Uncertainties in Achieving Energy Savings from HVAC Maintenance Measures in the Field

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ABSTRACT

HVAC maintenance measures in residential and small commercial buildings have been demonstrated in the laboratory to have the potential to save a significant amount of energy. This significant potential for savings has prompted utilities across the nation to include HVAC maintenance measures in energy efficiency programs. This is currently seen as the cutting edge of utility HVAC programs. However, evaluation, measurement and verification (EM&V) studies of these programs have shown mixed results. This paper presents analysis of the sources of uncertainty in delivering and measuring these programs. The gaps that can account for the discrepancy between the potential and the measured savings are described. By identifying the range of issues, program planners can address as many as possible of the potential sources of uncertainty.

Measurement issues are of particular focus. An analysis is done of the uncertainties in the measurements of common variables as measured in the laboratory, by EM&V teams, by participants in maintenance programs, and by typical contractors. These uncertainties were combined to identify the resulting uncertainty in the calculated subcooling, superheat, EER values and annual kWh. The remainder of this paper presents recommendations for improving maintenance measures, based upon the uncertainties identified.

INTRODUCTION

Maintenance measures have a significant potential for energy savings in residential and commercial unitary HVAC systems, prompting utilities across the nation to include HVAC maintenance measures in energy efficiency programs. With encouragement from the *California Long Term Energy Efficiency Strategic Plan* (CPUC 2007), California investor owned utilities (IOUs) have been embarking on an extensive program of incenting maintenance measures through rebates. These programs include measures such as refrigerant charge adjustment (RCA), airflow adjustment, duct leakage testing and sealing. Other proposed measures include condenser and evaporator coil cleaning, economizer retro-commissioning, and HVAC controls. The programs involved contractors and their technicians who do the maintenance work, Verification Service Providers (VSPs) who develop protocols and verify that the work is done correctly (note that the current round of programs is not using VSPs), and Evaluation, Measurement and Verification (EM&V) contractors who verify that expected savings are realized. This is currently seen in California as the cutting edge of utility HVAC programs.

HVAC maintenance measures have been demonstrated in the laboratory to have the potential to save a significant amount of energy. For example, Mowris et al. 2012 shows that by combining charge adjustment, airflow improvement, duct sealing, and elimination of non-condensables, over 30% of HVAC energy use can be saved.

However, EM&V studies of these programs have shown mixed and sometimes disappointing results. KEMA 2010 shows that savings range from greater than expected to much less than expected. While

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EM&V teams acknowledge significant unmet challenges in measuring the savings from this type of program, there is clearly a gap between potential and reality.

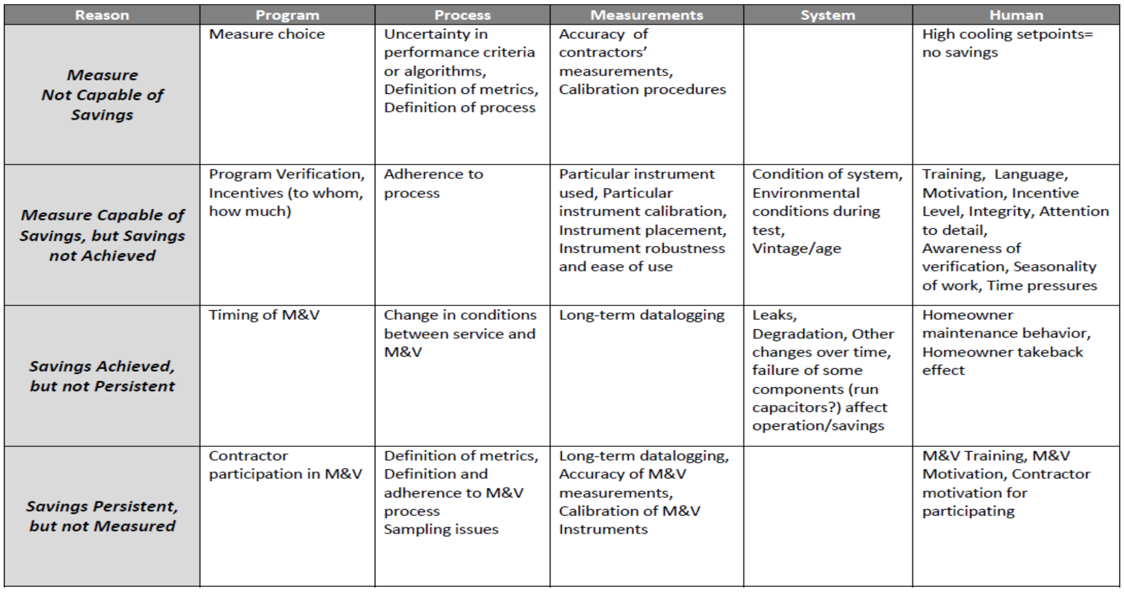
What is the source of this gap? There are multiple sources of uncertainty in maintenance measures that result in savings found in the field differing from savings found in the lab. This paper describes a study conducted to analyze these sources of uncertainty (Hunt et al, 2010). These sources include programmatic, process, measurement, system, and human factors. The gaps that can account for the discrepancy between the expected and the measured savings are described. These issues are presented in the following categories: factors that affect potential for savings from the measure, factors that affect the delivery of the savings in the field, factors that affect the persistence of savings in the field, and factors that affect the potential to measure the realized savings. By identifying the range of issues, program planners can address the potential sources of uncertainty.

Measurement issues were of particular focus. An analysis was done of the stated uncertainties in the measurements of common variables (such as dry bulb temperature, wet bulb temperature, refrigerant line temperatures, refrigerant pressures, airflow, and power) as measured in the laboratory, by EM&V teams, by participants in maintenance programs, and by typical contractors. These stated uncertainties were combined to identify the resulting uncertainty in the calculated subcooling, superheat, EER, and annual kWh values.

UNCERTAINTIES IN MAINTENANCE MEASURES

Uncertainties in maintenance measures go far beyond the inaccuracies in measurements. They include a host of factors including programmatic, process, instrumentation, system, and human factors. Table 1 shows a number of the factors that come into play in maintenance measures and the programs that provide them. What are the factors that can jeopardize savings in maintenance measures? They are described in the next few sections.

Table 1: Sources of Uncertainty in Maintenance Measures and Programs



Reason	Program	Process	Measurements	System	Human
Measure Not Capable of Savings	Measure choice	Uncertainty in performance criteria or algorithms, Definition of metrics, Definition of process	Accuracy of contractors' measurements, Calibration procedures		High cooling setpoints= no savings
Measure Capable of Savings, but Savings not Achieved	Program Verification, Incentives (to whom, how much)	Adherence to process	Particular instrument used, Particular instrument calibration, Instrument placement, Instrument robustness and ease of use	Condition of system, Environmental conditions during test, Vintage/age	Training, Language, Motivation, Incentive Level, Integrity, Attention to detail, Awareness of verification, Seasonality of work, Time pressures
Savings Achieved, but not Persistent	Timing of M&V	Change in conditions between service and M&V	Long-term datalogging	Leaks, Degradation, Other changes over time, failure of some components (run capacitors?) affect operation/savings	Homeowner maintenance behavior, Homeowner takeback effect
Savings Persistent, but not Measured	Contractor participation in M&V	Definition of metrics, Definition and adherence to M&V process Sampling issues	Long-term datalogging, Accuracy of M&V measurements, Calibration of M&V Instruments		M&V Training, M&V Motivation, Contractor motivation for participating

Human Factors

While HVAC maintenance is primarily a technical service, the service is provided by people who work for other people, and is performed for people who own and occupy the building--all of whom may behave in ways that help or hurt the success of the program.

Technicians: A maintenance measure is only effective if technicians have the tools, skills and training to implement it properly. While the maintenance tasks themselves may be quite simple to accomplish, the technician will need to exercise significant judgment in evaluating the data and the condition of the system, and deciding whether it makes sense to proceed with maintenance, which tasks to perform, and how to perform them and verify the effectiveness. Technicians need to have practical training that prepares them for the diagnostic and remediation tasks they must perform. Even when the maintenance measures are achievable in the lab by someone with a typical technician's skill set, actually achieving savings in the field is primarily in the hands of the technicians performing the work, using procedures provided and enforced by their employers. That is, assuming the technician can do the work, the question becomes whether they *will* do the work properly. The likelihood of high-quality work is affected by several factors including whether or not the technician understands and follows the specified processes and whether the technician has calibrated his/her instruments.

Contractors: Even when technicians are well trained and capable, however, they may not be given enough time to complete the necessary tasks at the job site because their employer (the contractor) has scheduled them to complete a certain number of service calls per day. The contractor's business model can be a limiting factor in the potential for savings. Activities that support changes in the contractor business model will help in this regard—e.g., by encouraging customer demand and willingness to pay for quality maintenance, reducing customer call-backs, and increasing the perceived value related to this type of service.

Building Owners: Building owners have a significant impact on the savings, by choosing to perform (or not) more comprehensive routine maintenance, and could make more informed decision with a basic knowledge of system maintenance requirements.

Occupants: Other behavioral challenges can be harder to overcome. Occupants will often "take back" a fraction of the savings from a measure by increasing their comfort level (and HVAC energy use) once the system is operating more efficiently.

State of an Air Conditioning System

The specific air conditioning system being serviced affects the estimated and measured energy savings, and their persistence. The range of savings from one unit to another can vary by an order of magnitude due to the mechanical status of each unit, the sizing and loads imposed on the unit, and, especially in residential applications, the behavior of the occupant. Maintenance programs must walk a fine line between a mass-market approach that is easily managed, and a specialized approach that addresses each individual system on a custom basis. The development of a measure that is a probabilistic package (menu) of technician quality maintenance (QM) activities or treatments shows promise.

If multiple faults are present, any single adjustment alone, such as a standard refrigerant charge adjustment process, has a limited potential for savings. Given the likelihood of multiple faults and their impact on the potential for savings, a standard procedure or protocol is needed to support the technician diagnostic efforts. If a unit and its duct system were badly designed or installed, then HVAC maintenance measures are likely to be more effective than assumed. A common residential system problem is ducts that are too small for the required airflow. Ducts with disconnects and other major, visible leaks can be fixed first because they are the dominant cause of system inefficiency. If ducts are inaccessible, then they cannot be adequately sealed using methods that most contractors would employ. If an air conditioner's design or installation leaves little room for accessing a (dirty) evaporator coil, the technician can optimize the charge of the system and savings can occur, although they will not be as great as if the underlying problem were addressed. If there is a leak in the refrigerant line, then simply adding charge will not address the problem and the low charge fault will reoccur. More research needs to be done to establish the likelihood of multiple faults and remediation techniques.

Diagnostic and Remediation Process Uncertainties

Even with high-quality instruments, the process used to take measurements and adjust air conditioning systems will determine whether or not savings can be achieved. This process must be effective, efficient, well-defined, clearly specified, and well-carried out.

The definition of a measure and the process used to implement that measure have a huge impact on the potential to save energy. For example, coil cleaning is a common practice but was not required by most past programs and, therefore, contractors did not receive an incentive for implementing it—so it was often neglected. The cost of cleaning a severely fouled evaporator coil can be prohibitive in cases where it is in a confined space and is not equipped with an access panel, yet some would say that it is a necessary part of the Air Conditioner Contractors of America Quality Maintenance standards, Standard 4 and Standard 180 (ACCA, 2008; ASHRAE, 2008).

MEASUREMENT UNCERTAINTY

The measurements that are taken during air conditioning maintenance are critical to saving energy because they dictate the remediation steps that should be taken. The accuracy of instrumentation required by the 2006-2008 California IOU program specifications (AEC, 2004) has been reexamined and there is a general consensus that some of the specifications should be revised. If the required specifications are inadequate, then the contractor may be unable to service the system effectively. Highly accurate instruments can support the technician in achieving savings, but the cost and fragility of laboratory instrumentation make them impractical for use in the field. Instrumentation sensitivity and cost must be balanced: how accurate do instruments need to be to attain the desired level of confidence, and what is the most cost-effective way to reach this precision? Advances in digital instrumentation such as digital refrigerant pressure gauges with 1% accuracy instead of the 3% achieved with analog dial gauges are making it possible to require improved accuracy—whether or not this is warranted has not been established.

Instrumentation is the first root of uncertainty of measurement. When considering specifying an instrument to measure a physical property, the instrument's accuracy must be taken into account in the reported reading. Commonly used instruments can vary in their levels of accuracy. Higher accuracy units are not in wide use because they cost more, are often more fragile, and must be sent off to be calibrated. Calibration errors add a second layer of uncertainty in measurement, which can only be addressed by implementing a consistent and regular calibration protocol. The current California refrigerant charge and airflow protocol (AEC 2004) calls for annual or monthly recalibration of instruments. A review of accuracy and calibration requirements on an instrument-by-instrument would identify the most cost effective means of calibrating technician instruments. The third layer of uncertainty relates to how the measurement is conducted. There is a need for a detailed description of where and how sensors are to be installed, including system diagrams, installation detail drawings, and photographs—especially for temperature measurements. The fourth layer of uncertainty occurs when measurements on a system are taken at different times and with different instruments. Measurements taken by the HVAC technician and then later by the EM&V technician are conducted under different ambient, space, and attic conditions, and without looking at the effect of these differences we cannot ascribe a major significance to the different findings.

Uncertainties in Temperature Measurement

Measurement of refrigerant line temperature (later used in superheat and subcooling determination) is performed by connecting a temperature measurement device to the bare and clean copper line, with insulation. Haorong Li's doctoral dissertation (Li 2004) summarized the evaluation of the difference in measuring line temperature with a resistance thermal device (RTD) versus a thermocouple. The factors affecting measurement include the presence of insulation, mechanics of heat transfer, and the temperature differential of line and ambient. Li summarized the heat transfer to an RTD in an equivalence resistance model, and concluded that even under the best of installations, the error in measurement is 20% of the total differential temperature, or 20 °F if there is a 100 °F differential temperature. A thermocouple in the same condition is capable of an error of 1.6%, or 1.6 °F if there is a 100 °F differential temperature. These uncertainties illustrate the need to consider not only the published accuracy but also the accuracy that is dependent on the application.

Suction line surface temperature is higher on the tube bottom due to the returning compressor oil, indicating that the probe must be located on the top of the tube. Technicians are taught to measure at the 3 or 9 o'clock positions to avoid this problem but protocols are needed to make it a standard practice. Exploratory testing done at the Pacific Gas & Electric laboratory shows the impact of using different sensors mounted in different manners on the accuracy of pipe surface temperature measurements. The best sensor and mounting method was the insulated and calibrated bead thermocouple which resulted in a 3%

error. This contrasts with a measured 7% error when using a clamp-on thermocouple as commonly used and as allowed by the 2004 RCA specifications (Davis, 2007).

Proctor Engineering Group has conducted additional testing on 5 commonly used temperature probes in support of California Energy Code (Title 24) revisions (Hairrell et al, 2010). Of particular concern is the time it takes for the relatively high mass thermistor probe to reach the terminal temperature. This research also found that one clamp-on thermocouple of the type preferred by technicians worked very well, while in general thermistors performed poorly. The work of Li, Davis and Proctor support the assertion that just considering the published accuracy of sensors is not sufficient. Additional testing is needed to develop the measurement and instrument specifications to support technician service work.

Uncertainties in Humidity Measurement

Moisture can be measured in three different ways, all of which have their own challenges and uncertainties. Dewpoint measurement is the preferred method in laboratory settings (although wetted temperature sensors are used), but it is not feasible for field measurement. Digital readout relative humidity (RH) instruments are common and reasonably priced, although these sensors have accuracy issues and tend to drift over time. Wet bulb temperature measurements are made with a wet cotton sock over a temperature probe, which can be a thermocouple, a mercury bulb thermometer, or a RTD. The sock must be kept moist and airflow is needed to keep evaporation maximized. Measurement of supply air moisture is difficult because most methods lose accuracy when RH is over 90%, which is a common condition.

UNCERTAINTY IN CALCULATED MEASURES

The research team analyzed the uncertainties in calculation of various system variables, as a function of the accuracy of primary measurements (Hunt et al, 2010). Uncertainties in the measured variables are published in instrument documentation, or can be obtained by testing the instrument. Performance metrics are obtained from a system equation that involves direct measurements of measured variables. The total uncertainty in the system variable is related to *sensitivity coefficients*—the calculated partial derivatives of the system variable with respect to the measured variables. For ease of calculation, the research team input system equations into an equation solver with built-in psychrometric and refrigerant charts.

Subcooling and Superheat

Subcooling temperature is dependent on two measurements, liquid line surface temperature and discharge pressure. Hence the uncertainty in subcooling is determined from the partial derivatives with respect to these measurements and the stated accuracies of both devices.

Energy Efficiency Ratio (EER)

In contrast to the onetime measurements that go into superheat and subcooling, the uncertainty of in-field determination of total EER and sensible EER makes a onetime determination of system performance suspect, especially given that improvements from fixing system faults, as measured under ideal laboratory conditions, do not rise to the 20% level. With monitoring over time, these gaps in uncertainty can be reduced with an analysis of *time-series* data that has been collected on an actual HVAC system. The two analytic techniques used to address this type of data are generalized additive models and the calculation of autocorrelation functions for each of the lower level (directly measured) variables. This sophisticated statistical analysis is documented in the project's final report (Hunt et al, 2010).

The conclusion of this analysis was that time series data must be collected to reduce measurement uncertainties in EER values, and due to computational complexity, the benefit of additional data decreases sharply after approximately 100 data points. A residential scale air conditioner is deemed to reach equivalent steady state in 15 minutes of operation after which a valid set of superheat and subcooling measurements can be taken. If 100 data points are needed and they are taken on a 1 minute interval then steady state operation needs to occur for almost two hours. In real-world applications with cooling equipment that is oversized even at peak conditions, two hours of operation will rarely occur. This makes it necessary to perform a field study to determine if a set of separated periods of steady state operation can be aggregated into a data set of 100 points. If this is not possible other methods will need to be developed such as ways to force the two hours of operation.

Annual Energy Use and Savings

Calculation of annual energy savings has considerably more uncertainty than even EER. These estimates are typically arrived at using building simulation based upon measured or assumed EER values. As one example of this type of analysis, five increasingly detailed levels of tuned simulations were performed using data from six buildings in Southern California (Alereza and Faramarzi 1994). “Level 1” simulations used building specific data for the inputs to the model. “Absolute estimation errors for HVAC End Use Intensity (EUI) ranged from 1 to 27 percent.” The average error was 17.8%. “Level 5” reduced the average error in HVAC EUI to 11.6% and “three buildings had reduced absolute errors and three had increased absolute errors.” One can expect that estimates of annual energy usage based upon even the best EER measurements and calculations is on the order of 20%, potentially masking the savings which are themselves on the order of 20%.

Resulting Uncertainties

Table 2, taken from the Hunt study (2010), presents the results of this statistical analysis in the context of measurements from a number of sources:

- A review of published instrument accuracies from several laboratory-testing facilities: PG&E (Davis and D’Albora 2001), Intertek (Mowris et al., 2010) and Purdue University Herrick Laboratory (Shen et al. 2006), (“Lab”)
- A review of the accuracies claimed in EM&V reports by KEMA (2010) and Robert Mowris (2004). (“EM&V”),
- 2006-2008 Program Specifications, AEC 2004 (“AEC 2004”),
- A review of the instrumentation used by contractors working for Verified Service Providers (“VSP”),
- A review of instrumentation typically used by contractors from a 2006 AEC report for PG&E, AEC 2006 (“Contractor Current”), and
- A recommended revision to the Program Specifications, described later (“Revised AEC 2010”).

Table 2: Uncertainties in Measured Values (from Hunt et al, 2010)

		Lab		EM&V		AEC 2004	VSP		Contractor	Revised AEC
Measured Variables	Units	Min	Max	Min	Max		Min	Max	Current	2010 Tech
Supply Air (Dry Bulb)	F	± 0.05	± 2.3	± 0.18	± 0.50	± 1.5	± 0.7	± 1.5	± 2.1	± 1.5
Return Air (Dry Bulb)	F	± 0.05	± 1.8	± 0.18	± 0.80	± 1.5	± 0.7	± 1.5	± 2.1	± 1.5
Outside Air (Dry Bulb)	F	± 0.05	± 1.8	± 0.18	± 1.00	± 1.5	± 0.7	± 1.5	± 2.1	± 1.5
Supply Air (Wet Bulb)	F	± 0.05	± 1.8			± 1.5			± 2.1	
Return Air (Wet Bulb)	F	± 0.05	± 1.8			± 1.5			± 2.1	
Outside Air (Wet Bulb)	F	± 0.05	± 1.8			± 1.5			± 2.1	
Supply Air (RH) (DEWPOINT)	%|F	± 0.005	± 0.4	± 1 %	± 2 %	± 3 %	± 2.0 %	± 3 %	± 3 %	± 2 %
Return Air (RH) (DEWPOINT)	%|F	± 0.005	± 0.4	± 1 %	± 2 %	± 3 %	± 2.0 %	± 3 %	± 3 %	± 2 %
Outside Air (RH) (DEWPOINT)	%|F	± 0.005	± 0.4	± 1 %	± 2 %	± 3 %			± 3 %	
Condenser Discharge (Dry Bulb)	F	± 0.05	± 0.9	± 0.2	± 1.0					
Suction Line (Dry Bulb)	F	± 0.30	± 0.9	± 0.5	± 1.5	± 1.5	± 1.5	± 3.2	± 3.5	± 1.5
Liquid Line (Dry Bulb)	F	± 0.30	± 0.9	± 1.0	± 1.5	± 1.5	± 1.5	± 3.2	± 3.5	± 1.5
Suction Pressure	psig	± 0.3	± 1.1	± 0.13	± 1.35	± 4.04	± 1.35	± 4.04	± 4.04	± 1.00
Discharge Pressure	psig	± 1.0	± 3.2	± 0.40	± 4.05	± 12.14	± 4.05	± 12.14	± 12.14	± 1.00
Condenser Power (True RMS)	W	± 0.2	± 10.0	± 1.5	± 3.0	± 3.0				± 3.0
Compressor Power (True RMS)	W	± 2.9	± 14.3	± 28.6	± 57.2	± 57.2				± 57.2
AHU Power (True RMS)	W	± 0.5	± 10.0	± 4.5	± 9.0	± 9.0				± 9.0
AHU Flow Rate	CFM	± 6.1	± 12.1	± 36	± 85	± 85	± 36	± 85		± 85
Atmospheric Pressure	Pa	± 0.03	± 0.3	± 1.0	± 1.0	± 1.0				± 0.05
Calculated Variables	Units									
Superheat	F	± 0.33	± 1.02	± 0.50	± 1.61	± 2.32	± 0.50	± 3.20	± 3.92	± 1.56
Subcooling	F	± 0.36	± 1.09	± 1.00	± 1.68	± 2.74	± 1.00	± 3.20	± 4.19	± 1.51
Condensing Over Ambient	F	± 0.19	± 1.90	± 0.79	± 1.00	± 2.74	± 0.70	± 2.74	± 3.11	± 1.51
EER (Total)		± 0.20	± 2.17	± 0.39	± 0.95	± 1.69				± 1.46
EER (Sensible)		± 0.03	± 1.04	± 0.15	± 0.38	± 0.78				± 0.77

From Table 2, we can see that lab measurements are more accurate than field measurements, (as expected) and that the EM&V measurements are more accurate than the measurements made by VSPs. Some VSPs are not meeting the program specifications, and the instrumentation typically used by contractors currently has a high degree of uncertainty. The Current Contractors column does not apply to contractors working with VSP that require instrumentation that meets or exceeds the AEC specification. The problem with EER uncertainties is that the impact of measures is often less that the uncertainty of the one-time measurement. This can be addressed by time-series monitoring, as discussed earlier.

RECOMMENDATIONS

In order to address uncertainties outlined above, carefully designed and implemented pilot programs with EM&V monitoring are needed to establish the potential energy and demand savings from implementing the diagnostic protocol. These programs will initially establish a baseline performance of representative systems as they are found. Residential split systems and commercial packaged units will be included in the monitoring. The performance of air conditioners with various changes in parameters has been established in lab testing and more of that needs to be done. We also need to determine what faults exist in the field—their prevalence and the distribution of the magnitude of the errors. Long-term, detailed monitoring of hundreds of sites is required. Additional laboratory testing needs to be part of the integrated research plan.

The minimum instrumentation requirements for maintenance programs need to continue to be examined and upgraded based on experience and data. A “Technical Forum” was held in August, 2010 in Stockton, CA, which included 31 of the most prominent researchers, contractors, manufacturers, VSPs, and others in the industry. A set of recommended changes to the 2006-2008 California IOU instrumentation and diagnostic protocol was drafted by the participants, shown in the last column in Table 2. While the proposals were discussed extensively, it was not the proper venue to adopt changes. Further work should be done, bringing stakeholders together to discuss the issues and develop a consensus.

A fault detection and diagnostic protocol needs to be developed that can deal with multiple system variables and multiple faults. This protocol will need to include an inventory and assessment component. Without IOU incentive programs, technicians use simple checklists to show the customer that the suite of tasks has been done. Technicians have little or no historical information on the unit being serviced. This can be the case even when a technician from the same company was the last one servicing the unit. ACCA Standards 4 and 180 require documentation to address this problem. The IOU RCA programs of necessity require documentation to qualify for incentive payments. But there is not a generic performance standard.

The foundation has also been laid for developing a generic, performance based measurement and diagnostic protocol that can be implemented by VSPs, instrument manufacturers, and other entities whose business is to support the work of HVAC technicians. The ACCA standards and the experience gained from implementing RCA programs provide the raw material from which stakeholders can hammer out the protocols. This will be a process that will first be tested in meetings and then be tested in the field.

SUMMARY

The California IOUs have shown a great deal of leadership in initiating maintenance-based HVAC programs. These and other energy efficiency programs have been in existence since the 1980s, and have reached millions of homes and small businesses. Despite their success in reaching the market, however, the energy savings attributable to HVAC maintenance programs have been called into question. For example, one evaluation of savings for RCA programs in the 2006-2008 California IOU program cycle found quite low savings rates, but also found wide variations in the different program performance metrics. These studies raised the possibility that some of the EM&V questions being asked and answered have such large uncertainties that conclusions and recommendations based on it should be considered carefully.

In reviewing the preceding sections, it is notable that the uncertainties in measurements made in maintenance services are large, and the savings from current programs are asserted to be small in relation to the uncertainties. We conclude that a holistic approach to both the design and implementation of the HVAC programs with integrated measurement and evaluation methods can reduce the uncertainties and increase the savings, such that investments in expanded HVAC QM programs can show prudent use of ratepayer funds. A holistic approach does not necessitate that the program implementing it be complicated, time consuming and therefore cost ineffective. Future programs will build upon the knowledge gained from previous programs to deliver a holistic set of site specific services to achieve significant savings that are needed to meet CPUC goals and which are verifiable.

In the short run, maintenance-based programs continue and continue to be refined, improved, and redesigned. The focus of this study was on how the industry can be moved from current programs to future even better programs. In the long run, achieving the ambitious California Public Utilities Commission (CPUC) “Big-Bold” HVAC goal of 50% improvement in residential and small commercial HVAC system efficiency will require new, more comprehensive programs that have the potential for greater impact. For these programs to constitute a prudent use of ratepayer money, however, they must be designed based on a good understanding of the impacts and interrelationships of individual and combined system faults (i.e., abnormal conditions that may lead to system performance degradation or failure) and maintenance measures. A simple “widgets” approach that focuses on individual measures that save 10% here and 5% there will not achieve the level of savings that is needed to meet this ambitious goal. HVAC technologies benefit from a broad based systems approach with a thorough understanding of the associated uncertainties.

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