QTY>	# of installed t-stats and/or supply fan control(s)

Introduction/Screener

I0 Hello, my name is __________, and I'm calling on behalf of the California Public Utilities Commission. May I speak with <**CONTACT NAME**>?

[IF NECESSARY:

We are conducting a survey on behalf of the Commission to better understand how your business is using its programmable thermostats (and/or supply fan). The utility will use your input to improve the programs they offer to commercial and industrial customers. This is NOT a sales call and the information that you provide will be kept strictly confidential. The survey should only take 10-15 minutes.

You may validate the legitimacy of this study by contacting Peter Biermayer of the CPUC via phone at 415-703-2384.

I1. Are you familiar with how **<COMPANY NAME>** controls their heating and cooling?

1	Yes	I2.
2	No	Find other contact/ Reschedule/TT
98	DON'T KNOW	Find other contact/ Reschedule/TT
99	REFUSED	Find other contact/ Reschedule/TT

I2. Is the heating and cooling controlled by thermostats or by an energy management system (EMS)?

1	Thermostats	I3
2	EMS	I3
98	DON'T KNOW	Find other contact/ Reschedule/TT
99	REFUSED	Find other contact/ Reschedule/TT

I3. Are you responsible for setting or adjusting your company's programmable thermostats (or EMS or supply fan controls as appropriate)?

1	Yes (tstats only)	I4. Ask tstat battery.
2	Yes (supply fans only)	I4. Ask supply fan battery.
3	Yes (both)	I4. Ask about both

4	Yes (EMS)	I4. Ask about both
5	No	Find other contact/ Reschedule/TT
98	DON'T KNOW	Find other contact/ Reschedule/TT
99	REFUSED	Find other contact/ Reschedule/TT

I4. Which of the following building type best describes your company's facility? **RECORD ANSWER.**

1	Assembly	12	Manufacturing - Bio/ Tech
2	Education- Primary School	13	Manufacturing - Light Industrial
3	Education- Secondary School	14	Office - Large
4	Education- Community College	15	Office - Small
5	Education- University	16	Restaurant - Sit-Down
6	Education - Re locatable Classroom	17	Restaurant - Fast-Food
7	Grocery	18	Retail - 3-Story Large
8	Health/Medical - Hospital	19	Retail - Single-Story Large
9	Health/ Nursing Home	20	Retail - Small
10	Lodging - Hotel	21	Storage - Conditioned
11	Lodging - Motel	22	Storage - Refrigerated Warehouse
98	Don't Know	99	Refused

I5. What's the total area of the facility? (please estimate in sq. feet, if multiple buildings, combine area). RECORD ANSWER.

I6. What percent of the building(s) area was retrofitted with programmable thermostats? RECORD ANSWER.

Operating/Occupied Hours.

Now I'd like to ask you a few questions about the regular hours of occupancy at **<COMPANY NAME>.**This info will allow us to compare the operating/occupied hours in program-provided data with the data collected off the thermostats.

OH1. During the week, Monday through Friday, what hours are <COMPANY NAME> occupied by employees? (Note: these may be different than the actual business hours if employees typically come in early or stay late) **RECORD ANSWER.**

OH2. During the weekend, Saturday and Sunday, what hours are <COMPANY NAME> occupied by employees? (Note: these may be different than the actual business hours if employees typically come in early or stay late) **RECORD ANSWER, then proceed to TB intro.**

T-stat Baseline.

[READ INTRO then proceed to TB1] Now I'd like to ask you a question about the old thermostats that were installed at your company <COMPANY NAME> prior to participating in the <PROGRAM NAME> and installing (or reprogramming) programmable thermostat.

TB1. What type of thermostat was installed prior to participating in the <PROGRAM NAME>? (Read list if necessary)

1	Programmable t-stat	TB2
2	Manual t-stat	TB2
3	Switch (on/off)	TB2
4	EMS	TB2
5	No t-stat	TB2
6	Other	Record answer, TB2
98	DON'T KNOW	TB2
99	REFUSED	TB2

TB2. Prior to participating in the <PROGRAM NAME>, did your company <COMPANY NAME> change the thermostat settings during unoccupied periods?

1	Yes	TB3
2	No	TV intro

98	DON'T KNOW	TV intro
99	REFUSED	TV intro

TB3. How frequently did you adjust the thermostat?

1	Frequently	TV intro
2	One-time adjustment	TV intro
3	Seasonal adjustments	TV intro
4	On-going/as needed adjustments	TV intro
5	Occupant controlled	TV intro
98	DON'T KNOW	TV intro
99	REFUSED	TV intro

T-stat Verification

[READ INTRO then proceed to TV1] Now I'd like to ask you a few questions about the programmable thermostats currently installed at your company. As a reminder, the <PROGRAM NAME> provides contractors with incentives and guidelines for replacing or reprogramming thermostats and supply fans. According to our records, your company <COMPANY NAME> at <ADDRESS> received a rebate for installing or reprogramming <MEASURE QTY> programmable thermostats (and <MEASURE QTY> supply fan controls if necessary) on <DATE>. In order to collect the necessary information about these programmable thermostats I'd like to ask you to read the programmed schedule and set points on 1-3 thermostats (depending on the <MEASURE QTY>).

NOTE: If more than 1 thermostat, mention that "the thermostats should be in non-adjacent areas. Ask questions about the different types of spaces at the business (i.e. offices, class rooms, storage rooms, workshops, kitchen, etc.) and if each space has different levels/times of occupancy. Push for different space/occupancy types depending on the information provided.

TV1. Are you able to walk around to <MEASURE QTY> thermostats and provide this information at this time?

1	Yes	TV2
2	No, not right now	Schedule follow-up

TV2. Where is the first thermostat located? **RECORD ANSWER. Proceed to TV3**

TV3. Please read me the complete schedule of the (occupied and unoccupied) thermostat including applicable days, time ranges, cooling set points, heating set points, operational mode (heating/cooling/auto (both)/off), and supply fan setting (on/off/auto). **Record answers below.** Probe if schedule/data is incomplete.

TV4. [If applicable] Where is the second thermostat located? **RECORD ANSWER. Repeat TV3.**

TV5. [If applicable] Where is the third thermostat located? **RECORD ANSWER. Repeat TV3.**

Thermostat schedule and set points.

Note: we need set points for 4 time periods weekday occupied/unoccupied (2) and weekend occupied/unoccupied (Add rows if necessary)

Period	**Name**	**Applicable Days and Times**	**Cooling SP**	**Heating SP**	**Operational mode (heating/ cooling/ auto/ off)**	**Supply Fan (on/off/auto)**
1	**TSTAT 1**	MF Occ.				
2		MF Unocc.				
3		SS Occ.				
4		SS Unocc.				
5						
6	**TSTAT2**					
7						

8						
9						
10						
11	**TSTAT3**					
12						
13						
14						
15						
16						

TV6. Since the initial programming by the HVAC contractor has your company <COMPANY NAME> change the thermostat settings during unoccupied periods?

1	Yes	TV7
2	No	TV intro
98	DON'T KNOW	TV intro
99	REFUSED	TV intro

TV7. Please describe the changes you made to the thermostat setting during unoccupied periods since the measure was installed and programmed by the HVAC contractor?

1	Frequent adjustments	TV intro
2	One-time adjustment	TV intro
3	Seasonal adjustments	TV intro
4	On-going/as needed adjustments	TV intro
5	Occupant controlled	TV intro
98	DON'T KNOW	TV intro
99	REFUSED	TV intro

SF Intro: Supply Fan Controls Verification

As I previously mentioned, according to our records <**COMPANY NAME**> implemented controls on their <**MEASURE QTY**> supply fans.

SF1. [If applicable] Are able to answer a couple of questions about how you were using the supply fans before the control measure was implemented?

1	Yes	SF2
2	No, not right now	TT

Ask these 2 questions of all customers that had supply fans controls installed or reprogrammed.

SF2. Prior to implementing controls, what was the setting on the company's supply fans when the building was occupied?

1	On (all the time)	SF3
2	Auto (intermittent)	SF3
3	Off	SF3
99	Don't know	C1

SF3. (This is the really important one!) Prior to implementing controls, what was the setting on the company's supply fans when the building was unoccupied?

1	On (all the time)	C1
2	Auto (intermittent)	C1
3	Off	C1
99	Don't know	C1

Contextual Information

I have just one final question about your HVAC maintenance practices prior to participating in <**PROGRAM NAME**> to provide context for this study.

C1. Prior to participating in the <**PROGRAM NAME**> did you regularly perform proactive preventative maintenance on your HVAC systems? **Y/N**

1	Yes	C2

2	No	TT
98	DON'T KNOW	TT
99	REFUSED	TT

C2. If yes, please describe the type of maintenance. Read list. RECORD ANSWER.

1	Clean condenser coil	
2	Clean evaporator coil	
3	Check refrigerant charge	
4	Tighten/replace fan belt	
5	Check economizer operation	
6	Check/replace thermostat	
7	Verify minimum ventilation fan setting	
8	ACCA 180 checklist	
98	Other	Record Verbatim
99	Don’t know	

Those are all of our questions. Thank you so much for your time. ☺

APPENDIX F. THERMOSTAT DATA

Table 93. PG&E phone and field collected thermostat survey set point data [°F]

Number of Thermostats Surveyed	Weekday Occupied Cooling	Weekday Occupied Heating	Weekday Unoccupied Cooling	Weekday Unoccupied Heating	Weekend Occupied Cooling	Weekend Occupied Heating	Weekend Unoccupied Cooling	Weekend Unoccupied Heating
2	75.0	68.0	85.0	50.0	75.0	68.0	85.0	50.0
1	74.0	55.0	89.0	54.0			89.0	54.0
2	75.0	68.0	85.0	50.0	75.0	68.0	85.0	50.0
2	75.0	68.0	85.0	50.0	75.0	68.0	85.0	50.0
1	75.0	68.0			75.0	68.0		
1	78.0	72.0			78.0	72.0		
1	74.0	70.0			74.0	70.0		
2	75.0	68.0	85.0	50.0	75.0	68.0	85.0	50.0
2	74.0	72.0	74.0	72.0	74.0	72.0	74.0	72.0
2	75.0	68.0	85.0	50.0	75.0	68.0	85.0	50.0
2	71.5	68.5	90.0	52.0	71.5	68.5	90.0	52.0
2	70.5	70.5	60.0	60.0	70.5	70.5	60.0	60.0
1	78.0	72.0						
1	76.0	68.0	90.0	55.0	76.0	68.0	90.0	55.0
1	71.0	68.0	84.0	58.0				
2	71.5	68.5	90.0	52.0			90.0	52.0
1	78.0	68.0	86.0	55.0				
1	72.0	68.0	90.0	55.0				
1	71.5		80.0				80.0	
1	74.0	68.0	85.0	55.0			85.0	55.0
3	72.0	68.0	90.0	50.0			83.3	50.0
3	71.3	67.3	90.0	50.0			90.0	50.0
3	71.3	67.3	90.0	50.0			90.0	50.0

Number of Thermostats Surveyed	Weekday Occupied Cooling	Weekday Occupied Heating	Weekday Unoccupied Cooling	Weekday Unoccupied Heating	Weekend Occupied Cooling	Weekend Occupied Heating	Weekend Unoccupied Cooling	Weekend Unoccupied Heating
1	74.0	68.0			74.0	68.0		
3	71.3	67.3	90.0	50.0			90.0	50.0
1	70.0	68.0	75.0	63.0	70.0	68.0	75.0	63.0
1	72.0	72.0			72.0	72.0		
3	73.7	69.0	80.3	63.7	73.7	69.0	80.3	63.7
2	74.0	68.0	83.0	59.0	71.0	67.0	71.0	54.5
2	71.5	68.0	81.5	55.0	85.0	53.5	81.5	53.5
3	72.7	68.0	85.0	56.7	72.0	68.0	85.0	56.7
2	70.0	70.0	61.0	61.0	70.0	70.0	61.0	61.0
1	70.0	66.0	80.0	65.0	70.0	66.0	80.0	65.0
1	74.0	68.0	85.0	62.0	85.0	62.0	85.0	62.0
1	71.0	68.0			68.0	71.0		
1	71.0	68.0	85.0	60.0			85.0	60.0
1	75.0	70.0	85.0	60.0	75.0	70.0	85.0	60.0
1	75.0	70.0	85.0	60.0	75.0	70.0	85.0	60.0
3	72.0	68.7	85.0	60.0	72.0	68.7	85.0	60.0
1	73.0				73.0			

Table 94. SCE phone and field collected thermostat survey set point data [°F]

Number of Thermostats Surveyed	Weekday Occupied Cooling	Weekday Occupied Heating	Weekday Unoccupied Cooling	Weekday Unoccupied Heating	Weekend Occupied Cooling	Weekend Occupied Heating	Weekend Unoccupied Cooling	Weekend Unoccupied Heating
1	74.0	68.0	85.0	55.0			85.0	55.0
1	74.0	68.0						
3	71.3	68.7	80.7	60.0			80.7	60.0
2	73.0	70.5	77.0	67.0	72.0	72.0	77.0	67.0
2	73.0	70.5	77.0	67.0	72.0	72.0	77.0	67.0
2	73.0	70.5	77.0	67.0	72.0	72.0	77.0	67.0
1	74.0	68.0			74.0	68.0		
3	73.3	69.0	85.0	55.0			85.0	55.0
3	72.3	69.5	72.3	69.5			72.3	69.5
3	79.3	66.0	90.0	44.0	79.3	66.0	82.7	58.7

Table 95. SDG&E phone and field collected thermostat survey set point data [°F]

Number of Thermostats Surveyed	Weekday Occupied Cooling	Weekday Occupied Heating	Weekday Unoccupied Cooling	Weekday Unoccupied Heating	Weekend Occupied Cooling	Weekend Occupied Heating	Weekend Unoccupied Cooling	Weekend Unoccupied Heating
1	70.0	84.0			70.0	84.0		
2	74.0	67.0	92.0	58.0	74.0	67.0	92.0	58.0
1	71.0	60.0						
1	73.0	69.0	79.0	61.0	73.0	69.0	79.0	61.0
1	77.0	66.0	80.0	58.0	77.0	66.0	80.0	58.0
1	80.0	72.0	80.0	72.0	80.0	72.0	80.0	72.0
1	70.0	53.0	83.0	53.0	70.0	53.0	83.0	53.0
1	72.0	68.0	85.0	58.0				
1	72.0	66.0	90.0	55.0	72.0	66.0	90.0	55.0
1	74.0	68.0	83.0	59.0			83.0	59.0

APPENDIX G. COMMERCIAL PROGRAM SIMULATION RESULTS

These tables show the eQuest simulation results by building type and climate zone.

Economizer tables

These tables show the results of the economizer measure group eQuest simulations by building type and climate zone.

Table 96. PG&E economizer repair/replace measure ex-post kWh/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	1,231	387	830	490	962						191	240	211			382	547
ECC	507	321	503	334	517						202	245	205			315	350
EPr	348	170	291	207	304						130	166	137			188	216
ERC	269	144	208	159	232						86	117	113			177	167
ESe	334	161	286	206	322						132	164	139			182	214
EUn	728	388	648	413	645						246	302	253			406	448
Hsp	671	353	750	491	698						251	302	256			311	454
Htl	-2,024	-1,403	-936	-951	-1,296						-1,106	-969	-943			-1,905	-1,281
MBT	793	517	682	482	687						322	418	345			447	521
MLI	97	132	207	173	182						93	134	117			117	139
Nrs	230	167	339	248	380						107	139	130			214	217
OfL	521	311	453	319	446						208	259	210			352	342
OfS	287	190	303	212	311						119	157	124			197	211
RFF	427	278	483	346	543						150	197	170			278	319
RSD	648	277	576	341	616						123	219	135			312	361
Rt3	790	377	681	407	778						151	207	174			264	425
RtL	1,140	349	707	428	812						152	203	175			293	473
RtS	456	243	428	265	506						108	164	132			220	280
SCn	0	13	14	25	7						21	12	33			47	19

Table 97. PG&E economizer repair/replace measure ex-post kW/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	0.31	0.01	0.16	-0.01	0.09						-0.01	-0.01	-0.02			0.00	0.06
ECC	0.27	0.01	0.07	0.00	0.08						-0.01	-0.01	0.00			0.00	0.05
EPr	0.21	0.00	0.00	0.00	0.08						0.00	0.00	0.00			0.00	0.06
ERC	0.16	0.00	0.02	0.00	0.05						0.00	0.00	0.00			0.00	0.05
ESe	0.23	0.00	0.00	0.00	0.09						0.00	0.00	0.00			0.00	0.05
EUn	0.34	0.01	0.10	0.00	0.09						-0.01	-0.01	0.00			0.00	0.06
Hsp	0.21	0.01	0.14	-0.01	0.08						-0.02	-0.02	-0.02			-0.01	0.04
Htl	0.17	-0.01	0.17	-0.07	0.09						-0.11	-0.10	-0.12			-0.04	0.00
MBT	0.28	0.01	0.06	0.00	0.04						0.00	-0.01	0.00			0.00	0.04
MLI	0.05	0.02	0.08	0.00	0.10						0.00	-0.01	0.00			0.00	0.03
Nrs	0.08	0.02	0.15	0.00	0.13						-0.01	-0.01	-0.01			0.00	0.04
OfL	0.24	0.01	0.15	0.00	0.07						-0.01	-0.01	-0.01			0.00	0.05
OfS	0.20	0.01	0.13	0.00	0.07						-0.01	-0.01	-0.01			-0.01	0.04
RFF	0.13	0.01	0.15	-0.01	0.10						-0.01	-0.01	-0.02			0.00	0.04
RSD	0.20	0.01	0.17	-0.01	0.11						-0.01	-0.01	-0.01			0.00	0.05
Rt3	0.25	0.02	0.17	0.00	0.10						-0.01	-0.01	-0.01			0.00	0.06
RtL	0.30	0.01	0.15	-0.01	0.08						-0.01	-0.01	-0.01			0.00	0.06
RtS	0.22	0.01	0.16	-0.01	0.09						-0.01	-0.01	-0.01			0.00	0.05
SCn	0.00	0.03	0.01	0.00	0.03						-0.01	-0.01	-0.01			0.00	0.00

Table 98. PG&E economizer repair/replace measure ex-post therm/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	-2.8	-2.9	-1.8	-1.7	-1.8						-3.4	-3.1	-2.9			-6.7	-3.0
ECC	-2.6	-1.9	-1.2	-1.2	-1.3						-2.4	-2.2	-2.1			-4.7	-2.2
EPr	-2.0	-1.9	-1.2	-1.2	-1.2						-1.8	-1.6	-1.6			-3.4	-1.8
ERC	-2.5	-2.4	-1.8	-1.6	-1.7						-2.2	-2.2	-2.0			-3.5	-2.2
ESe	-2.7	-2.6	-1.8	-1.6	-1.6						-2.4	-2.3	-2.1			-4.3	-2.4
EUn	-2.5	-2.2	-1.4	-1.4	-1.5						-2.3	-2.1	-2.0			-4.4	-2.2
Hsp	-11.0	-11.0	-6.8	-7.7	-8.2						-9.2	-9.5	-8.6			-15.6	-9.7
Htl	-8.4	-7.0	-4.5	-5.0	-5.4						-7.5	-7.1	-6.6			-11.8	-7.0
MBT	-0.6	-0.6	-0.3	-0.3	-0.2						-0.9	-0.7	-0.7			-2.3	-0.7
MLI	-4.8	-3.1	-2.3	-2.1	-2.3						-3.2	-3.2	-2.8			-6.2	-3.3
Nrs	-18.6	-15.4	-12.6	-11.7	-14.1						-12.1	-12.7	-11.3			-18.8	-14.1
OfL	-2.9	-2.4	-1.8	-1.5	-1.7						-2.2	-2.1	-2.0			-3.9	-2.3
OfS	-3.8	-2.9	-2.1	-1.9	-1.8						-2.9	-2.9	-2.7			-5.2	-2.9
RFF	-9.5	-8.7	-6.6	-6.2	-6.6						-7.9	-7.9	-7.2			-11.5	-8.0
RSD	-3.4	-3.6	-2.0	-2.3	-1.7						-3.9	-3.5	-3.8			-7.1	-3.5
Rt3	-2.6	-2.4	-1.3	-1.3	-0.8						-3.4	-3.3	-3.1			-7.8	-2.9
RtL	-3.2	-3.7	-2.3	-2.2	-2.0						-4.3	-4.1	-3.8			-8.8	-3.8
RtS	-5.6	-4.2	-3.3	-2.8	-2.6						-4.3	-4.3	-4.1			-8.4	-4.4
SCn	-8.4	-5.0	-4.5	-3.7	-4.3						-4.6	-4.5	-4.3			-8.4	-5.3

Table 99. SCE economizer repair/replace measure ex-post kWh/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm					912	534		447	275	240			170	205	101	318	356
ECC					485	406		371	242	223			164	163	98	273	269
EPr					287	239		177	152	125			115	97	57	168	157
ERC					209	174		126	110	91			91	76	41	141	118
ESe					303	243		205	155	130			112	101	66	157	164
EUn					608	478		387	278	246			208	183	103	356	316
Hsp					677	645		617	426	328			200	181	129	245	383
Htl					-1,333	-427		-362	-528	-702			-988	-1,085	-636	-1,974	-893
MBT					662	452		386	361	327			317	272	181	413	375
MLI					146	193		209	138	108			81	53	34	72	115
Nrs					334	287		247	143	109			63	71	32	137	158
OfL					426	310		264	224	206			185	183	104	316	246
OfS					290	253		215	168	148			104	104	79	168	170
RFF					468	391		358	206	193			113	97	74	200	233
RSD					548	465		353	227	209			92	119	55	240	256
Rt3					725	515		444	305	254			140	125	93	205	312
RtL					779	498		393	258	236			140	94	93	228	302
RtS					460	360		273	187	160			98	90	74	170	208
SCn					4	13		12	6	3			9	-3	-17	12	4

Table 100. SCE economizer repair/replace measure ex-post kW/ton savings

Building Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Average
Asm					0.05	0.00		-0.01	-0.02	-0.02			-0.01	-0.02	-0.02	0.00	-0.01
ECC					0.05	0.00		-0.01	-0.01	-0.02			0.00	-0.02	-0.02	0.00	0.00
EPr					0.05	0.00		-0.01	0.00	0.00			0.00	0.00	0.00	0.00	0.01
ERC					0.05	-0.01		-0.01	0.00	0.00			0.00	0.00	0.00	0.00	0.01
ESe					0.05	0.00		-0.01	0.00	0.00			0.00	0.00	0.00	0.00	0.01
EUn					0.05	0.00		-0.01	-0.01	-0.02			0.00	-0.02	-0.02	0.00	0.00
Hsp					0.05	-0.01		-0.01	-0.02	-0.02			-0.02	-0.03	-0.03	-0.01	-0.01
Htl					0.06	-0.04		-0.09	-0.14	-0.14			-0.12	-0.15	-0.16	-0.04	-0.09
MBT					0.03	0.00		-0.01	-0.01	-0.01			0.00	-0.01	-0.01	0.00	0.00
MLI					0.06	0.00		-0.01	-0.01	-0.01			0.00	-0.01	-0.02	0.00	0.00
Nrs					0.07	0.00		-0.01	-0.01	-0.01			-0.01	-0.02	-0.02	0.00	0.00
OfL					0.05	-0.01		-0.01	-0.02	-0.02			-0.01	-0.02	-0.02	0.00	-0.01
OfS					0.05	-0.01		-0.01	-0.02	-0.02			-0.01	-0.02	-0.02	-0.01	-0.01
RFF					0.05	0.00		-0.01	-0.02	-0.01			-0.02	-0.02	-0.02	0.00	-0.01
RSD					0.06	0.00		-0.01	-0.01	-0.01			-0.01	-0.02	-0.02	0.00	0.00
Rt3					0.05	0.00		-0.01	-0.01	-0.01			-0.01	-0.01	-0.02	0.00	0.00
RtL					0.05	-0.01		-0.01	-0.02	-0.02			-0.01	-0.02	-0.02	0.00	-0.01
RtS					0.05	-0.01		-0.01	-0.02	-0.01			-0.01	-0.01	-0.02	0.00	0.00
SCn					0.01	0.00		0.00	-0.01	-0.01			-0.01	-0.02	-0.02	0.00	-0.01

Table 101. SCG economizer repair/replace measure ex-post therm/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm					-1.8	-1.0		-0.8	-1.3	-1.4			-2.9	-2.6	-0.7	-6.5	-2.1
ECC					-1.3	-0.5		-0.4	-0.9	-1.0			-2.1	-2.2	-0.4	-4.6	-1.5
EPr					-1.2	-0.6		-0.7	-0.9	-1.0			-1.6	-1.8	-0.5	-3.3	-1.3
ERC					-1.7	-0.9		-1.0	-1.2	-1.3			-2.0	-1.9	-0.6	-3.4	-1.6
ESe					-1.6	-0.9		-0.8	-1.3	-1.4			-2.1	-2.3	-0.7	-4.2	-1.7
EUn					-1.5	-0.6		-0.7	-1.1	-1.3			-1.9	-2.3	-0.5	-4.2	-1.6
Hsp					-8.2	-4.3		-3.5	-4.8	-6.2			-8.6	-10.1	-2.8	-15.7	-7.1
Htl					-5.2	-2.4		-2.3	-3.5	-4.3			-6.6	-8.1	-1.9	-11.8	-5.1
MBT					-0.2	-0.1		-0.1	-0.2	-0.2			-0.7	-0.9	0.0	-2.2	-0.5
MLI					-2.3	-0.8		-0.7	-1.3	-1.5			-2.9	-3.3	-0.6	-6.3	-2.2
Nrs					-14.0	-7.8		-7.1	-8.2	-9.3			-11.3	-12.5	-4.6	-18.9	-10.4
OfL					-1.7	-0.7		-0.8	-1.1	-1.1			-2.0	-1.8	-0.5	-3.8	-1.5
OfS					-1.8	-0.7		-0.7	-1.2	-1.2			-2.7	-2.4	-0.4	-5.1	-1.8
RFF					-6.6	-3.7		-3.3	-4.6	-4.9			-7.2	-7.8	-2.4	-10.7	-5.7
RSD					-1.6	-0.5		-0.5	-1.2	-1.2			-3.7	-3.2	-0.7	-6.9	-2.2
Rt3					-0.8	-0.2		-0.2	-0.7	-0.8			-3.1	-3.0	-0.3	-7.8	-1.9
RtL					-1.9	-1.0		-0.9	-1.6	-1.6			-3.8	-4.4	-0.7	-8.7	-2.7
RtS					-2.6	-1.0		-1.0	-1.7	-1.8			-4.1	-3.8	-0.6	-8.4	-2.8
SCn					-4.3	-2.0		-1.9	-2.6	-2.7			-4.3	-4.6	-1.2	-8.4	-3.6

Thermostat tables

These tables show the results of the economizer measure group eQuest simulations by building type and climate zone.

Table 102. PG&E CQM thermostat measure ex-post kWh/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	128	287	265	315	242						329	318	346			258	276
ECC	278	312	285	316	276						352	333	337			357	316
EPr	260	231	205	216	226						266	240	263			265	241
ERC	163	222	221	248	213						239	240	256			190	221
ESe	221	215	178	217	162						297	268	296			283	237
EUn	472	412	403	404	410						463	410	443			531	439
MBT	228	336	326	357	324						387	370	419			306	339
MLI	256	175	104	155	86						400	285	413			376	250
OfL	548	526	500	494	540						536	497	529			545	524
OfS	227	278	212	269	200						414	326	406			419	306
RFF	194	150	141	148	149						211	172	210			191	174
RSD	280	186	161	186	173						301	229	296			329	238
Rt3	37	49	19	45	12						118	79	121			120	67
RtL	103	76	58	80	68						172	110	175			156	111
RtS	270	220	160	203	146						368	289	368			383	267
SCn	323	152	190	112	167						204	151	201			234	193

Table 103. PG&E CQM thermostat measure ex-post kW/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	0.01	-0.01	-0.01	-0.02	-0.02						-0.03	-0.02	-0.03			-0.02	-0.02
ECC	-0.01	-0.02	0.03	0.04	-0.02						0.02	-0.03	0.01			-0.02	0.00
EPr	0.01	0.01	0.00	0.03	0.00						0.02	0.03	0.01			0.03	0.02
ERC	0.14	0.04	0.01	0.02	0.14						0.02	0.02	0.02			0.03	0.05
ESe	0.00	0.01	0.00	0.01	-0.01						0.02	0.04	0.02			0.03	0.01
EUn	-0.01	0.07	0.17	0.17	-0.02						0.15	0.06	0.00			0.01	0.07
MBT	-0.02	-0.04	0.11	0.14	0.04						0.15	-0.06	0.17			0.06	0.06
MLI	0.00	0.00	0.00	0.02	0.00						0.16	-0.03	0.19			0.08	0.05
OfL	0.00	-0.02	0.04	0.03	-0.02						0.01	-0.03	0.02			-0.03	0.00
OfS	0.00	-0.02	0.08	0.08	-0.02						0.02	-0.03	0.02			-0.03	0.01
RFF	0.00	0.00	0.00	0.00	0.00						-0.01	-0.01	-0.01			-0.01	0.00
RSD	0.00	0.00	0.00	0.00	0.00						-0.02	-0.01	-0.02			-0.01	-0.01
Rt3	0.00	0.00	0.00	-0.01	-0.01						-0.05	-0.02	-0.05			-0.03	-0.02
RtL	0.01	0.00	0.00	0.00	0.00						-0.02	-0.01	-0.02			-0.01	-0.01
RtS	0.02	0.00	0.00	-0.01	0.00						-0.04	-0.02	-0.04			-0.03	-0.02
SCn	0.00	0.00	0.00	0.01	0.00						-0.01	0.01	-0.01			0.01	0.00

Table 104. PG&E CQM thermostat measure ex-post therm/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	4.7	1.9	2.4	1.7	3.5						1.1	0.8	0.9			3.3	2.3
ECC	0.3	-0.1	-0.2	-0.3	0.3						-0.9	-1.0	-0.8			1.5	-0.1
EPr	14.9	3.5	5.6	3.9	9.3						3.0	3.5	1.8			15.3	6.8
ERC	13.5	8.4	9.3	7.5	10.7						5.4	6.7	5.4			10.8	8.7
ESe	15.8	3.7	5.0	3.4	7.1						3.5	3.6	2.3			15.2	6.6
EUn	4.9	2.8	2.8	1.7	3.6						1.1	1.3	0.9			3.5	2.5
MBT	1.3	1.0	0.8	0.6	1.0						0.6	0.7	0.5			3.2	1.1
MLI	27.3	7.6	8.9	6.3	8.1						6.5	6.3	5.6			26.8	11.5
OfL	10.2	6.3	7.1	6.2	10.2						4.8	5.0	3.7			12.4	7.3
OfS	8.7	4.8	4.8	4.2	6.0						4.1	3.4	3.0			12.3	5.7
RFF	11.2	2.2	3.9	2.8	6.4						1.3	0.8	0.8			7.7	4.1
RSD	14.1	1.3	3.0	1.9	5.5						-0.3	0.8	-0.9			14.6	4.4
Rt3	1.6	0.3	0.3	0.3	0.3						0.2	0.1	0.0			1.9	0.6
RtL	11.5	2.7	3.4	2.7	5.5						1.6	1.4	1.2			7.9	4.2
RtS	13.4	4.7	5.0	4.0	7.6						2.8	2.8	2.1			13.9	6.3
SCn	21.1	5.5	8.0	5.3	8.1						2.9	2.4	3.3			23.4	8.9

Table 105. PG&E ACP thermostat measure ex-post kWh/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	131	321	290	355	258						380	365	402			294	311
ECC	292	343	309	350	298						398	372	383			397	349
EPr	266	241	210	228	231						289	257	287			284	255
ERC	169	240	229	264	227						260	257	280			204	237
ESe	225	230	187	237	169						331	295	332			305	257
EUn	491	432	424	428	430						492	434	473			551	462
MBT	245	378	362	402	359						444	421	482			341	382
MLI	263	204	113	188	91						474	338	495			426	288
OfL	575	562	530	532	569						588	541	583			590	563
OfS	235	302	227	296	213						462	360	456			450	333
RFF	197	158	144	157	152						237	188	236			210	187
RSD	282	194	167	201	177						337	250	335			349	255
Rt3	37	51	19	47	12						129	83	132			123	70
RtL	103	77	58	81	68						185	114	191			158	115
RtS	270	224	160	209	146						402	306	406			396	280
SCn	339	171	199	132	173						252	182	254			276	220

Table 106. PG&E ACP thermostat measure ex-post kW/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	0.01	-0.01	-0.01	-0.02	-0.02						-0.03	-0.02	-0.03			-0.03	-0.02
ECC	-0.01	-0.02	0.04	0.05	-0.02						0.03	-0.04	0.01			-0.02	0.00
EPr	0.01	0.01	0.00	0.04	-0.01						0.02	0.03	0.02			0.04	0.02
ERC	0.16	0.04	0.02	0.03	0.17						0.02	0.02	0.03			0.03	0.06
ESe	0.00	0.01	0.00	0.01	-0.02						0.03	0.05	0.02			0.04	0.02
EUn	-0.01	0.04	0.16	0.17	-0.02						0.16	0.03	0.00			0.00	0.06
MBT	-0.02	-0.05	0.13	0.17	0.05						0.18	-0.07	0.20			0.07	0.07
MLI	0.00	-0.01	0.00	0.05	0.00						0.19	-0.04	0.23			0.09	0.06
OfL	-0.01	-0.02	0.05	0.04	-0.02						0.02	-0.03	0.02			-0.03	0.00
OfS	0.00	-0.02	0.09	0.10	-0.02						0.03	-0.04	0.03			-0.04	0.01
RFF	0.00	0.00	0.00	0.00	0.00						-0.01	-0.01	-0.01			-0.01	0.00
RSD	0.00	0.00	0.00	-0.01	0.00						-0.03	-0.01	-0.02			-0.02	-0.01
Rt3	0.00	0.00	0.00	-0.01	-0.01						-0.06	-0.02	-0.05			-0.03	-0.02
RtL	0.01	0.00	0.00	0.00	0.00						-0.03	-0.01	-0.03			-0.01	-0.01
RtS	0.02	0.00	0.00	-0.01	0.00						-0.05	-0.03	-0.05			-0.03	-0.02
SCn	0.00	0.00	0.00	0.00	0.00						-0.02	0.00	-0.02			0.01	0.00

Table 107. PG&E ACP thermostat measure ex-post therm/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	4.7	1.9	2.4	1.7	3.5						1.1	0.8	0.9			3.3	2.3
ECC	0.3	-0.1	-0.2	-0.3	0.4						-0.9	-1.0	-0.8			1.6	-0.1
EPr	14.8	3.5	5.6	3.9	9.3						3.0	3.5	1.8			15.1	6.7
ERC	15.9	9.5	10.8	8.5	12.2						6.1	7.7	6.2			12.5	9.9
ESe	15.7	3.7	5.0	3.3	7.1						3.4	3.6	2.3			15.0	6.6
EUn	5.5	3.0	3.0	1.9	3.9						1.3	1.4	1.0			4.2	2.8
MBT	1.3	1.0	0.8	0.6	0.9						0.6	0.7	0.5			3.2	1.1
MLI	27.1	7.6	8.8	6.3	8.0						6.4	6.3	5.6			26.3	11.4
OfL	10.2	6.3	7.1	6.2	10.1						4.8	5.0	3.7			12.3	7.3
OfS	8.7	4.8	4.8	4.2	6.0						4.1	3.4	3.0			12.2	5.7
RFF	11.2	2.2	3.9	2.8	6.4						1.3	0.9	0.8			7.7	4.1
RSD	14.1	1.3	3.0	1.9	5.5						-0.3	0.8	-0.9			14.5	4.4
Rt3	1.6	0.3	0.3	0.3	0.3						0.2	0.1	0.0			1.9	0.6
RtL	11.5	2.7	3.4	2.7	5.5						1.6	1.4	1.2			7.9	4.2
RtS	13.4	4.7	5.0	4.0	7.6						2.8	2.8	2.1			13.9	6.3
SCn	20.8	5.4	7.9	5.2	8.0						2.8	2.4	3.2			22.7	8.7

Table 108. SCE thermostat measure ex-post kWh/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm					179	289		329	323	291			287	274	402	203	286
ECC					214	245		272	271	260			275	289	302	281	268
EPr					179	146		150	171	164			223	221	241	212	189
ERC					432	462		436	422	394			406	379	406	330	407
ESe					132	140		179	196	193			267	254	278	229	208
EUn					300	282		283	280	266			304	320	336	353	303
MBT					243	330		335	322	302			340	303	448	229	317
MLI					32	18		88	120	127			307	281	342	228	171
OfL					459	374		361	371	367			443	433	430	428	407
OfS					170	179		203	219	223			350	307	405	321	264
RFF					103	80		90	102	107			155	146	163	132	120
RSD					120	100		95	119	115			217	214	262	212	162
Rt3					10	21		46	47	55			95	84	132	89	64
RtL					58	44		53	67	69			136	127	197	103	95
RtS					124	91		120	150	154			296	264	314	270	198
SCn					67	-26		-45	-21	-28			79	75	127	115	38

Table 109. SCE thermostat measure ex-post kW/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm					-0.02	-0.02		-0.02	-0.02	-0.02			-0.02	-0.02	-0.03	-0.02	-0.02
ECC					-0.01	0.03		-0.03	-0.01	-0.03			0.02	0.02	0.01	-0.01	0.00
EPr					0.00	0.03		-0.01	0.04	0.03			0.02	0.02	0.01	0.04	0.02
ERC					0.15	0.03		0.05	0.02	0.02			0.03	0.03	0.02	0.03	0.04
ESe					-0.01	0.02		-0.03	0.06	0.06			0.03	0.03	0.01	0.04	0.02
EUn					-0.02	0.05		-0.02	0.00	-0.02			0.01	0.04	0.03	0.00	0.01
MBT					0.04	0.03		-0.04	0.04	-0.05			0.15	0.04	0.04	0.05	0.03
MLI					0.01	0.05		-0.03	0.05	-0.03			0.17	0.06	0.04	0.07	0.04
OfL					-0.01	-0.02		-0.02	-0.02	-0.02			0.02	-0.03	-0.04	-0.02	-0.02
OfS					-0.01	-0.02		-0.03	-0.03	-0.03			0.03	-0.04	-0.06	-0.03	-0.02
RFF					0.00	0.00		-0.01	-0.01	-0.01			-0.01	-0.01	-0.01	-0.01	-0.01
RSD					0.00	-0.01		-0.01	-0.01	-0.01			-0.02	-0.02	-0.02	-0.01	-0.01
Rt3					-0.01	-0.01		-0.03	-0.03	-0.03			-0.04	-0.04	-0.05	-0.02	-0.03
RtL						-0.01		-0.01	-0.01	-0.01			-0.02	-0.02	-0.03	0.00	-0.01
RtS					0.00	-0.01		-0.02	-0.02	-0.02			-0.04	-0.04	-0.05	-0.02	-0.03
SCn					0.00	0.01		0.02	0.01	0.01			0.00	0.00	-0.02	0.02	0.01

Table 110. SCG thermostat measure ex-post therm/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm					3.0	0.7		0.4	0.3	0.5			0.8	1.3	0.1	2.7	1.1
ECC					0.4	0.2		0.2	0.0	0.2			-0.6	-0.4	0.1	2.3	0.3
EPr					8.0	3.0		0.6	0.6	0.8			1.7	2.8	0.0	13.3	3.4
ERC					56.0	33.1		20.3	20.1	19.7			27.2	29.9	8.4	72.1	31.9
ESe					6.1	1.7		1.1	1.0	1.3			2.2	3.2	0.3	13.9	3.4
EUn					1.9	0.7		0.6	0.4	0.7			0.4	0.5	0.2	1.4	0.8
MBT					0.8	0.4		0.3	0.3	0.3			0.4	0.5	0.2	2.2	0.6
MLI					5.8	2.0		1.4	1.3	1.4			4.1	5.6	0.2	20.0	4.7
OfL					8.9	3.9		2.4	1.8	2.2			3.4	4.3	0.5	9.8	4.1
OfS					5.5	2.0		1.2	1.3	1.4			2.7	3.3	0.4	9.8	3.1
RFF					5.9	1.2		0.8	0.0	0.3			1.0	1.0	-0.1	6.1	1.8
RSD					4.1	1.1		0.3	-0.2	-0.1			-1.0	0.9	-0.2	9.0	1.5
Rt3					0.3	0.1		0.1	0.1	0.1			0.0	0.3	0.0	1.7	0.3
RtL					5.1	1.7		1.0	0.9	0.9			1.1	1.7	0.2	5.8	2.0
RtS					7.0	1.9		0.9	0.9	1.0			1.9	3.0	0.1	11.6	3.1
SCn					4.5	1.3		0.7	0.8	0.2			1.1	2.6	0.0	12.6	2.7

Table 111. SDG&E DI thermostat measure ex-post kWh/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm						443	503	496		462				373	532		468
ECC						376	388	406		400				410	359		390
EPr						194	160	202		241				318	337		242
ERC						579	597	546		517				473	540		542
ESe						201	215	255		283				345	373		279
EUn						419	433	421		413				470	435		432
MBT						511	554	509		501				465	688		538
MLI						144	100	255		296				451	482		288
OfL						505	444	488		530				595	583		524
OfS						272	281	312		354				470	571		377
RFF						141	120	167		193				234	228		180
RSD						187	173	196		234				366	386		257
Rt3						36	46	79		95				135	230		103
RtL						59	49	79		111				202	335		139
RtS						128	119	187		258				402	432		254
SCn						77	40	74		131				289	271		147

Table 112. SDG&E DI thermostat measure ex-post kW/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm						-0.03	-0.03	-0.03		-0.03				-0.03	-0.04		-0.03
ECC						0.04	-0.04	-0.05		-0.05				0.02	0.01		-0.01
EPr						0.03	-0.01	-0.02		0.04				0.03	0.01		0.01
ERC						0.04	0.11	0.08		0.03				0.03	0.03		0.05
ESe						0.01	-0.03	-0.04		0.06				0.04	0.01		0.01
EUn						0.06	-0.03	-0.03		-0.03				0.05	0.03		0.01
MBT						0.05	-0.09	-0.07		-0.08				0.03	0.01		-0.03
MLI						0.07	-0.02	-0.07		-0.06				0.04	0.04		0.00
OfL						-0.03	-0.04	-0.03		-0.04				-0.04	-0.05		-0.04
OfS						-0.03	-0.03	-0.04		-0.05				-0.07	-0.08		-0.05
RFF						-0.01	-0.01	-0.01		-0.01				-0.02	-0.02		-0.01
RSD						-0.02	-0.02	-0.02		-0.02				-0.03	-0.03		-0.02
Rt3						-0.02	-0.03	-0.06		-0.05				-0.07	-0.08		-0.05
RtL						-0.01	-0.01	-0.02		-0.02				-0.03	-0.05		-0.02
RtS						-0.02	-0.02	-0.04		-0.04				-0.06	-0.07		-0.04
SCn						0.00	0.00	-0.01		-0.01				-0.04	-0.05		-0.02

Table 113. SDG&E DI thermostat measure ex-post therm/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm						0.8	0.8	0.6		0.7				1.5	0.2		0.8
ECC						0.1	0.1	0.2		0.1				-0.6	0.2		0.0
EPr						3.3	1.9	0.8		0.9				3.2	0.0		1.7
ERC						35.7	33.3	22.3		23.4				31.2	10.2		26.0
ESe						2.1	1.7	1.4		1.4				3.7	0.4		1.8
EUn						1.0	1.3	0.9		0.8				0.6	0.4		0.8
MBT						0.5	0.5	0.4		0.5				0.6	0.2		0.5
MLI						3.2	1.0	2.2		1.9				7.8	0.3		2.7
OfL						4.7	2.0	2.8		2.8				4.9	0.6		3.0
OfS						2.3	0.7	1.3		1.7				4.4	0.5		1.8
RFF						1.2	0.7	0.8		0.1				0.8	-0.2		0.6
RSD						1.3	0.0	0.3		0.3				2.0	-0.3		0.6
Rt3						0.1	0.0	0.1		0.1				0.4	0.0		0.1
RtL						1.7	0.7	1.0		1.0				1.9	0.2		1.1
RtS						1.9	0.5	0.9		1.1				3.4	0.1		1.3
SCn						3.3	1.7	1.9		2.0				6.6	0.7		2.7

Condenser coil cleaning tables

These tables show the results of the condenser coil cleaning eQuest simulations by building type and climate zone. The savings are in kWh and kW per ton of cooling.

Table 114. Condenser coil cleaning measure ex-post kWh/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	3	33	20	40	22	40	37	52	47	54	55	44	56	62	95	25	43
ECC	11	32	22	33	23	37	39	46	41	44	54	38	47	53	75	29	39
EPr	6	16	16	24	15	21	27	24	25	30	26	23	32	31	46	14	24
ERC	5	20	13	22	17	26	25	26	27	28	32	26	36	32	54	16	25
ESe	3	20	15	19	17	26	23	30	29	26	33	27	35	28	59	14	25
EUn	21	40	37	47	38	56	63	58	51	56	58	50	59	57	88	37	51
Hsp	38	53	55	63	54	78	84	84	76	74	69	61	76	74	114	47	69
Htl	66	164	127	186	132	206	242	229	228	238	261	201	274	246	405	165	210
MBT	50	63	61	63	69	77	79	70	69	71	67	67	73	67	90	56	68
MLI	1	20	11	23	8	26	25	36	32	35	36	29	42	38	64	19	28
Nrs	4	21	13	26	14	27	26	34	34	36	39	30	41	42	75	19	30
OfL	31	45	40	46	44	53	57	54	47	54	52	51	55	49	72	41	50
OfS	23	40	34	40	36	48	51	51	45	51	49	46	53	51	73	37	45
RFF	9	36	26	42	27	44	46	55	49	60	60	46	62	67	102	30	47
RSD	10	36	19	38	18	42	37	52	50	59	56	51	56	62	84	28	44
Rt3	6	43	29	48	30	58	68	72	61	65	59	49	64	62	98	33	53
RtL	9	40	30	48	33	51	52	57	54	62	59	47	64	54	99	29	49
RtS	10	43	30	46	33	56	63	62	58	61	59	53	65	61	95	37	52
SCn	0	7	1	8	0	8	5	14	15	19	22	14	26	25	46	7	14

Table 115. Condenser coil cleaning measure ex-post kW/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	0.00	0.02	0.01	0.03	0.02	0.02	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.04	0.04	0.03	0.03
ECC	0.01	0.01	0.00	0.01	0.02	0.01	0.03	0.03	0.02	0.03	0.02	0.03	0.01	0.03	0.03	0.02	0.02
EPr	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.03	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01
ERC	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
ESe	0.00	0.00	0.00	0.00	0.02	0.00	0.03	0.03	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.01
EUn	0.01	0.02	0.01	0.01	0.02	0.02	0.04	0.04	0.02	0.03	0.02	0.03	0.01	0.03	0.03	0.02	0.02
Hsp	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.02	0.02
Htl	0.02	0.07	0.05	0.10	0.06	0.09	0.11	0.11	0.12	0.13	0.11	0.11	0.13	0.13	0.13	0.11	0.10
MBT	0.02	0.03	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.04	0.01	0.04	0.01	0.03	0.03	0.02	0.02
MLI	0.00	0.02	0.00	0.01	0.01	0.02	0.03	0.04	0.02	0.04	0.01	0.03	0.01	0.03	0.03	0.02	0.02
Nrs	0.00	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02
OfL	0.02	0.02	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.04	0.02	0.03	0.03	0.03	0.03
OfS	0.01	0.02	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.03	0.03	0.03	0.03
RFF	0.00	0.01	0.01	0.02	0.01	0.02	0.02	0.03	0.03	0.04	0.03	0.03	0.03	0.04	0.03	0.02	0.02
RSD	0.01	0.02	0.01	0.03	0.01	0.03	0.02	0.03	0.03	0.04	0.03	0.04	0.03	0.04	0.03	0.03	0.03
Rt3	0.00	0.02	0.02	0.03	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.04	0.04	0.04	0.03	0.03
RtL	0.00	0.02	0.01	0.03	0.02	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.04	0.04	0.03	0.03
RtS	0.00	0.02	0.02	0.03	0.02	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03
SCn	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.01

Evaporator coil cleaning tables

These tables show the results of the evaporator coil cleaning eQuest simulations by building type and climate zone. The savings are in kWh and kW per ton of cooling.

Table 116. Evaporator coil cleaning measure ex-post kWh/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	1	9	6	11	7	10	8	13	12	13	12	12	14	10	18	5	10
ECC	4	9	7	9	7	10	11	12	10	11	11	10	12	8	14	5	9
EPr	2	5	4	6	5	7	6	7	7	7	6	6	7	5	9	2	6
ERC	2	5	4	6	5	7	6	7	7	7	6	6	8	5	11	3	6
ESe	1	5	4	6	4	6	6	7	6	7	6	6	8	5	11	2	6
EUn	7	11	11	12	11	13	14	14	12	13	12	13	14	10	16	6	12
Hsp	9	11	12	13	12	15	18	18	15	16	14	13	16	12	19	7	14
Htl	13	23	24	30	19	24	26	33	32	34	26	29	39	30	54	17	28
MBT	10	12	12	13	13	14	14	14	14	14	12	13	13	9	14	7	12
MLI	1	6	4	7	4	7	7	10	9	9	9	8	10	7	14	4	7
Nrs	2	7	5	9	5	9	8	10	10	11	10	9	12	9	17	4	9
OfL	6	8	8	9	8	10	10	10	9	10	8	9	10	7	12	5	9
OfS	4	6	6	7	6	8	9	9	8	9	7	7	8	7	10	5	7
RFF	3	10	8	12	8	11	12	14	12	14	14	12	16	10	22	6	12
RSD	2	10	6	11	6	11	9	14	13	15	13	14	15	10	19	6	11
Rt3	2	12	9	13	9	14	16	18	15	17	14	13	17	12	20	7	13
RtL	3	11	8	13	8	12	13	15	13	15	13	12	16	10	21	6	12
RtS	3	11	8	12	9	13	14	14	13	15	13	13	16	11	19	7	12
SCn	0	2	0	3	0	3	2	4	5	5	5	4	7	4	11	2	4

Table 117. Evaporator coil cleaning measure ex-post kW/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01
ECC	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
EPr	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ERC	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00
ESe	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EUn	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01
Hsp	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01
Htl	0.00	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.01
MBT	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
MLI	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00
Nrs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
OfL	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00
OfS	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
RFF	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01
RSD	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01
Rt3	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01
RtL	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01
RtS	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01
SCn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00

RCA tables

These tables show the results of the refrigerant charge adjustment measure group eQuest simulations by building type, climate zone, and IOU. The results for each IOU were calculated using the distribution of HVAC metering device type (TXV or non-TXV) and whether systems were overcharged or undercharged upon entering the QM program found in the implementer data files from programs in each IOU territory.

Table 118. PG&E RCA measure ex-post kWh/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	3	25	16	30	18						35	31	37			19	24
ECC	11	25	21	27	21						33	28	34			22	25
EPr	4	14	12	16	13						19	17	21			10	14
ERC	5	16	11	17	14						22	19	25			13	16
ESe	3	13	10	16	12						21	17	23			10	14
EUn	20	34	32	36	32						41	37	42			28	34
Hsp	28	36	39	43	39						49	40	49			33	40
Htl	56	117	95	124	99						151	119	162			104	114
MBT	37	45	46	46	48						44	45	45			37	44
MLI	3	18	13	22	11						27	24	32			15	18
Nrs	5	19	15	23	15						30	25	32			16	20
OfL	22	29	29	32	31						33	32	35			28	30
OfS	15	26	24	28	25						31	28	32			25	26
RFF	9	28	21	33	23						41	33	43			23	28
RSD	4	26	16	29	16						38	36	38			20	25
Rt3	7	32	24	36	25						40	35	44			23	30
RtL	8	30	23	36	24						40	34	43			24	29
RtS	9	31	23	34	26						38	36	43			24	29
SCn	0	6	1	7	0						15	11	19			6	7

Table 119. PG&E RCA measure ex-post kW/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm	0.00	0.01	0.01	0.02	0.01						0.02	0.02	0.02			0.02	0.01
ECC	0.01	0.01	0.00	0.01	0.01						0.01	0.02	0.01			0.01	0.01
EPr	0.00	0.00	0.00	0.00	0.01						0.00	0.00	0.01			0.00	0.00
ERC	0.00	0.00	0.00	0.01	0.01						0.01	0.01	0.01			0.01	0.01
ESe	0.00	0.00	0.00	0.00	0.01						0.00	0.00	0.01			0.00	0.00
EUn	0.01	0.02	0.01	0.01	0.02						0.01	0.02	0.01			0.01	0.01
Hsp	0.01	0.01	0.01	0.02	0.01						0.02	0.02	0.01			0.01	0.01
Htl	0.02	0.05	0.04	0.07	0.04						0.07	0.07	0.08			0.07	0.06
MBT	0.01	0.02	0.01	0.01	0.01						0.01	0.02	0.01			0.01	0.01
MLI	0.00	0.02	0.00	0.01	0.01						0.01	0.02	0.01			0.01	0.01
Nrs	0.00	0.01	0.01	0.01	0.01						0.01	0.01	0.01			0.01	0.01
OfL	0.01	0.02	0.01	0.01	0.01						0.01	0.02	0.01			0.02	0.01
OfS	0.01	0.02	0.01	0.01	0.01						0.01	0.02	0.01			0.02	0.01
RFF	0.00	0.01	0.01	0.02	0.01						0.02	0.02	0.02			0.02	0.01
RSD	0.00	0.01	0.01	0.02	0.01						0.02	0.02	0.02			0.02	0.01
Rt3	0.00	0.01	0.01	0.02	0.02						0.03	0.02	0.02			0.01	0.02
RtL	0.00	0.02	0.01	0.02	0.02						0.02	0.02	0.02			0.02	0.02
RtS	0.00	0.02	0.01	0.02	0.02						0.03	0.02	0.02			0.01	0.02
SCn	0.00	0.01	0.00	0.01	0.00						0.01	0.01	0.01			0.01	0.01

Table 120. SCE RCA measure ex-post kWh/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm					14	24		31	28	28			28	26	41	14	26
ECC					21	33		38	31	31			32	28	45	19	31
EPr					12	18		18	16	17			18	16	27	8	17
ERC					11	17		17	17	17			19	17	27	9	17
ESe					13	20		22	21	20			23	20	34	9	20
EUn					26	35		36	30	32			33	29	45	21	32
Hsp					42	55		63	54	50			50	44	68	30	51
Htl					99	134		134	126	129			150	131	220	94	135
MBT					42	46		44	41	44			41	37	48	33	42
MLI					11	26		32	27	25			30	20	40	13	25
Nrs					13	23		27	25	26			28	25	47	13	25
OfL					27	32		33	28	31			29	29	38	23	30
OfS					26	34		36	32	32			32	31	41	23	32
RFF					18	29		36	31	36			37	31	58	19	33
RSD					15	31		38	35	37			34	30	46	16	31
Rt3					19	35		41	35	35			34	26	45	17	32
RtL					19	32		35	32	33			33	24	47	17	30
RtS					20	32		34	31	32			33	25	44	18	30
SCn					0	6		10	11	10			14	11	23	4	10

Table 121. SCE RCA measure ex-post kW/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm					0.01	0.01		0.02	0.02	0.02			0.01	0.01	0.01	0.01	0.01
ECC					0.01	0.01		0.03	0.01	0.02			0.00	0.01	0.01	0.01	0.01
EPr					0.01	0.00		0.02	0.00	0.00			0.00	0.00	0.01	0.00	0.01
ERC					0.00	0.00		0.02	0.01	0.01			0.01	0.01	0.01	0.00	0.01
ESe					0.01	0.00		0.03	0.00	0.00			0.01	0.01	0.01	0.00	0.01
EUn					0.01	0.01		0.02	0.01	0.02			0.00	0.01	0.01	0.01	0.01
Hsp					0.01	0.02		0.02	0.02	0.02			0.01	0.02	0.02	0.01	0.02
Htl					0.04	0.06		0.07	0.07	0.08			0.08	0.07	0.07	0.07	0.07
MBT					0.01	0.01		0.02	0.01	0.02			0.00	0.01	0.01	0.01	0.01
MLI					0.01	0.01		0.03	0.02	0.03			0.01	0.01	0.01	0.01	0.01
Nrs					0.01	0.01		0.01	0.01	0.02			0.01	0.01	0.01	0.01	0.01
OfL					0.01	0.01		0.02	0.02	0.02			0.01	0.01	0.01	0.01	0.01
OfS					0.01	0.02		0.02	0.02	0.02			0.01	0.02	0.02	0.02	0.02
RFF					0.01	0.01		0.02	0.02	0.02			0.01	0.01	0.02	0.02	0.02
RSD					0.01	0.02		0.02	0.02	0.02			0.02	0.01	0.02	0.02	0.02
Rt3					0.01	0.02		0.02	0.02	0.02			0.02	0.01	0.02	0.01	0.02
RtL					0.01	0.02		0.02	0.02	0.02			0.01	0.01	0.02	0.01	0.02
RtS					0.01	0.02		0.02	0.02	0.02			0.02	0.01	0.01	0.01	0.01
SCn					0.00	0.01		0.01	0.01	0.01			0.01	0.01	0.01	0.01	0.01

Table 122. SDG&E RCA measure ex-post kWh/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm						29	28	37		37				35	56		37
ECC						31	34	36		32				30	44		35
EPr						20	19	19		21				19	32		22
ERC						21	20	21		22				23	37		24
ESe						18	19	20		21				21	37		23
EUn						41	45	42		39				36	51		42
Hsp						52	61	59		51				48	63		55
Htl						129	145	133		139				142	240		155
MBT						51	52	49		48				41	53		49
MLI						23	23	29		27				21	43		28
Nrs						26	26	31		31				31	47		32
OfL						36	37	37		35				34	44		37
OfS						34	36	36		34				34	45		37
RFF						34	36	43		42				35	67		43
RSD						33	30	40		42				36	55		39
Rt3						43	50	52		47				35	60		48
RtL						39	41	45		44				33	63		44
RtS						40	45	43		42				34	59		44
SCn						7	5	12		15				17	34		15

Table 123. SDG&E RCA measure ex-post kW/ton savings

Building Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8	CZ 9	CZ 10	CZ 11	CZ 12	CZ 13	CZ 14	CZ 15	CZ 16	Average
Asm						0.02	0.02	0.02		0.03				0.01	0.02		0.02
ECC						0.01	0.02	0.02		0.02				0.01	0.01		0.02
EPr						0.00	0.02	0.02		0.00				0.01	0.01		0.01
ERC						0.00	0.02	0.02		0.01				0.02	0.01		0.01
ESe						0.00	0.02	0.02		0.00				0.01	0.01		0.01
EUn						0.01	0.03	0.03		0.02				0.02	0.01		0.02
Hsp						0.02	0.02	0.02		0.02				0.02	0.02		0.02
Htl						0.06	0.07	0.07		0.09				0.08	0.08		0.07
MBT						0.01	0.02	0.02		0.03				0.01	0.01		0.02
MLI						0.01	0.02	0.02		0.03				0.01	0.01		0.02
Nrs						0.01	0.01	0.02		0.02				0.02	0.01		0.01
OfL						0.02	0.02	0.02		0.02				0.01	0.02		0.02
OfS						0.02	0.02	0.02		0.02				0.02	0.02		0.02
RFF						0.02	0.02	0.02		0.03				0.02	0.02		0.02
RSD						0.02	0.02	0.02		0.03				0.01	0.02		0.02
Rt3						0.02	0.02	0.02		0.03				0.01	0.02		0.02
RtL						0.02	0.02	0.02		0.03				0.02	0.02		0.02
RtS						0.02	0.02	0.02		0.03				0.01	0.02		0.02
SCn						0.01	0.01	0.02		0.02				0.02	0.02		0.02

APPENDIX H. RESIDENTIAL PROGRAM TRACKING SAVINGS

In APPENDIX H the program tracking savings are presented using ex ante claims and savings values from the 2013 Workpaper Disposition. The ex ante claims and workpaper disposition values are climate zone and measure specific.

Table 124 presents PG&E's ex ante claimed first year savings values for residential QM measures by climate zone and year. These data indicate that residential QM in PG&E's program is a distribution of three measures. In 2013, no households received RCA while in 2014 very few households received a fan repair.

The second and third three sets of rows in the table lists the quantity of tons claimed per measure and the average quantity of tons per household. Next, the table lists the Workpaper Disposition savings per ton. The Workpaper disposition savings differ by climate zone and measure, but not by year. The Workpaper savings per ton are substantially lower than the ex ante savings per ton in PG&E's tracking data.

The next set of rows, labeled Ex Ante First Year Savings Using Workpaper Disposition, presents the PG&E ex ante first year savings using the Workpaper Disposition savings and the quantity of tons installed by climate zone and year. Comparing the Ex Ante Claimed Savings with the Ex Ante First Year Savings Using Workpaper Disposition indicates that the size of the claimed savings far exceeds the savings prescribed by the Workpaper Disposition. Comparing the PG&E tracking data ex ante first year savings claims to the PG&E ex ante first year savings claims using the Workpaper Disposition values, HVAC fan repair is anticipated to save 1% of PG&E's tracking data claim values (8,167/1,061224), 79% for Blower Motor Repair (6,393,630/8,060,766) and 52% for HVAC RCA (1,138,090/2,171,218).

Table 124. PG&E program tracking savings using ex ante claims and workpaper disposition

Year	2013			2014			2015			
Climate Zone	11	12	13	11	12	13	11	12	13	Total
Ex Ante Claimed Savings										
HVAC FAN REPAIR	47,588	138,521	587,742	7,865	8,958	30,587	8,644	111,923	119,397	1,061,224
HVAC MOTOR REPLACE MENT	6,609	35,486	1,990	38,708	1,353,804	2,046,743	55,238	2,045,854	2,476,334	8,060,766
HVAC RCA	-	-	-	6,162	185,174	1,172,732	9,251	230,396	567,503	2,171,218
Quantity of Tons										
HVAC FAN REPAIR	300	1,253	2,690	50	81	140	57	1,012	547	6,128
HVAC MOTOR REPLACE MENT	32	236	11	206	10,902	12,147	359	19,231	15,355	58,477
HVAC RCA	-	-	-	94	5,796	18,420	286	11,408	15,365	51,368

Year	2013			2014			2015			
Climate Zone	11	12	13	11	12	13	11	12	13	Total
Quantity of Tons/ household										
HVAC FAN REPAIR	3.57	3.31	3.73	2.75	3.24	3.59	3.77	3.41	3.62	
HVAC MOTOR REPLACE MENT	3.50	3.46	3.67	3.61	3.24	3.10	3.81	3.11	3.04	
HVAC RCA				3.46	3.26	3.34	3.86	3.17	3.13	
Work paper Disposition Savings per ton										
HVAC FAN REPAIR	1.40	0.87	1.65	1.40	0.87	1.65	1.40	0.87	1.65	
HVAC MOTOR REPLACE MENT	138.61	99.54	119.51	138.61	99.54	119.51	138.61	99.54	119.51	
HVAC RCA	22.36	13.90	26.36	22.36	13.90	26.36	22.36	13.90	26.36	
Ex Ante First Year Savings Using Workpaper Disposition										
HVAC FAN REPAIR	418	1,088	4,431	69	70	231	79	879	900	8,167
HVAC MOTOR REPLACE MENT	4,366	23,442	1,315	28,553	1,085,198	1,451,666	49,691	1,914,277	1,835,124	6,393,630
HVAC RCA	-	-	-	2,090	80,584	485,463	6,394	158,624	404,934	1,138,090
Ex Ante First Year Savings per household Using Workpaper Values										
HVAC FAN REPAIR	4.98	2.88	6.14	3.84	2.82	5.91	5.26	2.96	5.96	
HVAC MOTOR REPLACE MENT	485.12	344.73	438.21	500.93	322.98	370.32	528.62	309.30	363.75	
HVAC RCA	0.00	0.00	0.00	77.42	45.35	87.91	86.40	44.01	82.44	

The final set of rows in the table above illustrate the ex ante first year savings values per household using the Workpaper Disposition values for HVAC fan repair, blower motors, and RCA by climate zones and year. Yearly differences are due to differences in the quantity of tons installed per household over the three years analyzed. Climate zone differs are due to DEER estimates of HVAC usage by climate zone. The values in the last three rows show that the ex ante workpaper disposition savings per household from fan repair are extremely small, too small to be observed in billing data. The ex ante workpaper disposition savings per household for motor replacement and RCA are substantially larger than those for fan repair.

Table 125 lists the SDG&E's ex ante claimed first year savings values for program measures by climate zone and year. The table also lists the quantity of claimed measures and the average quantity per household.

SDG&E's tracking data did not list the number of ton per installed measure. Given the consistency of savings in the tracking data with the workpaper values, it is likely that SDG&E's tracking data accurately represents the workpaper disposition values. To know if SDG&E's tracking data represent the workpaper disposition values, it would be necessary to have the quantity of installed tons. The evaluation team has requested information on the tons installed in SDG&E residential QM program. Unfortunately, these data were not available in time for this evaluation.

The ex ante claimed savings from the SDG&E tracking data are small when compared to PG&E's claimed savings. In addition, most SDG&E's claims are associated with fan controls. The fan controls measure is the only measure for which the SDG&E ex ante claimed savings per unit installed changed over the analysis time period. The California HVAC Upgrade: Efficient Fan Controller (EFC) – Residential workpaper WPSDGEREHC0024 Revision #0 (October 25, 2012) saving differ substantially from the per unit savings claimed by SDG&E. It appears that SDG&E incorrectly claimed the climate zone weighted average ex ante savings for double-wide mobile homes instead of the much lower ex ante savings for single family homes. In the fourth quarter of 2015, SDG&E changed their ex ante claimed savings values for EFCs, but it is not clear where the updated values are derived from.

Table 125. SDG&E program tracking savings using ex ante claims and workpaper disposition

Climate Zone	2013					2014					2015					Total
	6	7	8	10	14	6	7	8	10	14	6	7	8	10	14	
Ex Ante Claimed Savings, kWh																
HVAC FAN REPAIR	1.8	25.6	6.1	49.0	0.0	1.8	27.7	0.0	52.5	0.0	0.0	8.5	3.1	31.5	0.0	207.7
HVAC MOTOR REPLACEMENT	0.0	362.7	48.6	815.6	0.0	0.0	302.3	0.0	667.3	0.0	0.0	60.5	0.0	222.4	0.0	2479.4
HVAC RCA	141.2	685.7	157.7	733.6	0.0	141.2	394.1	0.0	970.6	0.0	38.0	620.8	107.5	1021.7	0.0	5012.3
HVAC COIL CLEANING	111.1	1291.0	111.3	3072.9	363.6	111.1	307.1	38.0	654.5	10.4	32.7	1795.2	312.2	5706.4	348.0	14265.4
HVAC Fan Controls	9,513	114,689	3,171	164,370	9,513	5,285	45,981	3,700	64,479	529	15,434	97,574	9,155	168,915	8,161	720,545
Quantity Units																
HVAC FAN REPAIR	1	12	2	14	0	1	13	0	15	0	0	4	1	9	0	72
HVAC MOTOR REPLACEMENT	0	6	1	11	0	0	5	0	9	0	0	1	0	3	0	36
HVAC RCA	3	13	2	9	0	3	9	0	14	0	1	15	2	16	0	87
HVAC COIL CLEANING	34	340.5	20.5	493	35	34	81	7	105	1	10	473.5	57.5	915.5	33.5	2,641
HVAC Fan Controls	18	217	6	311	18	10	87	7	122	1	72	319	43	543	24	1,799
Quantity/Household																
HVAC FAN REPAIR	1.0	1.2	1.0	1.1		1.0	1.3		1.0			1.0	1.0	1.0		
HVAC MOTOR REPLACEMENT		1.2	1.0	1.6			1.3		1.1			1.0		1.0		
HVAC RCA	1.5	1.2	1.0	1.0		1.5	1.1		1.1		1.0	3.0	2.0	2.7		
HVAC COIL CLEANING	3.8	2.3	6.8	2.4	2.3	3.8	1.3	1.4	1.3	1.0	1.1	1.6	1.9	2.0	2.0	
HVAC Fan Controls	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	

Climate Zone	2013					2014					2015					Total
	6	7	8	10	14	6	7	8	10	14	6	7	8	10	14	
Workpaper Savings per Ton																
HVAC FAN REPAIR	1.8	0.7	1.0	1.2		1.8	0.7	1.0	1.2		1.8	0.7	1.0	1.2		
HVAC MOTOR REPLACEMENT	30.9	60.5	48.6	74.1		30.9	60.5	48.6	74.1		30.9	60.5	48.6	74.1		
HVAC RCA	9.8	11.4	16.3	18.7		9.8	11.4	16.3	18.7		9.8	11.4	16.3	18.7		
HVAC COIL CLEANING	1.2	1.4	2.0	2.3	3.9	1.2	1.4	2.0	2.3	3.9	1.2	1.4	2.0	2.3	3.9	
HVAC Fan Controls (per unit)	84	75	129	149	290	84	75	129	149	290	84	75	129	149	290	

APPENDIX I. RESIDENTIAL QM IMPACT MODEL SPECIFICATIONS AND PARAMETER ESTIMATES

The model specification for the PG&E gross model is provided in the report. The model specifications for the PG&E net model, SDG&E gross model, and the SDG&E net model are provided below.

PG&E Hourly Net Model Specification:

$$\begin{aligned}kWh_{it} = \gamma_i &+ \sum_d \beta_1^d \times DOW_d + \sum_m \beta_2^m \times Month_m + \beta_3 \times CDH65_{it} + \beta_4 \times HDH65_{it} \\ &+ \beta_5 \times EEkWh_{it} + \beta_6 \times QFan_{it} \times Post_{it} + \beta_7 \times QBlowerMotor_{it} \times Post_{it} \\ &+ \beta_8 \times QRCA_{it} \times Post_{it} + \beta_9 \times QFan_{it} \times CDH65_{it} \times Post_{it} \\ &+ \beta_{10} \times QBlowerMotor_{it} \times CDH65_{it} \times Post_{it} \\ &+ \beta_{11} \times QRCA_{it} \times CDH65_{it} \times Post_{it} \\ &+ \beta_{12} \times QFan_{it} \times HDH65_{it} \times Post_{it} \\ &+ \beta_{13} \times QBlowerMotor_{it} \times HDH65_{it} \times Post_{it} \\ &+ \beta_{14} \times QRCA_{it} \times HDH65_{it} \times Post_{it} \\ &+ \beta_{15} \times Post_{it} + \varepsilon_{it}\end{aligned}$$

SDG&E hourly gross model specification:

$$\begin{aligned}kWh_{it} = \gamma_i &+ \sum_d \beta_1^d \times DOW_d + \sum_m \beta_2^m \times Month_m + \beta_3 \times CDH65_{it} + \beta_4 \times HDH65_{it} \\ &+ \beta_5 \times EEkWh_{it} + \beta_6 \times D\_QM_i \times Post_{it} + \beta_7 \times CDH65_{it} \times D\_QM_i \times Post_{it} \\ &+ \beta_8 \times HDH65_{it} \times D\_QM_i \times Post_{it} + \varepsilon_{it}\end{aligned}$$

SDG&E hourly net model specification:

$$\begin{aligned}kWh_{it} = \gamma_i &+ \sum_d \beta_1^d \times DOW_d + \sum_m \beta_2^m \times Month_m + \beta_3 \times CDH65_{it} + \beta_4 \times HDH65_{it} \\ &+ \beta_5 \times EEkWh_{it} + \beta_6 \times D\_QM_i \times Post_{it} + \beta_7 \times CDH65_{it} \times D\_QM_i \times Post_{it} \\ &+ \beta_8 \times HDH65_{it} \times D\_QM_i \times Post_{it} + \beta_9 \times Post_{it} + \varepsilon_{it}\end{aligned}$$

The following tables present the impact parameter estimates for the PG&E gross and net hourly models. These tables are followed by similar tables for SDG&E.

Table 126. PG&E gross parameter coefficients, 2013, hourly weekday models (fans)

Hour	Quantity Fan Estimate	t Value	CDH65* Quantity Fan Estimate	t Value	HDH65* Quantity Fan Estimate	t Value	R^2
Hour_00	-0.0034	-2.9662	0.0019	14.5608	-0.0004	-5.3305	0.4514
Hour_01	-0.0006	-0.6440	0.0019	15.4010	-0.0005	-8.3521	0.4891
Hour_02	-0.0003	-0.3275	0.0015	11.5633	-0.0005	-8.7114	0.5152
Hour_03	-0.0022	-2.7714	0.0012	9.3898	-0.0003	-6.8903	0.5010
Hour_04	-0.0039	-5.0103	0.0003	2.3196	-0.0003	-5.6947	0.5115
Hour_05	-0.0001	-0.1025	-0.0001	-0.7376	-0.0004	-8.3597	0.5003
Hour_06	0.0014	1.4532	0.0004	2.1163	-0.0006	-9.5214	0.4702
Hour_07	-0.0046	-4.1029	0.0009	5.2042	-0.0004	-6.1151	0.4522
Hour_08	-0.0083	-6.9806	-0.0001	-0.6741	-0.0002	-3.4238	0.4152
Hour_09	-0.0105	-7.7633	-0.0003	-2.1465	-0.0004	-4.2475	0.3873
Hour_10	-0.0125	-8.3095	0.0001	0.6471	-0.0003	-1.9660	0.3656
Hour_11	-0.0059	-3.5319	-0.0002	-1.8662	-0.0003	-1.4617	0.3545
Hour_12	-0.0047	-2.5982	-0.0002	-1.6582	-0.0003	-1.1709	0.3693
Hour_13	-0.0101	-5.2555	0.0002	2.0649	0.0002	0.7018	0.4014
Hour_14	-0.0182	-9.0662	0.0003	3.3105	0.0006	1.8877	0.4395
Hour_15	-0.0282	-13.2774	0.0006	6.6028	0.0016	4.8089	0.4703
Hour_16	-0.0318	-14.4166	0.0011	10.7734	0.0025	7.2059	0.4913
Hour_17	-0.0312	-13.7339	0.0016	15.7461	0.0023	7.6490	0.4937
Hour_18	-0.0207	-9.3351	0.0019	18.0781	0.0014	5.8871	0.4822
Hour_19	-0.0182	-8.6894	0.0024	20.9095	0.0009	4.6789	0.4612
Hour_20	-0.0163	-8.3044	0.0025	20.3091	0.0004	2.2612	0.4514
Hour_21	-0.0084	-4.6227	0.0018	13.3493	-0.0002	-1.6744	0.4444
Hour_22	-0.0053	-3.2259	0.0021	15.1686	-0.0003	-2.6368	0.4368
Hour_23	-0.0024	-1.7112	0.0015	10.7089	-0.0006	-5.9132	0.4331

Table 127. PG&E gross parameter coefficients, 2013, weekend models

Hour	Quantity Fan Estimate	t Value	CDH65* Quantity Fan Estimate	t Value	HDH65* Quantity Fan Estimate	t Value	R^2
Hour_00	0.0031	1.5852	0.0006	3.1009	-0.0009	-6.4374	0.4286
Hour_01	0.0033	1.9734	0.0014	7.0225	-0.0008	-7.2476	0.4605
Hour_02	0.0038	2.5953	0.0014	7.0497	-0.0007	-7.6218	0.4939
Hour_03	0.0015	1.1385	0.0006	3.1664	-0.0005	-6.2006	0.4888
Hour_04	-0.0006	-0.4535	0.0004	1.7142	-0.0004	-4.9076	0.4984
Hour_05	0.0028	2.1728	0.0003	1.3656	-0.0005	-6.6255	0.4793
Hour_06	0.0069	4.8197	-0.0005	-1.8951	-0.0008	-9.2901	0.4383
Hour_07	0.0020	1.1285	0.0003	1.2616	-0.0005	-5.3326	0.4148
Hour_08	-0.0047	-2.3947	-0.0003	-1.2409	-0.0006	-5.3080	0.3912
Hour_09	-0.0139	-6.0894	-0.0003	-1.8746	-0.0005	-3.0193	0.3532
Hour_10	-0.0158	-6.2497	0.0000	0.1127	-0.0002	-0.7647	0.3426
Hour_11	-0.0126	-4.4068	0.0003	1.7557	0.0002	0.5700	0.3338
Hour_12	-0.0179	-5.8353	0.0005	2.7906	0.0010	2.6892	0.3638
Hour_13	-0.0200	-6.2104	0.0006	3.5921	0.0014	2.9911	0.3963
Hour_14	-0.0304	-9.0350	0.0010	6.5266	0.0017	3.4136	0.4347
Hour_15	-0.0334	-9.6935	0.0012	8.1613	0.0020	3.7011	0.4647
Hour_16	-0.0302	-8.5833	0.0014	9.0000	0.0022	4.0579	0.4869
Hour_17	-0.0244	-6.7916	0.0015	9.7156	0.0027	5.7276	0.4802
Hour_18	-0.0091	-2.5966	0.0017	10.5990	0.0009	2.4444	0.4759
Hour_19	-0.0058	-1.7503	0.0022	12.5187	0.0006	1.9933	0.4560
Hour_20	-0.0040	-1.2838	0.0020	10.4687	0.0000	-0.1713	0.4406
Hour_21	0.0024	0.8519	0.0009	4.5837	-0.0006	-2.7155	0.4345
Hour_22	0.0025	0.9906	0.0008	4.0582	-0.0007	-3.8867	0.4283
Hour_23	0.0021	0.9546	0.0008	4.0228	-0.0009	-5.9070	0.4272

Table 128. PG&E Gross parameter coefficients, 2014, hourly weekday models (blower motor)

Hour	Quantity Blower Motor Estimate	t Value	CDH65* Quantity Blower Motor Estimate	t Value	HDH65* Quantity Blower Motor Estimate	t Value	R^2
Hour_00	0.0057	12.7831	-0.0005	-9.8485	-0.0008	-23.6753	0.4106
Hour_01	0.0052	13.6137	-0.0005	-10.6014	-0.0008	-28.1165	0.4277
Hour_02	0.0050	14.9660	-0.0005	-10.7457	-0.0007	-31.1246	0.4444
Hour_03	0.0042	13.6174	-0.0006	-10.9032	-0.0006	-30.9292	0.4498
Hour_04	0.0038	12.5247	-0.0004	-7.1332	-0.0006	-31.0791	0.4469
Hour_05	0.0039	12.0066	-0.0002	-2.9170	-0.0006	-26.8396	0.4341
Hour_06	0.0059	15.8562	-0.0003	-3.5751	-0.0006	-27.2082	0.4315
Hour_07	0.0044	10.5564	-0.0001	-1.6177	-0.0006	-21.7959	0.3961
Hour_08	0.0016	3.7301	0.0000	0.5459	-0.0004	-14.4745	0.3591
Hour_09	0.0007	1.3136	0.0000	-0.2330	-0.0004	-11.0245	0.3314
Hour_10	0.0009	1.5726	-0.0001	-3.3788	-0.0003	-6.3311	0.3138
Hour_11	0.0024	3.7435	-0.0002	-5.8244	-0.0004	-5.9600	0.3179
Hour_12	0.0030	4.3478	-0.0003	-9.0810	-0.0006	-7.7553	0.3465
Hour_13	0.0041	5.5894	-0.0004	-11.7677	-0.0006	-6.1764	0.3875
Hour_14	0.0063	8.2548	-0.0005	-15.6642	-0.0008	-6.9532	0.4308
Hour_15	0.0095	11.9276	-0.0007	-19.2849	-0.0014	-11.7952	0.4702
Hour_16	0.0077	9.5088	-0.0006	-16.2688	-0.0018	-15.0698	0.4923
Hour_17	0.0041	4.8945	-0.0005	-12.3918	-0.0020	-17.8832	0.4921
Hour_18	0.0036	4.4619	-0.0004	-9.9999	-0.0016	-17.4130	0.4784
Hour_19	0.0031	4.1053	-0.0002	-4.7835	-0.0014	-18.0599	0.4492
Hour_20	0.0020	2.7790	0.0000	-0.2752	-0.0013	-19.6983	0.4275
Hour_21	0.0024	3.5500	-0.0001	-2.6615	-0.0013	-22.7280	0.4235
Hour_22	0.0030	4.8783	-0.0003	-5.0288	-0.0012	-23.1606	0.4123
Hour_23	0.0055	10.3405	-0.0003	-6.1154	-0.0010	-22.9118	0.4036

Table 129. PG&E Gross parameter coefficients, 2014, hourly weekend models (blower motor)

Hour	Quantity Blower Motor Estimate	t Value	CDH65* Quantity Blower Motor Estimate	t Value	HDH65* Quantity Blower Motor Estimate	t Value	R^2
Hour_00	0.0047	6.5618	-0.0001	-1.8188	-0.0008	-15.2084	0.3932
Hour_01	0.0038	6.2165	-0.0002	-1.8608	-0.0007	-15.7240	0.4106
Hour_02	0.0041	7.6382	-0.0002	-2.0920	-0.0007	-19.0427	0.4254
Hour_03	0.0038	7.9096	-0.0004	-4.8725	-0.0006	-19.0636	0.4338
Hour_04	0.0025	5.3007	-0.0001	-1.5703	-0.0005	-17.8383	0.4360
Hour_05	0.0033	7.0077	-0.0002	-1.8848	-0.0005	-17.3268	0.4281
Hour_06	0.0054	10.5302	-0.0002	-2.1952	-0.0006	-18.0190	0.4190
Hour_07	0.0063	10.4914	-0.0002	-2.0479	-0.0007	-19.1195	0.3934
Hour_08	0.0053	7.6053	-0.0003	-4.1231	-0.0008	-18.0173	0.3528
Hour_09	0.0040	4.7631	-0.0004	-5.5414	-0.0009	-13.9020	0.3142
Hour_10	0.0063	6.5914	-0.0008	-12.3281	-0.0012	-14.9610	0.2979
Hour_11	0.0097	9.0292	-0.0012	-19.2530	-0.0018	-17.5315	0.3069
Hour_12	0.0100	8.4876	-0.0012	-19.5727	-0.0019	-15.4016	0.3362
Hour_13	0.0088	6.8294	-0.0012	-19.7532	-0.0017	-11.5998	0.3779
Hour_14	0.0146	10.9003	-0.0014	-23.9854	-0.0021	-12.5421	0.4184
Hour_15	0.0168	12.3174	-0.0015	-25.4709	-0.0026	-13.7223	0.4530
Hour_16	0.0138	10.1647	-0.0014	-24.0848	-0.0027	-15.0405	0.4713
Hour_17	0.0125	9.2038	-0.0013	-21.8163	-0.0031	-19.1240	0.4678
Hour_18	0.0081	6.2118	-0.0011	-16.9941	-0.0021	-15.6637	0.4565
Hour_19	0.0075	6.1516	-0.0010	-14.1989	-0.0016	-14.8628	0.4310
Hour_20	0.0060	5.3631	-0.0010	-12.8925	-0.0014	-14.7416	0.4106
Hour_21	0.0044	4.1897	-0.0009	-11.7886	-0.0012	-14.5876	0.4031
Hour_22	0.0018	1.9292	-0.0006	-7.6393	-0.0010	-13.6370	0.3950
Hour_23	0.0037	4.5646	-0.0006	-7.4282	-0.0009	-14.6176	0.3915

Table 130. PG&E gross parameter coefficients, 2014, hourly weekday models (RCA)

Hour	Quantity RCA Estimate	t Value	CDH65* Quantity RCA Estimate	t Value	HDH65* Quantity RCA Estimate	t Value	R^2
Hour_00	-0.0061	-14.1893	0.0003	6.4683	0.0002	5.1469	0.4106
Hour_01	-0.0028	-7.6473	0.0001	2.1373	0.0000	1.7296	0.4277
Hour_02	-0.0025	-7.6798	0.0000	1.1089	0.0000	-1.0263	0.4444
Hour_03	-0.0021	-7.1633	0.0001	2.2007	-0.0001	-4.6586	0.4498
Hour_04	-0.0021	-7.2085	-0.0001	-2.3053	-0.0001	-7.2518	0.4469
Hour_05	-0.0032	-10.3809	-0.0002	-2.7327	-0.0002	-8.8358	0.4341
Hour_06	-0.0030	-8.6738	-0.0001	-1.5857	-0.0003	-13.7092	0.4315
Hour_07	-0.0040	-9.9678	0.0000	-0.2904	-0.0002	-7.3002	0.3961
Hour_08	-0.0070	-16.2598	0.0001	3.2370	0.0003	8.8738	0.3591
Hour_09	-0.0068	-13.9636	0.0001	3.1510	0.0004	10.3228	0.3314
Hour_10	-0.0073	-13.3283	0.0002	5.0761	0.0004	7.8501	0.3138
Hour_11	-0.0085	-14.1179	0.0003	9.5123	0.0004	5.6702	0.3179
Hour_12	-0.0099	-15.1969	0.0005	15.3235	0.0003	3.7492	0.3465
Hour_13	-0.0120	-17.1144	0.0008	23.4157	0.0003	3.1902	0.3875
Hour_14	-0.0146	-19.9993	0.0010	32.2505	0.0002	2.1841	0.4308
Hour_15	-0.0168	-22.1856	0.0012	38.2924	0.0000	0.3340	0.4702
Hour_16	-0.0226	-29.1701	0.0015	44.9218	0.0003	2.4620	0.4923
Hour_17	-0.0224	-28.3119	0.0014	41.8445	0.0006	5.9895	0.4921
Hour_18	-0.0221	-28.6166	0.0013	37.3917	0.0013	15.1732	0.4784
Hour_19	-0.0201	-27.4924	0.0011	28.3755	0.0014	18.2992	0.4492
Hour_20	-0.0194	-27.7986	0.0011	26.5862	0.0013	20.4686	0.4275
Hour_21	-0.0174	-26.6766	0.0010	22.7314	0.0011	19.4600	0.4235
Hour_22	-0.0163	-27.3693	0.0009	19.6176	0.0009	19.2974	0.4123
Hour_23	-0.0135	-26.0480	0.0009	18.4563	0.0007	17.1186	0.4036

Table 131. PG&E Gross parameter coefficients, 2014, hourly weekend models (RCA)

Hour	Quantity RCA Estimate	t Value	CDH65* Quantity RCA Estimate	t Value	HDH65* Quantity RCA Estimate	t Value	R^2
Hour_00	-0.0116	-16.8700	0.0010	14.5014	0.0007	13.9427	0.3932
Hour_01	-0.0085	-14.3569	0.0009	12.9636	0.0006	14.1897	0.4106
Hour_02	-0.0043	-8.3319	0.0008	11.8338	0.0003	7.9824	0.4254
Hour_03	-0.0030	-6.5838	0.0007	9.4540	0.0001	2.1997	0.4338
Hour_04	-0.0029	-6.6093	0.0003	3.9741	0.0000	1.0548	0.4360
Hour_05	-0.0020	-4.4582	0.0001	1.1478	-0.0001	-3.3682	0.4281
Hour_06	-0.0021	-4.2344	-0.0001	-0.7624	-0.0001	-4.8523	0.4190
Hour_07	-0.0028	-4.9064	-0.0001	-1.4546	-0.0001	-4.0387	0.3934
Hour_08	-0.0072	-10.6531	0.0000	-0.6815	0.0001	2.8355	0.3528
Hour_09	-0.0082	-10.1501	-0.0002	-2.7568	0.0001	2.4275	0.3142
Hour_10	-0.0098	-10.7343	-0.0001	-1.6293	0.0000	0.6469	0.2979
Hour_11	-0.0138	-13.4434	0.0001	2.3104	0.0000	-0.4359	0.3069
Hour_12	-0.0193	-17.1114	0.0006	10.8758	-0.0001	-0.5709	0.3362
Hour_13	-0.0251	-20.5811	0.0011	18.9683	0.0001	0.5345	0.3779
Hour_14	-0.0305	-23.9103	0.0014	25.5761	0.0006	3.9268	0.4184
Hour_15	-0.0282	-21.6358	0.0015	27.7894	0.0006	3.4754	0.4530
Hour_16	-0.0231	-17.8132	0.0015	27.2346	0.0003	1.7366	0.4713
Hour_17	-0.0259	-20.0648	0.0014	24.8452	0.0008	5.0436	0.4678
Hour_18	-0.0291	-23.1667	0.0012	21.1931	0.0018	13.9402	0.4565
Hour_19	-0.0203	-17.4567	0.0006	9.0755	0.0012	11.4324	0.4310
Hour_20	-0.0200	-18.3165	0.0005	6.9714	0.0013	14.5601	0.4106
Hour_21	-0.0187	-18.4250	0.0003	4.9280	0.0012	14.4469	0.4031
Hour_22	-0.0143	-15.8413	0.0002	3.4564	0.0008	11.9474	0.3950
Hour_23	-0.0099	-12.6490	0.0001	1.3095	0.0005	8.1704	0.3915

Table 132. PG&E net parameter coefficients, 2013, hourly weekday models (fans)

Hour	Quantity Fan Estimate	t Value	CDH65* Quantity Fan Estimate	t Value	HDH65* Quantity Fan Estimate	t Value	R^2
Hour_00	0.0037	3.2068	0.0011	10.3009	-0.0004	-5.8737	0.4270
Hour_01	0.0040	4.0934	0.0013	11.8514	-0.0004	-6.8731	0.4558
Hour_02	0.0030	3.3943	0.0009	7.9035	-0.0004	-8.0588	0.4846
Hour_03	0.0003	0.3272	0.0005	4.6093	-0.0002	-3.6069	0.4954
Hour_04	-0.0060	-7.4318	-0.0001	-1.1041	0.0000	-0.3276	0.5068
Hour_05	-0.0024	-2.7629	0.0001	0.9679	-0.0002	-3.5266	0.4798
Hour_06	0.0002	0.2192	0.0008	4.7919	-0.0003	-6.1971	0.4320
Hour_07	-0.0003	-0.2778	0.0008	5.5590	-0.0001	-2.0291	0.4086
Hour_08	-0.0022	-1.7741	-0.0002	-1.5152	0.0000	-0.0810	0.3744
Hour_09	0.0002	0.1542	-0.0002	-1.8949	-0.0003	-3.1458	0.3346
Hour_10	-0.0050	-3.3293	0.0003	3.5270	-0.0001	-0.6173	0.3226
Hour_11	-0.0009	-0.5372	0.0003	3.5398	0.0001	0.9083	0.3219
Hour_12	0.0006	0.3629	0.0002	2.5241	0.0003	1.3604	0.3478
Hour_13	-0.0029	-1.5205	0.0005	5.6617	0.0005	2.0549	0.3799
Hour_14	-0.0098	-4.9571	0.0005	5.7990	0.0007	2.3767	0.4166
Hour_15	-0.0208	-9.9372	0.0007	8.7275	0.0015	4.7605	0.4496
Hour_16	-0.0255	-11.6620	0.0009	11.1499	0.0023	7.4909	0.4702
Hour_17	-0.0326	-14.4146	0.0015	17.0978	0.0024	8.8624	0.4657
Hour_18	-0.0256	-11.5423	0.0016	17.5270	0.0016	7.4644	0.4603
Hour_19	-0.0238	-11.4518	0.0020	19.7312	0.0013	7.0147	0.4446
Hour_20	-0.0188	-9.6254	0.0021	19.6704	0.0008	5.1606	0.4322
Hour_21	-0.0082	-4.5147	0.0017	14.5445	0.0001	0.4482	0.4287
Hour_22	-0.0022	-1.3521	0.0018	15.1609	-0.0002	-1.5009	0.4218
Hour_23	0.0031	2.2000	0.0010	8.1799	-0.0006	-6.2964	0.4246

Table 133. PG&E net parameter coefficients, 2013, weekend models

Hour	Quantity Fan Estimate	t Value	CDH65* Quantity Fan Estimate	t Value	HDH65* Quantity Fan Estimate	t Value	R^2
Hour_00	0.0086	4.3423	0.0004	2.2242	-0.0007	-6.1815	-6.1815
Hour_01	0.0069	4.1102	0.0009	5.1461	-0.0005	-5.4521	-5.4521
Hour_02	0.0077	5.1948	0.0007	3.9005	-0.0005	-6.1441	-6.1441
Hour_03	0.0019	1.3867	0.0003	1.4098	-0.0002	-3.3738	-3.3738
Hour_04	-0.0032	-2.4980	0.0002	0.9500	-0.0001	-1.5120	-1.5120
Hour_05	-0.0013	-0.9750	0.0002	0.7536	-0.0002	-3.4169	-3.4169
Hour_06	0.0014	0.9819	-0.0002	-0.9850	-0.0004	-6.2450	-6.2450
Hour_07	0.0033	1.9106	0.0003	1.3305	-0.0002	-2.4096	-2.4096
Hour_08	0.0014	0.6844	0.0000	0.0877	-0.0002	-1.7155	-1.7155
Hour_09	-0.0039	-1.7080	-0.0001	-0.8774	-0.0003	-2.2633	-2.2633
Hour_10	-0.0053	-2.0891	0.0005	3.0784	0.0001	0.4454	0.4454
Hour_11	-0.0024	-0.8508	0.0006	4.3039	0.0005	1.8873	1.8873
Hour_12	-0.0060	-1.9850	0.0007	5.5563	0.0015	4.3252	4.3252
Hour_13	-0.0061	-1.9222	0.0008	5.9105	0.0018	4.3082	4.3082
Hour_14	-0.0165	-5.0127	0.0011	8.7500	0.0018	3.8981	3.8981
Hour_15	-0.0241	-7.1005	0.0013	10.0967	0.0017	3.4710	3.4710
Hour_16	-0.0226	-6.5081	0.0013	10.3454	0.0019	3.8817	3.8817
Hour_17	-0.0232	-6.6433	0.0014	10.5228	0.0025	5.8883	5.8883
Hour_18	-0.0201	-5.8394	0.0017	12.0673	0.0015	4.5088	4.5088
Hour_19	-0.0162	-4.9410	0.0020	13.0934	0.0011	3.8981	3.8981
Hour_20	-0.0113	-3.6820	0.0019	11.3432	0.0005	2.2222	2.2222
Hour_21	-0.0030	-1.0600	0.0011	6.5021	-0.0001	-0.5619	-0.5619
Hour_22	0.0020	0.7946	0.0010	5.6821	-0.0003	-1.7728	-1.7728
Hour_23	0.0064	2.9144	0.0006	3.6446	-0.0007	-5.2534	-5.2534

Table 134. PG&E net parameter coefficients, 2014, hourly weekday models (blower motor)

Hour	Quantity Blower Motor Estimate	t Value	CDH65* Quantity Blower Motor Estimate	t Value	HDH65* Quantity Blower Motor Estimate	t Value	R^2
Hour_00	0.0046	10.4136	-0.0006	-11.3744	-0.0007	-21.7356	0.4172
Hour_01	0.0046	12.1258	-0.0006	-12.2618	-0.0007	-26.6167	0.4312
Hour_02	0.0051	15.2278	-0.0007	-13.7385	-0.0007	-29.4654	0.4492
Hour_03	0.0050	15.9164	-0.0008	-14.5349	-0.0006	-29.0493	0.4550
Hour_04	0.0047	15.2453	-0.0006	-11.0046	-0.0006	-30.0887	0.4523
Hour_05	0.0052	15.4896	-0.0004	-6.8302	-0.0005	-26.6420	0.4389
Hour_06	0.0076	20.0401	-0.0004	-6.0688	-0.0006	-26.3657	0.4414
Hour_07	0.0075	17.6883	-0.0003	-4.1206	-0.0006	-23.0878	0.4101
Hour_08	0.0040	8.8665	-0.0001	-1.7226	-0.0005	-16.6770	0.3713
Hour_09	0.0024	4.6888	-0.0001	-1.5079	-0.0005	-12.4908	0.3407
Hour_10	0.0018	3.1174	-0.0001	-3.4727	-0.0004	-7.0620	0.3248
Hour_11	0.0027	4.3323	-0.0002	-4.7015	-0.0003	-5.4602	0.3303
Hour_12	0.0026	3.7784	-0.0002	-7.0374	-0.0005	-6.0971	0.3582
Hour_13	0.0025	3.3543	-0.0003	-10.0310	-0.0005	-4.9609	0.3968
Hour_14	0.0051	6.4902	-0.0005	-15.8459	-0.0006	-5.8461	0.4368
Hour_15	0.0080	9.8718	-0.0007	-20.1382	-0.0011	-9.8478	0.4720
Hour_16	0.0084	10.0332	-0.0006	-18.5875	-0.0015	-12.9383	0.4920
Hour_17	0.0062	7.2196	-0.0005	-14.3719	-0.0016	-15.3229	0.4910
Hour_18	0.0066	7.8405	-0.0005	-12.0507	-0.0012	-13.7514	0.4783
Hour_19	0.0050	6.3414	-0.0003	-6.7459	-0.0010	-13.5020	0.4539
Hour_20	0.0039	5.3387	-0.0002	-3.3596	-0.0010	-16.0081	0.4347
Hour_21	0.0043	6.3470	-0.0002	-4.8750	-0.0012	-20.8661	0.4316
Hour_22	0.0047	7.6197	-0.0004	-7.7569	-0.0011	-23.1528	0.4212
Hour_23	0.0054	10.0688	-0.0005	-9.0305	-0.0009	-22.5436	0.4125

Table 135. PG&E Gross parameter coefficients, 2014, hourly weekend models (blower motor)

Hour	Quantity Blower Motor Estimate	t Value	CDH65* Quantity Blower Motor Estimate	t Value	HDH65* Quantity Blower Motor Estimate	t Value	R^2
Hour_00	0.0044	6.3146	-0.0003	-3.3768	-0.0007	-15.3448	0.4001
Hour_01	0.0040	6.5442	-0.0003	-3.4652	-0.0007	-16.3140	0.4135
Hour_02	0.0036	6.8194	-0.0004	-4.4386	-0.0006	-18.7260	0.4304
Hour_03	0.0037	7.5567	-0.0006	-7.1508	-0.0006	-18.2428	0.4401
Hour_04	0.0029	6.2139	-0.0004	-4.1579	-0.0005	-17.6162	0.4408
Hour_05	0.0034	7.1766	-0.0004	-4.2397	-0.0005	-17.0274	0.4336
Hour_06	0.0058	11.1293	-0.0004	-4.2123	-0.0005	-17.4138	0.4225
Hour_07	0.0078	12.7916	-0.0003	-3.4633	-0.0007	-19.5565	0.3949
Hour_08	0.0081	11.5140	-0.0003	-4.3488	-0.0008	-19.4034	0.3560
Hour_09	0.0081	9.6133	-0.0003	-4.5206	-0.0009	-15.2105	0.3173
Hour_10	0.0105	10.8481	-0.0006	-9.5664	-0.0012	-15.0008	0.3011
Hour_11	0.0140	12.7929	-0.0009	-15.1925	-0.0015	-15.6708	0.3085
Hour_12	0.0139	11.5573	-0.0009	-15.6102	-0.0015	-12.8277	0.3380
Hour_13	0.0140	10.6816	-0.0010	-17.2422	-0.0014	-9.8898	0.3789
Hour_14	0.0179	13.0857	-0.0013	-22.1560	-0.0017	-10.7557	0.4193
Hour_15	0.0172	12.2291	-0.0014	-24.0796	-0.0020	-11.0870	0.4522
Hour_16	0.0136	9.6890	-0.0013	-22.8354	-0.0020	-11.4272	0.4693
Hour_17	0.0150	10.7082	-0.0012	-20.3743	-0.0024	-15.6105	0.4661
Hour_18	0.0121	9.0205	-0.0010	-16.2738	-0.0016	-12.2238	0.4575
Hour_19	0.0095	7.6850	-0.0009	-13.2373	-0.0011	-10.7003	0.4362
Hour_20	0.0078	6.8384	-0.0009	-12.2029	-0.0011	-11.7030	0.4173
Hour_21	0.0067	6.3975	-0.0009	-11.2896	-0.0010	-13.2935	0.4117
Hour_22	0.0041	4.3902	-0.0006	-7.8233	-0.0009	-13.4154	0.4053
Hour_23	0.0041	5.1316	-0.0005	-6.8828	-0.0008	-14.0958	0.4007

Table 136. PG&E net parameter coefficients, 2014, hourly weekday models (RCA)

Hour	Quantity RCA Estimate	t Value	CDH65* Quantity RCA Estimate	t Value	HDH65* Quantity RCA Estimate	t Value	R^2
Hour_00	-0.0069	-15.9452	0.0003	5.9222	0.0003	8.9592	0.4172
Hour_01	-0.0032	-8.8040	0.0000	1.0436	0.0001	5.7105	0.4312
Hour_02	-0.0020	-6.1365	-0.0001	-1.8436	0.0001	2.4242	0.4492
Hour_03	-0.0010	-3.3133	-0.0001	-1.2241	0.0000	-1.3432	0.4550
Hour_04	-0.0009	-3.0830	-0.0003	-6.9656	-0.0001	-4.7503	0.4523
Hour_05	-0.0015	-4.7343	-0.0004	-7.4988	-0.0002	-8.1875	0.4389
Hour_06	-0.0008	-2.1917	-0.0003	-5.6820	-0.0003	-12.8636	0.4414
Hour_07	-0.0002	-0.4164	-0.0001	-1.9280	-0.0002	-8.4436	0.4101
Hour_08	-0.0043	-9.8634	0.0000	0.9867	0.0002	6.7910	0.3713
Hour_09	-0.0047	-9.5781	0.0001	1.3746	0.0003	8.4942	0.3407
Hour_10	-0.0066	-12.0733	0.0002	6.3839	0.0003	6.7720	0.3248
Hour_11	-0.0085	-14.0544	0.0004	12.9406	0.0004	6.7976	0.3303
Hour_12	-0.0106	-16.2790	0.0006	19.9411	0.0004	6.2033	0.3582
Hour_13	-0.0136	-19.2419	0.0009	27.6679	0.0005	5.4274	0.3968
Hour_14	-0.0156	-21.0886	0.0011	34.0805	0.0004	4.1732	0.4368
Hour_15	-0.0181	-23.4635	0.0012	39.9387	0.0004	3.3347	0.4720
Hour_16	-0.0212	-26.6760	0.0014	44.6424	0.0006	5.5146	0.4920
Hour_17	-0.0196	-24.1934	0.0014	41.8189	0.0009	9.3589	0.4910
Hour_18	-0.0183	-23.0811	0.0013	37.2094	0.0016	18.9948	0.4783
Hour_19	-0.0168	-22.4064	0.0010	27.4043	0.0017	22.8667	0.4539
Hour_20	-0.0159	-22.3862	0.0010	24.6156	0.0015	24.4445	0.4347
Hour_21	-0.0145	-22.0371	0.0010	22.2491	0.0013	23.0374	0.4316
Hour_22	-0.0141	-23.6505	0.0009	19.1205	0.0010	21.2336	0.4212
Hour_23	-0.0128	-24.7261	0.0007	16.7630	0.0008	19.3256	0.4125

Table 137. PG&E gross parameter coefficients, 2014, hourly weekend models (RCA)

Hour	Quantity RCA Estimate	t Value	CDH65* Quantity RCA Estimate	t Value	HDH65* Quantity RCA Estimate	t Value	R^2
Hour_00	-0.0117	-17.1181	0.0010	14.4339	0.0007	15.7834	0.4001
Hour_01	-0.0084	-14.3565	0.0008	12.4031	0.0006	15.8764	0.4135
Hour_02	-0.0041	-7.8980	0.0006	8.9743	0.0003	9.4337	0.4304
Hour_03	-0.0026	-5.5786	0.0005	6.5689	0.0001	3.9945	0.4401
Hour_04	-0.0019	-4.2364	0.0000	0.3310	0.0001	2.1074	0.4408
Hour_05	-0.0011	-2.3607	-0.0001	-1.6792	-0.0001	-2.5832	0.4336
Hour_06	-0.0008	-1.6349	-0.0003	-3.9246	-0.0001	-3.8557	0.4225
Hour_07	-0.0005	-0.8062	-0.0002	-2.8662	-0.0001	-4.2006	0.3949
Hour_08	-0.0043	-6.2506	0.0000	-0.6349	0.0001	2.0486	0.3560
Hour_09	-0.0048	-5.8450	-0.0001	-0.9945	0.0001	1.7015	0.3173
Hour_10	-0.0069	-7.4691	0.0002	3.4011	0.0001	1.3262	0.3011
Hour_11	-0.0116	-11.0839	0.0005	9.6198	0.0003	3.0175	0.3085
Hour_12	-0.0171	-14.9484	0.0010	17.8290	0.0004	3.7686	0.3380
Hour_13	-0.0214	-17.2376	0.0013	24.4189	0.0005	3.8971	0.3789
Hour_14	-0.0276	-21.2621	0.0016	29.5419	0.0010	6.9589	0.4193
Hour_15	-0.0276	-20.6967	0.0016	30.9230	0.0012	6.9388	0.4522
Hour_16	-0.0230	-17.3119	0.0016	29.7498	0.0010	6.2027	0.4693
Hour_17	-0.0230	-17.3144	0.0015	27.5046	0.0014	9.4914	0.4661
Hour_18	-0.0249	-19.2628	0.0013	23.0079	0.0022	17.9382	0.4575
Hour_19	-0.0172	-14.4739	0.0006	10.9346	0.0016	16.1970	0.4362
Hour_20	-0.0173	-15.6736	0.0006	8.9275	0.0016	18.8382	0.4173
Hour_21	-0.0161	-15.7527	0.0005	7.1708	0.0013	17.6485	0.4117
Hour_22	-0.0119	-13.1209	0.0003	4.9339	0.0009	13.8101	0.4053
Hour_23	-0.0093	-11.9683	0.0003	3.7958	0.0005	10.2901	0.4007

Table 138. SDG&E gross parameter coefficients, hourly weekday models

Hour	QM Estimate	t Value	CDH65*QM Estimate	t Value	HDH65*QM Estimate	t Value	R^2
Hour_00	-0.0095	-2.3217	0.0152	11.7537	-0.0018	-4.2052	0.5276
Hour_01	-0.0071	-2.0510	0.0150	12.4369	-0.0015	-4.3417	0.5585
Hour_02	0.0023	0.7250	0.0096	8.3562	-0.0020	-6.1760	0.5630
Hour_03	0.0049	1.5842	0.0083	7.0603	-0.0021	-7.0517	0.5520
Hour_04	-0.0030	-0.9145	0.0082	6.5939	-0.0008	-2.4996	0.5535
Hour_05	0.0087	2.5600	0.0062	4.6507	-0.0018	-5.6771	0.5842
Hour_06	0.0036	0.6679	0.0035	1.7809	-0.0017	-3.3979	0.4973
Hour_07	-0.0064	-1.2367	-0.0107	-6.7018	-0.0021	-4.0291	0.5058
Hour_08	0.0021	0.4245	-0.0081	-8.2227	-0.0041	-6.6584	0.5072
Hour_09	-0.0107	-2.0937	-0.0051	-7.0968	-0.0041	-4.5913	0.5149
Hour_10	-0.0197	-3.5939	-0.0048	-7.7498	-0.0015	-1.2190	0.4998
Hour_11	-0.0395	-6.5029	-0.0037	-6.0791	-0.0012	-0.7413	0.4679
Hour_12	-0.0603	-8.8433	-0.0028	-4.2201	0.0033	1.4792	0.4445
Hour_13	-0.0374	-4.9936	-0.0051	-7.1427	0.0014	0.5786	0.4388
Hour_14	-0.0299	-3.7379	-0.0060	-7.6210	0.0029	1.0890	0.4151
Hour_15	-0.0328	-3.8861	-0.0048	-5.5875	0.0064	2.3623	0.4089
Hour_16	-0.0182	-2.0919	-0.0029	-3.0879	0.0051	2.1613	0.4051
Hour_17	-0.0080	-0.9066	0.0023	2.2055	-0.0008	-0.4435	0.3968
Hour_18	0.0061	0.7442	0.0073	6.2647	-0.0067	-4.8705	0.4067
Hour_19	0.0123	1.6116	0.0086	6.3550	-0.0083	-7.5707	0.4364
Hour_20	-0.0249	-3.5357	0.0092	6.3258	-0.0044	-4.8715	0.4698
Hour_21	-0.0274	-4.2833	0.0054	3.6153	-0.0033	-4.3480	0.4964
Hour_22	-0.0132	-2.3584	0.0098	6.8752	-0.0037	-5.7324	0.5046
Hour_23	-0.0060	-1.2376	0.0094	6.8868	-0.0035	-6.5855	0.5153

Table 139. SDG&E gross parameter coefficients, hourly weekend models

Hour	QM Estimate	t Value	CDH65*QM Estimate	t Value	HDH65*QM Estimate	t Value	R^2
Hour_00	0.0113	1.6496	0.0048	2.3475	-0.0030	-4.2364	0.5084
Hour_01	0.0118	2.0106	0.0066	3.6043	-0.0025	-4.1146	0.5342
Hour_02	0.0196	3.7649	0.0051	2.9786	-0.0029	-5.7294	0.5333
Hour_03	0.0074	1.4961	0.0098	5.7887	-0.0021	-4.5044	0.5286
Hour_04	0.0011	0.2249	0.0098	5.5638	-0.0005	-1.0225	0.5335
Hour_05	0.0105	1.9792	0.0090	4.4757	-0.0016	-3.2162	0.5335
Hour_06	0.0076	0.9838	0.0069	2.4648	-0.0015	-2.1634	0.4794
Hour_07	0.0203	2.5037	-0.0098	-3.9744	-0.0044	-5.7068	0.4858
Hour_08	0.0219	2.8309	-0.0103	-6.5765	-0.0065	-6.8106	0.4789
Hour_09	0.0063	0.7729	-0.0075	-6.3003	-0.0027	-1.9376	0.4815
Hour_10	-0.0025	-0.2662	-0.0066	-6.2806	0.0020	1.0404	0.4718
Hour_11	0.0174	1.6364	-0.0069	-6.5818	-0.0033	-1.2137	0.4244
Hour_12	0.0155	1.3271	-0.0054	-4.9282	-0.0044	-1.3153	0.4141
Hour_13	0.0169	1.3200	-0.0052	-4.3177	-0.0018	-0.4417	0.4127
Hour_14	0.0214	1.5801	-0.0070	-5.3222	-0.0060	-1.4213	0.3985
Hour_15	0.0039	0.2801	-0.0037	-2.6684	-0.0005	-0.1110	0.3991
Hour_16	0.0261	1.9034	-0.0032	-2.1746	0.0008	0.2233	0.4005
Hour_17	0.0401	2.8909	-0.0002	-0.0952	-0.0035	-1.2479	0.3823
Hour_18	0.0252	1.9599	0.0059	3.0753	-0.0036	-1.7266	0.3939
Hour_19	0.0272	2.4072	0.0079	3.7736	-0.0087	-5.5460	0.4256
Hour_20	-0.0100	-0.9475	0.0015	0.6615	-0.0048	-3.6386	0.4589
Hour_21	-0.0099	-1.0308	0.0036	1.5083	-0.0039	-3.4414	0.4784
Hour_22	0.0016	0.1842	0.0081	3.4334	-0.0044	-4.6265	0.4858
Hour_23	0.0005	0.0692	0.0114	5.0805	-0.0039	-4.9088	0.5096

Table 140. SDG&E net parameter coefficients, hourly weekday models

Hour	QM Estimate	t Value	CDH65*QM Estimate	t Value	HDH65*QM Estimate	t Value	R^2
Hour_00	0.0041	0.9536	0.0067	5.9603	-0.0024	-6.3178	0.4969
Hour_01	0.0077	2.0838	0.0062	5.9747	-0.0024	-7.5880	0.5194
Hour_02	0.0173	5.0841	0.0019	1.8771	-0.0024	-8.5548	0.5233
Hour_03	0.0162	5.0886	0.0020	2.0803	-0.0021	-8.2759	0.5252
Hour_04	0.0094	2.9232	0.0024	2.4424	-0.0007	-2.6961	0.5279
Hour_05	0.0230	6.7047	0.0013	1.2421	-0.0015	-5.6876	0.5441
Hour_06	0.0153	3.0957	0.0010	0.7207	0.0007	1.7810	0.4942
Hour_07	0.0223	4.2647	-0.0078	-7.6673	-0.0004	-0.9872	0.4972
Hour_08	0.0409	7.7964	-0.0064	-9.1003	-0.0018	-3.2234	0.4952
Hour_09	0.0473	8.5765	-0.0052	-9.4739	-0.0023	-2.9031	0.4937
Hour_10	0.0366	6.0592	-0.0049	-9.6190	-0.0015	-1.3385	0.4856
Hour_11	0.0006	0.0909	-0.0039	-7.6800	-0.0013	-0.8439	0.4764
Hour_12	-0.0145	-1.9889	-0.0033	-6.1315	0.0005	0.2653	0.4751
Hour_13	0.0037	0.4612	-0.0047	-8.1078	-0.0012	-0.5227	0.4670
Hour_14	0.0176	2.0631	-0.0052	-8.1721	0.0000	-0.0154	0.4412
Hour_15	0.0186	2.0781	-0.0053	-7.5184	0.0028	1.1437	0.4185
Hour_16	0.0324	3.5277	-0.0054	-7.0171	0.0030	1.4420	0.4031
Hour_17	0.0292	3.1224	-0.0012	-1.3197	-0.0014	-0.8260	0.3962
Hour_18	0.0107	1.2146	0.0057	5.7000	-0.0055	-4.5767	0.4085
Hour_19	0.0207	2.5676	0.0091	7.9410	-0.0075	-7.8455	0.4514
Hour_20	0.0059	0.8020	0.0090	7.4289	-0.0041	-5.1788	0.4927
Hour_21	0.0142	2.0966	0.0061	4.9665	-0.0035	-5.2455	0.5042
Hour_22	0.0085	1.4276	0.0079	6.5442	-0.0038	-6.7018	0.4872
Hour_23	0.0037	0.7130	0.0061	5.2154	-0.0035	-7.4893	0.4921

Table 141. SDG&E net parameter coefficients, hourly weekend models

Hour	QM Estimate	t Value	CDH65*QM Estimate	t Value	HDH65*QM Estimate	t Value	R^2
Hour_00	0.0102	1.4043	0.0007	0.3777	-0.0030	-3.9547	0.4688
Hour_01	0.0174	2.7802	0.0001	0.0920	-0.0025	-4.6987	0.4856
Hour_02	0.0239	4.2850	-0.0019	-1.2579	-0.0029	-6.2851	0.4889
Hour_03	0.0137	2.6229	0.0031	2.1505	-0.0021	-4.4595	0.4935
Hour_04	0.0105	2.0741	0.0038	2.6298	-0.0005	-1.1043	0.5023
Hour_05	0.0162	3.0657	0.0050	3.1111	-0.0016	-2.4633	0.5029
Hour_06	0.0012	0.1761	0.0029	1.4275	-0.0015	1.9641	0.4617
Hour_07	0.0287	3.6050	-0.0085	-4.8506	-0.0044	-3.4226	0.4680
Hour_08	0.0467	5.6821	-0.0076	-6.3009	-0.0065	-3.3480	0.4658
Hour_09	0.0525	6.0234	-0.0057	-6.0022	-0.0027	-0.6932	0.4662
Hour_10	0.0412	4.1876	-0.0050	-5.7409	0.0020	1.4873	0.4620
Hour_11	0.0324	2.9046	-0.0055	-6.2350	-0.0033	-0.8454	0.4386
Hour_12	0.0238	1.9700	-0.0044	-4.7902	-0.0044	-1.2917	0.4391
Hour_13	0.0265	2.0099	-0.0042	-4.1324	-0.0018	-0.6374	0.4369
Hour_14	0.0421	3.0199	-0.0058	-5.2722	-0.0060	-1.5468	0.4198
Hour_15	0.0371	2.5669	-0.0044	-3.6356	-0.0005	-0.8735	0.4074
Hour_16	0.0503	3.4835	-0.0048	-3.6931	0.0008	-0.4124	0.3943
Hour_17	0.0368	2.5412	-0.0038	-2.5041	-0.0035	-1.7736	0.3820
Hour_18	0.0088	0.6395	0.0036	2.0698	-0.0036	-2.5682	0.3960
Hour_19	0.0256	2.1011	0.0065	3.3688	-0.0087	-5.7597	0.4348
Hour_20	0.0125	1.0992	0.0018	0.8542	-0.0048	-3.9523	0.4712
Hour_21	0.0285	2.7117	0.0029	1.3814	-0.0039	-4.5112	0.4793
Hour_22	0.0170	1.8161	0.0058	2.7916	-0.0044	-5.3237	0.4693
Hour_23	0.0163	2.0155	0.0052	2.5895	-0.0039	-5.5938	0.4864

APPENDIX J. RESIDENTIAL PROPENSITY SCORE MATCHING STATISTICS

The following presents the equations and the t-test comparison results from the propensity score matching analysis.

The following lists the equations used in the first step of the propensity score matching process and describes the variables used in the models. The first step propensity models use monthly data. The first step PG&E and SDG&E models only differ by the CARE/FERA variable that is in the SDG&E model but not the PG&E model. The PG&E data is stratified by CARE/FERA, therefore the variable cannot be an independent variable in the model.

Step 1 PG&E SPSM Logit Model

$$Logit(P_i) = \beta_0 + \beta_1 \times MaxWinter_i + \beta_2 \times MaxSummer_i + \beta_3 \times AvgShoulder_i + \beta_4 \times AvgAnnual_i + \beta_5 \times CVkWh_i + \beta_6 \times CORR\_HDD\_Winter_i + \beta_7 \times CORR\_CDD\_Summer_i + \beta_8 \times Flag\_OtherEE_i + \varepsilon_i$$

Step 1 SDG&E SPSM Logit Model

$$Logit(P_i) = \beta_0 + \beta_1 \times MaxWinter_i + \beta_2 \times MaxSummer_i + \beta_3 \times AvgShoulder_i + \beta_4 \times AvgAnnual_i + \beta_5 \times CVkWh_i + \beta_6 \times CORR\_HDD\_Winter_i + \beta_7 \times CORR\_CDD\_Summer_i + \beta_8 \times Flag\_OtherEE_i + \beta_8 \times Flag\_CARE\_FERA_i + \varepsilon_i$$

Where:

$MaxWinter_i$	Is customer *i's* maximum monthly usage during winter months
$MaxSummer_i$	Is customer *i's* maximum monthly usage during summer months
$AvgAnnual_i$	Is customer *i's* average monthly usage across the whole year
$CVkWh_i$	Is the coefficient of variation of customer *i's* monthly usages
$CORR\_HDD\_Winter_i$	Is the correlation coefficient between customer *i's* monthly usages and HDD during winter months
$CORR\_CDD\_Summer_i$	Is the correlation coefficient between customer *i's* monthly usages and CDD during summer months
$Flag\_OtherEE_i$	Is a dummy variable that indicating if customer *i* had participated in any other energy efficiency programs during the matching period
$Flag\_CARE\_FERA_i$	Is a dummy variable that indicating if customer *i* was in CARE or FERA program

The second-stage propensity score matching models are listed below. The PG&E and SDG&E models have slightly different variables, this was largely a fit issue.

Step 2 PG&E PSM Logit Model

$$Logit(P_i) = \beta_0 + \beta_1 \times DailyAvgSummer_i + \beta_2 \times DialyAvgShoulder_i + \beta_3 \times DailyAvgWinter_i + \beta_4 \times CVSummer_i + \beta_5 \times CVShoulder_i + \beta_6 \times CVWinter_i + \beta_7 \times MaxSummer_i + \beta_8 \times MaxWinter_i + \beta_9 \times corrHDDWinter_i + \beta_{10} \times corrCDDWESummer_i + \beta_{11} \times corrCDDWDSummer_i + \beta_{12} \times PeakAvgWEAll_i + \beta_{13} \times PeakAvgWDAll_i + \beta_{14} \times cvPeakAll_i + \beta_{15} \times cvPeak3WE_i + \beta_{16} \times cvPeak3WD_i + \beta_{17} \times corrPeakCDDWE_i + \beta_{18} \times corrPeakCDDWD_i + \beta_{19} \times Peak3Max_i + \beta_{20} \times Flag\_OtherEE_i + \varepsilon_i$$

Step 2 SDG&E PSM Logit Model

$$Logit(P_i) = \beta_0 + \beta_1 \times DailyAvgSummer_i + \beta_2 \times DialyAvgShoulder_i + \beta_3 \times DailyAvgWinter_i + \beta_4 \times CVSummer_i + \beta_5 \times CVShoulder_i + \beta_6 \times CVWinter_i + \beta_7 \times corrHDDWinter_i + \beta_8 \times corrCDDWESummer_i + \beta_9 \times corrCDDWDSummer_i + \beta_{10} \times PeakAvgWEAll_i + \beta_{11} \times PeakAvgWDAll_i + \beta_{12} \times cvPeakWE_i + \beta_{13} \times cvPeakWD_i + \beta_{14} \times corrPeakCDDWE_i + \beta_{15} \times corrPeakCDDWD_i + \beta_{16} \times Peak3Max_i + \beta_{17} \times Flag\_OtherEE_i + \varepsilon_i$$

Where:

$DailyAvgSummer_i$	Is customer *i's* average daily usage during summer months
$DailyAvgShoulder_i$	Is customer *i's* average daily usage during spring and fall months
$DailyAvgWinter_i$	Is customer *i's* average daily usage during winter months
$CVSummer_i$	Is the coefficient of variation of customer *i's* average daily usage during summer months
$CVShoulder_i$	Is the coefficient of variation of customer *i's* average daily usage during spring and fall months;
$CVWinter_i$	Is the coefficient of variation of customer *i's* average daily usage during winter months
$MaxSummer_i$	Is customer *i's* maximum daily usage during summer months
$MaxWinter_i$	Is customer *i's* maximum daily usage during winter months
$corrHDDWinter_i$	Is the correlation coefficient between customer *i's* daily usages and HDD during winter months
$corrCDDWESummer_i$	Is the correlation coefficient between customer *i's* daily usages and CDD during weekends in summer months
$corrCDDWDSummer_i$	Is the correlation coefficient between customer *i's* daily usages and CDD during weekdays in summer months
$PeakAvgWEAll_i$	Is customer *i's* average peak hour (from noon to 6 pm) hourly usage during weekends
$PeakAvgWDAll_i$	Is customer *i's* average peak hour (from noon to 6 pm) hourly usage during weekdays
$PeakCVAll_i$	Is the coefficient of variation of customer *i's* hourly usage during peak hours (from noon to 6 pm)
$cvPeakWE_i$	Is the coefficient of variation of customer *i's* hourly usage during peak hours (from noon to 6 pm) in weekends
$cvPeakWD_i$	Is the coefficient of variation of customer *i's* hourly usage during peak hours (from noon to 6 pm) in weekdays
$cvPeak3WE_i$	Is the coefficient of variation of customer *i's* hourly usage during peak hours (from 2 pm to 5 pm) in weekends
$cvPeak3WD_i$	Is the coefficient of variation of customer i's hourly usage during peak hours (from 2 pm to 5 pm) in weekdays

$cvPeak3WD_i$ is the coefficient of variation of customer *i*'s hourly usage during peak hours (from 2 pm to 5 pm) in weekdays;
$corrPeakCDDWE_i$ is the correlation coefficient between customer *i*'s hourly usages and CDH during weekends for the peak hours (from noon to 6 pm);
$corrPeakCDDWD_i$ is the correlation coefficient between customer *i*'s hourly usages and CDH during weekdays for the peak hours (from noon to 6 pm);
$Peak3Max_i$ is customer *i*'s maximum hourly usage during peak hours (from 2 pm to 5 pm);
$Flag\_OtherEE_i$ is a dummy variable that indicating if customer *i* had participated in any other energy efficiency programs during the matching period;

Table 142 through Table 171 lists the variables in the logit propensity score matching model for SDG&E stage 1 and stage 2 and PG&E Stage 1 and stage 2 matching. Each stratum (2 for SDG&E and 16 for PG&E) is associated with a separate table. The stage 1 tables include information on the average difference between the control minus the treatment value of the independent variable before matching, after matching, and the best match. The after matching column is the average difference using the 10 or 15 non-participant matches for each participant while the best match compares the best non-participant match and the participants. The stage 1 matching was implemented using monthly kWh. The stage 2 tables only include the before match (stage 1 match) and the best match.

The t-test findings show the statistical likelihood that the participant and non-participant values differ for variables in the logit model. A good match would imply that the t-tests improve following the match, hopefully leading to few, if any, of the average values being statistically different. If the t-test value is larger than 1.96, it implies that the difference between the participants and matched non-participants is statistically significant and there is a more than 5% likelihood that the values differ statistically.

Table 142 and Table 143 list the stage 1 average differences between the participant and potential matched non-participant samples for SDG&E. Table 142 lists the statistics for yearly participants while Table 143 lists the comparison for later participants. These tables show that the participants and potential matches differed observably prior to matching and that they are not statistically different along these variables following matching. As anticipated, the before match participants have a higher usage, their usage is more correlated with weather and more variable, and their participation during the pre-participation period is higher than the general population. The participation in the CARE and FERA program is less for participants than the average population prior to matching. It is also important to note that the propensity models control for household participation in other non-upstream energy efficiency programs run by the IOUs during the pre-installation matching period. If the participant households differ from the non-participant households in some unobservable way that increases the likelihood of general energy efficiency program participation, controlling for participation in the previous year will help to make the participation and non-participant households similar along this characteristic. Following the first-round matching, none of the differences are found to be statistically significant.

Table 144 through Table 159 list the stage 1 average differences between the participant and potential matched non-participant sample for PG&E. These 16 tables list the statistics for each PG&E stratum based on customer consumption size (small and large), CARE and non-CARE status, and four different time periods for participation. The PG&E models do not include the CARE and FERA independent variable because this is a strata variable.

Table 160 and Table 161 list the stage 2 average differences between the participant and matched non-participant sample for SDG&E. The second stage matching uses hourly usage data to estimate the likelihood of participation in the QM program. The matching process and the t test analysis illustrates that the participant and non-participant households are very similar in the hourly usage and the response of their usage to variations in heating and cooling degree days.

Table 162 through Table 171 list the stage 2 average differences between participant and the matched non-participant sample for PG&E. The second stage matching process had only 10 stratum for PG&E, only the late participation in 2014 was stratified by CARE participation due to the smaller participant population of the early strata limiting the ability to stratify and develop high quality matched pairs.

Table 142. SDG&E stage one propensity score matching t-test results, early participation strata

Variable	Before matching: Average Control Minus Treatment	Before matching: t test value	After first round matching: Average Control Minus Average Treatment	After first round matching: t test value	Best match: Average Control Minus Average Treatment	Best match: T test value
Annual kWh	-198.289	-7.82	1.501	0.06	32.983	0.85
Shoulder month kWh	-155.64	-7.53	3.89	0.17	37.091	1.05
Correlation CDD & summer kWh	-0.211	-11.18	0.013	0.66	-0.014	-0.51
Correlation HDD & winter kWh	-0.081	-2.24	0.003	0.08	-0.021	-0.42
Coefficient of Variation kWh	1.95	8.59	-0.032	-0.14	0.141	0.45
Max summer kWh	-381.496	-9.54	-3.709	-0.09	28.472	0.49
Max winter kWh	-171.975	-6.67	6.187	0.21	38.358	0.88
Probability of participation	-0.2	-14.36	0	0	0	0
CARE or FARA	0.076	2.44	0.011	0.35	-0.009	-0.23
Participate in other EE	-0.044	-2.61	-0.01	-0.6	0	0

Table 143. SDG&E stage one propensity score matching t-test results, late participation strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	T test value
Annual kWh	-191.61	-5.31	-10.689	-0.28	-44.02	-0.91
Shoulder month kWh	-146.752	-4.52	-9.665	-0.29	-43.818	-1.02
Correlation CDD & summer kWh	-0.235	-7.98	0.001	0.04	0.004	0.1
Correlation HDD & winter kWh	-0.059	-1.24	0.021	0.39	0.087	1.31
Coefficient of Variation kWh	1.776	7.17	-0.164	-0.58	-0.447	-1.34
Max summer kWh	-366.331	-7.14	-15.088	-0.27	-56.024	-0.79
Max winter kWh	-163.268	-4.21	-13.771	-0.34	-43.23	-0.83
Probability of participation	-0.188	-10.43	0	0	0	0
CARE or FARA	0.131	3.81	-0.002	-0.06	0.008	0.17
Participate in other EE	-0.023	-1.25	-0.017	-0.94	-0.033	-1.66

Table 144. PG&E stage one propensity score matching t-test results, early 2013 participation, non-CARE, and large consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	32.324	0.93	-12.689	-0.36	-7.211	-0.15
Shoulder month kWh	52.571	1.63	-10.26	-0.32	-14.329	-0.33
Correlation CDD & summer kWh	-0.031	-0.87	0.007	0.22	0.03	0.79
Correlation HDD & winter kWh	0.108	2.09	0.025	0.42	0.058	0.73
Coefficient of Variation kWh	0.961	4.28	-0.03	-0.13	-0.189	-0.66
Max summer kWh	-72.892	-1.32	-20.208	-0.35	4.521	0.06
Max winter kWh	124.099	3.56	-16.561	-0.42	-14.648	-0.28
Probability of participation	-0.065	-5.2	0	0	0	0
Participate in other EE	-0.023	-0.82	-0.012	-0.44	-0.038	-1.16

Table 145. PG&E stage one propensity score matching t-test results, early 2013 participation, CARE, and large consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	40.16	1.29	9.054	0.3	-15.315	-0.41
Shoulder month kWh	31.522	1.07	8.079	0.28	-7.462	-0.22
Correlation CDD & summer kWh	-0.05	-2.52	0.007	0.33	-0.002	-0.07
Correlation HDD & winter kWh	0.059	1.12	-0.044	-0.74	-0.008	-0.11
Coefficient of Variation kWh	-0.106	-0.44	-0.105	-0.41	0.149	0.42
Max summer kWh	23.556	0.46	16.683	0.32	-49.598	-0.8
Max winter kWh	105.281	3.16	-0.37	-0.01	-13.269	-0.29
Probability of participation	-0.05	-4.08	0	0	0	0
Participate in other EE	-0.05	-1.82	-0.011	-0.42	-0.011	-0.29

Table 146. PG&E stage one propensity score matching t-test results, early 2013 participation, non-CARE, and small consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	-51.176	-3.31	4.901	0.28	8.123	0.37
Shoulder month kWh	-36.768	-2.63	6.216	0.39	5.816	0.29
Correlation CDD & summer kWh	-0.086	-2.8	-0.009	-0.26	-0.028	-0.6
Correlation HDD & winter kWh	-0.129	-3.06	0.001	0.03	0	0
Coefficient of Variation kWh	0.157	0.54	0.264	0.84	0.199	0.4
Max summer kWh	-90.267	-2.67	-1.654	-0.05	11.832	0.29
Max winter kWh	-46.475	-1.95	5.598	0.24	6.885	0.23
Probability of participation	-0.054	-5.17	0	0	0	0
Participate in other EE	-0.009	-0.47	-0.003	-0.15	0.012	0.38

Table 147. PG&E stage one propensity score matching t-test results, early 2013 participation, CARE, and small consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	-71.441	-4.81	3.511	0.22	26.22	1.14
Shoulder month kWh	-58.168	-4.28	1.196	0.08	17.894	0.87
Correlation CDD & summer kWh	-0.094	-4.2	0.014	0.64	0.022	0.74
Correlation HDD & winter kWh	-0.207	-4.45	0.008	0.17	-0.009	-0.14
Coefficient of Variation kWh	-0.293	-0.9	-0.002	-0.01	-0.188	-0.38
Max summer kWh	-102.524	-3.73	7.568	0.26	31.272	0.7
Max winter kWh	-74.493	-3.72	3.703	0.17	27.805	0.77
Probability of participation	-0.142	-7.73	0	0	0	0
Participate in other EE	-0.077	-2.24	-0.023	-0.73	-0.027	-0.6

Table 148. PG&E stage one propensity score matching t-test results, late 2013 participation, non-CARE, and large consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	24.52	1.02	-9.823	-0.42	-5.152	-0.16
Shoulder month kWh	66.426	3.03	-5.242	-0.26	-3.939	-0.14
Correlation CDD & summer kWh	-0.053	-1.79	0.004	0.14	-0.021	-0.53
Correlation HDD & winter kWh	0.047	1.18	-0.026	-0.57	-0.003	-0.05
Coefficient of Variation kWh	1.072	9.03	-0.072	-0.55	-0.16	-0.98
Max summer kWh	-112.349	-2.92	-9.312	-0.23	0.611	0.01
Max winter kWh	125.948	5.49	-24.105	-1.01	-15.556	-0.47
Probability of participation	-0.113	-9.74	0	0	0	0
Participate in other EE	-0.046	-2.16	-0.011	-0.54	-0.025	-0.88

Table 149. PG&E stage one propensity score matching t-test results, late 2013 participation, CARE, and large consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	-56.743	-2.18	-4.553	-0.14	-38.366	-1.06
Shoulder month kWh	-9.821	-0.41	-5.516	-0.24	-26.63	-0.9
Correlation CDD & summer kWh	-0.056	-1.65	0.009	0.27	-0.004	-0.1
Correlation HDD & winter kWh	-0.007	-0.14	-0.04	-0.77	-0.021	-0.32
Coefficient of Variation kWh	0.598	6.19	-0.133	-1.31	-0.138	-1
Max summer kWh	-214.542	-4.27	16.331	0.3	-38.681	-0.57
Max winter kWh	49.697	1.69	-29.296	-0.95	-76.299	-1.87
Probability of participation	-0.126	-8.12	0	0	0	0
Participate in other EE	-0.125	-3.97	-0.016	-0.5	0	0

Table 150. PG&E stage one propensity score matching t-test results, late 2013 participation, non CARE, and small consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	-91.51	-5.5	2.939	0.2	1.194	0.06
Shoulder month kWh	-56.12	-4.79	2.564	0.2	8.366	0.53
Correlation CDD & summer kWh	-0.101	-2.96	0.007	0.18	-0.03	-0.59
Correlation HDD & winter kWh	0.016	0.32	0.012	0.21	0.023	0.34
Coefficient of Variation kWh	0.694	2.59	0.044	0.14	0.34	0.83
Max summer kWh	-198.791	-6.78	5.793	0.19	-23.241	-0.58
Max winter kWh	-50.954	-2.48	0.772	0.04	-0.066	0
Probability of participation	-0.128	-8.11	0	0	0	0
Participate in other EE	-0.072	-2.52	-0.006	-0.21	0.028	0.66

Table 151. PG&E stage one propensity score matching t-test results, late 2013 participation, CARE, and small consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	-74.662	-4.94	3.898	0.24	3.367	0.15
Shoulder month kWh	-41.956	-3.35	-1.069	-0.08	-1.394	-0.08
Correlation CDD & summer kWh	-0.114	-3.03	-0.005	-0.13	0.041	0.87
Correlation HDD & winter kWh	-0.021	-0.41	0.05	0.84	0.011	0.13
Coefficient of Variation kWh	0.455	2.25	-0.237	-1.05	-0.249	-0.83
Max summer kWh	-179.588	-5.51	19.397	0.56	25.021	0.55
Max winter kWh	-28.958	-1.83	-4.074	-0.24	-14.05	-0.57
Probability of participation	-0.185	-7.74	0	0	0	0
Participate in other EE	-0.223	-4.94	-0.018	-0.37	-0.022	-0.35

Table 152. PG&E stage one propensity score matching t-test results, early 2014 participation, non-CARE, and large consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	41.882	3.62	4.593	0.38	22.362	1.32
Shoulder month kWh	70.811	6.6	6.809	0.59	17.297	1.13
Correlation CDD & summer kWh	-0.074	-7.72	-0.002	-0.16	0.004	0.27
Correlation HDD & winter kWh	0.027	1.28	-0.012	-0.5	0.019	0.62
Coefficient of Variation kWh	0.917	12.45	-0.031	-0.39	-0.053	-0.51
Max summer kWh	-80.683	-3.99	3.047	0.14	36.926	1.21
Max winter kWh	129.428	9.12	-2.414	-0.16	16.677	0.78
Probability of participation	-0.069	-13.55	0	0	0	0
Participate in other EE	-0.005	-0.55	-0.002	-0.27	-0.012	-1.08

Table 153. PG&E stage one propensity score matching t-test results, early 2014 participation, CARE, and large consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	-18.6	-2.3	-6.562	-0.78	6.023	0.51
Shoulder month kWh	17.765	2.41	-4.48	-0.58	8.555	0.79
Correlation CDD & summer kWh	-0.062	-11.37	0.002	0.4	-0.005	-0.65
Correlation HDD & winter kWh	0.01	0.69	-0.013	-0.84	-0.013	-0.65
Coefficient of Variation kWh	0.522	9.96	-0.1	-2.1	-0.122	-1.97
Max summer kWh	-181.296	-12.22	-8.301	-0.55	12.985	0.62
Max winter kWh	85.52	7.71	-15.735	-1.36	-8.115	-0.5
Probability of participation	-0.065	-18.89	0	0	0	0
Participate in other EE	-0.02	-3.21	0	0.01	-0.008	-0.95

Table 154. PG&E stage one propensity score matching t-test results, early 2014 participation, non-CARE, and small consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	-69.931	-11.58	0.636	0.1	4.867	0.56
Shoulder month kWh	-32.107	-6.24	0.519	0.1	3.953	0.52
Correlation CDD & summer kWh	-0.156	-13.3	-0.002	-0.13	-0.006	-0.35
Correlation HDD & winter kWh	-0.102	-5.35	-0.018	-0.85	0.019	0.72
Coefficient of Variation kWh	1.038	12.6	-0.047	-0.54	0.026	0.21
Max summer kWh	-195.146	-15.62	3.771	0.29	5.98	0.33
Max winter kWh	-22.878	-3.2	0	0	8.34	0.77
Probability of participation	-0.121	-17.71	0	0	0	0
Participate in other EE	-0.022	-2.45	-0.002	-0.26	-0.014	-1.14

Table 155. PG&E stage one propensity score matching t-test results, early 2014 participation, CARE, and small consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	-94.571	-23.68	5.276	1.27	7.152	1.24
Shoulder month kWh	-51.879	-15.15	7.224	2.02	9.53	1.9
Correlation CDD & summer kWh	-0.095	-13.92	-0.001	-0.1	-0.004	-0.42
Correlation HDD & winter kWh	-0.113	-8.18	-0.011	-0.8	-0.017	-0.86
Coefficient of Variation kWh	0.576	10.23	0.05	0.83	0.084	0.87
Max summer kWh	-244.374	-26.55	2.102	0.22	3.168	0.24
Max winter kWh	-41.994	-7.76	4.545	0.8	7.393	0.86
Probability of participation	-0.151	-28.07	0	0	0	0
Participate in other EE	-0.018	-3.13	0	-0.04	-0.002	-0.24

Table 156. PG&E stage one propensity score matching t-test results, late 2014 participation, non-CARE, and large consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	48.896	5.3	-4.796	-0.5	-0.534	-0.04
Shoulder month kWh	61.703	7.45	-3.994	-0.46	-3.193	-0.27
Correlation CDD & summer kWh	-0.06	-6.1	-0.001	-0.13	-0.005	-0.35
Correlation HDD & winter kWh	-0.012	-0.72	-0.013	-0.75	0.021	0.98
Coefficient of Variation kWh	0.625	7.91	-0.01	-0.12	0.016	0.15
Max summer kWh	-2.353	-0.14	-2.614	-0.15	-2.221	-0.09
Max winter kWh	106.092	9.07	-7.655	-0.6	-0.366	-0.02
Probability of participation	-0.037	-11.3	0	0	0	0
Participate in other EE	-0.008	-1.1	-0.007	-0.95	-0.017	-1.79

Table 157. PG&E stage one propensity score matching t-test results, late 2014 participation, CARE, and large consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	13.989	2.38	-5.185	-0.85	-8.082	-0.95
Shoulder month kWh	35.651	6.86	-3.776	-0.7	-7.202	-0.96
Correlation CDD & summer kWh	-0.06	-10.81	0.004	0.76	0.003	0.38
Correlation HDD & winter kWh	-0.02	-2.02	-0.007	-0.67	0.001	0.06
Coefficient of Variation kWh	0.39	10.4	-0.005	-0.12	-0.001	-0.01
Max summer kWh	-56.72	-5.12	-5.252	-0.46	-14.219	-0.9
Max winter kWh	80.324	10.09	-8.305	-1.01	-5.377	-0.46
Probability of participation	-0.032	-17.2	0	0	0	0
Participate in other EE	-0.006	-1.67	-0.002	-0.55	-0.007	-1.49

Table 158. PG&E stage one propensity score matching t-test results, late 2014 participation, non-CARE, and small consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	-55.244	-10.67	-0.923	-0.17	0.314	0.04
Shoulder month kWh	-28.255	-6.4	0.22	0.05	2.097	0.32
Correlation CDD & summer kWh	-0.135	-12.38	0.008	0.7	0.014	0.95
Correlation HDD & winter kWh	-0.092	-6.13	0.007	0.42	-0.005	-0.2
Coefficient of Variation kWh	0.8	8.75	-0.018	-0.19	-0.004	-0.03
Max summer kWh	-144.063	-13.01	-5.465	-0.45	-6.253	-0.4
Max winter kWh	-25.473	-4.02	0.473	0.07	-0.638	-0.07
Probability of participation	-0.072	-15.89	0	0	0	0
Participate in other EE	-0.005	-0.88	-0.001	-0.2	0	0

Table 159. PG&E stage one propensity score matching t-test results, late 2014 participation, CARE, and small consumption strata

	Before matching		After first round matching		Best match	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value	Average Control Minus Average Treatment	t test value
Annual kWh	-83.114	-27.31	3.781	1.2	3.969	0.92
Shoulder month kWh	-45.868	-17.57	5.756	2.11	6.77	1.79
Correlation CDD & summer kWh	-0.092	-14.45	-0.002	-0.31	-0.007	-0.77
Correlation HDD & winter kWh	-0.075	-7	0.001	0.07	-0.02	-1.32
Coefficient of Variation kWh	0.615	14.02	0.02	0.43	0.033	0.5
Max summer kWh	-211.701	-29.84	0.685	0.09	3.765	0.37
Max winter kWh	-34.731	-9.5	4.44	1.15	-2.683	-0.48
Probability of participation	-0.113	-31.79	0	-0.03	0	0
Participate in other EE	-0.002	-0.64	0.003	0.97	0.006	1.31

Table 160. SDG&E stage two propensity score matching t-test results, early participation strata

	After first round matching		After second round matching	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily shoulder kWh	-0.918	-1.16	-0.08	-0.07
Daily summer kWh	-1.515	-1.44	-0.128	-0.09
Daily winter kWh	-1.164	-1.37	-0.018	-0.01
Daily Correlation CDD & weekday summer kWh	-0.016	-0.93	-0.013	-0.54

	After first round matching		After second round matching	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily Correlation CDD & weekend summer kWh	-0.043	-2.38	-0.011	-0.46
Daily Correlation HDD & winter kWh	-0.003	-0.17	0.019	0.89
Daily covariation of shoulder kWh	0.004	0.47	0.002	0.15
Daily covariation of summer kWh	-0.04	-3.5	0.013	0.77
Daily covariation of winter kWh	0.018	2.22	0.006	0.48
Probability of participation	-0.096	-8.93	0	0
Maximum peak period hourly usage	-1.127	-5.83	0.146	0.56
Peak period weekday hourly usage	-0.134	-1.9	0.014	0.15
Peak period weekend hourly usage	-0.132	-1.93	0.024	0.24
Peak period correlation CDD and weekday usage	-0.016	-1.1	0.004	0.2
Peak period correlation CDD and weekend usage	-0.034	-2.14	0.007	0.33
Covariance of peak usage and weekday usage	-0.068	-2.95	0.014	0.45
Covariance of peak usage and weekend usage	-0.12	-5.3	-0.001	-0.04
Participate in other EE	-0.011	-0.66	0.026	0.93

Table 161. SDG&E stage two propensity score matching t-test results, late participation strata

	After first round matching		After second round matching	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily shoulder kWh	0.086	0.08	-0.108	-0.07
Daily summer kWh	0.069	0.05	0.642	0.31
Daily winter kWh	0.288	0.25	0.006	0
Daily Correlation CDD & weekday summer kWh	-0.013	-0.52	0.034	1.11
Daily Correlation CDD & weekend summer kWh	-0.047	-2.45	0.009	0.33
Daily Correlation HDD & winter kWh	-0.007	-0.31	0.007	0.23
Daily covariation of shoulder kWh	0.019	1.81	0.011	0.74
Daily covariation of summer kWh	-0.05	-3.4	0.015	0.86
Daily covariation of winter kWh	0.018	1.76	-0.012	-0.88
Probability of participation	-0.152	-9.32	0	0
Maximum peak period hourly usage	-1.021	-3.87	0.117	0.32
Peak period weekday hourly usage	-0.013	-0.14	0.054	0.44
Peak period weekend hourly usage	-0.055	-0.56	0.027	0.2
Peak period correlation CDD and weekday usage	-0.025	-1.27	0.027	1.04
Peak period correlation CDD and weekend usage	-0.047	-2.52	0.012	0.44
Covariance of peak usage and weekday usage	-0.1	-3.73	0.029	0.63

Variable	After first round matching		After second round matching	
	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Covariance of peak usage and weekend usage	-0.146	-5.11	0.021	0.48
Participate in other EE	-0.012	-0.66	0	0

Table 162. PG&E stage two propensity score matching t-test results, early 2013 participation, large consumption strata

Variable	After first round matching		After second round matching	
	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily shoulder kWh	-0.468	-0.64	-0.557	-0.56
Daily summer kWh	-0.693	-0.61	-0.366	-0.23
Daily winter kWh	-0.484	-0.63	-1.053	-1.05
Daily Correlation CDD & weekday summer kWh	0.005	0.38	-0.004	-0.24
Daily Correlation CDD & weekend summer kWh	0.018	1.12	-0.008	-0.34
Daily Correlation HDD & winter kWh	-0.006	-0.38	-0.001	-0.04
Daily covariation of shoulder kWh	0.004	0.52	-0.006	-0.55
Daily covariation of summer kWh	-0.002	-0.32	-0.001	-0.12
Daily covariation of winter kWh	0.006	0.74	-0.004	-0.39
Daily max summer kWh	-1.453	-0.7	-0.758	-0.27
Daily max winter kWh	0.513	0.34	-1.664	-0.86
Probability of participation	-0.043	-5.56	0	0
Covariance of peak usage and weekday usage	-0.031	-1.63	-0.011	-0.4
Covariance of peak usage and weekend usage	-0.037	-2.06	-0.02	-0.74

Variable	After first round matching		After second round matching	
	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Maximum peak period hourly usage	-0.163	-1.07	-0.28	-1.27
Peak period weekday hourly usage	0.04	0.5	-0.071	-0.62
Peak period weekend hourly usage	-0.009	-0.11	-0.043	-0.35
Peak period correlation CDD and weekday usage	-0.005	-0.35	-0.003	-0.18
Peak period correlation CDD and weekend usage	0.002	0.16	-0.004	-0.18
Covariance of peak usage	-0.027	-1.56	-0.003	-0.14
Participate in other EE	-0.036	-1.59	-0.007	-0.23

Table 163. PG&E stage two propensity score matching t-test results, early 2013 participation, small consumption strata

Variable	After first round matching		After second round matching	
	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily shoulder kWh	0.308	0.81	-0.198	-0.37
Daily summer kWh	0.33	0.55	0.006	0.01
Daily winter kWh	0.138	0.35	-0.635	-1.11
Daily Correlation CDD & weekday summer kWh	0.004	0.23	0.018	0.78
Daily Correlation CDD & weekend summer kWh	0.007	0.4	0.032	1.33
Daily Correlation HDD & winter kWh	0.01	0.62	0.001	0.05
Daily covariation of shoulder kWh	0.025	2.63	-0.011	-0.85

	After first round matching		After second round matching	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily covariation of summer kWh	-0.027	-2.45	0.003	0.23
Daily covariation of winter kWh	0.013	1.42	-0.013	-0.96
Daily max summer kWh	-2.981	-2.04	0.064	0.03
Daily max winter kWh	0.925	0.89	-1.768	-1.21
Probability of participation	-0.105	-7.69	0	0
Covariance of peak usage and weekday usage	-0.055	-2.32	0.044	1.15
Covariance of peak usage and weekend usage	-0.09	-3.3	0.024	0.69
Maximum peak period hourly usage	-0.4	-2.56	-0.001	-0.01
Peak period weekday hourly usage	0.086	1.57	-0.006	-0.09
Peak period weekend hourly usage	0.125	2.54	0.032	0.45
Peak period correlation CDD and weekday usage	0.027	1.64	0.018	0.8
Peak period correlation CDD and weekend usage	0.014	0.81	0.027	1.17
Covariance of peak usage	-0.064	-2.73	0.018	0.54
Participate in other EE	-0.018	-0.9	-0.021	-0.75

Table 164. PG&E stage two propensity score matching t-test results, late 2013 participation, large consumption strata

	After first round matching		After second round matching	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily shoulder kWh	-0.319	-0.59	-0.563	-0.76
Daily summer kWh	-0.644	-0.66	-0.534	-0.37
Daily winter kWh	-0.71	-1.29	-0.758	-0.96
Daily Correlation CDD & weekday summer kWh	-0.007	-0.73	-0.005	-0.35
Daily Correlation CDD & weekend summer kWh	0.005	0.47	-0.001	-0.04
Daily Correlation HDD & winter kWh	-0.004	-0.25	0.003	0.13
Daily covariation of shoulder kWh	0.019	2.79	-0.004	-0.5
Daily covariation of summer kWh	0.001	0.25	0.004	0.47
Daily covariation of winter kWh	0.001	0.24	-0.007	-0.84
Daily max summer kWh	0.355	0.21	-0.471	-0.19
Daily max winter kWh	-0.918	-0.82	-1.003	-0.61
Probability of participation	-0.046	-6.75	0	0
Covariance of peak usage and weekday usage	-0.013	-0.94	0.016	0.77
Covariance of peak usage and weekend usage	-0.018	-1.42	0.011	0.6
Maximum peak period hourly usage	-0.26	-2.15	-0.13	-0.73
Peak period weekday hourly usage	-0.068	-1.04	-0.064	-0.66
Peak period weekend hourly usage	-0.046	-0.68	-0.033	-0.33
Peak period correlation CDD	-0.01	-0.98	-0.001	-0.08

Variable	After first round matching		After second round matching	
	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
and weekday usage				
Peak period correlation CDD and weekend usage	0.003	0.33	0.007	0.5
Covariance of peak usage	-0.015	-1.26	0.012	0.66
Participate in other EE	-0.058	-2.71	-0.008	-0.28

Table 165. PG&E stage two propensity score matching t-test results, late 2013 participation, small consumption strata

Variable	After first round matching		After second round matching	
	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily shoulder kWh	0.095	0.3	0.61	1.52
Daily summer kWh	-0.005	-0.01	0.418	0.5
Daily winter kWh	-0.137	-0.33	0.954	1.75
Daily Correlation CDD & weekday summer kWh	-0.023	-1.53	-0.02	-0.97
Daily Correlation CDD & weekend summer kWh	-0.017	-1.06	0.002	0.08
Daily Correlation HDD & winter kWh	0.028	1.62	-0.013	-0.54
Daily covariation of shoulder kWh	0.026	2.51	-0.006	-0.4
Daily covariation of summer kWh	-0.019	-1.92	0.003	0.23
Daily covariation of winter kWh	0.015	1.63	-0.004	-0.37
Daily max summer kWh	-0.968	-0.78	1.511	0.8
Daily max winter kWh	0.881	1.04	1.658	1.4
Probability of participation	-0.09	-8.91	0	0

	After first round matching		After second round matching	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Covariance of peak usage and weekday usage	-0.07	-2.85	-0.013	-0.38
Covariance of peak usage and weekend usage	-0.08	-3.53	0.001	0.02
Maximum peak period hourly usage	-0.461	-3.8	0.208	1.15
Peak period weekday hourly usage	-0.001	-0.02	0.016	0.23
Peak period weekend hourly usage	0.018	0.33	0.038	0.53
Peak period correlation CDD and weekday usage	-0.017	-1.21	-0.018	-0.94
Peak period correlation CDD and weekend usage	-0.009	-0.61	0	0.01
Covariance of peak usage	-0.068	-2.99	-0.015	-0.47
Participate in other EE	-0.056	-1.95	-0.011	-0.28

Table 166. PG&E stage two propensity score matching t-test results, early 2014 participation, large consumption strata

	After first round matching		After second round matching	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily shoulder kWh	-0.165	-0.76	-0.078	-0.25
Daily summer kWh	-1.477	-4.15	-0.54	-1.07
Daily winter kWh	-0.423	-1.63	0.233	0.63
Daily Correlation CDD & weekday summer kWh	-0.019	-5.36	-0.002	-0.5

	After first round matching		After second round matching	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily Correlation CDD & weekend summer kWh	-0.016	-3.93	-0.002	-0.33
Daily Correlation HDD & winter kWh	0.012	2.11	0.01	1.21
Daily covariation of shoulder kWh	-0.002	-0.8	-0.004	-0.94
Daily covariation of summer kWh	-0.002	-1.02	-0.001	-0.24
Daily covariation of winter kWh	-0.006	-2.33	0.001	0.32
Daily max summer kWh	-1.306	-2.1	-0.907	-1.01
Daily max winter kWh	-0.648	-1.28	0.558	0.75
Probability of participation	-0.032	-14.01	0	0
Covariance of peak usage and weekday usage	0.005	0.96	0.005	0.58
Covariance of peak usage and weekend usage	0	-0.07	0.005	0.62
Maximum peak period hourly usage	-0.228	-4.88	0.001	0.02
Peak period weekday hourly usage	-0.158	-6.59	-0.027	-0.79
Peak period weekend hourly usage	-0.128	-5.02	-0.037	-1.04
Peak period correlation CDD and weekday usage	-0.023	-6.14	-0.004	-0.82
Peak period correlation CDD and weekend usage	-0.015	-3.76	-0.002	-0.35
Covariance of peak usage	0.002	0.34	0.005	0.74
Participate in other EE	-0.006	-1.14	0.001	0.18

Table 167. PG&E stage two propensity score matching t-test results, early 2014 participation, small consumption strata

	After first round matching		After second round matching	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily shoulder kWh	0.149	1.46	0.113	0.77
Daily summer kWh	-0.71	-3.41	0.004	0.01
Daily winter kWh	0.004	0.04	0.069	0.39
Daily Correlation CDD & weekday summer kWh	-0.02	-4.46	0.001	0.24
Daily Correlation CDD & weekend summer kWh	-0.009	-1.77	0.003	0.39
Daily Correlation HDD & winter kWh	0.013	2.53	-0.002	-0.23
Daily covariation of shoulder kWh	0.007	1.91	-0.004	-0.82
Daily covariation of summer kWh	-0.023	-6.69	0.001	0.23
Daily covariation of winter kWh	0.003	1	-0.004	-0.85
Daily max summer kWh	-2.791	-6.16	0.633	0.96
Daily max winter kWh	0.169	0.55	-0.174	-0.39
Probability of participation	-0.052	-18.3	0	0
Covariance of peak usage and weekday usage	-0.044	-5.15	0.002	0.16
Covariance of peak usage and weekend usage	-0.053	-7.02	-0.007	-0.67
Maximum peak period hourly usage	-0.46	-11.38	0.079	1.32
Peak period weekday hourly usage	-0.093	-5.42	0.001	0.06
Peak period weekend hourly usage	-0.1	-5.53	0.02	0.77
Peak period correlation CDD	-0.021	-4.54	0	0.03

Variable	After first round matching		After second round matching	
	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
and weekday usage				
Peak period correlation CDD and weekend usage	-0.01	-1.94	0.003	0.48
Covariance of peak usage	-0.052	-6.92	-0.003	-0.33
Participate in other EE	-0.002	-0.5	0.007	0.9

Table 168. PG&E stage two propensity score matching t-test results, late 2014 participation, large consumption, non-CARE strata

Variable	After first round matching		After second round matching	
	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily shoulder kWh	-0.076	-0.25	-0.108	-0.26
Daily summer kWh	-0.219	-0.44	-0.046	-0.06
Daily winter kWh	-0.286	-0.83	-0.172	-0.35
Daily Correlation CDD & weekday summer kWh	-0.012	-1.94	-0.009	-0.99
Daily Correlation CDD & weekend summer kWh	-0.009	-1.18	-0.008	-0.77
Daily Correlation HDD & winter kWh	0.004	0.51	-0.015	-1.25
Daily covariation of shoulder kWh	0.002	0.45	0	0.06
Daily covariation of summer kWh	0.004	1.02	-0.003	-0.52
Daily covariation of winter kWh	-0.001	-0.15	-0.002	-0.33
Daily max summer kWh	0.43	0.45	-0.504	-0.35
Daily max winter kWh	-0.316	-0.42	-0.438	-0.42
Probability of participation	-0.015	-5.94	0	0

	After first round matching		After second round matching	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Covariance of peak usage and weekday usage	0.005	0.53	-0.012	-0.91
Covariance of peak usage and weekend usage	-0.006	-0.63	-0.002	-0.18
Maximum peak period hourly usage	-0.075	-0.97	-0.056	-0.49
Peak period weekday hourly usage	-0.073	-1.96	0.001	0.02
Peak period weekend hourly usage	-0.045	-1.15	-0.026	-0.47
Peak period correlation CDD and weekday usage	-0.011	-1.69	-0.007	-0.79
Peak period correlation CDD and weekend usage	-0.007	-1.06	-0.008	-0.84
Covariance of peak usage	0.004	0.46	-0.007	-0.59
Participate in other EE	-0.005	-0.68	0.009	0.72

Table 169. PG&E stage two propensity score matching t-test results, late 2014 participation, large consumption, CARE strata

	After first round matching		After second round matching	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily shoulder kWh	-0.228	-1.22	0.153	0.58
Daily summer kWh	-0.8	-2.51	0.333	0.74
Daily winter kWh	-0.466	-2.02	0.145	0.45
Daily Correlation CDD & weekday summer kWh	-0.006	-1.83	0.002	0.4

	After first round matching		After second round matching	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily Correlation CDD & weekend summer kWh	0.004	1.04	0	-0.03
Daily Correlation HDD & winter kWh	0.017	3.41	-0.001	-0.13
Daily covariation of shoulder kWh	-0.006	-2.22	0.002	0.45
Daily covariation of summer kWh	-0.003	-1.67	0	-0.06
Daily covariation of winter kWh	-0.008	-3.74	0	-0.03
Daily max summer kWh	-0.855	-1.5	0.544	0.68
Daily max winter kWh	-1.102	-2.42	0.266	0.41
Probability of participation	-0.037	-16.24	0	0
Covariance of peak usage and weekday usage	-0.007	-1.35	0	0.04
Covariance of peak usage and weekend usage	-0.011	-2.33	0.002	0.36
Maximum peak period hourly usage	-0.252	-6.19	0.067	1.12
Peak period weekday hourly usage	-0.135	-6.15	0.013	0.44
Peak period weekend hourly usage	-0.112	-4.86	0.016	0.49
Peak period correlation CDD and weekday usage	-0.014	-3.76	-0.002	-0.32
Peak period correlation CDD and weekend usage	-0.005	-1.27	-0.004	-0.64
Covariance of peak usage	-0.01	-2.07	0.001	0.2
Participate in other EE	-0.004	-1.01	-0.002	-0.33

Table 170. PG&E stage two propensity score matching t-test results, late 2014 participation, small consumption, non-CARE strata

	After first round matching		After second round matching	
Variable	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily shoulder kWh	0.139	0.91	0.257	1.15
Daily summer kWh	-0.527	-1.8	0.224	0.54
Daily winter kWh	0.003	0.02	0.218	0.79
Daily Correlation CDD & weekday summer kWh	-0.002	-0.28	-0.004	-0.36
Daily Correlation CDD & weekend summer kWh	0.007	0.81	-0.003	-0.24
Daily Correlation HDD & winter kWh	0.02	2.48	0.006	0.51
Daily covariation of shoulder kWh	0.004	0.82	-0.004	-0.59
Daily covariation of summer kWh	-0.02	-3.68	0.007	0.92
Daily covariation of winter kWh	-0.002	-0.51	0.003	0.39
Daily max summer kWh	-2.562	-3.59	1.43	1.35
Daily max winter kWh	-0.095	-0.21	0.552	0.82
Probability of participation	-0.04	-10.32	0	0
Covariance of peak usage and weekday usage	-0.032	-2.37	0.014	0.75
Covariance of peak usage and weekend usage	-0.053	-3.99	0.009	0.48
Maximum peak period hourly usage	-0.4	-6.4	0.115	1.25
Peak period weekday hourly usage	-0.071	-3.11	-0.001	-0.04
Peak period weekend hourly usage	-0.052	-2.03	0.024	0.64
Peak period correlation CDD	-0.007	-0.96	-0.007	-0.75

Variable	After first round matching		After second round matching	
	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
and weekday usage				
Peak period correlation CDD and weekend usage	0.004	0.54	-0.003	-0.29
Covariance of peak usage	-0.037	-2.98	0.009	0.54
Participate in other EE	-0.001	-0.11	0.008	0.8

Table 171. PG&E stage two propensity score matching t-test results, late 2014 participation, small consumption, CARE strata

Variable	After first round matching		After second round matching	
	Average Control Minus Treatment	t test value	Average Control Minus Average Treatment	t test value
Daily shoulder kWh	0.189	2.08	0.046	0.35
Daily summer kWh	-0.827	-4.35	-0.023	-0.09
Daily winter kWh	0.142	1.3	0.078	0.5
Daily Correlation CDD & weekday summer kWh	-0.006	-1.55	0.004	0.77
Daily Correlation CDD & weekend summer kWh	-0.001	-0.13	0	-0.06
Daily Correlation HDD & winter kWh	0.03	5.98	0.007	0.96
Daily covariation of shoulder kWh	-0.002	-0.45	-0.001	-0.13
Daily covariation of summer kWh	-0.034	-11.82	0.001	0.23
Daily covariation of winter kWh	-0.02	-6.61	-0.005	-1.32
Daily max summer kWh	-4.255	-10.73	0.729	1.24
Daily max winter kWh	-0.725	-2.58	-0.034	-0.08
Probability of participation	-0.105	-29.76	0	0

	After first round matching		After second round matching	
Variable	**Average Control Minus Treatment**	**t test value**	**Average Control Minus Average Treatment**	**t test value**
Covariance of peak usage and weekday usage	-0.075	-10.02	0.004	0.34
Covariance of peak usage and weekend usage	-0.07	-10.11	0.005	0.55
Maximum peak period hourly usage	-0.649	-18.21	0.074	1.41
Peak period weekday hourly usage	-0.128	-8.24	-0.004	-0.17
Peak period weekend hourly usage	-0.149	-8.97	0	-0.02
Peak period correlation CDD and weekday usage	-0.019	-4.64	-0.001	-0.11
Peak period correlation CDD and weekend usage	-0.009	-2.04	-0.002	-0.29
Covariance of peak usage	-0.077	-11.69	0.007	0.78
Participate in other EE	0.004	1.32	-0.001	-0.13

APPENDIX K. APPENDIX AA - STANDARDIZED HIGH LEVEL SAVINGS[114]

[114] The tables in Appendix AA summarizing natural gas savings make use of the unit MTherms – 1,000 Therms – rather than MMTherms – 1,000,000 Therms – for formatting purposes.

APPENDIX L. APPENDIX AB - STANDARDIZED PER UNIT SAVINGS

APPENDIX M. APPENDIX AC - RECOMMENDATIONS

TITLE OF REPORT:	DRAFT Impact Evaluation of 2015 Commercial Quality Maintenance Programs (HVAC3)					
Subject:	**Entity:**	**Section:**	**Page:**	**Type:**	**QUESTION or COMMENT:**	**DNV GL Response:**
IESR	Carol Yin			Question	Would it be possible for the evaluation team to include an appendix with recommendations presented using the table from the CPUC Energy Division Impact Evaluation Standard Reporting Guidelines? Thank you!	Yes, it will be included with the final version as Appendix AC.
Conclusions and Recommendations	SCE	1.3 Table 2	5, 79	Question	Could the report include a brief discussion of possible reasons behind the low realization rates for kW savings? REALIZATION RATE kW: Could you comment as to why the SCE QM Evaluated Realization Rate kW is so low (33%) compared to the Evaluated Realization Rate kWh (137%), in terms of changes to the ex ante modeling assumptions? Section 4.1.6.2 (p.77) includes a statement listing the drivers to the Evaluated Realization Rate kWh (137%), but there is no mention of the Evaluated Realization Rate kW.	Text added in section 1.3 discussing demand savings: This report has very little discussion of demand savings because they are low for most of the measures installed through HVAC QM and tune up programs. The most significant demand savings come from RCA and coil cleaning measures which increase the efficiency of the HVAC unit, hence reducing the kW draw when it is running. Economizer measures have slight kW savings caused by climates where the economizer operates during peak demand periods. Similarly, thermostat measures produce very small demand savings, and supply fan measures have no demand savings. Some of the reported demand realization rates are large or small, and that is caused by the difficulty of calculating

						and reporting a small number. Small modeling changes have a relatively large effect on the demand savings.
Conclusions and Recommendations	SCE	1.5.1, paragraph 5	9	Question	Were faults related to non-condensable, restrictions or poorly functioning metering devices as included in the RCA measure considered? Would the evaluator recommend that those faults be included in the measure?	The correction of the listed faults (non-condensable, restrictions or poorly functioning metering devices) were not included in the evaluated RCA measure savings. It would make sense to include correction of those faults within the scope of the RCA measure if sufficient budget is allocated in the future and if the FDD technology is robust enough to identify the faults. These faults can create false negatives or false positive RC results, and should be considered as part of a comprehensive refrigerant side diagnostic and repair protocol.
Conclusions and Recommendations	SCE	1.5, paragraph 4	8,22	Question	Can more detailed information regarding the missing link between tracking data claims and the implementer data be provided? The Program collects more data than is used to support standardized savings claims and further explanation will help bridge the connection between the data collected and the noted verification concerns. Are the references to unique record identifiers on Page 22 the concern that we can look to address?	Additional information is provided in section 3.1.

Conclusions and Recommendations	SCE	1.5.1, paragraph 5	9	Question	Refrigerant circuit pressures are required upon initial enrollment in the SCE CQM program in alignment with the recommendations of the Standard 180 Maintenance Task working group report for System Performance Analysis. The program does not require additional pressure readings after the initial commissioning of the unit into the CQM program, unless condition indicators of a refrigerant fault are present. Would the Evaluator recommend that criteria be established to determine when refrigerant pressure readings should be taken for FDD purposes upon initial program enrollment?	Yes, we agree that criteria should be established to determine when refrigerant pressure readings should be taken for FDD purposes upon initial program enrollment. Potentially refrigerant charge could be checked at initial enrollment, but not at follow up maintenance visits unless certain criteria are met.
Residential Program Recommendation	SDG&E	1.5.2	10	Comment	"Given these findings, the evaluation team recommends the residential QM programs apply the workpaper disposition savings per ton for RCA and fan repair." It seems that the only fan measure considered was Supply fan repair or adjustment, which would most closely align with our advanced measure (ECM Fan replacement) with is not implemented by a large proportion of participants. Our most common fan measure is the Efficient Fan Controller, not fan repair.	Thanks for the comment. The recommendation was addressing PG&E's use of ex ante savings values that exceeded the workpaper disposition. For SDG&E, the evaluation analyzed the energy savings for the QM program. The billing analysis finding that the gross realization rate is only 26% implies that the ex ante savings from the efficient fan controller measure was not observable in the billing analysis.

Conclusions and Recommendations	SCE	1.5.3, bullet 2	10	Question	The SCE CQM program collects as-found economizer data that indicates the fault. What additional information is requested?	Damper position should be recorded and defined in some measurable way (e.g. control signal volts or percent stroke on the damper motor) that can be replicated in the field. As found airflow is probably too much of an ask at this point since outside airflow measurement techniques are not well developed.
Conclusions and Recommendations	SCE	1.5.3, bullet 2	10	Comment	Collecting airflow measurements is not within the Scope of ASHRAE 180-2012 Table 5-12 and would not be considered within the scope of a routine maintenance inspection.	Noted
Conclusions and Recommendations	SCE	1.5.1	10	Comment	"A potential change in strategy may be to identify the high-quality practices and contractors and focus on getting those contractors to sites most in need of performance improvements. The program would then not seek to improve the quality of all contractors, but focus on getting the top-quality contractors to the poorest performing sites." The statement listed below would potentially have a negative affect on NTG figures by focusing on contractors that are already performing quality maintenance on a regular basis. To influence the contractor market the program would want to coach contractors that would otherwise conduct	This strategy does not address the low NTG ratio problem. Text has been added with a potential strategy for addressing the low NTG ratio, namely performing a baseline contractor practice survey and updating ex ante workpapers so that they reflect the baseline of current practice rather than a baseline of no HVAC maintenance at all. It is also important to find a way to improve the maintenance practices of additional contractors beyond the top quality pool as an overall market transformation activity.

					maintenance, repairs and upgrades below the level of Standard 180. A potential change in strategy may be to identify the high-quality practices and contractors and focus on getting those contractors to sites most in need of performance improvements. The program would then not seek to improve the quality of all contractors, but focus on getting the top-quality contractors to the poorest performing sites.	
Evaluation approach	SCE	2.4, paragraph 6	21	Comment	Footnote 13 appears to be missing from the document. The contractor survey methodology cannot be evaluated without this data.	It seems like you are referring to footnote 14 on page 20. The footnote has been added.
Tracking data findings	PG&E	3.1.1	21	Comment	The first bullet in this section states that one erroneous name appeared 44,468 times in the ContactName_1 field in PG&E's commercial HVAC program. PG&E found that the name appeared only 4,468 times. Please correct this typographical error.	Typo corrected.
Supply Fan	SCE	3.1.2.3	26	Question	"Two programs had extensive fan control data - SCE QM and PG&E Commercial QM." Was the supply fan program tracking data used in combination with the survey results to inform changes to the ex ante models?	The field data was used instead of program data to independently evaluate the supply fan control measure.

Thermostat Data	SCE	3.1.2.2, paragraph 1	26	Question	The SCE CQM program also collects pre and post implementation thermostat set-point temperatures. Perhaps this was a typo? Previously, the report stated that "SDG&E Direct Install program contained no measure-level data at all, only customer contact information."	Typo corrected.
Coil Cleaning	SCE	3.1.2.4, paragraph 1	27	Question	The SCE CQM program collects evaporator and condenser coil splits and supply fan motor amperage before and after coil cleaning. Does this qualify as coil cleaning data?	We did not find any pre/post coil cleaning data in the implementer data file provided by SCE to this evaluation, and did not find any motor amp data at all.
Phone Survey Activities	SCE	3.3.3 paragraph 3	38	Comment	Footnote 18 references a study that we could not locate. Without this information the thermostat survey that customers took could not be evaluated.	revised text and added the complete phone survey to a referenced appendix.
Thermostats	SCE	3.3.3, paragraph 2	38	question	The SCE QM measure specifies at least a 3 degree dead band between occupied set points and aligning run-time with scheduled occupancy. Are these occupied settings included in this measure and were they evaluated for savings?	The occupied time period settings used in the evaluation align with the DEER prototypes used for modeling.
Thermostats	SCE	3.3.3, paragraph 5, Table 18	39	Question	It is noted that ex post ante on-site data supplemented the survey data. What was the SCE CQM sample size for the on-site data collection?	SCE thermostat data collection included 7 phone surveys and 9 on-sites.
Residential non-participant selection;	PG&E	3.2.3, 4.4	39, 90	Question	We applaud DNV GL's efforts to use billing analysis to estimate the savings from residential QM programs. However,	1) It is never possible to prove that a quasi-experimental design leads to the development of a matched non-

Residential program gross and net-savings evaluation methods and results					as you know, billing analysis relies on several key assumptions, whose limitations we suggest the report address more fully. These include:(1) Comparability of the program and comparison groups. As you know, the validity of the propensity score matching approach is based on the assumption that the primary difference between the groups is the treatment received by the program group. In this case, that comparability is questionable due to the opt-in nature of QM programs. While the report notes that the groups are quite similar based on observed variables, it is unclear if or how much of this matching addresses the inherent selection bias. Could the report include a more robust discussion of the challenges, limitations, and threats to validity of this approach, and any ways the evaluation team considered addressing the issue of omitted variable bias (e.g., using the Heckman correction)? In addition, could the report include a fuller and clearer discussion of the PSM methods used--for example, how the two stages were executed--and report standard regression diagnostics and raw differences between the program and comparison groups on dependent variables included in the matching model? This information could be	participant group that is similar to the participant group. The development of the non-participant sample, however, followed best practices in the development of the matched sample. The analysis used a two step process to match along all characteristics observable to the utility. The analysis tried including independent variables from the Census tract data, including average neighborhood income and home ownership percentages. The inclusion of these variables, however, did not improve the matched. The analysis also included as an independent variables the incidence of participation in other down stream EE programs during the matching period. If participation in EE programs is associated with an unobservable desire to reduce general energy usage, the inclusion of the other EE variable in the logit model will help to proxy for some of this unobservable. The report section on the matching process was expanded. The analysis of energy savings did not incorporate a Heckman correction. Including a Heckman correction would require the specification to eliminate the site specific fixed effect since both the Heckman and the site specific fixed effect are individual specific but constant over time. Given the substantial effort put

					included in a technical appendix.(2) Billing analysis is generally seen as a way to directly estimate net savings. Could the report include a discussion of the rationale for estimating ex-post gross savings? (3) The impact model for PG&E's program disaggregates the impact of the different QM measures. Could the report include a discussion of potential collinearity issues, whether any arose, and how they were addressed, if so? Conversely, was modeling interaction effects between different QM measures (which could yield more savings if implemented together) considered?(4) The inclusion of ex ante savings estimates of other, non-residential QM, EE measures installed at the customer's home (the EEkWit variable in the equation on page 84) introduces the potential for significant measurement error and bias in unknown directions. Could this be considered in the discussion of threats to validity?(5) Could the report please provide the final gross and net impact model specifications for PG&E and SDG&E? While the report discusses their differences, the discussion would be easier to follow if all four equations were included (in a technical appendix if not the body of the report). In addition, could the report include standard regression diagnostics for the gross and	into the development of the matched non-part sample, the analysis team believes that the energy estimation analysis would suffer more from the elimination of the individual fixed effect than from the inclusion of an inverse mills ratio. The report added an appendix with more information on the matching process. (2) Billing analysis is a method for developing both net and gross savings. The report explains that the gross estimate of savings is needed given that QM is an ESPI measure. (3) PG&E's program participation, or the measures implemented by program participants, differed by year. In 2013, almost all of the program participants installed only the fan measure, in 2014 almost 1/3 of participants installed only RCA, 1/3 blower motors, and 1/3 both RCA and blower motors. The billing analysis for PG&E was implemented separately for 2013 and 2014 to develop estimated impacts for the three QM measures. The 2013 analysis only estimated the impact for fans. There was no issue with multicollinearity because it was the measure installed at nearly all participant homes and very few other measure were installed. The 2014 analysis estimated the impact for RCA and blower motors. To determine if multicollinearity was an issue, we

					net savings estimates, as well as a table of raw differences between the program and comparison groups on dependent variables included in the impact models? This information could be included in a technical appendix.(6) While relatively unlikely, it is possible that members of the comparison group undertook one or more of the QM measures incented by the program without receiving an incentive for doing so. If this occurred, it would cause the billing analysis approach to would undercount net savings. We suggest acknowledging this consideration in the discussion of threats to validity.Overall, we urge that the relevant sections be revised to caveat the residential QM gross and net impact findings appropriately, and to discuss in greater detail the challenges, limitations, and threats to validity of the matched comparison billing analysis approach.	developed various specifications, those that did and those that did not interact the RCA and blower motor independent variables with HDD and CDD. The models were also specified as two simple binaries for RCA and blower motors and where the RCA and blower motor variable were the quantity of tons of these measures the household received. Ultimately the model included the quantity of tons and the quantity of tons interacted with HDD and CDD. The 2014 model was also estimated using only RCA participants and only blower motor participants. The estimated savings for the joint 2014 model and the separate models were very similar, suggesting that multicollinearity was not a substantial issue in this analysis. (4) The model was estimated with and without the "other EE variable". The other EE variable used in the PG&E model was a binary variable that is one after the household participates in other EE programs and a zero prior to participation. In the model without the EE participation variable, the estimated impact of QM is slightly higher. It is the study teams belief that controlling for other EE participation helps the model isolate the energy savings attributable to the QM program and that specifications without the other EE participation

						attribute some of the savings from other EE measures to the QM program. We believe that leaving out the other EE savings variable would be a threat to the validity of the QM savings estimate. (5) The final net and gross model specification have been added to the report. The report has added the requested information. The technical appendix on the estimated parameters for the QM savings measures has been expanded to include information on the adjusted R2. An illustration has been added to show how both the participant and non-participant households had a distribution of households that increased and decreased their consumption values and that these distributions are very similar across both sets of households. (6) It is certainly possible that the comparison group had their AC serviced. The billing analysis approach to estimating net savings is supposed to determine the savings that are attributable to the program. If households in the comparison group are servicing their AC without a rebate, this is one of the attributes that the net analysis is supposed to eliminate from the savings that are attributable to the program. I do not consider this a threat to validity. I consider this the one of the purposes of the net analysis. Perhaps I

						do not understand the concern? (7) We have expanded our discussion of the potential issues associated with a billing analysis approach. Thanks for the great questions and comments.
Commercial program gross savings evaluation methods and results	PG&E	4.1	42	Comment	The executive summary states that: "For commercial QM measures, DNV GL used an engineering approach for assessing savings…updated parameters were then run through the same DEER eQuest models that were used to develop ex ante program savings estimates." (p. 2) Using the same models for ex post and ex ante estimates seems counter intuitive to the concept of independent evaluation. PG&E made similar comments on the Impact Evaluation of 2013-14 Upstream HVAC Programs (2013-14 HVAC1 impact evaluation). We believe that heavy reliance on DEER inputs and models (or similar models) to determine ex post savings has led to questionable results throughout the evaluation. While DEER may provide a good basis for savings calculations, evaluators must perform due diligence into where models and parameters are not appropriate for program realities. We urge that these estimates of ex post savings be treated cautiously. In future evaluations, we urge the CPUC and its evaluators to develop independent	Conducting an independent savings calculation can provide an average realization rate on the ex-ante savings, but won't give much guidance to the DEER team on how to improve their models. Agree that DEER model calibration is on ongoing concern, but the data required are beyond the scope of this evaluation. We need an updated CEUS study or something similar to address the overall issue of DEER model calibration. An independent calculation of savings at the participant sites with a comparison to the input adjusted DEER models could give some evidence of bias introduced by the DEER process, but this would be limited in scope and would not likely provide enough data to make global changes to the DEER prototypes and/or DOE-2 simulation techniques.

					models against which to check ex ante estimates.	
Results	SCE	Table 24 and Table 25	47	Question	Is it possible for "Table 24. Economizer functionality results" and "Table 25. Economizer installation rate results summary" to include IOU? The prior HVAC3 2013-2014 included this level of detail (in Table 34 and Table 35 of that report).	Report revised to show IOU in Table 24.
Economizer savings by program	SCE	Table 28	52	Question	From "Table 28. Economizer savings by program", we see the Ex Post kW Savings are greater than the Ex Ante kW Savings - did a similar economizer kW improvement also happen to the SCE QM results?	Yes
Thermostats	SCE	4.1.2.1, paragraph 3	53	Comment	In the SCE CQM program, minimum accepted setback cooling temperature is 80F. This was also referenced on page 54, Table 29 and on Table 86, Page C-4.	Revised
Field Results	SCE	4.1.2.1 Field Results, Paragraph 1	54	Comment	The SCE CQM program does require program stickers on all enrolled thermostats. If there were not stickers present they may not have been enrolled.	We asked the site contact if the thermostat was changed or reprogrammed through the program, and only recorded set points from those reportedly in the program.
Field Results	SCE	4.1.2.1 Field Results, Paragraph 1	54	Question	Did the Evaluator consider sites with 24 hour occupancy schedules? Many locations, including fitness gyms and convenience stores, in the SCE CQM program operate 24 hours a day, 7 days	Yes, we considered this, and excluded these types of facilities. We also excluded server rooms for this reason.

					a week and therefore would not have unoccupied setback settings.	
Program Tracking Data	SDG&E	3.4.1	40	Comment	" The smaller size of SDG&E's participant population could lead to increased difficulty finding a good non-participant match…" and "The matching was done with replacement so that a non-participant may be a match for more than one participant." There doesn't seem to be a discussion of the number of Participants and Matched Nonparticipants for the Residential QM.	Thanks for the comment. We have provided a table listing the number of participant and non-participant households at different stages of the matching process.
Economizer	SCE	4.1.4, paragraph 1	72	Comment	Economizer decommissioning has not been incentivized as part of the SCE CQM measure since 2013.	Report revised to remove economizer decommissioning
Commercial program gross savings evaluation methods and results	PG&E	4.3	81	Question	We are concerned that this study reuses problematic NTG values for commercial programs calculated in the Net-to-gross Evaluation of 2013-14 Commercial Quality Maintenance Programs (2013-14 HVAC 3 NTG). PG&E continues to be concerned with the NTG estimation methodology, which includes a self-report survey instrument and scoring algorithm. In addition, we are concerned that the estimation of NTG ratios for commercial QM programs was based solely on contractor surveys. However, both participating technicians and customers are important market actors,	Comments on the NTG report were responded to in Q3 2016 rand we are unable to revise the analysis. We decided to apply the values to 2015 claims given the similarities in program delivery from 2013-14 to 2015. We believe the comments should be considered when developing future NTG or when deciding whether to apply the NTG results to programs that have changed in 2016 and into the future. This is consistent with the CPUC position that the findings should be applied to 2015 claims, but that they will not necessarily be applied to future claims.

					and customers received approximately 30% of the incentive dollars. As stated in PG&E's comments on the 2013-14 HVAC3 NTG study, the NTG analysis should not be considered complete without a direct assessment of the influence of the program on the workforce executing the EE measures and on customer decision makers. In addition, Figure 25 (p. 82) shows that the NTG ratios calculated are have large error bars associated with them. Could the report include a discussion of the limitations of using these ratios?	The ex ante team has been instructed to take the report under advisement as one potential information source.
SDG&E Analysis and Results	SDG&E	4.4.3.2	95, 96	Comment	Gross Ex Post estimate = 197 kWh per HH for hourly model and 153 kWh per HH for the daily model. "The gross realization rate was very high in part due to SDG&E's very low claimed savings. Once the nonparticipants were added to the model, however, the program was not found to contribute any statistically significant net savings." It's conceivable that the ex ante savings was too small for the billing analysis to discern from noise in the usage data, i.e., billing analysis was not the appropriate approach estimating the savings for measures that save 200 kWh per year in	The size of the ex ante estimate of per household savings was substantially higher than the ex post findings.

					HH that consume 600 to 900 kWh per months (7,000 to 10,800 kWh per year) with ex ante savings of about 1.8 to 2.8%.	
SDG&E Analysis and Results	SDG&E	4.4.3.2	95, 96	Comment	Gross Ex Post estimate = 197 kWh per HH for hourly model and 153 kWh per HH for the daily model. "The SDG&E gross realization rate was 12.6 times the claimed savings but the net realization rate was zero given that the residential QM parameter estimate were not statistically different from zero. The estimated net normalized savings were also of the wrong sign." Seems the NTG should be zero, but there is a lack of any meaningful discussion on the NTG for SDG&E.	The NTG for SDG&E res QM should be zero. Going forward it would be wrong to extract the NTG ratio from this billing analysis and apply it to an engineering estimate of gross savings, since the participant and non-participant consumption differences were likely driven by a variety of actions besides QM. Or in other words, the gross savings from the billing analysis are not equivalent to an engineering based ex-ante savings calculation.
Economizer Measure Group	PG&E	5.1.1	98	Question	The report notes that several economizers categorized as "repaired" were not operating at the time of a data collection site visit. Could the report clarify how long it had been since last maintenance of these units?	All the economizers evaluated in this effort participated in the 2015 program year so the period of time between economizer repair and economizer evaluation is from 8 months to 20 months.
Thermostat Measure Group Results	PG&E	5.1.2	98	Comment	The report includes a recommendation that program adjusted thermostats be periodically checked. We suggest delineating these comments between one-time maintenance programs and CQM. CQM follows ACCA 180	Noted and report revised.

					requirements, and contractors are required to adjust thermostats quarterly, so it may not be relevant for these programs.	
Commercial Program Recommendations	SCE	5.4, paragraph 1	102	Question	The SCE CQM Program does not have optional training, contractors are required to participate in classroom and rooftop training. Economizer upgrades to digital controls require additional economizer training. Does the stated conclusion intend to mean that the QM training is optional? *"The conclusion that we arrive at is that some QM contractors are taking advantage of the program training resources and improving the services that they offer while others are not. Still other contractors may have had high-quality maintenance practices before joining the programs, hence little influence from the program."*	The conclusion does not necessarily mean the training is optional. A contractor may attend the training, but not take advantage of it by absorbing the material and incorporating it into his/her business practices.
Thermostat Survey Results	SCE	Appendix E, Table 91	E-2, E-3	Question	In rows 2 and 7, there are no unoccupied set points reported for these sites. Is this because these sites have 24 hour occupancy periods? How were these accounted for in the realization analysis?	No, those facilities did not have 24 hour occupancy. Some times we were not able to collect unoccupied set points, and in those cases the site was excluded from the analysis.
Thermostat Survey Results	SCE	Appendix E, Table 91	E-2, E-3	Question	Were the three separate sites with identical set points from the same customer?	Yes, same customer, different sites.

Thermostat Survey Results	SCE	Appendix E, Table 91	E-2, E-3	Question	This set point complies with the SCE CQM measure definition of 'baseline'. However, the evaluation reports the minimum unoccupied cooling set point at 85. Were these counted as non-compliant with the workpaper?	Yes, they were counted as non-compliant with the workpaper. Text is added in the thermostat section to describe how savings would be different if they were counted as compliant.
Sample Size Representing SCE CQM	SCE	Appendix B	B-1, Table 78	Comment	The savings differences may be explained by the fact that SCE had reported an aggregated measure in 2015 while SDG&E and PG&E reported individual measures.	Yes, the savings per record for SCE would be expected to be higher since each record is a group of bundled measures.
Research plan	PG&E	N/A	N/A	Comment	A research plan for this study does not seem to have been posted for public comment on the PDA. Is there a reason this process was skipped?	The 2015 activities were added to the same study for 2013-14. We made only slight changes to the methods and expanded the sample to 2015 program claims. The research roadmap was posted to the PDA and indicated the plan not to produce a new plan in order to get into the field in summer 2016. The activities were discussed on a monthly basis with the IOUs at the HVAC PCG.
	RMA			Comment	Please revise or remove incorrect data and replace with corrected data and analysis discussed in these comments. [See comments 1 through 4 on pages 3 through 10 of the RMA_Comments_HVAC03_20170324.pdf document.]	Corrections have been made to 1) the economizer statement about outside air damper adjustment; 2) economizer therm savings are now negative across all programs; 3) the commenter suggests using a baseline of over-ventilation, but this was rejected since it in inconsistent with the ex ante baseline and is outside the scope of this study; 4) thermostat therm savings have been

						scrutinized, and explanatory text added; 5) Statements about the relationship between thermostat set point and building energy use have been clarified. 6) Note the "pre" OA damper setting was not available, so it was not possible to evaluate the effect of the damper repositioning measure.
	RMA			Comment	Based on the lack of adherence to the CPUC California Evaluation Framework and AEA guidelines and biased NTG survey questions and analysis, please remove the following sections from the HVAC3 report: section 1.4 Net Program Savings Results and Section 4.3 Commercial program NTG savings ratio methods and results. [See comments 1 and 5 on pages 3 and 11 through 12 of the RMA_Comments_HVAC03_20170324.pdf document.]	This comment is similar to one posted for the NTG report. Our formal response to the previous similar comment was: Our process for conducting this evaluation was very transparent and received approval from a wide range of stakeholders. The methodology used for this report, as well as the contractor interview guides, were posted on BaseCamp and reviewed by the IOU's and available to their implementers. The methodology documents were reviewed and approved by the CPUC and the CPUC consultants. Direct responses and adjustments were made at each stage of the process. Like all deliverables the final report also includes public stakeholder review which we are responding to now. The feedback provided is used not only in the current report review, but is also considered by the CPUC and IOUs to inform long term research needs and future studies. These consultants and stakeholders

						included individuals with decades of HVAC and net savings assessment experience. In addition to this extensive review process, before we started our contractor interviews, our evaluation partners at the Western Cooling Efficiency Center at UC Davis also conducted a focus group-type meeting with some of the participating contractors to make sure we were covering the relevant issues. The commenter makes assertions about "biased" interviews questions but doesn't explain why he thinks the questions were biased beyond claiming that "the failed to differentiate between "generic" and "quality" HVAC maintenance measures." As to this last point, the interview guide had over a half dozen questions that allowed HVAC contractors to distinguish the maintenance services, and related sales practices, they routinely offer from those they offered through the HVAC3 programs. Therefore if the participating HVAC contractor did think that the program had changed these maintenance services or sales practices, they had ample opportunity to state this. The relevant interview guide questions included: 1) Frame6. Has the <program> caused

						you to change your HVAC maintenance or tune-up service offerings? 2) Frame6. b) How has the program caused you to change your HVAC maintenance and tune-up service offerings? 3) Frame7. If the program were to end tomorrow, would you continue to offer all of the same HVAC maintenance and tune-up services that you are currently offering? 4) Frame 9. You indicated earlier that you also offer HVAC maintenance or tune-up services to customers who are not in this program. How do you sell non-program maintenance or tune-up services to customers? [If it is a different sales method than the program sales method (see response to Frame8), probe for reasons for these differences] 5) Frame 10. You indicated earlier that you offered HVAC maintenance or tune-up services to customers before you joined the program? What were your sales practices for these HVAC maintenance or tune-up services before participating in the program? [If it is a different sales method than the program sales method (see response to Frame8), probe for reasons for these differences] 6) Frame 11. Has the program caused you to change your sales practices for

						HVAC maintenance or tune-up services? 7) Frame11b. b) How has the program caused you to change your sales practices for HVAC maintenance or tune-up services? 8) Frame 12. If the program were to end tomorrow, would you continue to use the same sales practices for your maintenance and tune-up services that you are currently using? In addition to these more direct questions, there were also other questions such as the open-ended follow-up questions (e.g. "Why do you say that?") to the program attribution questions which also allowed respondents to comment on how the program might have changed what they typically did for maintenance. It is also important to point out that the report did discover that the HVAC3 programs did encourage a few of the contractors to improve the quality of their maintenance practices. However, these program effects were very limited.
	RMA			Comment	For residential quality maintenance programs, the net savings analysis should be rejected as speculative without sufficient evidence to support the participant and matched nonparticipant samples. The gross energy savings for	Thanks for the comments. The propensity score matching process used by Itron to develop the matched non-participants has been used in other reports submitted to the CPUC. The CPUC is familiar with the approach and

					PG&E and SDG&E programs should be further evaluated to better understand variations in gross savings. Further research should be performed to determine an appropriate method for selecting appropriate participant and matched non-participant samples. Please revise Section 4.4.3 to remove net measure and net program savings based on the participant and matched nonparticipant samples which are not matching samples. [See comment 4 on pages 7 through 11 of the RMA_Comments_HVAC03_20170324.pdf document.]	has, through the acceptance of other reports using this approach, implicitly accepted it as a valid approach to develop matched non-participants. The differences between the SDG&E and PG&E regression results could be due to many factors. First, the usage of air conditioning between inland PG&E, where it is hot in the summer, and SDG&E, where it is more temperate, may impact the findings. Second, the timing of measure installation in PG&E allowed for the estimation of measure level savings whereas the SDG&E's model estimated program level savings. Third, the measure installed by the two program differed. Forth, PG&E tended to claim more than allowed in the workpaper for all measures installed while SDG&E only claimed more than the workpaper ex ante values for one measure. All of these differences, and likely many other, can contribute to differences in the regression results. The net savings analysis and the development of the non-participant matched group is consistent with approved methods. The 10% billing data fractional impact was established prior to the general availability of AMI data. The additional disaggregation of the data, and the larger number of observations, work to

						allow billing analyses to observe savings within pooled models that are less than 10%. The CPUC has been accepting hourly and daily pooled billing analyses with less than 10% fractional savings. In addition, the ex ante claims for the SDG&E program exceeded 8%, making them very close to the prior requirement of 10%. Itron supports the findings in this report.
	RMA			Comment	Revise or correct analysis and reporting of HVAC maintenance measures based on laboratory test data. [See comments 2 through 4 on pages 3 through 11 of the RMA_Comments_HVAC03_20170324.pdf document.]	Under HVAC5 we checked all of the laboratory data, and have used the final HVAC5 laboratory in the HVAC3 analysis. Refer to HVAC5 responses to comments for specifics about laboratory data corrections.
	RMA			Comment	The economizer measure group section 4.1.1 including all measurements of outdoor air flow (OAF) should be removed from the report since the OAF measurements are incorrect and provide false and misleading information about using an incorrect method to measure airflow through economizer dampers. [See comment 2 on pages 3 through 6 of the	The commenter has several points including 1) the SDG&E "air damper re-positioning" measure is an economizer measure and should have been evaluated. Our report has been revised for clarity. The measure was not evaluated not because it is not an economizer measure, but because we were not able to determine the baseline damper position, and the savings were a small part of the overall portfolio. 2) questions the validity of using True Flow to measure the outside air flow, and

					RMA_Comments_HVAC03_20170324.pdf document.]	recommends temperature measurements instead to infer airflow. We moved away from temperature-based flow measurements because of the uncertainty in mixed air temperature measurements due to velocity stratification across the coil, which makes it difficult to get an accurate mass flow weighted average temperature. We tried the True Flow method based on a suggestion from communication with Gary Nelson, and the procedure documented in Bob Davis' 2002 ACEEE paper "Identifying Energy Savings Potential on Rooftop Commercial Units", which we cite in the report.
	RMA			Comment	The economizer measure group gross energy savings claims should be passed through with realization rates of 100%. [See comment 2 on pages 3 through 6 of the RMA_Comments_HVAC03_20170324.pdf document.]	Disagree with the recommendation to pass through economizer savings, since we feel the air flow measurements are valid per the response above. We note that in-situ outdoor air flow measurements are inherently difficult and future research is needed to address this measurement issue.
	RMA			Comment	Please evaluate therm savings for all commercial and residential HVAC maintenance programs and provide analysis and recommendations regarding how thermostat setback, Air damper re-positioning (ADR), economizer repair, supply fan control, and maintenance measures can reduce natural gas space	Therm savings are evaluated for all measures, and are discussed in the text where appropriate. There are no significant therm savings from RCA or coil cleaning measures in the ex ante and in the ex post so therm savings are not discussed; economizer measures produce negative therm savings and

					heating energy use. [See comment 3 on pages 6 through 7 of the RMA_Comments_HVAC03_20170324.pdf document.]	they are discussed; thermostat therm savings are significantly lower than ex ante savings, and are discussed; and supply fan therm savings are not re-modeled, so are consistent with ex ante claims and are not discussed.
	RMA			Comment	Please require higher quality data collection, analysis, and reports with greater transparency, oversight and accountability (i.e., field and laboratory test measurements and analysis methods must be available for public review). [See comment 5 on pages 11 through 12 of the RMA_Comments_HVAC03_20170324.pdf document.]	Request noted.
	RMA			Comment	Please require all EM&V studies to adhere to the AEA guidelines for data-based systematic inquiry, competence, integrity, respect, and responsibility for all stakeholders.[See comment 5 on pages 11 through 12 of the RMA_Comments_HVAC03_20170324.pdf document.]	Request noted.
	RMA			Comment	Please revise the 2017 draft HVAC3 report with input from stakeholders in public workshops convened by the CPUC. The workshops should promote transparency, systematic inquiry, competence, integrity, respect, and	Per CPUC policy, a public webinar was hosted to present the results of the report, and the report was revised with input from public written comments. A record of the comments and responses

					responsibility for general and public welfare per AEA guidelines and The California Evaluation Protocols. Previous EM&V studies should be discussed where similar issues have occurred including but not limited to the 2006-08 EM&V HVAC study, 2010-12 Work Order 32 HVAC Study, 2012-14 HVAC3 Study, 2016 HVAC3 NTG study and the 2017 HVAC3 study. [See comment 5 on pages 11 through 12 of the RMA_Comments_HVAC03_20170324.pdf document.]	is attached to the final posted version of the report.
Previously submitted IOU comments to be addressed						
Conclusions and Recommendations	IOU	1.5.3, bullets 1, 2	10 & 22	Comment	Many technicians report that data collection requirements for the program are already too onerous. Any incremental savings benefit that may result from these recommendations need to be weighed against the administrative burden placed on participants. Were the noted data tracking issues (missing contact information, missing key information) an issue for all programs?	Missing data was an issue for all programs at least to some extent. We suggest that the program data collection process be streamlined to reduce unnecessary information and collect the most important parameters. Key stake holders in this process would include contractors, program administrators, and evaluators.

Conclusions and Recommendations	IOU	1.5.1, bullet 5	11	Comment	Are measure-specific measurement approaches really necessary when the program is ultimately only interested in the overall system's performance after measures are implemented?	The measure level analysis was motivated in part because of how measures were tracked by other IOUs. There are limitation of the measure approach (interactive effects not considered), but unit pre/post kWh analysis was very difficult in 2010-12 and needed an extremely large sample because of large CV. It is not clear that an overall HVAC system savings approach would yield a better estimate of program savings, see the uncertainties and difficulties described in section 2.3.
Economizer repair	IOU	2.2.1.3, last sentence	14	Question	Should the last sentence read, "They are not required on residential units so this measure group is not installed ***inspected*** through the residential QM programs"?	Perhaps the term "included" would be better since it's not installed or inspected. Changed in report.
Thermostat adjustment	IOU	2.2.1.4, last sentence	15	Question	Should the last sentence read, "This measure group was commonly installed in the commercial QM programs, and not installed ***inspected*** in any of the residential QM programs in 2015"?	Term changed to "included" as previous.
Repair history and issues	IOU	2.3, All 5 bullet points	20	Question	Given the list of issues raised here, Is it possible design a QM program that mitigates all of them and provides reliable and repeatable energy performance results for the near infinite variability of building types, orientation,	The issues raised have to do with QM evaluation challenges. It's not necessary for a program to mitigate these challenges. The 2013-14 and 2015 evaluation was able to overcome most of these challenges through the evaluation methodology focused on refining ex ante simulation model input parameters. As

					climate zones, unit configurations, and system designs?	to the question of reliable and repeatable energy performance results: the simulation results show that energy saving results vary significantly across building types and climates. The challenge remains for the programs to figure out how to offer the program in a way that ensures savings from installed measures.
Evaluation approach	IOU	2.4, last para, last sentence	21	Question	"The realization rates from the 2013-14 measures were applied to the 2015 residential QM measures" Is this appropriate? On page 28, it report says the programs were "essentially" the same. What aspects of the program were changed? Were these changes programmatic or administrative?	The changes, that we are aware of, are a reduction in some of the ex ante per measure claims. This was taken into account when developing the yearly realization rates and explains why come of the realization rates increase from 2013 to 2014 to 2015.

ABOUT DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter, and greener.