DNV·GL

IMPACT EVALUATION RESEARCH PLAN

2013-14 HVAC-3: Quality Maintenance

California Public Utilities Commission, Energy Division
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Prepared by DNV GL

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1 INTRODUCTION: EVALUATION RELATIONSHIP TO HVAC RESEARCH ROADMAP

This impact evaluation of commercial and residential quality maintenance (QM) programs is part of the overall California Public Utilities Commission (CPUC) 2013-14 heating, ventilation, and air conditioning (HVAC) Research Roadmap. The QM impact evaluation will coordinate data collection and analysis to recognize synergies between the related research areas within the roadmap. More information on all of these activities can be found in the 2013-14 roadmap summary.

2 PROJECT SCOPE & RESEARCH QUESTIONS

This section discusses the overall research objectives for this evaluation and an overview of our proposed approach to achieve them.

2.1 Research Objectives

The primary objective of this evaluation is to determine the *ex post* gross and net impacts for kWh, kW, and therms achieved by the 2013-2014 HVAC QM programs offered through California's investor-owned electric utilities: San Diego Gas and Electric (SDG&E), Southern California Edison (SCE), and Pacific Gas and Electric (PG&E).

The secondary objectives of the 2013-14 impact evaluation include:

1. Determine reasons for deviations from *ex ante* savings.
2. Estimate participant free-ridership and spillover to support the development of net-to-gross (NTG) ratios and net savings values.
3. Provide results and data that will assist with updating *ex ante* workpapers and the Database for Energy Efficiency Resources (DEER) values.
4. Provide timely feedback to the CPUC, investor owned utilities (IOUs), and other stakeholders on the evaluation research study in order to facilitate timely program improvements and support future program design efforts and *ex ante* impact estimates.
5. Conduct field observations and measurements of commercial HVAC maintenance faults to provide guidance for the laboratory research study.

The team lead by DNV GL with significant contributions from Robert Mowris & Associates, Inc. (RMA) and support from the Western Cooling Energy Center at UC Davis will achieve these objectives by reviewing program data and collecting new primary data that support defensible *ex post* savings estimates. This 2013-14 *ex post* evaluation does not address all uncertain *ex ante* parameters for all QM measures and package combinations. The plan addresses only the high impact measures (HIMs) driving program savings and their associated parameters. The proposed approach will provide a defensible estimate of *ex post* savings, consistent with the allocated budget for this research. Any attempt to address all uncertain parameters would result in a research budget that cannot be justified, currently, based on the current and expected future impact of the associated programs.

2.2 Research Considerations

The following information, previous research results, and evaluation options informed the final research plan.

2.2.1 HVAC System Fundamentals

Utility QM programs focus primarily on unitary HVAC systems serving commercial and residential buildings. These systems mostly share common attributes, even though some variation exists due to a unit's size and its application. Three components account for the bulk of HVAC-system electricity consumption: 1) compressor, 2) condenser fan, and 3) evaporator fan.[1] The compressor increases refrigerant pressure and temperature and circulates superheated vapor to the condenser where it is condensed to a liquid and sub-cooled through the condenser heat transfer coils and then circulates through the expansion device where the pressure is reduced causing the liquid to further cool and it enters the evaporator coil as cold refrigerant.

[1] Controls account for a very small amount of electricity consumption.

The condenser fan moves outdoor air through the condenser coil to reject heat from the refrigeration system that has been absorbed from the building return air and outdoor air mixture. The evaporator blower fan moves mixed air made up of return air from the conditioned space and outdoor air (required to meet ASHRAE 62.1 outdoor air ventilation requirements) through the air handler where the air is cooled and dehumidified by passing through the evaporator coil (or heated by the heating coil) and supplied to the conditioned space. Compressors, condenser fans and evaporator blower fans operate simultaneously when the cooling system is operating without the economizer.[2] The evaporator fan operates by itself in ventilation-only mode or when the economizer is operating properly in 1st-stage cooling mode (using only outdoor air to cool.) The compressor and condenser fan operate simultaneously with the evaporator fan in 2nd-stage cooling (with economizer dampers closed, partially open, or fully open) to provide cooling and ventilation.

Individual unit power consumption typically peaks at the highest outdoor air temperatures. As a result, the number of individual units simultaneously operating across a region of the state also peaks. Consequently, peak HVAC electric consumption has high coincidence with the electricity grid's system peak demand in California.

Aspects of the HVAC system that influence its energy consumption and peak power include:

- The amount and quality of refrigerant in the system;
- Effectiveness of the heat exchangers including the evaporator coil, furnace heat exchanger and condenser coil;
- Outdoor airflow required to meet ventilation requirements;
- Unintended outdoor airflow through the system (including unintended damper leakage, duct leakage, cabinet leakage, and curb leakage);
- Compressor operation, controls, and efficiency;
- Indoor/outdoor fans, fan motors, controls, speed, sheaves, pulleys, belts, operation, and efficiency;
- Electrical (contactors/capacitors) and control system operation and efficiency;
- Furnace operation and efficiency;
- Effectiveness and operation of the economizer, dampers, sensors, and controls;
- Fault detection diagnostic (FDD) operation and controls; and
- Thermostat and/or Energy Management System (EMS) controls.

Tuning and maintaining these aspects will optimize the HVAC system's operating efficiency with respect to meeting the space cooling and heating requirements. If the maintenance services increase the delivered system efficiency this will reduce the length of time the unit operates to achieve the thermostat set point. The maintenance services are intended to reduce the unit's average annual energy consumption and coincident system peak demand.[3] For units that are accidentally overcharged under the programs, the cooling capacity and compressor power can increase and operational time can decrease with no net energy savings. Annual energy consumption for a unit is determined by the operational cooling and heating efficiency and the cooling, heating, and ventilation requirements for that unit.

[2] Many commercial packaged units (greater than 5 tons cooling capacity) with multiple condenser fans will cycle off one or more condenser fans when compressor is operating at low outdoor air temperatures to avoid low pressure cut-out or icing of the evaporator coil.

[3] Under peak cooling conditions, a properly-sized and properly charged packaged unit might use more power to maintain the cooling setpoint than an undercharged unit that runs continuously but uses less power and cannot maintain the cooling setpoint on a hot day. This will typically not occur since most commercial packaged units are over-sized.

2.2.2 HVAC System Faults

Maintenance and repair measures fundamentally seek to improve the various components mentioned in Section 2.2.1. Utility programs include measures that seek to identify and repair a number or deficiencies or faults with existing HVAC units. Ideally, the repairs lead to optimized cooling efficiency that reduces runtime and/or power draw at the same conditions. When evaluating program measures using whole-building interval data and sub-metered data it can be difficult to separate the normal energy use variations that are present before and after maintenance from the faults corrected by the program. The previous WO32 EM&V study attempted to collect this kind of data for a representative sample of units receiving QM services in the IOU programs. Units included in the data logger sample did not receive many QM services offered in the programs to repair faults such as failed economizers, stuck-open dampers, suboptimal airflow, damaged/corroded coils, or other issues. Therefore, the WO32 sub-metered data found either no change in energy usage or increased energy usage. Whole-building interval data has not been demonstrated to evaluate energy savings from QM services since the estimated savings are less than 10% of total building energy usage.[4]

Considering this situation, direct methods to assess each system component are time consuming while alternative indirect diagnostic methods cannot disaggregate measure savings unless all other system changes are controlled. For example, using indirect diagnostics based on refrigerant pressures and temperatures to assess refrigerant charge amount requires that heat exchanger coils are clean, air filters are cleaned or replaced, system airflow is within design specification, and (for commercial units) outside air is accounted for in measuring return air conditions. The direct method to evaluate refrigerant charge measures is to recover the as-found refrigerant charge and weigh the amount on a digital scale. This evaluation focuses on direct methods, which are more expensive but allow for isolation of specific measure characteristics. Direct measurements are possible and very reliable for power input, refrigerant amount, return air temperature, supply air temperature, and outside air temperature. Direct measurements are possible but with notable uncertainty for mixed air temperature, all humidity[5] and thus enthalpy readings, and airflow. In this evaluation, direct methods will be used wherever possible, and indirect methods will be used where direct methods are unreliable. For instance, an indirect method to get outside air fraction is being considered because the direct method is unreliable due to the uneven profile of the mixed air temperature across the evaporator coil. The indirect method is to measure return, outside, and supply temperatures, air handler fan energy, and system airflow (with cooling coil not operating). The supply temperature with the compressor off is a well-mixed representation of the mixed air temperature once fan heat is accounted for. The outside air fraction is calculated knowing the total airflow and the temperatures of the mixed air (modified supply air temperature used as a proxy), return air and outside air.

2.2.3 QM and HVAC Tune-up Program Evaluation Challenges

There is a big challenge with evaluating deemed savings for a package of quality maintenance related measures. The Commercial Quality Maintenance (CQM) “package” is much more like custom retrofit than a deemed measure because each unit has a different start and end point. Because of low savings per unit it may not be cost effective to run this program on a custom basis. Thousands of units currently participate in

[4] Page 146 of the California Evaluation Framework states the following. “Option C is limited to projects where the expected savings exceeds the metered energy consumption by at least 10% (footnote 142). Footnote 142 states the following. “10% is the minimum savings criterion established in ASHRAE Guideline 14. Depending on the variability of the data, a greater energy savings fraction may be required for a successful billing analysis.” According to the Federal Energy Management Program (FEMP) [Insert FEMP reference here], “Utility bill comparison is a very simple and, typically, an unreliable method.”

[5] The issue measuring humidity is the time delay in the sensors. Temperature sensors, on the other hand, react almost immediately. When there is an abrupt change in humidity, the enthalpy will be incorrect until the humidity sensor stabilizes.

the program to generate program savings. The IOUs (with the exception of SCE) have been moving away from the CQM "package" toward individually claimed measures which work better with the deemed savings structure where there is one defined baseline efficiency (code or standard practice) and fairly well defined efficiencies after the measure is applied. Evaluation of the individual measures is straightforward by developing the standard practice baseline and the measure case but it tends to be expensive per sample point. DNV GL will apply this evaluation strategy, however, due to the cost per sample point, we will focus on highest-impact measures to maintain high enough sample in each measure category to keep sampling precision within acceptable range. The approach to SCE's "package" quality maintenance measure (only 6.1% of overall QM claimed savings) will be to take the individual measure results and build the package savings using the structure outlined in the quality maintenance measure's workpaper. Actual distribution of measures installed through the SCE QM program will be compared to the workpaper distribution assumption. PGE's "EE tasks" measure (which accounts for 30% of the PGE QM program savings and 9.6% of overall QM savings and being phased out in 2014) will be addressed in a similar manner.

2.2.4 Program Measures

The QM programs expect to save energy by improving the efficiency of HVAC equipment and systems that have not historically received regular maintenance. Sometimes these systems have not been providing adequate comfort or fresh ventilation air and service on these systems increases energy use. While there is some variation by IOU, all programs provide a suite of residential and non-residential QM measures. Previous research documented the opportunities and associated procedures for HVAC system maintenance.[6] However, there is limited reference to primary data in the workpapers supporting the impact on equipment efficiency of the known faults and combinations of faults on HVAC systems. Primary data used in workpapers is generally limited to laboratory tests for refrigerant charge and assumptions of other measures and combinations of faults. Therefore, the impact of QM programs on annual energy consumption is currently uncertain. Section 3 of this document contains detailed discussions of the measures installed through QM programs.

2.2.4.1 Pre-Retrofit Condition / Measure Baseline

In impact evaluation the term "baseline" is commonly used to refer to the pre-retrofit condition of the measure. Hence, the measure baseline for a QM measure is the equipment operating before its participation in a QM program. The elapsed time between the baseline operation and measure completion varies by program. The QM programs (currently only offered through PG&E and SCE) require a three-year service contract and maintenance measures are generally installed or performed within the first 6 months of the contract. The pre-retrofit condition (entering the contract) and post-retrofit condition (after measure completion) could therefore be up to six months apart. The tune-up programs generally allow participation once per program cycle and are not technically considered "quality maintenance" programs.

2.2.4.2 Post-Retrofit Condition / Performance Baseline

In the QM programs the term "baseline" refers to the state of the HVAC system as it should be functioning according to the performance objectives in ANSI/ASHRAE/ACCA Standard 180.[7] The IOU QM programs

[6] 2010-2012 HVAC Impact Evaluation Report WO32 prepared for the CPUC by DNV GL; Hunt, Marshal, Kristin Heinemeier, Marc Hoeschele, and Elizabeth Weitzel. *HVAC Energy Efficiency Maintenance Study*. Davis Energy Group and Southern California Edison, 2010. http://www.calmac.org/publications/HVAC_EE_Maintenance_Final.pdf

[7] Standard 180 Appendix A lists some of the possible sources that can be used to establish performance objectives including: 1. Design documents for the system with the provision that those documents still reflect the current loads, space utilization and other system requirements, 2. A duly licensed individual authorized to perform HVAC design work, 3. Manufacturers' technical material or generally accepted industry criteria, 4. Guidance from ASHRAE Standards 55, 62.1 and 90.1, 5. Authority having jurisdiction, 6. Licensed HVAC design professional, 7. Contractor, professional engineer, and 8. Owner's Program Requirements.

provide incentives for participants to make repairs and provide QM services to correct system faults and achieve energy efficiency performance objectives (hereinafter referred to as the performance baseline). Incentives are also provided for periodic maintenance throughout a three-year service contract to ensure persistence of energy savings. The performance baseline is not to be confused with the impact evaluation measure baseline defined above. The performance baseline as described by Appendix A of Standard 180 is ideally the unit's as-new condition installed to meet the design requirements of the building per California Title 24 building codes and ASHRAE 55, 62.1, and 90.1. The tune-up programs have no such requirement.

2.2.5 Maintenance Standards

For non-residential maintenance, the applicable standard is the American National Standards Institute (ANSI)/American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)/Air Conditioning Contractors of America (ACCA) Standard 180-2012, Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems.[8] For residential maintenance, the applicable standard is ANSI/ACCA 4, Maintenance of Residential HVAC Systems-2007. [9] Tune-up programs do not reference specific standards. However all programs and measures use the assumption that the service technician has the capability to return the unit to (or near) "initially- installed" operating efficiency.

2.2.6 Previous CPUC Research

QM programs were researched during the evaluation of the 2010-2012 programs. The 2010-2012 QM impact evaluation encountered the following challenges:

- Long-term time series measurements of system efficiency are 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 proper instruments and procedures to obtain accurate measurements of mixed-air temperatures and hence outdoor air fractions.
- Pre-maintenance sampling with long-term system monitoring requires commitment from program implementers. Only service providers know which sites and units will receive maintenance within a given program cycle, making program sampling efforts very difficult to achieve. Furthermore, it is unknown which measures will be applied to the pre-maintenance unit when monitoring equipment is installed. These issues were found to lead to sampling bias in WO32.
- 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 have not distinguished measure level savings for each unit due to the completion of multiple measures during the same implementation visit.
- Documentation of the HVAC system pre-maintenance condition is poor for some programs, based on the last evaluation, providing challenges for re-creation of baseline for testing. Programs without adequate documentation for an M&V evaluation will be at risk and will be subject to true-up based on available data from other programs and IOU's.
- As noted above, the previous WO32 evaluation attempted to collect whole-building interval data and sub-metered data for a representative sample of units receiving QM services in the IOU programs. Units included in the data logger sample did not receive many QM services offered in the programs to repair faults such as failed economizers, stuck-open dampers, suboptimal airflow, damaged/corroded coils, or other issues. Therefore, the WO32 sub-metered data found either no change in energy usage or

[8] http://www.techstreet.com/products/1832333?product_id=1832333&sid=goog&gclid=CLbZ-IOKkcACFSxk7AodjnoA-g
[9] http://www.acca.org/release/accas-quality-maintenance-standard-updated/

increased energy usage. Whole-building interval data could not be used to evaluate energy savings from QM services since the estimated savings are less than 10% of total building energy usage.[10]

Some of these difficulties remain for the 13-14 evaluation effort. This plan either addresses these challenges or accepts them within the research design.

2.3 Research Summary

2.3.1 Gross Impacts Analysis

DNV GL will utilize information collected during the following seven research activities to determine the *ex post* gross savings for the QM measures and programs:

1. **Workpaper Review**: We will review and compare the workpapers associated with identified key program measures. This review will document the key parameters and assumptions used to estimate *ex ante* savings. This will also include a review of the Energy Division disposition of 2013-14 workpapers regarding ex-ante savings estimates.
2. **Participation Records Review**: We will request detailed participation data from the IOUs that includes information recorded by implementation technicians. The received information is expected to document the pre and post-maintenance conditions observed by the program.
3. **Field M&V Pilot**: The team will test the Field M&V plan by completing a series of pilot tests at 16 locations before executing the full data collection plan. Results of the pilot will be used to finalize the Field M&V plan for all remaining data collection activities. The results of the field test effort will be reviewed as a demonstration of the evaluation program plan and serve as a stopping point if insurmountable obstacles are found. It will also be used to establish the efficacy of DNV-GL's efforts and ability to produce useful and timely field measurement results.
4. **Implementation Ride-Along**: RMA Master HVAC Technicians will complete 45 "ride-along" visits where the master HVAC technicians will make measurements to support the coil cleaning impact assessment, record observations of the baseline economizer and thermostat operating conditions of the treated units and observe program implementation technicians as they perform program maintenance services as part of the Field M&V effort. Since program year 13-14 is complete, we will observe work performed in 2015, assuming that work is performed in a similar manner across program years. Data collected will inform the analysis and future laboratory testing. Ride-along data will be used to evaluate the primary objective of gross load impacts and secondary objectives 1, 3, 4, and 5.
5. **Post-Maintenance Site Visits**: The team will visit 55 participant units representative of the program population to collect data on economizer operation, refrigerant charge, supply fan control and thermostat replacement. Sites will be sampled from the tracking database and visited after the program cycle is complete. Post-maintenance data will be used to evaluate the primary objective of gross load impacts and secondary objectives 1, 3, and 4.
6. **Laboratory Testing**: RMA will complete laboratory testing under the 2013-14 HVAC Laboratory Testing (HVAC_5) work order to estimate some parameters needed to relate indirect field measurements to the parameters needed in the analysis. Lab testing is particularly important for the condenser/evaporator coil cleaning measures and the refrigerant charge measure. Laboratory data will be used to evaluate the primary objective of gross load impacts and secondary objectives 1, 3, and 4.

[10] Ibid

7. **Analysis**: The above activities will provide data to develop load impacts using Engineering Analysis and/or Simulation Modeling.

Further details on the above tasks are available in Section 5: M&V Plan.

2.3.2 Net Impacts Analysis

DNV GL will be collaborating with the Western Cooling Efficiency Center for the NTG portion of this evaluation. The first phase of the NTG analysis task will be to determine the approved methodology for estimating the NTG ratio, and produce a memo to the CPUC detailing the approach. DNV GL will execute the methodology after its approval by the CPUC and their advisors. At this time, DNV GL expects to estimate the program NTG ratios based on responses to customer and contractor surveys. DNV GL will design and conduct separate surveys for tune-up programs implementing comprehensive tune-ups and QM programs implementing QM maintenance programs based on Standard 180.

The results from the Phase II Behavioral study will also be utilized where possible. Unfortunately, the behavioral study does not distinguish between participating and non-participating technicians thus having limited utility in the NTG effort. Possible methodologies under consideration to allow for inclusion of the study are:

- Conduct one participant sample and replace participant attribution with vendor (contractor) attribution. This will use the scoring method for the participant survey.
- Conduct two independent samples for participant customers and contractors.
- Conduct two independent samples of participant and non-participant contractors to determine the difference in services. The survey will account for the major program redesign and participation uptake in 2013.

2.3.2.1 Historic Challenges to NTG Ratio Estimation

The net impact analysis for HVAC QM programs is one of the more complicated NTG efforts that DNV GL has undertaken. Because of the complexity of the research concerns, stakeholder disagreement on NTG methodology may result. In the WO32[11] evaluation, DNV GL began to triangulate towards a NTG ratio, but dissention over the survey methodology was not resolved in the comment phase. The information gathered and lessons learned during the previous evaluation will serve as a foundation for the methodology that DNV GL will propose. The final methodology implemented will require vetting with the IOUs and approval by the CPUC.

2.3.3 Measure Costs (Including Incremental Costs)

There was a measure cost study performed for the 2010-2012 program cycle. There are no current plans to update the results during this evaluation cycle. In the course of the evaluation, any data on baseline equipment or service and incremental measure cost will be collected and available for future research.

2.3.4 Key Elements in Research Planning

2.3.4.1 Field M&V Pilot

The plan for a field M&V pilot task is a direct result of our experience evaluating similar measures installed during the previous program cycle. The objective is to investigate methods to improve on the pre/post time series analysis techniques we used in WO32. The master HVAC technician team will develop and test

[11] 2010-2012 HVAC Impact Evaluation Report WO32 prepared for the CPUC by DNV GL

innovative field protocols during the pilot to determine if the protocols and instrumentation can be expected to produce confident results. This will include the refrigerant charge adjustment (RCA) weigh in/weigh out refrigerant procedure to assess proper charge, economizer damper functioning procedures, and airflow measurement procedures. More specifics are provided in section 5.2.3.

2.3.4.2 Implementation Ride-Along

Our understanding of current program methods will be informed by observations recorded during ride-along site visits. These visits are our best opportunity to gather non-disruptive pre/post measure data on coil cleaning in programs where this measure is being implemented, and observe technician protocols. We may additionally identify potential opportunities for program improvements during these visits. Units in the ride-along sample must not have received condenser coil cleaning previously under the program and must not be receiving regular condenser coil cleaning maintenance outside the program. We recognize the potential for installer bias during the ride-along portions of the study, however the ride-along observations conducted during 2010-12 still revealed significant issues with field protocols and procedures. More specifics are provided in section 5.2.4.

2.3.4.3 Pre/Post Monitoring and Site Visits

This evaluation will not attempt to complete pre/post monitoring of treated units for a large enough sample to provide statistically reliable results. However, the plan does have the flexibility to leave power and outdoor/indoor dry-bulb temperature monitoring equipment on the units observed during pre-maintenance site visits, if requested, and provided additional budget is made available. The post-maintenance data collected from these same units may include installer bias.

2.3.4.4 Post-Maintenance Assessment

The M&V effort for this evaluation is primarily focused on post-maintenance visits to sites with high impact measures installed. Four out of the five Commercial QM programs have tracking data that clearly indicate the installed measures. The remaining SCE QM program lists measures as “Quality Maintenance.” This measure contains a distribution of energy efficiency tasks as defined in the workpaper. It is not completely clear if site data are entered into the program tracking system at commencement of the quality maintenance contract or at measure installation completion six months later. We will request all program tracking data collected and used to pay incentives and track accomplishments. We will confirm what data is collected with the program managers so the DNV GL HVAC master technicians are able to visit sites where quality maintenance measures are completed. See M&V section 5.2.6 for details.

2.3.4.5 Possible 2015 Add-On: Waitlisted Participants

This evaluation cannot complete pre-maintenance data collection on units claimed in the 2013-2014 cycle. Instead, if this portion is funded, the project will recruit pre-maintenance study participants from 2015 program participants that have agreed to participate in the program, but have not received treatment. This is the most cost efficient method for collected pre-maintenance data for this quasi-experimental design and results in a set of pre-participants that is similar to program participants. The research team will mitigate the potential for bias in this data by sampling sites across programs, IOUs, building types, and contractors (if necessary). The primary risk of this approach is that units may originally be listed for treatment and later receive none or otherwise be dropped from the program. This was a primary issue for the 2010-12 evaluation.

3 MEASURES AND PROGRAMS OF INTEREST

The primary measure groups selected for this evaluation were chosen from the core offerings of the CPUC's QM (statewide) and tune-up (local) residential and commercial HVAC programs.

Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E) are implementing commercial and residential HVAC maintenance activities through a variety of different administrative channels and program structures. "Quality Maintenance" is reported as a measure in the tracking data, but it is, in fact, a group of measures with a specific procedure for implementation based on ANSI/ASHRAE/ACCA Standard 180. Instead of focusing exclusively on the QM measure, this evaluation will disaggregate the QM measure into its component HVAC maintenance measures and examine those measures across programs. The term "HVAC maintenance measures" is used in this evaluation to refer to the component measures that make up the QM measure. Gross impacts will be determined for the primary component measures, and will be used to update the QM savings claims by updating savings for these components in the QM workpaper and accompanying disposition. This evaluation will only report program-level findings for programs that are exclusively comprised of HVAC maintenance measures.

The following sections will convey the evaluation team's understanding of current HVAC maintenance (QM and QM-related) activity across the three utilities with respect to the measures being implemented, the programs they are being administered through, and the workpapers that support their *ex ante* estimates. Note, program tracking data, upon which our assessment relies, is only available from Q1 2013 through Q2 2014 at this time. Section 3.3 summarizes the data and describes which measures will be evaluated under this effort.

3.1 QM Program Description

There are three types of IOU HVAC maintenance programs in California 1) residential, 2) non-residential QM and 3) non-residential tune-up. The non-residential programs do not include industrial HVAC applications so the words "non-residential" and "commercial" are used interchangeably in the context of this evaluation. This section will include descriptions of all types of HVAC maintenance programs, however not all of the programs nor all of the measures within programs will be evaluated due to budget constraints. Since residential programs comprise 5% of total HVAC maintenance savings in the tracking data as of 2014 Q2, we will omit these programs from this evaluation. HVAC-4: Deemed Incentives, another portion of this work, will perform uncertainty analysis on residential QM and HVAC maintenance *ex ante* savings claims.

In order to allocate resources most wisely in the commercial QM program evaluation we ranked all of the measures by savings across the QM and tune-up programs and picked the highest-saving measures for impact evaluation under this plan. The next-highest set of measures were recommended for uncertainty analysis under HVAC-4, however a decision has not yet been made about whether those will be included in that work. The lowest-saving measures will not be evaluated under this plan, nor are they recommended for evaluation under another HVAC segment.

3.1.1 Commercial QM Programs

The QM programs are based on the ANSI/ASHRAE/ACCA Standard 180-based QM Service Agreements. The intent of the agreements is to facilitate optimal functioning of the HVAC systems via comprehensive and competent maintenance approaches. Although common measures, such as RCA, airflow correction, and duct sealing, are included as part of this measure group, this is largely a continuation of the 2010-12 program

structure that uses a comprehensive approach that treats the entire HVAC unit as a system of interrelated faults and treatments rather than individual issues.

The Commercial QM process consists of three major steps:

1. **Service Agreement**: Defines QM policies and the customer's interests and inventories the customer's equipment.
2. **Address Deferred Maintenance**: Assess existing equipment to identify and complete required repairs. Maintenance services are completed in a set order to encourage ideal diagnostics and repairs.
3. **Ongoing Maintenance**: The technician documents HVAC system condition indicators and provides the customer a recommended maintenance schedule. The maintenance plan sets out to establish unambiguous criteria for when maintenance is required. Customer incentives are paid in installments to encourage continued maintenance.

This approach engages customers through an ongoing service agreement, with the expected result of sustained maintenance and improved energy savings compared to previous program models. The workpapers make first year savings claims that are realized in the first year. Since participants have signed a three-year maintenance contract those savings are expected to have at least a three-year EUL.

SCE, SDG&E and PG&E all offer QM programs, though SDG&E QM tracking data claims are indistinguishable from the tune-up program claims and the PG&E program has undergone changes since the previous program cycle and now reports savings at a measure level in the tracking data. We assume that measures reported in the tracking data have been installed and are operating. It is possible that QM savings are reported at the time the contract is signed, and may not be realized until six months later. This will be investigated as part of the evaluation effort. The SCE QM program is largely a continuation of the previous program cycle.

3.1.2 Commercial AC Tune-up Programs

In addition to the commercial QM programs there are two third-party tune-up AC tune-up programs implemented by PG&E and SDG&E that offer similar measures. PG&E's tune-up program is called "Air Care Plus" and SDG&E's tune-up program is called "Premium Cooling Efficiency: Silver or Platinum" with "Direct Install" and "Deemed Incentives" program elements. SCE is not implementing a commercial tune-up program. The measures offered through these programs include condenser coil cleaning, evaporator coil cleaning, air filter replacement, refrigerant charge adjustment, thermostat replacement, thermostat reprogramming, economizer repairs, digital economizer controller/sensors, notched v-belt, fan-speed controls, and demand control ventilation.

3.1.3 Residential QM Programs

PG&E and SDG&E offer residential QM programs. SCE's residential QM activity has been only through the "Comprehensive Manufactured Homes" program. Residential program measures may include refrigerant charge adjustment, coil cleaning, thermal expansion valve (TXV) attachment, supply fan motor upgrades with time delay relay, duct insulation, and condenser fan and motor upgrade.

3.2 QM Program Activity by IOU

The tables below show the claimed savings for all of Program Year 2013 and Q1-Q2 of Program Year 2014 from all the measures of interest to the QM evaluation. The measure names shown in the tables are the measure names that are given in the tracking data. Some of the measure names describe the activity

sufficiently, and other measure names are less descriptive. We will determine the specific activities conducted for each of these claims during our records review. Each claim represents a line item in the tracking data and is not necessarily at the unit level. See Section 3.3 for details on which measures are being included in the evaluation. This section includes a larger overview to show that savings for measures not evaluated are small relative to those being evaluated.

3.2.1 SDG&E

SDG&E is implementing HVAC maintenance measures in the residential and commercial sectors via four different programs:

1. SDGE3212 Residential HVAC-QI/QM
2. SDGE3224 SW-COM-Deemed Incentives - Commercial HVAC
3. SDGE3223 SW-COM-Deemed Incentives Add-on
4. SDGE3226 SW-COM-Direct Install.

The following information is provided on each SDG&E program.

3.2.1.1 SDGE3212 Residential HVAC-Quality Installation (QI)/QM Program

SDG&E's residential QM measures are part of the program referred to as SDGE3212. This program also provides quality installation (QI) measures, which DNV GL will be evaluating via the HVAC QI evaluation element of the overarching HVAC evaluation activities (2013-14 HVAC-2: Residential Quality Installation and Code Compliance). According to the available tracking data for Q1 2013 – Q2 2014, SDG&E has claimed savings for six HVAC maintenance measures through this program, as shown in Table 1 (though one of the six is just a combination of two other maintenance measures. Three basic maintenance measures (airflow correction, refrigerant charge adjustment, and coil cleaning) are being performed as well as efficient fan controllers and new, more efficient blower motors. The fan controllers and efficient blower motors are add-on measures rather than maintenance measures. The efficient fan controller is the dominant measure for the program as it accounts for 97% of the kWh saving claims for the program. HVAC-4: Deemed Incentives will provide an uncertainty analysis for all measures in this program.

Table 1: 2013 SDG&E3212 Residential HVAC maintenance Activity (2013 Q1 – 2014 Q2)

Measures	Claims	kW	kWh/yr	Therms /yr
Adjust refrigerant charge in residential AC unit	24	2.5	1,403	-8
Airflow Correction	50	0.2	142	0
Efficient Fan Controller	744	178.6	393,219	16,606
New Blower Motor	24	2.3	1,644	-186
Residential refrigerant charge and airflow adjustment	23	2.5	1,492	46
Residential SF Condenser Coil Cleaning	1074	9.4	5,712	-10
Total	**1,939**	**195.4**	**403,612**	**16,448**

The workpaper for SDG&E's residential QM program is WPSDGEREHC1065, *Residential HVAC Quality Maintenance and Motor Retrofit*. The measures described in the workpaper are 1) blower motor replacement and 2) QM package. The possible treatments for QM listed in the workpaper are as follows:

- Refurbish degraded ducts
- Restore and improve duct system insulation
- Duct sealing
- Condenser coil cleaning
- Evaporator coil cleaning
- New air filter to match the blower
- TXV attachment and insulation correction
- Refrigerant system test and charge adjustment

3.2.1.2 SDGE3224 SW-COM-Deemed Incentives - Commercial HVAC

This third party HVAC program is called "Premium Efficiency Cooling" and provides tune-up and QM options. The program includes silver, gold and platinum tune-up options. The silver option includes ANSI/ ASHRAE / ACCA Standard 180 compliant inspections and maintenance (excluding combustion analysis). The gold option aligns with the commercial QM program and provides incentives for a 3-year maintenance agreement (or 1-year with continuous renewal for three years). Platinum requires a three-year agreement similar to the Gold QM program but includes matching incentives for minor repairs and measures not covered in the QM program. Both of these options provide incentives for condenser and evaporator coil cleaning, refrigerant charge adjustment, thermostat replacement, thermostat reprogramming, economizer repairs, digital economizer controller/sensors, and fan-speed controls. (Thermostat reprogramming and economizer decommissioning were discontinued in mid-2014.) The tune-up program also includes guest room controls and contractor and customer incentives for HVAC equipment replacement. Lastly, the tune-up program offers customers programmable communicating thermostats in conjunction with SDG&E's Small-Medium Business Thermostat Deployment.

According to the Q1 2013 – Q2 2014 tracking data, savings activity for SDG&E was claimed savings across six measure line items. In addition to the standard maintenance measures of refrigerant charge adjustment and coil cleaning, this program is claiming savings for controller retrofits on packaged terminal air conditioning/packaged terminal heat pump (PTAC/PTHP) units. Though not technically a maintenance measure, the controller measures are included in this overview because they are related to QM.

Table 2: SDG&E3224 Commercial Deemed Program QM Activity (2013 Q1 – 2014 Q2)

Measures	Claims	kW	kWh/yr	Therms /yr
Amana PTAC/PTHP Controllers EMS-DI	345	68	165,825	0
Commercial Condenser Coil Cleaning	37,105	1,558	4,764,038	0
Commercial Evaporator Coil Cleaning	30,888	439	1,411,199	0
PTAC/PTHP Controllers ACC-DI	5	1	3,063	0
PTAC/PTHP Controllers EMS-DI	1,299	262	622,455	0
RCA Inc Refr Chg - Savings Only	29,201	1,657	2,158,958	-2,397
Total	**98,842**	**3,985**	**9,125,537**	**-2,397**

3.2.1.3 SDGE3223 SW-COM-Deemed Incentives - Commercial HVAC Add-On Program

This evaluation effort considers Program 3223 measures because they are related to QM, and do not fall obviously within the scope of other HVAC evaluation elements.

Table 3: SDG&E Commercial Deemed Incentives – Commercial HVAC Program HVAC maintenance Activity (2013 Q1 – 2014 Q2)

Measures	Claims	kW	kWh/yr	Therms /yr
Motors - VFD - HVAC Fans (per Hp)	1224	248.6	1,471,583	-31,737
Variable Air Volume Box	17	13.7	91,970	11,084
Ventilation Control - Retrofit	194	147.1	868,041	-
Ventilation Control- New	20	15.2	89,720	-
VSD Cooling Tower Fans (Two Speed Tower Fan to VFD Fan Control)	700	8.7	6,013	-
Total	**2,154**	**433**	**2,527,327**	**-20,653**

3.2.1.4 SDGE3226 SW-COM-Direct Install

Five HVAC maintenance measures are being claimed through this SDG&E direct install program. Even though the measures are similar to other programs, the program tracks measures differently. For example, while the deemed incentive has a single line item for a refrigerant charge measure, the direct install program has four items based on DEER, depending on the magnitude of the adjustment and whether the system was over or under charged. The initial investigation will determine why SDG&E tracks similar measures differently in different programs. Table 4 shows the measures tracked for this program. The dominant HVAC maintenance measure in this program is condenser coil cleaning which accounts for nearly half of kWh savings of the HVAC maintenance savings for this program in Q1 2013 – Q2 2014.

Table 4: SDG&E3226 Commercial Direct Install Program QM Activity (2013 Q1 – 2014 Q2)

Measures	Claims	kW	kWh/yr	Therms /yr
Checked and re-positioned outside air dampers	48	0.1	14,761	-1,413
Cleaning Coil	14,622	585.1	1,936,244	0
Duct Seal Testing	12,140	266.4	1,010,317	0
Replaced air filter	27	0.5	709	3
Refrigerant Charge Adjustment	4,861	338	432,365	-334
Total	**31,698**	**1190**	**3,394,396**	**-1,744**

Workpapers for SDG&E's non-residential QM measures include WPSDGENRHC1010 Commercial Evaporator Coil Cleaning, WPSDGENRHC1020 Commercial Condenser Coil Cleaning and WPSDGENRHC1030 Air Filter Replacement. DNV GL was not able to locate the workpaper associated with "Duct Seal Testing" or "Checked and re-positioned outside air dampers." We have been informed by the *ex ante* team that the Evaporator and Condenser Coil Cleaning workpapers have not been approved, and that they expect the Commercial QM workpaper and related disposition to apply to the coil cleaning measures in SDGE's tune-up programs.

3.2.2 SCE

SCE has submitted workpapers for both residential and commercial QM measures. The only residential program reporting QM activity is the "Comprehensive Manufactured Homes Program" for Q1 2013 – Q2 2014. The evaluation team does not know if SCE expects to complete additional residential QM during the program cycle, but we will determine this during the investigation into program activities and revise the research plan if necessary.

3.2.2.1 SCE-13-TP-001 Comprehensive Manufactured Homes

SCE's Comprehensive Mobile Home (CMH) program is a continuance of the existing mobile home program within SCE's residential energy efficiency portfolio, in coordination with SCG. CMH is a direct install program designed to provide a comprehensive energy efficiency program to mobile home customers. The program provides for installation of energy-efficient (electric and gas) products in the mobile home dwellings and common areas of mobile home parks at no charge to the customer. The QM measure savings from this program are shown in Table 5 below.

Table 5: SCE Residential Comprehensive Manufactured Homes Program Activity (2013 Q1 – 2014 Q2)

Measures	Claims	kW	kWh/yr	Therms /yr
HVAC Quality Maintenance	10,576	774.5	625,454	12,499

We were not able to locate the workpaper for this program.

3.2.2.2 SCE-13-SW-002F Commercial Quality Maintenance

SCE administers all of its commercial HVAC maintenance activities through this broad-based core commercial HVAC program. Aside from the cogged drive belts measures, all of the program's tracking data measures refer to a QM package of measures. The various claims are based upon the specifics of the cooling system including system type (air conditioner, heat pump or evaporative cooled air conditioner) and whether or not the unit has an economizer. The term "Plus Quality Maintenance" typically refers to a unit with an economizer.

The actual QM activities performed are uncertain, since not all units receive all potential HVAC maintenance measures. The team will make data requests to determine the HVAC maintenance measures performed or installed on each unit, similar to request made for the 2010-2012 evaluation.

Table 6: SCE Commercial Quality Maintenance Program Activity (2013 Q1 – 2014 Q2)

Measures	Claims	kW	kWh/yr	Therms /yr
Air conditioner with Evaporatively Cooled Condenser	176	50.3	31,169	-1565
Economizer and Quality Maintenance	10,338	579.6	1,467,488	5229
Economizer Heat Pump plus Quality Maintenance	1,814	108.5	242,040	-61
Heat Pump plus Quality Maintenance	1,026	54.9	121,710	-29
HVAC Fan Cogged V-Belt replacing Smooth V-Belt	784	1.9	7,824	0
Quality Maintenance	823	40.1	89,787	602
Total	**14,961**	**835.3**	**1,960,018**	**4,176**

SCE's workpaper is SCE13HC037, Comprehensive Commercial HVAC Rooftop Unit Quality Maintenance. This workpaper describes the assumptions and methodology for generating an estimate of the "typical unit" participating in the program. The savings are provided by building type, using climate zone and unit tonnage as inputs.

3.2.3 PG&E

PG&E is offering QM for the residential and non-residential sectors through its core HVAC offerings. Additionally, Air Care Plus, a third-party AC tune-up program administered by PECI (now ClearResult), is available to commercial PG&E customers.

3.2.3.1 21006 – Residential HVAC

PG&E is implementing HVAC maintenance measures through this core residential HVAC program. In Q1 2013 to Q2 2014, the specific measures claimed in the tracking data are airflow correction, blower motor retrofits, and refrigeration system assessments. It is unclear if airflow correction is an accurate depiction of the activity or is merely the line item where savings for all maintenance measure packages are being claimed. This will be clarified in the participant data review task of the evaluation.

Table 7: PG&E Residential HVAC Program HVAC maintenance Activity (2013 Q1 – 2014 Q2)

Measures	Claims	kW	kWh/yr	Therms /yr
Air Flow Correction	4,378	490.4	793,920	28,566
Blower Motor Retrofit	1,745	261.1	272,951	0
Refrigeration System Assessment with Savings	214	30.2	24,263	0
Total	**6,337**	**781.7**	**1,091,134**	**28,566**

The workpaper for PG&E's residential QM program is PGECOHVC139 Residential HVAC QM. It is very similar to the SDG&E's residential workpaper. The possible treatments, listed below, match SDG&E's list of possible treatments:

- Refurbish Ducts
- Restore and Improve Duct Insulation
- Duct Sealing
- Clean Evaporator Coil and Blower
- New Air Filter to Match the Blower
- Clean Condenser Coil
- TXV Insulation and Attachment Correction
- Refrigerant Charge Correction

3.2.3.2 21015 – Commercial HVAC

PG&E is implementing QM measures for the non-residential sector through this core HVAC program. Table 8 shows the measure descriptions found in the tracking data provided as well as the number of claims and aggregate kW, kWh, and therm savings. The specific measures include unoccupied fan controls (re-program thermostat during unoccupied periods), programmable thermostat installation, refrigerant charge adjustment and economizer repair measures.

Table 8: PG&E Non-Residential HVAC QM Activity (2013 Q1 – 2014 Q2)

Measures	Claims	kW	kWh/yr	Therms /yr
Adjust Refrigerant Charge	8,116	515.3	607,499	0
Economizer Control-Adjust-DXGF	1,197	0.1	186,371	0
Economizer Control-Replace-DXGF	9,753	-0.2	1,319,613	0
Economizer Control-Replace-HP	82	0	14,168	0
Economizer Repair	6,375	-139.9	456,244	0
Non-Residential HVAC EE Tasks for Units without an Economizer	4,209	310.7	1,312,711	7,919
Non-Residential HVAC EE Tasks for Units With an Economizer	4,561	385.2	1,741,172	14,543
Programmable Thermostat	7,546	0	1,655,397	227,511
Unoccupied Supply Fan Control	13,838	0	2,966,968	363,621
Total	**55,677**	**1,071**	**10,260,143**	**613,594**

The detailed workpaper for PG&E's nonresidential QM program is PGECOHVC138 Nonresidential HVAC RTU Quality Maintenance. This document is very similar to the SCE nonresidential QM workpaper in nearly all respects.

3.2.3.3 21016 – Air Care Plus

Air Care Plus is a third-party program implementing HVAC QM-type measures. The program is open to commercial customers in PG&E's service territory. The claimed measures include refrigerant charge adjustment, coil cleaning, cogged drive belt retrofits, programmable thermostat installation, unoccupied fan control (re-program thermostat during unoccupied periods) and economizer repair. The programmable thermostat is responsible for the largest amount of energy savings in the program.

Table 9: Air Care Plus Program Activity (2013 Q1 – 2014 Q2)

Measures	Claims	kW	kWh/yr	Therms /yr
Adjust Refrigerant Charge	61,006	590.8	944,013	0
Condenser Coil Cleaning	8,411	34.5	53,539	0
Economizer Control-Adjust-DXGF	1,361	0.1	133,666	0
Economizer Control-Replace-DXGF	5,352	-0.1	581,928	0
Economizer Control-Replace-HP	10	0.0	1,611	0
Economizer Repair	7,369	-157.5	430,838	0
Evaporator Coil Cleaning	7,170	14.8	23,154	0
HVAC Fan Cogged V-Belt Gas Heat	3,937	16.9	54,608	0
HVAC Fan Cogged V-Belt Heat Pump	4	0.0	34	0
HVAC Fan Cogged V-Belt Package VAV	70	0.1	828	0
Programmable Thermostat	8,269	0.0	1,938,558	277,584
Unoccupied Supply Fan Control	788	0.0	190,323	27,239
Total	**103,746**	**499.5**	**4,353,099**	**304,822**

3.2.4 Summary of Savings by Program

Table 10 summarizes the claimed 2013 savings from QM and HVAC maintenance measures for each IOU program with "quality maintenance related activity." The PG&E commercial program and SDG&E's non-residential direct install program have the greatest energy savings of all of the QM measure containing programs. Due to the low residential activity, the impact evaluation will focus primarily on commercial programs. The scope of HVAC-4 Deemed Measures – Year 1 has included an uncertainty analysis of residential QM measures, although it is not in their scope to do a full impact evaluation. Sampling for each commercial program will be proportional to the primary measure savings in that program.

Table 10: QM Savings by Program (2013 Q1 – 2014 Q2)

Program	Claims	kW Savings	kWh Savings	therm Savings
SDG&E Non Residential Deemed Incentive	100,996	4,418.2	11,652,864	-23,049
PG&E Commercial QM	55,677	1,071.2	10,260,143	613,594
PG&E Air Care Plus	103,746	499.5	4,353,099	304,822
SDG&E Non Residential Direct Install	34,834	1,215.1	3,493,238	-1,745
SCE Commercial QM	14,961	835.4	1,960,018	4,176
PG&E Residential QM	6,337	781.7	1,091,134	28,566
SDG&E Residential QM	1,939	195.4	403,612	16,448
SCE Comprehensive Manufactured Home	10,576	774.5	625,454	12,499
Total	**329,065**	**9,791.1**	**33,839,563**	**955,311**

3.2.5 Summary of Savings by IOU

Table 11 shows the QM measure savings claims by IOU for Q1 2013 – Q2 2014. PG&E and SDG&E have very similar kWh savings claims but different therm savings. SCE QM has lowest tracked kWh savings to date of the three. SDG&E has already surpassed their 2013-2014 program cycle projected savings claim, as reported in the Energy Saving Performance Index (ESPI) decision.[12] PG&E has completed less than half of their projected claims and SCE has completed less than 10%. It is possible that the programs may dramatically increase participation ("hockey stick") to complete claimed savings by the end of the program cycle.

Table 11: QM Savings by IOU (2013 Q1 – 2014 Q2)

IOU	Number of Claims	kW Savings	kWh Savings	therm Savings	ESPI 2013-2014 Compliance Filing Portfolio Projection [kWh]
PG&E	165,760	2,352	15,704,376	946,982	>40,000,000
SCE	25,537	1,610	2,585,472	16,675	>30,000,000
SDG&E	137,769	5,829	15,549,714	-8,346	>9,000,000

3.3 Commercial QM Savings by Measure

As shown in the preceding sections, though the QM programs are similar with many overlapping measures, they also have measures distinct to a particular program. To decide where to focus evaluation efforts we

[12] Dictated in CPUC D.13-09-023 http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M076/K775/76775903.PDF

ranked all the measures found in Commercial QM programs by claimed savings from each measure. Table 12 shows this ranking. The first five rows are highlighted blue because those are the measures that we propose to evaluate in this research plan. The SCE Quality Maintenance measure will also be evaluated to the extent that it is a mixture of the first five measures. Measures will be evaluated across all programs and IOUs and the average results will be applied to claimed measures across all programs and IOUs.

Table 12: Non-Residential QM Measures and Savings Ranked by Percent of Total Non-Residential QM Savings (2013 Q1 – 2014 Q2)

Program(s)	Measure	Savings [therm/ year]	Percent of Total QM Therm Savings	Savings [kWh/year]	Percent of Total QM kWh Savings	Cumulative Percent of Total QM kWh Savings	Measure will be evaluated under this plan?
SDGE (AC+)	Coil Cleaning	0	0.0%	9,297,332	29.3%	29.3%	Yes
All Programs	RCA	-2,730	-0.3%	4,142,834	13.1%	42.4%	Yes
PGE (QM and AC+)	Thermostat	505,095	56.1%	3,593,955	11.3%	53.7%	Yes
PGE (QM and AC+)	Supply Fan Control	390,861	42.4%	3,157,291	10.0%	63.7%	Yes
PGE (QM and AC+)	Economizer	0	0.0%	3,124,438	9.9%	73.5%	Yes
PGE (QM)	EE tasks	22,462	2.5%	3,053,883	9.6%	83.1%	Yes
SCE (QM)	Quality Maintenance	5,741	0.6%	1,921,025	6.1%	89.2%	Yes
SDGE (D)	Motor and Fan VFD	-31,737	-3.5%	1,477,596	4.7%	93.8%	No*
SDGE (D)	Ventilation control	0	0.0%	957,761	3.0%	96.9%	No*
SDGE (D)	PTAC controllers	0	0.0%	791,342	2.5%	99.4%	No*
SDGE (D)	Variable Air Volume Box	11,084	1.2%	91,970	0.3%	99.7%	No* [13]
SCE (AC+)	V-Belt	0	0.0%	63,295	0.2%	99.9%	No
SCE (QM)	AC with Evaporator Cooled Condenser	-1,565	-0.2%	31,169	0.1%	100.0%	No
SDGE (DI)	Reposition Dampers	-1,413	-0.2%	14,761	0.0%	100.0%	No
SDGE (DI)	Duct Testing	0	0.0%	709	0.0%	100.0%	No
Total		**897,798**		**31,719,362**			

DI = Direct Install, D=Deemed, AC+=Air Care Plus, QM=Quality Maintenance

The program column indicates all programs that installed the given measure, and the percent of total QM savings indicates the total savings for that measure (across all programs) as a percent of total QM savings from all five non-residential QM programs. The top five measures comprise 73.5% of total QM program savings. The sixth and seventh measures are “EE tasks” and “Quality Maintenance” which likely contain some combination of the first five measures. The top five measures could therefore be capturing up to 89.2% of QM program savings. We plan to take a focused approach on these five high impact measures, evaluating only Coil Cleaning, RCA, Thermostat, Economizer and Supply Fan Control measures.

[13] The star indicates measures being considered for “year 2” *ex ante* uncertainty analysis through HVAC-4: Deemed Incentives.

Measures ranked 8th to 11th have been referred to the HVAC-4 Deemed Incentives team as a potential candidate for their Year 2 uncertainty analysis. Note that their scope does not include impact evaluation. Their criteria for measure selection include:

- Not being evaluated by another HVAC Roadmap evaluation
- Can determine the input parameters and equations used to estimate the savings
- The associated savings are either moderately big or appear to be growing according to the available tracking data or IOU updates during the PCG calls

Table 13 lists each program, total program savings claimed, savings claims from the five highest impact measures plus the SCE Quality Maintenance measure, and the percent of program savings due to those measure claims. As the table shows, this project's focus on high impact measures will evaluate the large majority of savings claimed by each program.

Table 13: High Impact Measures and Savings by Non-Residential Program (2013 Q1 – 2014 Q2)

Program	High Impact Measures	Program kWh Savings	Top Measure kWh Savings	Top Measure % of Total Program
SDGE Deemed Incentive	Coil Cleaning, RCA	11,652,864	8,334,194	72%
SDGE Direct Install	Coil Cleaning, RCA	3,493,238	3,477,768	100%
PGE QM	RCA, Economizer, Supply Fan Control, Thermostat	10,260,143	7,206,260	70%
Air Care Plus	RCA, Economizer, Thermostat[14]	4,353,099	4,030,614	93%
SCE QM	Quality Maintenance	1,960,018	1,921,025	98%

[14] Coil cleaning and Supply Fan Control are also measures in Air Care Plus, but at 2% and 4% of program savings they are not high impact measures for this program and won't be evaluated. PJ comment: Suggest sampling across all programs containing measure. Won't be many units from this program in the sample, but savings can be extrapolated across all programs with the measure. If excluded, will be a pass-through.

4 SAMPLE DESIGN

The Evaluation Team will use samples of program participants to estimate the gross and net *ex post* impacts of the programs. Only installations receiving incentives from the 2013-14 program cycle will be sampled for post-maintenance data collection. The following five independent samples will be used for this research:

- **Field data:** 45 current program participants selected for the ride-along task. In programs with coil cleaning measures, the ride-alongs will be performed at visits where there is intent to clean evaporator and condenser coils.
- **Field data:** 55 post-maintenance program participants sampled from program tracking data for field data collection. If the program data include measure-level information, then only sites and units with high impact measures will be included in the sampling population. If no measure-level information is available (as in the SCE program), then all projects will be included in the sampling population (stratified by implementation contractor activity,) but the evaluation field effort will still focus on the same five high impact measures.
- **Participant NTG Survey data:** Post-maintenance program participants sampled from program tracking data for NTG surveying. The size and allocation of this sample will be determined when the net impact methodology is determined.
- **Contractor NTG Survey data:** Participating and non-participating HVAC contractors will be sampled separately for NTG surveys from the HVAC contractor pool participating in AC tune-up programs and IOU QM programs. The size and allocation of this sample will be determined when the net impact methodology is determined.

Each sample will be segmented by IOU, program type, and service contractor if possible. Further segmentation is not expected, but will be completed if determined to be informative and feasible. In some cases, the format of the service tracking data may allow segmentation/stratification based on additional parameters, such as cooling capacity in tons, AC type, or contractor. Our review of program participation records will determine the segmentation/stratification variables used.

Sampling of the participant population will be at the measure, unit, or site level, depending on the granularity of the data, and will exclude sites that are known to exclude all program high impact measures. The analysis methodology will account for the bias introduced by sampling in this manner for QM programs where the measure (namely “quality maintenance” and “EE tasks”) includes a mix of high and low impact components. When site level sampling is used, the units will be sampled at 90/20 per California Energy Efficiency Evaluation Protocols, Table 22.[15]

Table 14 shows the preliminary sample size targets by evaluation task and by program. The allocation of sample points to programs was completed using the expected energy savings for each 2013-2014 program cycle based on Q1 2013 – Q2 2014 tracking for the high impact measures delivered by each program. A data request for detailed contractor records has been submitted and the team will revisit the sample allocation after reviewing detailed contractor data submitted by the IOUs. Additionally, SDGE coil cleaning claims will be adjusted to QM workpaper and disposition levels before the final sample is drawn. The final sample plan will be further adjusted, if needed, when final 2014 data becomes available.

[15] Required Protocols for Sampling of Measures Within a Site. California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals. Prepared by TecMarket Works for the CPUC. April, 2006.

Table 14: Sample Targets by Evaluation Task and Program

Program	High Impact Measures	Ride-Along Sites	Post-Maintenance Data Collection
SDG&E Deemed Incentive	RCA, Coil Cleaning	15	5
SDG&E Direct Install	RCA, Coil Cleaning	15	5
PG&E QM	RCA, Economizer, Supply Fan Control	5	15
PG&E Air Care Plus	RCA, Economizer, Thermostats	5	15
SCE QM	Quality Maintenance	5	15
TOTAL		**45**	**55**

Table 15 shows the same sample size targets by evaluation task and key measure. The targets shown were developed from the research activities expected and the participation data received to date. The sample target is lower than the number of site visits because we may not be able to collect data, or may not get good results at some of the sites. These sample targets are meant to be conservative estimates of the number of good data points that we will achieve. Since ride-along visits are targeted at coil cleaning measures, we have made an estimate of how many systems will also receive thermostat and supply fan measures where we can obtain direct observations of the pre and post condition. If no information on the measure mix was available, the expected incidence assumptions from the workpapers were used.

Table 15: Sample Targets by Evaluation Task and Program

Measure	Ride-Along Sites	Post-Maintenance Data Collection
Coil Cleaning	29	-
RCA	-	22
Economizer	-	21
Supply Fan Control	5	14
Thermostat	5	15

At ride-along sites, both baseline and post-maintenance data will be collected for the coil cleaning measure in the SDG&E territory. Baseline data for the supply fan control measure and the thermostat measure is collected at PG&E ride-along visits as well as at 2015 pre-maintenance visits. Baseline data for the RCA and economizer measures is collected through re-creation of the baseline condition or at 2015 pre-maintenance visits. Post-installation data is collected for all measures except coil cleaning at post-maintenance visits.

Table 16 shows the planned precision of model inputs gathered during on-site field data collection at 90% confidence using 1.0 as the estimate of error ratio.[16] This estimate is based in part on 2006-08 findings of variation in HVAC simulation input parameters (0.6 error ratio found in that study), which matches the kind of analysis we are proposing here. The error ratio is significantly increased to 1.0 based on WO32 findings

[16] The error ratio measures the variability of measured energy savings relative to the program tracking estimate of energy savings . The California Evaluation Framework, Chapter 13 further describes this terms with examples of its application.

where variation in energy savings per ton from HVAC end use pre-post metering is in the range of 1.5 to 3.5. An error ratio in that range would require hundreds (~400 sample points to achieve 20% precision at 90% confidence and CV=2.5) of sample points to achieve reasonable precision levels. This evaluation proposes an alternative to pre-post metering which consists of post only visits, and is expected to produce results with less unit to unit variation than the pre-post metering in WO32. This EM&V approach was successfully piloted in 2014 based on lessons learned from WO32 findings (discussed in the WO32 interim and final reports). If program year 2015 is added to this evaluation cycle and additional funding becomes available, the sample sizes will be increased and the estimates will become more precise.[17]

Table 16: Dataset Size for Model Input Parameters with Corresponding Sampling Precision at 90% Confidence

Measure	Model Parameter Dataset Size		Precision at 90% confidence	
	Baseline	Post-Installation	Baseline	Post-Installation
Coil Cleaning	29	29	± 31%	± 31%
RCA	-	22	-	± 35%
Economizer	-	21	-	± 36%
Supply Fan Control	-	12	-	± 47%
Thermostat	-	15	-	± 42%

[17] The ultimate error bound for savings will be determined by the uncertainty of the modeling process used for ex-ante and ex-post results and will not have a quantified error estimate nor will it be feasible to determine the error for this study. The ultimate realized precision levels do not project error bounds on energy and demand savings.

5 M&V PLAN

5.1 Overview

Measurement and verification of QM programs will occur through multiple tasks each designed to improve the accuracy of QM measure savings estimates. The data reviewed and collected during each task is planned to provide information on the pre-maintenance baseline operating condition and post-maintenance installed operating condition of the equipment serviced. This information will inform laboratory testing and the lab testing in turn will inform the analysis that will estimate the *ex post* savings achieved by QM measures. The M&V Plan (Section 5 of this research plan) will be revised, expanded and presented to the CPUC and advisors for approval before the field data collection effort (ride along visits and post-maintenance visits) begins.

5.2 M&V Tasks

5.2.1 Workpaper Review

The first M&V activity completed will be a review and comparison of the workpaper dispositions issued by the CPUC and workpapers associated with identified key program measures. This review will document the key parameters, assumptions and calculation methodology used to estimate *ex ante* savings. This review is necessary for M&V as it provides the key parameters for comparison to the research results. Impact evaluation provides load impact findings that are used to improve ex-ante assumptions for future programs. Linking interim and final evaluation results back to the workpapers is an important ex-post activity. Simply providing load impacts, i.e., kWh/ton savings values or realization rates, has limited usefulness for future ex-ante savings updates. The workpaper review will inform the analysis methodology, and will be performed before the M&V Plan is sent to the CPUC for review.

5.2.2 Participation Records Review

Each IOU will receive initial and regular data requests for detailed participation data that includes information recorded by implementation technicians. It is expected that the information received will vary by program and that some programs' data will include more detail than others will. Program implementers will be expected to provide full participant tracking data as this will help the evaluation define the best methodologies for selecting sites representative of units receiving comprehensive services by technicians who performed the majority of work under the programs for post-maintenance observations. Ideally, the received information will document the pre and post-retrofit conditions observed by the programs. The research team recognizes the potential for bias due to the expected variety in data received. However, the information is still expected to be informative even with bias. Initial data requests show that several programs record the weight of refrigerant added or removed during refrigerant charge adjustment (namely SCE and PGE AirCare Plus), however at least one program (PGE QM) does not record the weight of added or removed refrigerant. The team will need to decide how to deal with this issue in the revised EM&V plan. One possible solution is to apply the results from the programs that record charge to all of the programs. Data from the AirCare Plus program currently form the basis of the PGE SW workpaper savings claims so the approach should be acceptable. The participation records will be thoroughly reviewed and discussed in the revised EM&V Plan.

All site-specific information necessary for sampling, scheduling, and surveying will be requested at the same time.

5.2.3 Field M&V Pilot

In the M&V pilot the team will investigate field techniques including those that can be used in post-only applications to re-create pre-measure-installation HVAC conditions. The previous round of evaluation experienced considerable difficulty with pre/post visit scheduling so DNV GL proposes to investigate M&V methods requiring only a post retrofit visit. The following procedures will be explored in the pilot:

- Refrigerant adjustment to pre-condition by reversing what was done in measure installation if information is adequate. Optimal condition achieved at visit completion by weighing in manufacturer's recommended charge.
- Investigate condenser coil blockage faults regarding pre- and post-condition by measuring discharge pressure, liquid temperature, total power, and condenser fan power at similar pre/post indoor/outdoor conditions.
- Investigate evaporator coil (and air filter) blockage faults regarding pre- and post-condition by measuring suction pressure, evaporator/suction temperature, static pressure, airflow, total power, and blower fan power at similar pre/post indoor/outdoor conditions.
- Investigate thermostat reprogramming by checking unoccupied cooling and heating schedules and settings. Evaluate baseline and current schedules using contractor records, customer interviews, thermostat settings, or EMS control settings.
- Investigate economizer control strategy, minimum airflow setting, maximum airflow setting, and changeover setpoint. Recreate baseline using contractor records and measure outdoor airflow if possible.

Training on the M&V procedure will include a comprehensive review of the protocol and the data-collection instrument. The field staff performed non-residential QM site visits for WO32 in 2013 and are familiar with the procedures and equipment; this experience will provide consistency between the two studies.

The team will produce site specific M&V plans and site reports for all sites visited during the pilot. It is crucial that the team complete the pilot investigation and begin the field effort as soon as possible which will be when the weather starts to warm up in the southern part of the state. The team will test the Field M&V plan on the first five ride-along and post-maintenance site visits. At this juncture there will be a CPUC review of how the field methods are working, and if reliable measurements are being made before executing the data collection plan on the full sample. The review will include an evaluation of the data analysis effort (generation of ex-post EUS and installation rate values), the field data collection efforts and confirmation that field efforts properly feed the data analysis effort. This review may be used to re-direct efforts away from evaluation process that, for technical reasons, are not providing acceptable results to those measure evaluations that have been shown to be successful. Details of suggested program adjustments will be provided as a part of the pilot review process. At a minimum, the pilot review will provide specific data analysis methodologies and calculation examples that will be used to produce eventual program findings.

5.2.4 Implementation Ride-Along

We will complete 45 ride-along visits with implementation technicians. We will use these ride-along visits to collect data on the change in refrigerant suction and discharge pressure to assess the refrigerant system changes before and after evaporator and condenser coil cleaning, as well as the static (air) pressure across the evaporator coil before and after cleaning. Lab data is required to relate the suction and discharge pressure changes to a change in EER. The data collected in the field will define the range of suction and

discharge pressures tested in the laboratory. To record the change in refrigerant pressure across the coils, the unit must be operating in cooling mode. These visits will therefore occur during times agreeable with contractors in the three IOU territories. See below for more details on the data collection procedure.

We will also record observations of the operating conditions of the units treated, including supply fan operating schedule and thermostat settings including any energy management system overrides. These recorded observations will provide baseline data points for the supply fan control and thermostat measures.

In addition, these visits allow for observation of the maintenance decision-making process and "real life" issues faced by technicians. These observations are expected to support the discussion of any variance between *ex ante* and *ex post* estimates.

5.2.5 2015 Add-On: Pre-Retrofit Site Visits

If additional 2015 funding is granted to this project we will visit 30 (or more) pre-maintenance units to complete spot measurements of refrigerant charge, economizer operation, supply fan control schedule, and thermostat schedule. We will not collect data on coil cleaning because without matched pre and post cleaning data the resulting data is not useful. This task is specific to determining the baseline condition and does not include post-maintenance data collection, though some units may be treated through the program and provide an opportunity for pre/post data collection after the treatment. The data will define the average baseline conditions simulated in the *ex post* savings calculations. *Ex ante* savings estimates are based on assumed baseline operating conditions. This task will provide data on the actual operating conditions of units before maintenance. All data collected during this task will be compared to any program data documenting the pre-maintenance condition of units. All monitoring will occur in one day if possible and no equipment will remain installed, due to the challenges associated with pre/post monitoring of QM measures. The WO32 evaluation report documents these challenges.

5.2.6 Post-Retrofit Site Visits

We will visit 55 participant sites to collect data on current refrigerant charge and outside air flow rates under different economizer conditions. We will use the weigh in/out method to evaluate RCA and will cycle the economizer through its normal "open" and "closed" positions to test airflow at those conditions and determine changeover setpoint temperature. These visits can occur during cooler temperatures when the building cooling is not required. This allows for removal of refrigerant without interrupting building conditioning. Testing of economizer outside air flow is benefited by cooler outdoor temperatures where an enthalpy-based mixed airflow measurement method that was found to be effective in the lab (not confirmed in the field) can be used.

5.2.7 Laboratory Testing

Knowledge of the energy and peak demand impacts that result from implementing measures as part of QM programs is essential to conduct any kind of impact assessment. HVAC systems are relatively complex assemblies of several subsystems and components. Their complex nature and difficult to control field conditions make field measurement of system performance imprecise almost to the point of being unusable. In addition there are insufficient independent test results that provide reliable estimates of the impact of QM measures.

The energy impacts of individual QM measures will be determined through a series of highly controlled and closely monitored series of laboratory based testing runs. To support the entire suite of HVAC evaluations the CPUC is conducting ongoing HVAC laboratory system testing under the 2013-14 HVAC Laboratory

Testing (HVAC_5) work order. The purpose of this laboratory testing is to estimate the energy savings achievable by the high impact measures included in the QM and other programs. The actual lab testing procedures used will be determined from the data and information collected in the activities described above. Two specific areas where lab testing will support the QM impact evaluation are 1) in the development of regressions between discharge pressure and EER for different kinds of systems at different indoor and outdoor temperature conditions and 2) the development of refrigerant charge versus EER curves. Use of laboratory testing is necessary for this evaluation as it is the only method available to implement repeated controlled environment tests and directly quantify the impact of QM activities on an HVAC unit-level performance in emulated field conditions. Program level impacts are expanded from unit level impacts at sampled sites.

The laboratory protocol for testing under emulated field conditions has been developed over the last two CPUC evaluation cycles. The conditions and test procedures are very distinct from normal AHRI test conditions that are used to demonstrate equipment compliance with performance ratings. Each different fault to be corrected by the QM program will need independent evaluation. To illustrate how that process will work, the following example is provided to explain how the laboratory test results will be used to evaluate the impact of the QM coil cleaning measure.

Laboratory tests were performed to evaluate the impact of condenser blockage faults on the application efficiency (EER* or the actual operating efficiency under the test conditions). The HVAC unit used for these tests was a 7.5-ton 2-compressor TXV unit with an economizer installed, dampers closed, and airflow of 360 scfm/ton.[18] Tests were performed at outdoor conditions of 95 degrees Fahrenheit (F) and indoor conditions of 75F DB and 62F WB. All tests were performed with factory charge. The condenser coil was blocked on the outside of the coil with plastic corrugated cardboard (in order to block but not damage fins). Coil blockage was increased incrementally to produce a discharge pressure increase across both refrigerant circuits. Table 17 provides the test results for condenser blockage causing discharge pressure to increase by 1.9 to 33.2% with efficiency impacts of -1.5 to -25.6% and total power impacts of 1.2 to 24.4%. Figure 1 shows a graphical representation of these test data. Testing like this will be continued on systems of different size under different temperature conditions.

During field observations the measured discharge pressure change due to dirty or blocked condensers varied from 1% to 28%. Using the correlations developed in the lab, as illustrated in Figure 1, we can convert the discharge pressure change to EER* change. The difficulty will be in relating EER* change at the actual testing conditions to the EER at standard test conditions which would then be used in DEER models to update the *ex ante* savings.

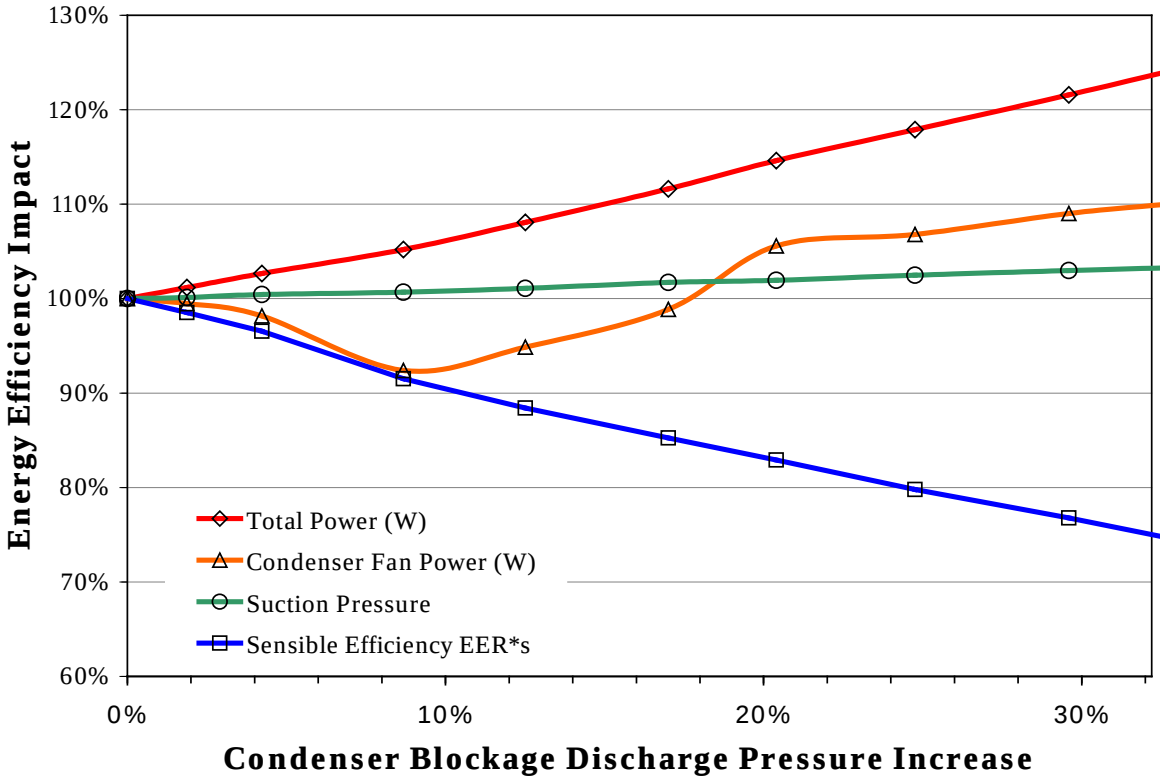
Without the lab data, instantaneous EER would have to be measured in situ. Given the uncertainty band around instantaneous EER field measurements and the relatively small savings fractions for all but the dirtiest condenser coils, there would be little confidence in the field-measured estimates. In this case the lab testing data provides a much more precise and defensible estimate.

[18] SCFM is cubic feet per minute at standard conditions. The standard conditions used in this test were atmospheric pressure (101,325 Pa) and 68 degrees Fahrenheit

Table 17: Condenser Blockage Fault Impacts versus Discharge Pressure for 7.5-ton TXV RTU2 at 360 scfm/ton with Economizer Damper Closed

Test	Discharge Pressure Increase %	Total Power Impact %	Sensible Cooling Capacity Impact %	Sensible EER*s Impact
T2-MFB3-100C1-100C2-90A-95-CE-2	0.0	0.0%	0.0%	0.0%
T2-MF45-100C1-100C2-90A-CB05-CCE	1.9	1.2%	-0.6%	-1.5%
T2-MF46-100C1-100C2-90A-CB10-CCE	4.2	2.7%	-1.7%	-3.4%
T2-MF47-100C1-100C2-90A-CB20-CCE	8.7	5.2%	-5.1%	-8.5%
T2-MF48-100C1-100C2-90A-CB30-CCE	12.5	8.1%	-6.1%	-11.6%
T2-MF49-100C1-100C2-90A-CB40-CCE	17.0	11.6%	-7.1%	-14.8%
T2-MF50-100C1-100C2-90A-CB50-CCE	20.4	14.6%	-7.5%	-17.1%
T2-MF51-100C1-100C2-90A-CB60-CCE	24.8	17.9%	-9.1%	-20.2%
T2-MF52-100C1-100C2-90A-CB70-CCE	29.6	21.6%	-10.9%	-23.2%
T2-MF53-100C1-100C2-90A-CB80-CCE	33.2	24.4%	-12.3%	-25.6%

Figure 1: Condenser Blockage Fault Impacts versus Discharge Pressure for 7.5-ton TXV RTU2 at 360 scfm/ton with Economizer Damper Closed



Unit-level-analysis approaches and measurement uncertainties were explored in WO32 Tasks 3.1 and 3.2 (during the 2010-2012 evaluation).

5.2.8 Analysis

The engineering analysis and simulation modeling are discussed in detail in Section 5.5: Analysis.

5.3 Field M&V Plan

The site field M&V plan for non-residential QM will be tested during the M&V pilot task. The final site data collection plan will be modified as a result of the lessons learned in the pilot

5.3.1 Safety

Any project or activity involving fieldwork escalates risk. To mitigate risk, DNV GL requires business line managers, project managers, contractor representatives, and all affected employees to complete the Job Safety and Environmental Analysis (JSEA) prior to undertaking fieldwork. The JSEA serves as a template to identify risks associated with any task to be completed in the field. It also provides a means of documenting the field task procedure, risk mitigation strategies, required tools and personal protective equipment (PPE), and any required authorizations, permits, or forms. One of the forms is the Energized Electrical Form. Whenever a field task involves work on exposed energized conductors over 50 V, a DNV GL or RMA Qualified Electrical Worker (QEW) will be required to perform that task. In the event the task is to be completed by a subcontractor of DNV GL, the subcontractor is expected to provide its QEWs with training comparable to that

outlined in the DNV GL Energy Advisory QEW Program. The DNV GL QEW program is designed to be consistent with Occupational Safety and Health Administration (OSHA) standards 29CFR1910.269 and 29CFR1910.339 as well as the 2012 edition of the National Fire Protection Association (NFPA) 70E Standard for Electrical Safety in the Workplace.

5.3.2 Data Collection Plan

Table 18 is a high level summary of the data that will be recorded for each unit tested. This summary table is followed by a detailed list of the metering and testing equipment to be used for field data collection at pre-maintenance and post-only site visits. Monitoring equipment will be installed only for the day that we visit the site and may be supplemented by additional spot measurements. Data collected with this equipment will feed into laboratory testing and the program level DEER prototype energy simulation analyses. Those analyses will produce program-level savings estimates on a measure by measure basis. The uncertainty associated with field measurements and the modeling analyses was covered in the 2010-12 WO32 Task 3.1 and 3.2 deliverables (see Appendix A.)

Table 18: M&V Data Summary – Non-Residential QM

	Plan	Pilot Considerations
Program	IOU Program Number & Name	
Measure Type	Non-Residential QM	
Relevant Workpaper	IOU workpaper supporting measure	
M&V Scope	Direct measurement of sampled HVAC units	
Site Data Dependency	No dependence, need access to units.	Assess access issues
Site Sample Stratum and Weight	IOU-Program based sample	From Sample Design Memo; does not apply to pilot
System Information	Thermostat schedule and settings; distribution type (duct locations, duct insulation)	Record information; assess need to change data collection
Zone Information	Whole building or Partial, % glazing of zone envelope, envelope characteristics if applicable	Record information; assess need to change data collection
Contextual Data Collection	Documentation of required ventilation per ASHRAE 62.1 or building codes (if available); other data as requested by HVAC PCG.	Record information; assess need to change data collection
Unit Information	Make/model, tonnage, efficiency, AC/hp, compressor/fan sizes, thermostat temperature setback and fan control schedule and settings. Setpoint deadband and stage to stage time delay data as available.	Record information; assess need to change data collection
Site Visit Date	Date and time of visit recorded by field tech.	
Date of Coil Cleaning	If coil cleaning was recorded for the site, the date of the last coil cleaning will be taken from program documentation.	Determine if date of cleaning is included in documentation and/or can be determined on-site.
Refrigerant Added	If an RCA measure was completed, the amount of refrigerant added or removed by the program will be recorded.	Determine if the amount of refrigerant added or removed is included in documentation and/or can be determined on-site.
Measurements	See Table 19: Field Data Collection Plan.	Record information; assess options for measurements
Measure Information per Unit	Tests: airflow, programmable thermostat, coil cleaning, refrigerant charge, line restrictions, non-condensables, economizer repairs, thermostat reprogramming,	Record test results and observations; assess need to change data collection

Table 19 lists all the sensor-based measurements that will be used to estimate model input parameters, HVAC unit capacity and efficiency as well as diagnostic information used in programs to determine if measures should be implemented.

Table 19: Field Data Collection Plan

Parameter to Measure	Parameter Range	M&V Equipment Brand and Model	Rated Full Scale Accuracy	Accuracy of Expected Measurement	Minimum Planned Metering Duration	Planned Metering Interval
Supply Air – Temperature/RH	45°F-65°F	Onset Smart sensor S-THB-M002 Rotronics HC2-S Probe (WB/DB) and HygroLog HL-NT data logger	Onset: ± 0.36°F ± 3.5% RH Rotronics: ±0.8 %rh / ±0.18 F		90-120 minutes	1 minute
Return Air – Temperature/RH	50°F-80°F	Onset Smart sensor S-THB-M002 Rotronics HC2-S Probe (WB/DB) and HygroLog HL-NT data logger	Onset: ± 0.36°F ± 3.5% RH Rotronics: ±0.8 %rh / ±0.18 F		90-120 minutes	1 minute
V, A, kW, kWh, Pf	0 to 250 kW	PowerSight PS3500 Or Dent ElitePro	1% kW, 0.5% Amps, phase shift and 50th harmonic (PS3500)		Average over 15 minutes	N/A
Ambient Air Temperature	30°F-120°F	Onset Smart sensor S-THB-M002 Rotronics HC2-S Probe (WB/DB) and HygroLog HL-NT data logger	Onset: ± 0.36°F ± 3.5% RH Rotronics: ±0.8 %rh / ±0.18 F		90-120 minutes	1 minute
Airflow	300-35,000 CFM	Energy Conservatory True Flow Grid	± 7% CFM	-10% to +5% CFM	Average of 2 tests	N/A

5.3.3 Sensor Location

For all systems, air-side measurements and direct measurements of unit power will be used to estimate capacity and efficiency. Figure 2 shows schematically the locations of air-side measurements taken within the unit, outside the building, and within the served space. The laboratory testing will evaluate the accuracy of different types of sensor arrangements and adding sensors to improve accuracy and compare field to laboratory measurements. All sensors need shielding to avoid radiation from unit components such as the cooling coil influencing air temperatures.

Figure 3 shows the location of static pressure measurements used for airflow diagnostics indicating restrictions in the duct system or fouling of the evaporator coil. The return static pressure sensor will be moved from the return duct up to the evaporator inlet to provide a measurement of total static pressure. Additionally, the difference in static pressure between the outside and return plenum will be collected.

Figure 4 shows the placement of the True Flow grid and sensors used to determine system airflow.

Figure 2: Temperature, Relative Humidity, Damper Displacement, and Power Measurement Points

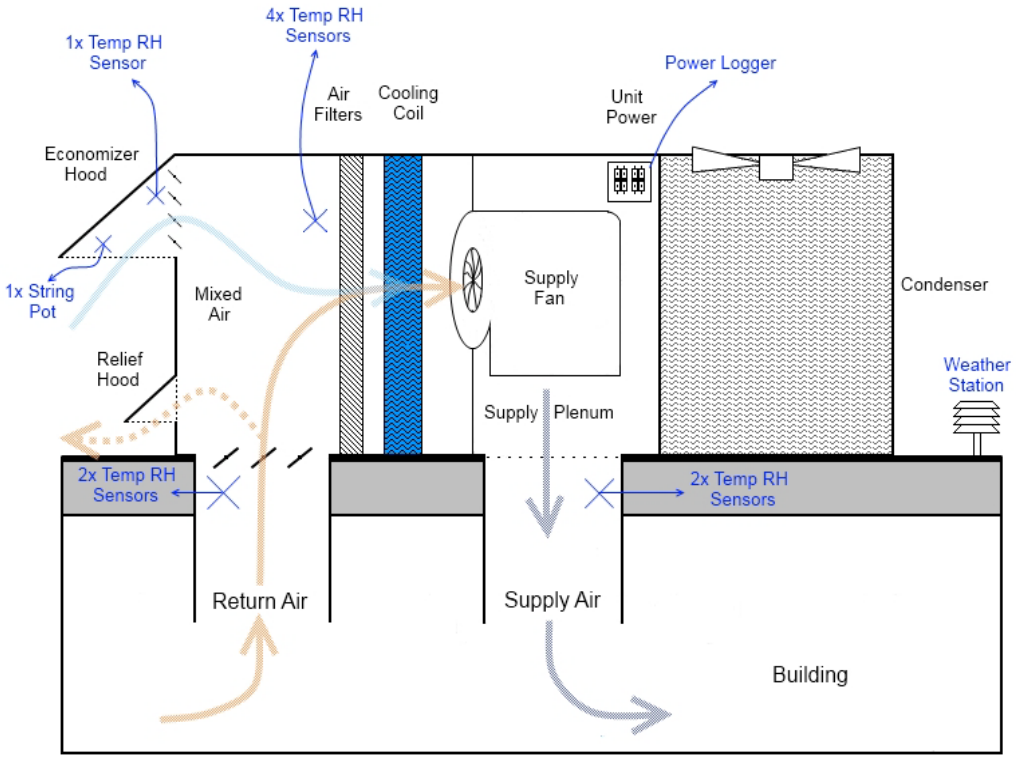


Figure 3: Static Pressure Measurement Points

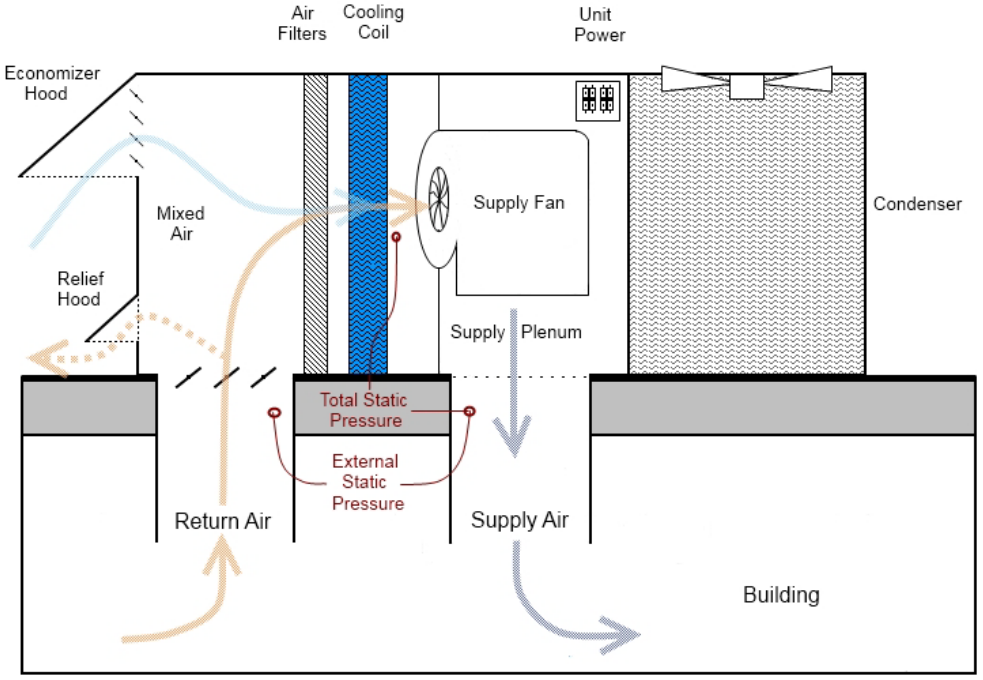
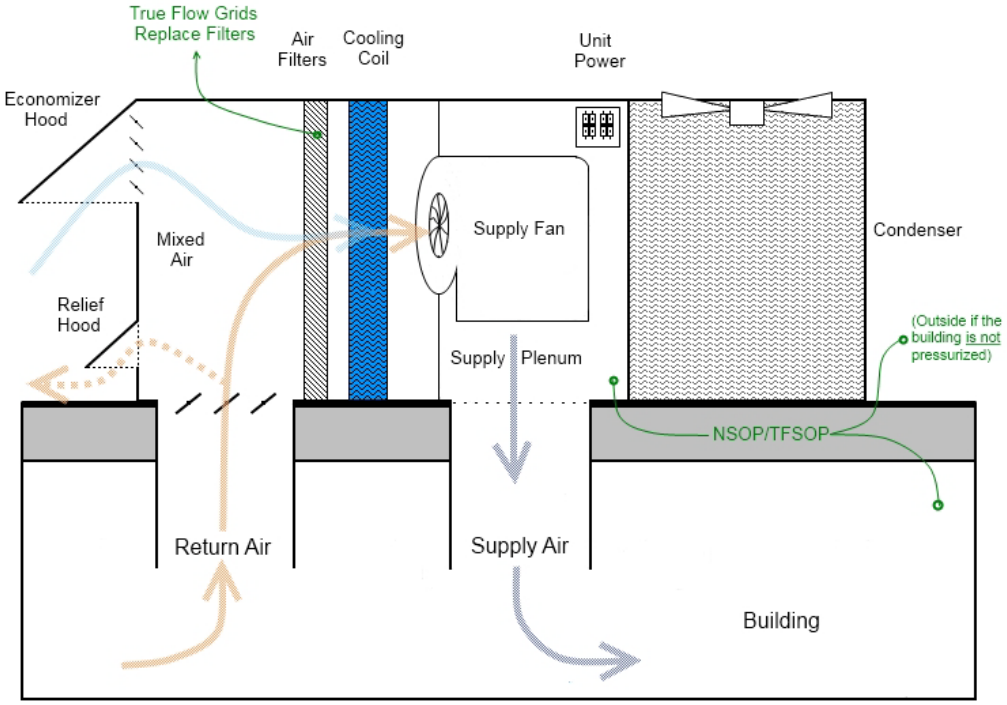


Figure 4: True Flow Measurement Points



5.4 Measure Specific Data Collection

Field data collection will acquire data associated with coil cleaning, RCA, thermostat, economizer and supply fan adjustment measure assumptions. This section documents the protocol to be followed when collected data for each of these measures.

5.4.1 Coil Cleaning (Condenser or Evaporator)

Coil cleaning is thought to save energy by reducing 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 change in air enthalpy across the coil. Dirt and debris build-up on the coil increases total static pressure, and reduces airflow and heat transfer rates. This increases the refrigerant temperature and discharge pressure of the coil. Discharge pressure can be measured on most units. A dirty coil will increase the refrigerant pressure in the entire high side of the system so even though the discharge pressure port is before the coil the pressure is still affected by the dirty coil. The compressor discharge pressure and inlet/outlet dry bulb temperature will be measured before and after coil cleaning (suction pressure and evaporator saturation temperature will be measured for evaporator coils). The discharge pressure (or discharge-to-suction pressure difference) change will be correlated to laboratory data on unit performance.

During the ride-along visit, the ambient temperature, static pressure across the coil. inlet/outlet temperatures, discharge (or suction) pressures, fan power, and total power will be measured in the "as found" condition and in the "clean" condition. The "as found" condition is the coil's condition when the technician walks on site. The "clean" condition will be achieved when the implementing technician cleans the coils during the ride-along visit. The cleaning methods will be noted such as pre-rinse and direction, water and/or chemicals used to clean the coil, dwell time, and post-rinse and direction.

If possible, the date of the most recent previous cleaning will be determined from participation records or site interviews. This will provide a dataset of heat transfer and capacity increase due to coil cleaning and length of time since previous cleaning. The ratio of as-found condenser coil cleaning measures that are sufficiently cleaned and operating at program recommended specifications divided by the total number inspected will be the basis for calculating the installation rate. Additionally, the measured ratio of as-found to faulted discharge pressure and corresponding unit performance based on laboratory tests may also be used to inform realization rate calculations on coil cleaning measures .

Only the SDG&E Direct Install Program, the SDG&E Deemed Program, and the Air Care Plus Program indicate specific coil cleaning activity during the 2013-14 program cycle. The SCE QM program may also be completing coil cleaning. It has come to light that the SDG&E coil cleaning savings may be overstated because the workpaper used is different than that used in the other programs. Savings for this program will be adjusted using the QM workpaper, and the ride-along sample may be redistributed across the IOU programs.

5.4.1.1 Coil Cleaning Pilot Testing

The pilot testing will include the following tasks.

- Coils at a few pilot sites will be cleaned in the pilot, making measurements before and after the cleaning. Discharge pressure will be measured and the following additional data may be collected in the pilot phase: fan/total power, evaporator airflow, return/supply dry bulb temperature, sensible cooling capacity, and sensible EER*s,

- The date of the previous cleaning is required to model coil degradation over time. However, the participation records may not include this information. The pilot and records review tasks will determine if the date is available directly through a data request or if the date should be determined through other means such as site interviews.

5.4.2 Refrigerant Charge Adjustment

The RCA measure saves energy by optimizing refrigerant charge in the unit. An optimal refrigerant charge results in energy savings compared to both an under or over charged system. The post-maintenance refrigerant charge will be determined in the field by weighing the refrigerant in the system. The pre-maintenance refrigerant charge will be determined by subtracting the refrigerant added by the program from the amount of refrigerant found on site. The identified pre-maintenance and post-maintenance charge levels will be compared to the factory charge for the unit. This method works well for package systems up to 25 tons. For very large units the procedure intended may not be cost feasible as they may require special tools and additional labor. Fortunately many very large systems have onboard diagnostics that may help identify charge levels; otherwise the team will need to develop site-specific plans based on the very large units that are in the sample, if any. The programs are dominated by package systems, but split systems must be considered as they may be included in the sample. Split systems have the addition of the refrigerant line between the evaporator and the condenser needing additional refrigerant from factory specifications. The needed refrigerant can be estimated by measuring the refrigerant line length, though this adds uncertainty, it is the approach that we will take.

This method for refrigerant charge measures was successfully demonstrated in the 2013 Pilot Study reported on in WO32 (see HVAC Impact Evaluation FINAL Report WO32 HVAC – Volume 1: Report 2015, Section 2.5 Installation Rate Based on Ex-Post Observations).

5.4.2.1 RCA Pilot Testing

The RCA pilot testing will include the following tasks.

- As-found performance tests of RCA data, fan/total power, evaporator airflow, fan/total power, return/supply dry bulb, sensible cooling capacity, sensible EER*s.
- We expect to arrive on site with the original RCA diagnostic test results and the amount of refrigerant removed or added to the system. As such, only programs that collect this information can be evaluated in the manner proposed above. The pilot task and records review will determine if this information is available from the programs performing this measure.

5.4.3 Thermostat

PG&E, SCE, and SDG&E programs installed the programmable thermostat and thermostat reprogramming measures. These measures are thought to save energy by adjusting the occupied and unoccupied thermostat set point schedules to reduce the required cooling and heating load. The as-found thermostat settings will be recorded during all site visits. Thermostat data and any overlying energy management controls will also be collected on ride-along visits to supplement the post maintenance sample. Site interviews will attempt to determine the pre-maintenance schedules and settings during post-maintenance site visits. All collected information will be compared to program records. Based on the adjustment date and the observed thermostat settings relative to program objectives, an estimate will be developed regarding the installation rate and persistence of these

measures. There will be difficulty and resulting uncertainty separating installation rate from persistence, as they may be indistinguishable to an observer at the time of the site visit.

The impact of the thermostat replacement and thermostat reprogramming measures will be determined for each IOU program implementing a thermostat measure using pre/post data regarding occupied and unoccupied thermostat schedules and settings to develop realization rates.

5.4.3.1 Thermostat Pilot Testing

The pilot testing will include the following tasks.

- As-found characteristics of thermostat and reprogramming (schedule and settings).
- We expect to arrive on site with only the thermostat adjustment date. Ideally, we would have the previous and implemented thermostat schedule information recorded by the installer. The pilot task and records review will determine if this information is available from the programs performing this measure. The pilot will determine if it is possible to determine the pre-maintenance settings during a post-maintenance site visit.

5.4.4 Economizer

This measure includes economizer repairs and may include an economizer controller replacement with an advanced digital economizer controller (ADEC). The measure is thought to save 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. Economizer flow rate testing will be determined via mixed air calculations where the cooling unit (with the compressors off) mixes return and outside air to generate supply air. The condition of the various air streams provides an estimate of the outside air rate. Ideally, this test would occur if the outside air temperature is at least 20 degrees Fahrenheit different from the indoor air temperature as these conditions give lower uncertainty in airflow calculated from temperature differences. The cold spray economizer method will be utilized to check economizer functionality with outdoor dry bulb sensors and controls.

The ratio of as-found economizer measures that are installed and functional with the potential to generate savings will be the basis for the installation rate. Airflow (total system flow and outdoor air fraction), changeover setpoint and economizer control strategy, data collected will be used to determine the realization rate of *ex ante* energy impacts of economizers. If the pre-retrofit damper positions and changeover setpoint cannot be determined through program records, then that site will be eliminated from the sampling population for the economizer measure. If baseline data is missing for a whole program then average baseline data from the other programs will be applied.

5.4.4.1 Economizer Pilot Testing

The economizer pilot testing will include the following tasks.

- As-found characteristics of economizer repairs (functionality), digital economizer controller/sensors (functionality), fan-speed controls (speed, performance, controls), and demand control ventilation (minimum and maximum damper position and OA fraction).
- We expect to arrive on site knowing what repairs were made to the economizer by the program (i.e., replace actuator, controller/sensor, renovate linkage, integrate economizer wiring, install ADEC). The program data typically includes pre/post economizer changeover information (i.e., adjust economizer change-over from C-60 or D-55 to A-75 or B-65). Ideally, we will also know the

condition the economizer was in before maintenance. The pilot task and records review will determine if this information is available from the programs performing this measure. If this information is not available, this will be reported and may limit the evaluation of the measure.

- Interviews with building facilities managers or implementation contractors or manufacturer default settings will be used to obtain pre-existing economizer information.
- The pilot task will determine the field protocol for adjusting input signals to the economizer controller to determining the unit's changeover points. We will test multiple methods during the pilot.
- The pilot will determine if typical units have intermediate economizer points between open and closed to confirm integrated controls.
- Our ability to estimate *ex post* economizer savings is contingent on the collection of accurate air flow measurements. Our strategy will be to infer outdoor air fraction from supply, return and outdoor air temperatures and the HVAC fan energy added to the airstream.

5.4.5 Unoccupied Supply Fan Control

According to workpaper PGE3PHVC157, "unoccupied supply fan control" is DEER measure D03-071, Time Clock, which includes demand, electric, and gas energy savings. While the DEER measure is for a retrofit of a time clock to schedule the supply fan in auto mode rather than an adjustment, the IOU programs assume energy savings are applicable. DEER measure D03-071 is also reported as the basis for the programmable thermostat measure. It is currently unknown what efficiency improvements are associated with the "unoccupied supply fan control" that might be different from the "thermostat reprogramming" measure. The workpaper review and interviews with program implementers will determine the actual measure theory. We expect the measure to include adjustments to the thermostat schedule that result in a reduction of heating and cooling energy (therm savings are claimed by PGE QM and AC+ programs). Post-maintenance site visits will determine the actual thermostat (and unoccupied supply fan) operating sequence through interviews with facility personal and tests on the equipment. The pre-maintenance condition will be determined through either program records or interviews with facility managers.

Energy savings impacts of unoccupied supply fan control (thermostat reprogramming) will be calculated using pre-existing and post-program thermostat (and supply fan) schedules. If the pre-retrofit schedule cannot be determined then a baseline assumption consistent with measure workpapers will be used. The ratio of as-found unoccupied supply fan controllers that have evidence of having been reprogrammed or replaced according to program specifications divided by the total number inspected will be the basis for calculating the installation rate. Schedule and setpoint data used in engineering analysis or simulation modeling (methodology guided by workpapers) will inform the realization rate to determine energy impacts.

5.4.5.1 Supply Fan Control Pilot Testing

The supply fan control pilot testing will test the following tasks.

- As-found thermostat schedule with and without reprogramming will be collected to inform the baseline.
- Prior to starting the pilot, we will determine the measure theory through the workpaper review task. The actual measure theory may result in protocol adjustments for the pilot.

- We expect to arrive on site knowing what the installed condition is expected to be. Ideally, we will also know the baseline condition. The pilot task and records review will determine if this information is available from the programs performing this measure.
- The pilot task will determine what information can be gathered for this measure through site interviews.

5.5 Analysis

Impact analysis can have two components: calculation of installation rate and calculation of realization rate. Installation rate is determined by the portion of claimed installations that, upon verification, are found to have been actually installed. The realization rate is the ratio of installed measure savings to the corresponding *ex ante* savings. When a measure is not installed, the realization rate cannot be determined. Installation rate is applied to the number of claims, whereas realization rate is applied to the gross savings. This evaluation will attempt to calculate both rates for the measures in the M&V Measure Specific Data Collection Section 5.4: RCA, coil cleaning, economizer repair, thermostat replacement, and supply fan control. However, low installation rate reduces the sample size on which to calculate realization rate, thus reducing precision.

Because measure savings vary across building type and climate zone (which affect HVAC load), and have wide variation of impact depending on the condition of the HVAC unit (i.e. a thermostat saves more if the unit is operating at non-peak performance), a very large sample is required to capture the range of savings variation from HVAC QM-type measures. Some have suggested using billing analysis or end-use metering to satisfy large sample size at minimal cost. This was attempted in the 2010-12 QM impact evaluation, but difficulties were encountered as noted in the report. As a way to maximize the value of the evaluation effort, DNV GL recommends using the collected measure data to refine the inputs to the *ex ante* workpapers, and run the required DEER prototype building models in eQuest to determine savings.

The measure sample across all programs will be used to determine impact in each IOU territory unless there is a significant difference in how the measure is implemented by the program. (For example, when RCA is implemented using different diagnostic protocols, field evaluation determined that the results were different.) For each program, the distribution of treated HVAC system size and type will be compared to verify that programs have no significant differences in this respect. Similarly, participant building type and vintage distributions will be developed to determine any differences in building stock between programs.

In almost all cases, the tracking data claims savings on an individual measure level so the savings will be rolled up to program level based on weighting in the sampling strata. For the two notable exceptions: SCE's "quality maintenance" measure and PGE's "EE tasks" measure, which both contain a mix of measures, the distribution of individual measures making up the set will be determined from program records. "EE Tasks" will only be evaluated if it is found to contain measures that are assessed through this effort. Results of the data collection effort described in section 5.4 will be applied (where appropriate) to the measures making up these composite measures and rolled into the composite measure savings using the workpaper described methods. *Ex ante* savings for any component measures not included in section 5.4 data collection activities will be passed through to the composite measure "roll-up" savings.

The net savings estimates will be informed not only by the impact realization rate, but also by market actor interviews and surveys as described in the NTG section of this plan (2.3.2). All data developed from the analysis will be provided to the DEER team for use in their updates.

6 QUALITY CONTROL (QC) AND REVIEW

DNV GL considers project management to be the process of meeting established goals regarding technical scope, schedule, and budget by managing risks, uncertainties, expectations, constraints, and resources in the planning and execution of sponsored contract work. QC for projects in each of these areas is an essential goal in all of our project management policies and practices. To ensure that each task and project is completed within budget, on time, and meeting the required scope, DNV GL uses project management techniques, tools and controls based on the Project Management Body of Knowledge, as published by the Project Management Institute (PMI).

This section documents the project's anticipated quality control steps.

6.1 Pilot Task

The entire pilot task is a quality control element. In the pilot phase, the EM&V section of the plan will be scrutinized to confirm that all the necessary field data is collected for the analysis. The M&V Plan will be revised as a separate deliverable to the CPUC before the main field data collection task begins. The revised Plan will detail the analysis methodology, including how each measurement collected in the field will inform the impact analysis. The Plan will also include an uncertainty discussion.

Experienced field staff will perform these tests, paying particular attention to developing and testing on-site field protocols for clarity and completeness of instructions. Field staff will also focus closely on the data-collection instrument, again checking for clarity and completeness of the form. Their observations will be reviewed, and necessary protocol and data collection form adjustments will be made. All adjustments will be communicated to all evaluation field staff. The data collected during the pilot task will be reviewed and analyzed prior to full project implementation. Review and analysis of pilot data prevents systematic errors from occurring during full implementation.

6.2 Data Collection

6.2.1 Recruiting

During recruiting, the evaluation team will confirm that names, addresses, phone numbers, program participation status, equipment size and replacement date (if any) match tracking data for participants. Recruiters will confirm driving instructions, check for access codes for security gates (including roof hatch and ladder locks), and gather any other information that will help prevent late arrivals and ensure more on-site quality time. Essentially, recruiters will confirm that this site has received maintenance and that reaching the site will proceed as expected.

6.2.2 On-Site

During site visits, field staff will perform power measurements, temperature monitoring, refrigerant and airflow tests using methods determined during the pilot.

While conducting spot power and refrigerant charge tests, one team member will perform the tests while the other team member observes technique, records results, and reads results back for confirmation. Both staff members will be fully trained in, and in compliance with, all applicable DNV GL safety policies.

Field staff will take photographs of the building exterior, the True Flow grid installation, HVAC compressor unit nameplates, air handling unit (AHU) nameplates, supply fan nameplates, and all unusual situations. These photos will help resolve any post-visit issues.

Field staff will be encouraged and expected to consult with senior technical advisors immediately whenever unexpected, unusual, or potentially dangerous situations arise.

6.2.3 Post Visit

After the site visit, one member of each team will transcribe the results and observations into digital form. The other team member will then review the transcription for accuracy and completeness.

6.3 Analysis

After the results have been transcribed and reviewed by the field team, the analysis team will perform the following quality control activities:

- Review HVAC airflow data to ensure that they are within range of nominal airflow values.
- Review supply fan and condensing-unit spot power measurements.
- For airflow, and power consumption, investigate any outliers. Outliers will be investigated through photographs, field notes, and field staff interviews.
- Verify that refrigerant pressure and temperature measurements were properly labeled and recorded and are consistent with the corresponding air-side temperature and relative humidity values.

As WO32 found that batch analysis poses challenges due to unique situations at each site, a different analysis approach will be taken in this impact evaluation. The data collected on site will be aggregated and inputs developed for DEER prototype building simulation models to evaluate each top measure in each program. Instead of modeling each site, one set of prototypes will be run for each California climate zone in each IOU program. The workpapers for the QM programs use a similar, but more complex methodology to develop savings so the evaluation will also serve to assess the workpaper assumptions on model input values where possible.

7 TIMELINE OF PROJECT ACTIVITIES

Figure 5 and Figure 6 show the preliminary estimated date ranges for high-level project activities. This timeline is based on the ESPI decision requirement for interim reporting in February 2015. Year 1 data collection efforts will occur prior to the interim report. Because the research plan has been delayed, the volume of work that can be completed in Year 1 is smaller than expected, and we are in discussion with the *ex ante* team around this issue. Because some tests are sensitive to ambient conditions, not all types of data collection can occur in the Year 1 timeframe. Year 2 will include data collection activities required during the cooling season.

Year 1 preliminary results based workpaper review and tracking data review will be delivered to the HVAC PCG mid-February 2015 assuming the research plan is approved by the end of January 2015. An interim report based on workpaper review, program data review, and results from some ride-along observations will be drafted by late-February, 2015. This draft report will be made available to the CPUC and their consultants for comments and suggestions and will be revised as needed. Following this, the draft report will be submitted to the IOUs for their comments and again revised as needed. Finally it will go through a comment period for members of the Western HVAC Performance Alliance and public review followed by the final round of revisions. Each comment period will last for two weeks. ED consultants will join the evaluation team in reviewing comments and shaping the report throughout the analysis, report drafting, and comment processes.

The same steps will follow completion of Year 2 data collection and will result in the delivery of the final report. These timelines were designed to meet ESPI reporting requirements and additional summary reporting may take place in 2016.

Figure 5: Year 1 Report Timeline

		2014										2015	
Task ID	Task Name	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Task 001	HVAC PCG Reporting, Admin, and QC												
Task 002	Develop QM Research Plan												
Task 003	Staff Training and Field Procedure Pilots												
Task 004	Interim Reporting												

Figure 6: Year 2 Report Timeline

		2015									
Task ID	Task Name	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Task 001	HVAC PCG Reporting, Admin, and QC										
Task 002	Develop QM Research Plan										
Task 003	Staff Training and Field Procedure Pilots										
Task 004	Interim Reporting										
Task 005	Commercial Impact										
Task 006	Net to Gross										
Task 007	Final Reporting										

7.1 Progress and Status Updates

Summaries of the project's progress will be provided monthly. Summaries will include descriptions of changes to this Research Plan and other project documentation as well as updates of the numbers of sites recruited, scheduled, and completed.

7.2 Feedback Memoranda

In addition, early feedback memos may be generated throughout the evaluation period. These will include suggestions for program improvements, feedback from Master Technician observations, and other comments about evaluation efforts.

8 WO TASK DESCRIPTIONS AND BUDGETS

8.1 Task 1: HVAC PCG Reporting, Project Administration, and QC

Under the direct supervision of DNV GL's Prime Contractor Project Sponsor and Project Manager, staff will support the Prime Contractor Project Management Team with reporting to the HVAC PCG, general project administration, and QC of all tasks and deliverables:

- Provide regular status updates for the HVAC PCG and the Project Status Reporting (PSR) website
- Create invoices, progress reports, subcontracts, and perform project budget control
- Ensure adherence to quality standards of all analysis and reporting
- Provide technical writing support

8.2 Task 2: Develop Research Plan

Under the direct supervision of the Prime Contractor Project Manager, staff will support the Prime Contractor Project Management Team with evaluation planning, general start-up activities, and administration including, but not limited to:

- Attending project kick-off meeting with ED staff and other ED contractors
- Developing detailed HVAC Research Plan and leveraging 2010-12 residential QM procedures where possible (current document)
- Performing tasks involved in the development and management of the research plan and future WOs, including review and comment by the IOU's and stakeholders

The present document is the overall HVAC Research Plan. This plan will continue to be reviewed and evolve over time as new program tracking data and proposed data to support the workpaper *ex ante* review response becomes available, as well as when pilot findings become available. A detailed M&V plan document will be developed to supplement this plan at the conclusion of the pilot test phase (Task 3) below. At a minimum, this plan will be thoroughly reviewed and updated annually as program tracking data and relevant pilot or other research (for example, laboratory results) findings become available.

This plan has been developed using the guidelines presented in the WO and identifies specific deliverables with their respective milestone schedules.

8.3 Task 3: Field Procedure Pilot and Staff Training

There will be a deliverable from this task, which is a detailed M&V Plan that expands and revises Section 5 of this research plan. The revised M&V plan will take into account findings from review of implementer data, detailed workpaper review, and results of pilot testing to flesh out details of exactly which measurements will be recorded during the field data collection, and exactly how those measurements will be used in the analysis.

DNV GL requires that all employees complete a JSEA prior to undertaking fieldwork (Section 5.3.1). This will be standard procedure on this project as well. The JSEA will document the field task procedure, risk mitigation strategies, required tools and PPE, and any required authorizations, permits,

or forms. Whenever live electrical work is required, such as spot power measurements, a DNV GL QEW will perform the task.

8.3.1 Task 3.1: Field Procedure Pilot

The pilot will investigate innovative field techniques including those that can be used in post-only applications to re-create pre-measure-installation HVAC conditions. The previous round of evaluation experience considerable difficulty with pre/post visit scheduling so DNV GL proposes to investigate M&V methods requiring only a post retrofit visit. The following procedures will be explored in the pilot:

- Refrigerant adjustment to pre-condition by reversing what was done in measure installation if information is adequate. Optimal condition achieved at visit completion by weighing in manufacturer's recommended charge. Efficiency is measured at each condition.
- Investigate sensor configurations to measure mixed-air temperature and relative humidity more accurately.
- Investigate economizer control strategy, minimum setting airflow, maximum setting airflow, and changeover setpoint. Recreate baseline using contractor records and measure outdoor airflow. Note baseline operation.
- Develop and test analytical procedures on the pilot test sites to demonstrate the viability of the analytical approach and refine data collection protocols.

Partial results from the pilot have been reported in the interim ESPI report.

8.3.2 Task 3.2 Staff Training

Once the project pilot is complete and the protocol and data-collection form have been finalized, field staff will be scheduled and trained. Training will include a comprehensive review of the protocol and the data-collection instrument. The field staff performed non-residential QM site visits for WO32 in 2013 and are familiar with the procedures and equipment; this experience will provide consistency between the two studies and allow the use of WO32 non-participant data to supplement the non-participant data collected specifically for this evaluation.

8.4 Task 4: Interim Report

Preliminary results from workpaper review, tracking data review, and possibly some ride-along observations will be presented as well as RCA and economizer savings found at pilot sites where commercial HVAC data is collected during 2014 and early 2015. Savings will be preliminary and based on a per-unit and per-site basis instead of a program-based approach. These results and program assessments will be summarized and a written report will be produced for review by the CPUC ED, the IOUs, Commission Consultants, and the *Ex Ante* Review Team.

8.5 Task 5: Commercial QM Program Impact Assessment

All data collection and analysis activities discussed in Section 5 (M&V Plan) will be completed under this task except for the pilot site visits. All sampling activities required for the gross impact evaluation will also be completed under this task.

8.5.1 Site Visits

Site visits and associated field M&V will be completed 55 post-maintenance participants for this evaluation. An additional 45 participants will be visited through ride-along visits. If 2015 funding is

allocated to this task then 30 (or more) unique pre-maintenance participant site visits will additionally be completed.

8.5.2 Data Analysis

The evaluation team will produce analysis results to represent the 2013-14 *ex post* savings based on engineering and simulation analysis drawn from the *ex ante* workpapers. The team will then work with the PCG to define other analyses to inform future *ex ante* and DEER assumptions. The team will meet with the PCG on a regular basis to continue discussions around the form of future savings estimates and work to ensure the evaluation provides feedback on program performance.

8.6 Task 6: Net to Gross

DNV GL will facilitate CPUC advisor discussions focused on determining the QM program NTG methodology. DNV GL expects the process of developing a methodology to require extensive review due to the difficulties combining customer and contractor survey information. Once the methodology is approved, DNV GL will proceed with survey design and execution. All sampling activities required for the NTG data collection will also be completed under this task Program net *ex post* savings will be determined from the results of this task.

8.7 Task 7: Final Reporting

The analytic findings will be assembled into a Draft Final Report that will be circulated for comment among the stakeholders. A Final Report will be prepared after the comments are received and reviewed. DNV GL will work with the CPUC to develop a review process that balances the need to give reviews adequate review time against the need to finalize the report in a timely manner.

8.8 Project Budget

The evaluation has a two-year budget of $1,500,000. See Section 8.9 for an estimate of costs per site for data collection. Estimated expenses and budget are listed by high-level task in Table 20 and staff billing rates are shown in Table 21. Due to the overlapping of tasks and collaboration with other WOs, subtasks will have budget amounts listed if there are distinct expenses independent from other tasks or cross-cutting and collaborative efforts.

The first year will focus on developing a research plan, assessing the QM programs across the IOUs, performing pilot sites, beginning ride-along observation visits and delivering a preliminary analysis and report. The second year efforts will include completion of ride-along observations, pre-maintenance commercial site (if 2015 funding is added), post-maintenance commercial site visits, a full analysis of all collected data, and the release of the final report.

The budget presented here is still under CPUC review, and subject to change.

Table 20: Project Budget by Task

Task	Budget
Task 1: HVAC PCG Reporting, Project Administration, and QC	$115,000
Task 2: Develop Research Plan	$160,000
Task 3: Staff Training and Field Procedure Pilot	$290,000
Task 4: Interim Report	$90,000
Task 5: Commercial QM Program Impact Assessment	$610,000
Task 6: NTG Analysis	$140,000
Task 7: Final Report	$150,000
Total	**$1,555,000**

8.9 Costs

The labor and recruiting estimates used to develop this research budget will be reviewed against pilot actual costs, noting that significant additional time has been allocated for pilot sites to test the data collection methods, see Table 21 for pilot site costs. If the actual costs differ significantly from estimates, considerations will be made to decrease or increase overall sample sizes.

Due to the cost and difficulty of pre-post metering, pre-maintenance and post-maintenance methods are developed as part of this plan. The expected cost of these visits are laid out in Table 22 and Table 23, and include travel and labor expenses for a two-person team to spend one day at each site. The total of 35 hours per visit (38 for pre-only due to increased recruiting costs) includes scheduling, site time, travel, follow-up data transcription and management support. Pre-Post Monitoring site visit costs are shown in Table 25 for reference.

The plan also calls for ride-along visits. The costs for these visits are shown in Table 24, and include travel and labor expenses for a master technician to spend three hours at each site. The total of nine hours per ride-along includes scheduling, site time, travel, follow-up data transcription and management support.

For all types of visits, direct expenses include airfare, lodging, meals, vehicle rentals, and incentives. Both program participants and pre-program participants will receive site visits in this evaluation.

Table 21: Commercial QM Pilot Per-Site Cost Estimates

Cost	Hours/ Site	Cost/ Site	Notes
Field Labor, $125/hour, each	39	$4,875	Assumes 3 people on site for 1 day and 5 hrs of travel per person
Management support, $180/hour	8	$1,440	Support while team is in field
Direct Expenses	-	$1,350	Travel, lodging, meals, rentals, incentive
Participant Recruiting, $142/hour	3	$426	
Analysis, $142/hr	8	$1,136	Custom analysis at each site
Site Total	**58**	**$9,227**	

Table 22: Commercial QM Pre-Maintenance Per-Site Cost Estimates

Cost	Hours/ Site	Cost/ Site	Notes
Field Labor, $125/hour, each	22	$2,750	Assumes 2 people on site for 1 day and 3 hours of travel per person
Management support, $180/hour	8	$1,440	Support while team is in field
Direct Expenses	-	$750	Travel, lodging, meals, rentals, incentive
Participant Recruiting, $142/hour	6	$852	
Analysis, $142/hr	2	$284	Data processing to feed to lab and engineering analysis
Site Total	**38**	**$6,076**	

Table 23: Commercial QM Post-Maintenance Per-Site Cost Estimates

Cost	Hours/ Site	Cost/ Site	Notes
Field Labor, $125/hour, each	22	$2,750	Assumes 2 people on site for 1 day and 3 hours of travel per person
Management support, $180/hour	8	$1,440	Support while team is in field
Direct Expenses	-	$750	Travel, lodging, meals, rentals, incentive
Participant Recruiting, $142/hour	3	$426	
Analysis, $142/hr	2	$284	Data processing to transmit to lab and engineering analysis
Site Total	**35**	**$5,650**	

Table 24: Commercial QM Ride-Along Per-Site Cost Estimates

Cost	Hours/ Site	Cost/ Site	Notes
Field Labor, $110/hour	4	$440	Assumes 1 Master Tech or Sr. Eng. on site for 3 hours plus travel
Management support, $180/hour	2	$360	Support while team is in field
Direct Expenses	-	$500	Travel, lodging, meals, rentals
Participant Recruiting, $142/hour	3	$425	
Site Total	**9**	**$1,725**	

Table 25: Commercial QM Pre-Post Monitoring Per-Site Cost Estimates

Cost	Hours/ Site	Cost/ Site	Notes
Field Labor, $125/hour, each	50	$6,250	Assumes 3 people on site for 1.5 days and 5 hrs of travel per person
Management support, $180/hour	10	$1,800	Support while team is in field
Direct Expenses	-	$1,350	Travel, lodging, meals, rentals, incentive
Participant Recruiting, $142/hour	3	$426	
Analysis, $142/hr	8	$1,136	Custom analysis at each site
Site Total	**71**	**$10,962**	

9 PROJECT CONTACT LIST

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10 ACRONYMS AND ABBREVIATIONS

AC	air conditioning
ACCI	Air Conditioning Contractors of America
AHU	air handling unit
AMI	advanced metering infrastructure
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
C&I	Commercial and Industrial
CPUC	California Public Utilities Commission
CQM	commercial quality maintenance
CZ	climate zone
DEER	Database for Energy Efficiency Resources
DI	direct install
DOE	Department of Energy
E-Quest	E-Quest building modeling software
EER	Energy efficiency ratio
EE Task	Energy efficiency task
EMI	Energy Management Institute
EMS	Energy management system
ESPI	Energy savings performance index
EUL	effective useful life
ex ante	before the program evaluation
ex post	after the program evaluation
FCM	forward capacity market
HTSDA	HVAC Technology Systems and Diagnostics Advocacy
HVAC	heating, ventilation and air conditioning
IOU	investor-owned utility
JSEA	Job Safety and Environmental Analysis
kW	kilowatt
kWh	kilowatt hour
M&V	measurement & verification
MBSS	model-based statistical sampling
NFPA	National Fire Protection Association
NTG	net-to-gross

OSHA	Occupational Safety and Health Administration
PCG	Project Coordination Group
PECI	Portland Energy Conservation, Inc.
PG&E	Pacific Gas & Electric
PMI	Project Management Institute
PPE	personal protective equipment
PRISM	Princeton Scorekeeping Method
PTAC	packaged terminal air conditioning
PTHP	packaged terminal heat pump
PSR	Project Status Reporting
QC	Quality control
QEW	Qualified Electrical Worker
QI	quality installation
QM	quality maintenance
R-value	Resistance to heat transfer
RCA	Refrigerant charge adjustment
RH	Relative humidity
RUL	remaining useful life
SCE	Southern California Edison
SCFM	Cubic Feet per Minute at Standard Conditions
SDG&E	San Diego Gas & Electric
therms	A unit of heat equivalent to 100,000 British thermal units
TXV	Thermal Expansion Valve
UES	unit energy savings
WO	work order

APPENDIX A. WORK ORDER 032 (WO32) UNCERTAINTIES

This Appendix is the Evaluation Methodology chapter of Impact Evaluation Research Plan WO032—Residential and Small Commercial heating, ventilation and air conditioning (HVAC).

APPENDIX B. ADDITIONAL RESEARCH OPPORTUNITIES

This is the third HVAC program evaluation cycle completed by DNV GL. The activities below represent additional analysis that could be conducting using the data collected during this evaluation and previously collected data. None of the activities are budgeted for at this time.

- Analyze data already collected during non-residential fan-only operation mode to look at economizer operation and determine the quantity of energy gained during economizer operation (damper position "open") and lost due to ventilation load when the economizer position is set at "closed" or minimum position. We could compare this to the required ventilation to see the energy penalty of incorrectly set minimum position.
- Install data loggers to evaluate "supply-fan control" integrated with variable speed fan controller, digital economizer controller, EMS software, and FDD.[19] The website claims cooling and heating energy savings ranging from 25 to 50%.[20] We could compare the performance of this product on two or more identical (make and model) units serving similar spaces with similar schedules. We could also implement an on/off test; enabling and disabling the controller on a two week on/two week off sequence.
- Install data loggers to evaluate digital economizer controller with optimal economizer damper position, sensors, and changeover settings. Laboratory tests indicate this measure could save 3 to 20% on cooling (likely to also save on heating). We could compare the performance of this product on two or more identical (make and model) units serving similar spaces with similar schedules.
- Analyze pre-retrofit data with a mix of HVAC faults to look at the baseline variability in performance of non-residential HVAC systems in the population.
- Perform uncertainty analysis on field-collected data to see if it's reasonable to do lab-like tests in the field. If so then perform case studies on field-tested units that have the same make and model as lab-tested units. Use lab data to predict capacities and efficiencies of field-tested units to see how the prediction compares to measurements on real systems. The evaluation team can normalize the curves by dividing nominal efficiency by capacity and develop a factor that can be used to adjust the nominal efficiency and capacity of program-participant equipment for fault conditions, pre and post retrofit.
- The *ex ante* savings assume a single measure in isolation, but in reality there are multiple measures being installed on a given unit. We have conducted laboratory tests of units with multiple faults and are comparing test results regarding load impacts and FDD. We could evaluate the savings uncertainty for each *ex ante* measure and provide "scenarios" which include multiple measures. We would then develop distributions of typical HVAC faults in various strata and run a Monte Carlo simulation for each unit in a given stratum to determine the expected pre- and post-service capacity and efficiency as determined from the claimed program activities. This differs from the IOU expected-value approach because the measure savings are not summed, but rather considered in the aggregate, and the uncertainty in measure performance due to pre-existing conditions and measure combinations is addressed. After looking at the results, assuming the system fault diagnosis was correct, we can look at potential faulty diagnoses.

[19] https://www.premiumcooling.com/commservices/
[20] http://transformativewave.com/catalyst

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