

Incorporating IPMVP and Six Sigma Strategies into Monitoring and Evaluation

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Keywords

International Performance Measurement and Verification Protocol, Six Sigma, monitoring, energy efficiency, reliability, cost effectiveness, performance, quality, global warming, building commissioning, Annex 40

Abstract

Increased emphasis on energy efficiency to reduce energy use and mitigate global warming requires rigorous evaluations based on the International Performance Measurement and Verification Protocol (IPMVP). The California Public Utilities Commission, New York State Energy Research and Development Authority (NYSERDA), the World Bank, and many state and federal agencies require adherence to IPMVP. The World Resources Institute recommends evaluation standards such as IPMVP for the Kyoto Protocol. Increased emphasis on customer satisfaction and resource efficiency to improve profitability has motivated businesses worldwide to adopt Six Sigma strategies. Motorola, General Electric, Sony, Honda, Toyota, and many other companies have adopted Six Sigma to decrease costs and increase profitability and market share.

The objectives of IPMVP and Six Sigma are similar to IEA Annex 40 which provides tools, guidelines, and recommendations for commissioning HVAC systems to optimize building energy efficiency. IPMVP provides a framework to measure, verify, and commission energy efficiency and renewable energy savings. Six Sigma provides a framework to measure and verify energy efficiency performance metrics at critical steps in the market chain (i.e., design, manufacturing, installation). Incorporating IPMVP and Six Sigma into monitoring and evaluation will help program implementers, utilities, consumers, corpora-

tions, and government agencies better understand the value of energy efficiency.

This paper provides an example of how to incorporate IPMVP and Six Sigma strategies into monitoring and evaluation studies of four residential air conditioner incentive programs implemented by public utilities in California. The net realization rates for the four residential air conditioner programs are 0.53 ± 0.1 for kWh and 0.58 ± 0.04 for kW. The net realization rates are lower than anticipated due to lower baseline usage, lower ex post savings, and lower net-to-gross ratios. Findings for the four utility programs underscore the importance of incorporating IPMVP and Six Sigma into monitoring and evaluation.

Introduction

Energy efficiency offers the largest and most cost-effective opportunity for industrialized and developing countries to reduce the financial, health, and environmental costs associated with burning fossil fuels and mitigate global warming (USDOE 2002). Available cost-effective global investments in energy and water efficiency are estimated to be tens of billions of dollars per year. The foundation of energy efficiency is the assumption that Energy Conservation Measures (ECMs) will reduce energy use. Customers, businesses, utilities, and government agencies need to know how much energy will be saved and how long savings will last when they invest in energy efficiency.

The International Performance Measurement and Verification Protocol (IPMVP) has become a worldwide standard for evaluation, measurement, and verification (EM&V) of energy savings resulting from implementation of ECMs. The California Public Utilities Commission, New York State Research and

Table 1. IPMVP Options

IPMVP Option	Savings Calculation	Typical Applications
Option A. Partial Measured Retrofit Isolation Savings are determined by short-term or continuous field measurements of energy use. Partial measurement means some parameters may be stipulated.	Engineering calculations using short term or continuous measurements and stipulations.	Lighting retrofit where power draw is measured and operating hours are measured with light loggers or based on interviews with building personnel.
Option B. Retrofit Isolation Savings are determined by short-term or continuous measurements of energy use.	Engineering calculations using short term or continuous measurements.	Air conditioners or chillers where electricity use is measured and compared to labeled energy use.
Option C. Whole Facility Savings are determined by measuring energy use at the whole facility level. Short-term or continuous measurements are taken during post-retrofit period.	Analysis of whole facility utility meter or sub-meter data using comparison or regression analyses.	Energy management program affecting many systems in a building. Pre- and post-retrofit energy use is measured with utility meters.
Option D. Calibrated Simulation Savings are determined through simulation of components or whole facility. Simulation models actual energy performance measured in the facility.	Energy use simulation, calibrated with hourly or monthly utility billing data and/or end-use metering.	Weather-sensitive measures in a building. Savings based on simulations calibrated with pre- or post-retrofit utility data.

Source: USDOE 2002

Development Authority (NYSERDA), the World Bank, and many government agencies require adherence to IPMVP. The World Resources Institute is recommending evaluation standards such as IPMVP for the Kyoto Protocol. The latest version of IPMVP includes requirements to promote best EM&V practices that conform to best engineering practices (ASHRAE 2002). The EM&V protocols in California require adherence to these additional IPMVP requirements (Hall et al. 2005).

Six Sigma strategies have been used by businesses worldwide to save billions of dollars by designing and monitoring systems to improve quality, efficiency, and customer satisfaction. Motorola, General Electric, Allied Signal, Sony, Honda, Toyota, Maytag, Raytheon, Canon, Texas Instruments, Bombardier, Hitachi, Lockheed Martin, Polaroid, and many other companies have adopted Six Sigma strategies to improve quality, reduce waste, decrease costs, grow profit margins, and increase market share (Harry 2000).

IPMVP and Six Sigma provide a framework to measure and verify energy efficiency characteristics and savings and perform comparative analyses to identify and adopt best practices. Incorporating IPMVP and Six Sigma into monitoring and evaluation will help program implementers, utilities, consumers, corporations, and government agencies better understand the value of energy efficiency.

IPMVP

The IPMVP is a resource savings-verification tool applicable to residential, commercial, and industrial energy efficiency projects and programs. The IPMVP defines four options to quantify energy, power, water, and renewable energy savings from ECMs (Table 1). The four options titled A, B, C, and D, are the cornerstones of standardized evaluation procedures contained in the IPMVP.

None of the four IPMVP options allow exclusive use of stipulated values. According to IPMVP, whenever a parameter is not measured, it is a stipulated value. Unreasonable stipulations create risks and uncertainties especially when program implementers select lowest cost EM&V options or pay more money for evaluators to use stipulated savings estimates when con-

ducting evaluations. Greenhouse gas trading policy encourages rigorous EM&V by applying savings discount factors tied to the IPMVP Option.¹ Selection of the IPMVP Option is a balance between accuracy and cost. In general, IPMVP Option A is the least accurate and least costly option. IPMVP Options B or D, are the most accurate and costly options. All measures can be evaluated using Options A, B, and D, but the accuracy of the estimates provided under Option A decreases as the measure complexity increases. Option C is limited to projects where the expected savings exceeds the metered energy consumption by at least 10 %.² The USEPA Conservation Verification Protocols direct evaluators to report verified savings at the low end of the confidence interval to encourage more precise estimates.³

The IPMVP provides approaches that best match project costs and savings, technology-specific requirements, and risk assessment. It provides savings techniques using suitable and available data and disclosure of data analysis enabling one party to perform saving determinations while another verifies savings. The IPMVP has become standard in most energy efficiency projects where contractor payments are based on energy savings (USDOE 2002). Preparation of an EM&V plan is central to properly measure and verify savings and forms the basis for verification under IPMVP. The EM&V plan should include the following eight steps.

1. **Recognize or select the IPMVP Option** consistent with ECMs in the project or program.
2. **Define the ECM boundaries** and gather relevant energy and operating data for the base year.
3. **Measure** or evaluate ex-ante assumptions (i.e., savings, incremental cost, effective useful life, net-to-gross ratios),

1. A discussion of other approaches is found in Vine et al. 2003.

2. The minimum savings criterion established in ASHRAE Guideline 14 is 10 percent. Depending on the variability of the data, a greater energy savings fraction may be required for successful billing analysis.

3. Savings are reported with 75% confidence at the low end of the confidence interval. See USEPA 1995.

critical-to-quality (CTQ) characteristics, and cost effectiveness.^{4,5}

4. **Prepare an EM&V Plan** to define “savings” for each project or program.
5. **Design**, install, and test measurement equipment required for the EM&V plan.
6. **Verify** or commission installed measures and operating procedures to ensure compliance.
7. **Gather post-retrofit energy/operating data** consistent with EM&V plan.
8. **Compute and report savings** and improvements consistent with the EM&V plan.

Six Sigma

Six Sigma is a performance target that applies to a single critical-to-quality (CTQ) characteristic and focuses on non conformance within a product or process. Products or processes that are complex, such as air conditioners, have greater opportunities for defects especially with respect to energy efficiency performance that is dependent upon installation quality. Six Sigma literally means 3.4 defects per million opportunities of a given CTQ characteristic. The typical corporation in the United States operates at a 3.5 sigma level or 22,750 defects per million opportunities. The difference between 3.5 and 6 sigma can be illustrated with the following example. If a wall-to-wall carpet in a 150 square meter home were cleaned to a 3.5 sigma level, about 3.4 square meters of carpet would be left dirty. If the same carpet were cleaned to Six Sigma, the dirty carpet area would be less than 5 square centimetres.

Six Sigma strategies are used to measure and verify energy savings and performance metrics at critical steps in the market chain (i.e., design, manufacturing, installation, and service). Companies operating below a three sigma level usually don't survive because the cost of poor quality is roughly 25 to 40 % of sales revenue. At the Six Sigma level, the cost of quality declines to less than 1 % of sales revenue. When General Electric reduced its cost associated with poor quality from 20 % to less than 10 % and raised its overall quality from a 4 to 5 sigma level, the company achieved a \$ 1 billion increase in net income over two years (Harry 2000). This is the reason why corporations are adopting Six Sigma strategies and why Six Sigma should be incorporated into energy efficiency evaluations.

The purpose of the Six Sigma is to improve profitability through measurement and verification of quality and efficiency improvements through the application of eight strategies.

1. **Recognize the true states of the business.** Business states describe conditions created by systems used to guide and manage. Companies and programs cannot improve what they do not measure.

2. **Define what plans must be in place to realize improvements of each business state.** Companies cannot initiate plans for improvement if they do not know how customer satisfaction relates to key business systems.
3. **Measure business systems that support the plans.** There are three obstacles to measuring: 1) what to measure and when to measure, 2) how to measure, and 3) gaining approval to measure. Reluctance to measure is often based on over promising results. This pitfall is one of seven key program design guidelines identified in the *National Energy Efficiency Best Practices Study* (Rufo 2004).
4. **Analyze the gaps in system performance benchmarks.** Analyzing gaps in system performance benchmarks helps to understand energy efficiency performance and process improvements.
5. **Improve system elements to achieve performance goals.** Before a program can improve, it must define measurement systems, analytical methods, and reporting requirements. Then it must create measurement instruments, collect and analyze data, and prioritize improvements.
6. **Control system-level critical-to-quality (CTQ) characteristics.** Regular system-level audits must be performed to evaluate, identify, analyze, and control CTQ characteristics such as building commissioning for optimal energy efficiency per IEA Annex 40 (IEA 2004).
7. **Standardize the systems that prove to be best-in-class.** Once a program or business has uncovered best-in-class practices, it should seek to standardize and transfer knowledge to relevant sectors.
8. **Integrate best-in-class systems into strategic planning.** Best-in-class systems become institutionalized when they are integrated into policies and procedures and reinforced through reward and recognition systems.

IPMVP and Six Sigma Objectives

The objectives of IPMVP and Six Sigma are similar to IEA Annex 40 which provides tools, guidelines, and recommendations for commissioning HVAC systems to optimize building energy efficiency. IPMVP provides a framework to measure and verify energy efficiency and renewable energy savings. Six Sigma provides a framework to measure and verify energy savings and performance metrics at critical steps in the market chain (i.e., design, manufacturing, installation, and service). IPMVP and Six Sigma offer similar strategies to measure performance (Table 2).

EM&V studies in California have recently tended to rely more on “deemed” savings and lower levels of rigor regarding load impact and energy savings than what would be required under EM&V protocols (Hall et al. 2005b). The EM&V protocols in California require studies adhere to the IPMVP to obtain more rigorous load impact evaluations (Hall et al. 2005). Incorporating IPMVP and Six Sigma strategies in evaluation and implementation will yield more reliable and cost effective energy and peak demand savings. The ultimate goal of energy efficiency programs is to transform the market so that the cost

4. Ex ante is Latin for “beforehand”. In models where there is uncertainty that is resolved during the course of events, the ex antes values (e.g. of expected gain) are those that are calculated in advance of the resolution of uncertainty.

5. CTQ characteristics within IPMVP are energy efficiency performance metrics of a product or process whose performance standards or specification limits must be met to satisfy performance requirements (i.e., energy savings).

Table 2. IPMVP and Six Sigma Strategies

1) Recognize or select the IPMVP Option consistent with ECMs in the project or program.
2) Define the ECM boundaries and gather relevant energy and operating data for the base year.
3) Measure or evaluate ex ante assumptions , Critical to Quality (CTQ) Characteristics, and performance standards.
4) Prepare an EM&V plan consistent with IPMVP. Analyze savings, gaps in performance, and when and where defects occur.
5) Design, install, and test measurement equipment . Improve systems to achieve savings and performance goals.
6) Verify or commission measures and procedures to ensure compliance. Control CTQ characteristics to improve performance.
7) Gather post-retrofit energy/operating data consistent with EM&V plan. Standardize best-in-class systems .
8) Compute and report savings and improvements. Integrate best-in-class systems into strategic planning.

for delivering energy efficiency products and services is included within the transaction costs and intervention is no longer necessary (i.e., exit strategy). This goal can be achieved by understanding the value of energy efficiency and by incorporating IPMVP and Six Sigma into program design, implementation, monitoring, and evaluation.

Steps to Incorporate IPMVP and Six Sigma into Evaluation Studies

The following example shows how to incorporate IPMVP and Six Sigma into an evaluation study of residential air conditioner incentive programs implemented by four public utilities in California (Mowris 2005). The programs were implemented by Modesto Irrigation District (MID), Plumas Sierra Electric Cooperative (PSREC), Redding Electric Utility (REU), Roseville Electric, and Turlock Irrigation District (TID). The programs realized peak kW and kWh savings by paying incentives to consumers for installing high efficiency air conditioners. The programs provided 1,892 air conditioner rebates from 2001 through 2003 with \$ 1,344,803 of SB5X funds administered by NCPA. The evaluation study budget was \$ 56,658.

STEP 1: SELECT IPMVP OPTIONS AND RECOGNIZE THE TRUE STATE OF THE BUSINESS OR PROGRAM

The first step is to select the IPMVP options. These programs require all of the IPMVP Options A, B, C, and D. Option A is used to measure the Energy Efficiency Ratio (EER) with short term measurements for a statistical random sample to compare in-situ performance with manufacturer data.⁶ Option B is used to measure kW demand with short-term or continuous measurements during the peak period (2 PM to 7 PM weekdays). Option C is used to evaluate pre- and post-retrofit electricity usage to determine kWh savings. Option D is used to perform calibrated building energy computer simulations to normalize

and adjust for weather and occupancy variations. Companies and programs cannot improve what they do not measure.

STEP 2: DEFINE RELEVANT ECM BOUNDARIES AND GATHER BASE YEAR DATA

The second step is to define the energy conservation measure boundaries and gather relevant energy and operating data for the base year. Once programs have defined and characterized their baseline, they can begin to achieve improved performance. Baseline cooling energy use is evaluated using utility billing data for 50 participant sites as shown in **Tables 8, 9, and 10**. The PRInceton Scorekeeping Method is used to obtain normalized baseline cooling energy use from monthly billing data for each site (PRISM, Fels et. 1995).

STEP 3: MEASURE OR EVALUATE EX ANTE ASSUMPTIONS AND CTQ CHARACTERISTICS

The third step is to measure or evaluate ex ante assumptions and critical to quality (CTQ) characteristics. There are three obstacles to measuring: 1) what to measure and when to measure, 2) how to measure, and 3) gaining approval to measure. Reluctance to measure is often based on over promising results. The average Seasonal Energy Efficiency Ratio (SEER), baseline energy use, and ex ante savings per unit for each utility program are shown in **Table 3**.⁷ Also shown are average savings from the Database for Energy Efficiency Resources (DEER, XENERGY 2001). The average ex ante energy savings for the utility programs are 92 % higher than the DEER kWh savings and 118 % higher than the DEER kW savings. Ex ante kWh savings for Roseville are 22 % greater than the baseline kWh and four times greater than the DEER kWh savings. The preliminary evaluation indicates potential problems with ex ante assumptions that merit further research. Other assumptions requiring evaluation or commissioning include CTQ characteristics such as refrigerant charge, airflow, duct leakage, proper sizing, and indoor/outdoor coil matching.

STEP 4: PREPARE AN EM&V PLAN TO ANALYZE GAPS

The fourth step is to prepare an EM&V plan to address baseline information, energy efficiency measure information, measurement and verification approach, and the evaluation approach. Analyzing gaps in system performance benchmarks helps to understand energy efficiency performance and process improvements.

STEP 5: DESIGN, INSTALL, AND TEST MEASUREMENT EQUIPMENT AND IMPROVE SYSTEM ELEMENTS

The fifth step is to define, install, and test measurement equipment required for the EM&V plan. In order to improve a program, measurement systems, analytical methods, and reporting requirements must be defined.

6. In the United States, the labeled EER is measured at standard conditions with condenser entering air temperature of 35°C and evaporator entering air of 26.7°C drybulb and 19.4°C wetbulb (ARI 2003). EER is the cooling capacity (kW) divided by total air conditioner electric power input (kW) including evaporator fan, condenser fan, compressor, and controls. EER field measurements are made at non-standard temperature conditions and are not directly comparable to laboratory measurements at standard conditions where airflow, return air, and condenser air temperatures are controlled. EER is derived from simultaneous enthalpy, airflow, and power measurements.

7. In the United States the SEER and EER are defined as the cooling capacity in British thermal units (Btu) per hour divided by total air conditioner electric power input (kW) including evaporator fan, condenser fan, compressor, and controls. The Btu is the energy required to raise one pound of water one degree Fahrenheit. This paper converts SEER and EER to SI units (i.e., kW/kW) through division by 3.413 Btu/kW. SEER is defined as the cooling capacity divided by the electric power input and is an adjusted rating based on a specified EER measurement multiplied by a 0.875 Part Load Factor where the EER is measured at condenser entering air temperature of 27.8°C and evaporator return temperatures of 26.7°C drybulb and 19.4°C wet bulb (ARI 2003).

Table 3. Baseline Energy Use and Ex Ante Savings per Unit Compared to DEER

NCPA Utility	Qty.	Baseline SEER	Program Average SEER	Baseline Unit kWh/yr	Baseline Unit kW	Ex Ante Savings per Unit kWh/yr	Ex Ante Savings per Unit kW	DEER Savings per Unit kWh/yr	DEER Savings per Unit kW
MID	316	2.93	3.65	2,802	4.34	350	0.64	430	0.42
Redding	704	2.93	3.70	2,254	4.46	666	0.76	453	0.44
Roseville	134	2.93	4.05	2,129	4.46	2,594	2.59	630	0.62
TID	656	2.93	3.52	2,802	4.05	721	0.74	306	0.30
Average		2.93	3.66	2539	4.29	801	0.87	418	0.40

Table 4. EER Measurements and Efficiency Gain for TXV Air Conditioners

Site	Cooling Cap. kW	Factory Charge kg	Charge Adjust +Add –Remove	Pre-EER	Post-EER	Relative Efficiency Gain	Average Outdoor Temp °C	Ave. Return DB/WB Temp °C	Notes
1	17.6	3.2	Refused (9%)	3.05	n/a	n/a	27.8	27.8/23.9	R410A
39	8.8	2.7	-78%	2.43	3.46	43%	32.2	32.2/26.1	R410A
40	14.1	4.0	40%	3.28	3.84	17%	26.7	26.7/25.6	R410A
41	10.5	2.8	18%	2.90	3.55	22%	27.8	27.8/25	R22
42	12.3	2.8	16%	3.19	3.46	8%	26.1	26.1/23.9	R410A
44	12.3	4.8	Refused (6%)	n/a	n/a	n/a	26.7	26.7/23.3	R22
45	17.6	5.7	0%	3.16	n/a	n/a	35.6	35.6/23.9	R22
46	17.6	5.7	9%	3.08	3.31	8%	35.0	35.0/25	R22
47	17.6	5.0	11%	3.16	3.43	8%	31.1	31.1/21.1	R22
48	14.1	4.8	15%	3.02	3.63	20%	30.0	30.0/23.3	R22
49	14.1	4.8	Refused (7%)	3.40	n/a	n/a	31.7	31.7/25	R22
50	10.5	4.3	34%	2.64	3.60	37%	35.0	35.0/26.1	R22
51	14.1	4.6	n/a (100%)	n/a	n/a	n/a (100%)	30.0	30.0/29.4	R22
61	17.6	4.7	0%	3.22	n/a	n/a	28.9	28.9/25	R22
Ave	14.1	4.3	25.0%	2.81	3.55	20.4%	30.0	30.0/25	

Table 5. EER Measurements and Efficiency Gain for non-TXV Air Conditioners

Site	Cooling Capacity kW	Factory Charge oz.	Charge Adjust +Add –Remove	Pre-EER	Post-EER	Relative Efficiency Gain	Average Outdoor Temp °C	Ave. Ret. DB/WB Temp °C	Notes
43	14.1	3.3	Okay	3.16	3.16	n/a	35.0	35/25	R22
62	10.5	3.7	Okay	2.90	2.90	n/a	27.2	27.2/21.1	R22
63	17.6	2.7	Okay	3.57	3.57	n/a	27.2	27.2/22.8	R22
64	12.3	3.7	-7%	2.81	2.93	4%	32.8	32.8/28.9	R22
65	12.3	2.3	Okay	2.72	2.72	n/a	28.9	28.9/24.4	R22
66	14.1	3.2	38%	2.49	2.90	16%	32.2	32.2/27.2	R22
67	17.6	4.5	-15%	2.52	2.87	14%	27.2	27.2/23.9	R22
Ave	14.1	3.3	20.0%	2.87	3.02	11.3%	30.0	30/25	

STEP 6: VERIFY OR COMMISSION INSTALLED MEASURES AND CONTROL CTQ CHARACTERISTICS

The sixth step is to verify or commission installed measures and operating procedures to ensure compliance. Verification or commissioning of installed measures includes checking refrigerant charge and airflow (RCA), thermostatic expansion valve (TXV) sensing bulb installation, and duct leakage. Regular system-level audits must be performed to evaluate, identify, analyze, and control CTQ characteristics. The primary goal of building commissioning, from an energy efficiency perspective, is to verify and optimize the performance of energy systems within a building. The objective of IEA Annex 40 is to develop, validate and document tools for commissioning buildings and building services to help achieve this goal. These tools include guidelines on commissioning procedures and recommendations for improving commissioning processes, as well as prototype software implemented in stand alone tools and/or embedded in building energy management systems (BEMS).

STEP 7: GATHER POST-RETROFIT ENERGY DATA AND STANDARDIZE BEST-IN-CLASS SYSTEMS

The seventh step includes gathering post-retrofit energy and operating data consistent with the EM&V plan. Once a program or business has uncovered best-in-class practices, it should seek to standardize and transfer knowledge to relevant sectors. Field measurements of the Energy Efficiency Ratio (EER) were made to evaluate in-situ efficiency before and after correcting refrigerant charge and airflow (RCA) on a sample of 14 air conditioners with TXVs and seven air conditioners without TXVs. The relative efficiency gains due to proper RCA for fourteen TXV and seven non-TXV air conditioners are shown in **Tables 4 and 5**.⁸ The average efficiency gain was 20.4 ± 8 percent for TXV air conditioners with an average charge adjustment of 25 ± 14 percent. The average efficiency gain for non-TXV air conditioners was 11.3 ± 8 percent with an average charge adjustment of 20 ± 14 percent.

8. Factory charge is the manufacturer recommended refrigerant weight. Sites labeled "n/a" had improper RCA and the customer refused corrections. Charge adjustments in parentheses are software recommendations.

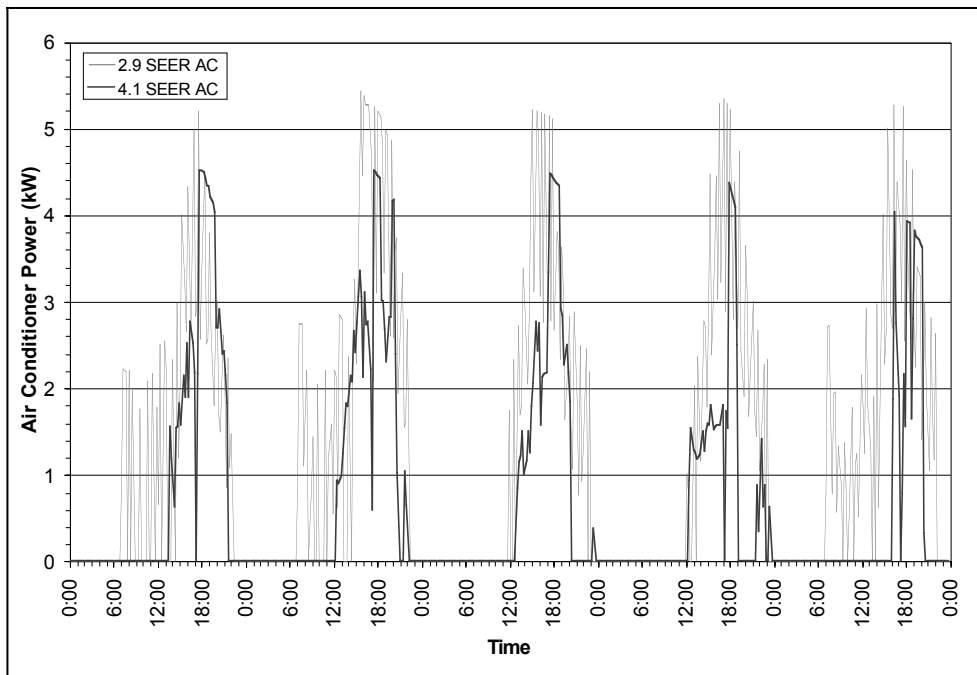


Figure 1. Field Measurements of 2.9 SEER and 4.1 SEER 14.1-kW Air Conditioners

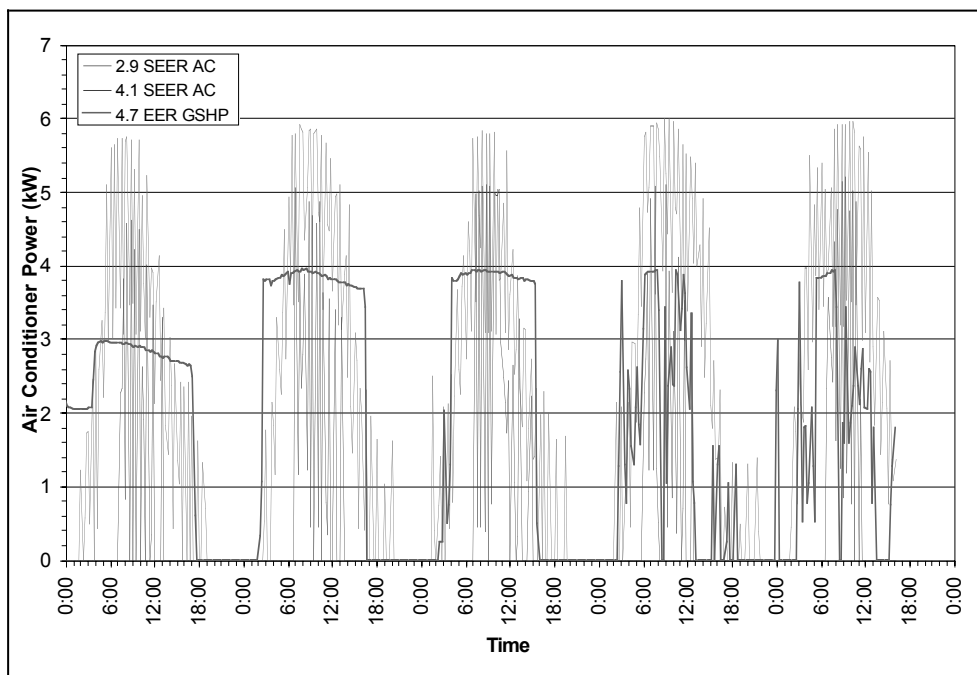


Figure 2. Field Measurements of 2.9 and 4.1 SEER 17.6-kW Air Conditioners and 4.7 SEER GSH

Table 6. Average Measured kW Savings vs. Derived Savings from Manufacturer Data

Cooling Capacity kW	Existing Unit Average Peak kW	Existing Unit SEER	New Unit Average Peak kW	New Unit SEER	Average Measured kW Savings	Manufacturer Rated kW Savings	Return DB/WB & Outdoor Air Temp. °C
8.8	3.75	2.6	3.16	4.1	0.59	0.58	27/19.4/40.6
10.5	4.05	2.9	3.64	3.5	0.41	0.56	27/19.4/37.8
10.5	4.05	2.9	3.52	3.8	0.53	0.63	27/19.4/37.8
10.5	4.05	2.9	3.15	4.1	0.89	0.87	27/19.4/37.8
12.3	4.34	2.9	3.52	3.8	0.82	0.32	27/19.4/37.8
12.3	4.34	2.9	3.50	4.1	0.84	0.60	27/19.4/37.8
14.0	5.44	2.9	4.63	4.1	0.81	0.64	27/19.4/40.6
17.6	6.01	2.9	5.50	3.5	0.51	0.30	27/19.4/40.6
17.6	6.01	2.9	5.16	4.1	0.85	0.57	27/19.4/40.6

Table 7. Measured kW Savings versus Calculated kW Savings from Manufacturer Data

Cooling Capacity kW	Measured kW Baseline and kW Savings					Calculated kW from Manufacturer Data				
	Existing Unit kW	Age of Existing Unit	3.5 SEER ΔkW	3.8 SEER ΔkW	4.1 SEER ΔkW	Base 2.9 SEER kW	3.2 SEER ΔkW	3.5 SEER ΔkW	3.8 SEER ΔkW	4.1 SEER ΔkW
7	n/a	n/a				2.89	0.17	0.26	0.29	0.47
8.8	3.75	1991			0.59	3.36	0.20	0.29	0.37	0.58
10.5	4.05	1989	0.41	0.52	0.89	4.07	0.24	0.56	0.63	0.87
10.5	4.34	1988		0.82	0.84	4.29	0.17	0.17	0.32	0.60
14	5.44	1991			0.81	5.42	0.22	0.18	0.28	0.64
17.6	6.01	1992	0.51	0.85	0.80	6.25	0.19	0.30	0.14	0.57

Table 8. MID Baseline and EM&V Data for Residential HVAC Units

Site	Base Cooling (kWh/yr)	Cooling Capacity kW	SEER	Ex Ante Savings kWh/yr	Ex Ante Savings kW	M&V Ex Post Savings kWh/yr	M&V Ex Post Savings kW
1	5,822	17.6	3.5	435	0.79	491	0.51
2	71	14.1	3.5	348	0.63	12	0.56
3	3,762	8.8	3.5	218	0.4	627	0.38
4	4,025	7.0	3.5	174	0.32	671	0.35
5	1,570	10.5	3.5	261	0.47	262	0.41
6	2,432	10.5	3.5	261	0.47	405	0.41
7	931	8.8/12/3	3.5	804	1.46	155	0.44
8	7,170	10.5	3.5	261	0.47	1,195	0.41
9	896	10.5	4.1	261	0.47	256	0.89
10	1,347	10.5	4.1	261	0.47	385	0.89
Average	2,802	11.0	3.6	353	0.64	446	0.52
90% CI	1,214	1.5	0.0	16	0.03	173	0.11

Table 9. Redding Baseline and EM&V Data Savings for Residential HVAC Units

Site	Base Cooling (kWh/yr)	Cooling Capacity kW	SEER	Ex Ante Savings kWh/yr	Ex Ante Savings kW	M&V Ex Post Savings kWh/yr	M&V Ex Post Savings kW
11	3,664	14.1	4.1	1,012	1.13	1,047	0.81
12	639	14.1	3.8	715	0.8	148	0.82
13	2,523	14.1	4.1	886	0.99	148	0.84
14	240	10.5	4.1	886	0.99	69	0.89
15	2,603	10.5	4.1	759	0.847	744	0.89
16	1,136	14.1	4.1	1,012	1.13	325	0.81
17	910	10.5	4.1	633	0.71	260	0.59
18	942	14.1	3.5	517	0.58	157	0.48
19	1,404	14.1	3.8	816	0.91	324	0.68
20	2,712	14.1	3.5	590	0.66	452	0.56
21	2,712	14.1	4.7	1,328	1.48	1,017	0.84
22	3,913	17.6	4.1	1,265	1.41	1,118	0.85
23	2,626	10.5	3.5	443	0.49	438	0.41
24	655	14.1	3.5	517	0.58	109	0.48
25	3,247	10.5	4.7	996	1.11	1,218	0.75
26	3,691	17.6	3.5	738	0.82	615	0.51
27	1,432	14.1	3.8	818	0.91	331	0.68
28	5,517	14.1	4.1	886	0.99	1,576	0.84
Average	2,254	12.6	3.7	666	0.72	561	0.71
90% CI	553	0.8	0.0	39	0.04	176	0.06

Field measurements of participant and non-participant air conditioners are used to determine in-situ kW usage. Data loggers were installed at 21 sites to measure peak demand and energy use for standard and high efficiency air conditioners. The average measured kW savings are based on field measurements of standard and high efficiency air conditioners shown in **Figures 1 and 2**

The measured peak demand savings range from 0.59 kW for a 8.8-kW 4.4 SEER unit to 0.80 kW for a 17.6-kW 4.4 SEER unit. Average measured kW savings versus calculated kW savings based on manufacturer data are shown in **Table 6** and

7 (Carrier 1997). The average age of existing units was 10 to 14 years as shown in **Table 7**.⁹

The EM&V savings for MID are shown in **Table 8**. The EM&V savings for Redding are shown in **Table 9**. The EM&V savings for Roseville are shown in **Table 10**.

Findings of the participant surveys for each program are presented in **Table 11**. The weighted average net-to-gross ratio is 0.83 based on average participant survey results multiplied

9. National Appliance Energy Conservation Act (P.L. 100-12, P.L. 100-357) required minimum 10 SEER for split-systems on 1-1-92 and for packaged systems on 1-1-93.

Table 10. Roseville Baseline and EM&V Data Savings for Residential HVAC Units

Site	Base Cooling (kWh/yr)	Cooling Capacity kW	SEER	Ex Ante Savings kWh/yr	Ex Ante Savings kW	M&V Ex Post Savings kWh/yr	M&V Ex Post Savings kW
29	685	8.8	4.1	1,821	1.821	196	0.59
30	2,121	14.0	4.1	2,914	2.914	606	0.81
31	3,445	10.5	3.8	2,018	2.018	795	0.53
32	903	12.3	4.1	2,550	2.55	258	0.84
33	2,977	10.5	4.1	2,186	2.186	851	0.89
34	2,511	12.3	4.1	2,550	2.55	603	0.84
35	2,018	17.6	4.1	3,643	3.643	576	0.85
36	3,038	17.6	4.1	3,643	3.643	868	0.85
37	1,405	17.6	3.8	3,363	3.363	324	0.68
38	1,977	13.6	4.1	2,914	2.914	565	0.81
39	2,478	13.6	4.1	2,914	2.914	575	0.81
40	1,416	10.5	3.8	2,018	2.018	327	0.53
41	1,421	13.6	4.1	2,914	2.914	406	0.81
42	782	10.5	4.1	2,186	2.186	224	0.89
43	1,234	10.5	4.1	2,186	2.186	353	0.89
44	3,035	8.8	4.1	1,821	1.821	867	0.59
45	1,226	10.5	4.1	2,186	2.186	350	0.89
46	3,095	10.5	4.1	2,186	2.186	884	0.89
47	3,912	10.5	4.1	2,186	2.186	1,118	0.89
48	3,827	12.3	4.1	2,550	2.55	1,093	0.84
49	1,145	14.0	4.1	2,914	2.914	327	0.81
50	2,197	10.5	4.1	2,186	2.186	628	0.89
Average	2,129	12.3	4.1	2,594	2.59	581	0.79
90% CI	350	1.05	0.0	90	0.09	98	0.04

Table 11. Findings of Participant Surveys

NCPA Utility	Rebate Qty.	Completed Surveys	Ex Post Program Savings kW	Weighting Factor w_h	Actual Net-to-Gross Ratio	Coefficient of Variation Cv	Required Sample to Meet 90/10 Criteria	Weighted Net-to-Gross Ratio
MID	316	10	165.6	0.1504	0.82	0.15	6	0.12
Redding	704	10	497.8	0.4522	0.83	0.17	8	0.38
Roseville	134	19	106	0.0963	0.86	0.1	3	0.08
TID	656	10	331.4	0.3011	0.81	0.16	7	0.24
Total	1,810	49	1,100.80	1		0.15	23	0.83

times savings for each program divided by total savings for all programs. The average net to gross ratio is consistent with the California Public Utilities Commission statewide residential program net-to-gross ratio of 0.80 (CPUC 2003).

STEP 8: COMPUTE AND REPORT SAVINGS AND IMPROVEMENTS AND INTEGRATE BEST-IN-CLASS SYSTEMS

The eighth step is to compute and report savings and to standardize and integrate best-in-class systems. Best-in-class systems become institutionalized when their cross-applicability is interwoven into operating policies and procedures and reinforced through reward and recognition systems. Computing and reporting energy savings and results provide feedback for reward and recognition systems. Statistical survey sampling methods were used to select a sample of customers or projects from each program population in order to evaluate and compute load impacts (Cochran 1977, Thompson 1992). Selecting participants for the sample was guided by the statistical sampling plan as well as input from the utilities. Statistical analysis methods were used to analyze the data and extrapolate mean savings estimates from the sample sites to the population of all program participants and to evaluate the statistical precision of the results. Savings were normalized on a per unit basis in the statistical analyses (e.g., kW/ton). Normalizing the savings allows clearer interpretation of the savings data. Considering

each utility program within a category as a stratum, the sample mean within a program is calculated using **Equation 1**.

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

Where,

\bar{y}_h = EM&V mean kW or kWh savings for stratum “h.”

N_h = Number of measures or sites in stratum “h.”

y_k = EM&V kW or kWh savings estimate for measure “k.”

The mean savings for each program category is based on the sample mean savings estimate across utility program strata. The program category sample mean savings is calculated using **Equation 2**.

$$\text{Eq. 2 Program Category Sample Mean} = \bar{y}_p = \sum_{h=1}^L W_h \bar{y}_h$$

Where,

\bar{y}_p = Program category sample mean savings estimate.

$$W_h = \frac{N_h}{N_p} = \text{Weighting factor across all strata.}$$

N_p = Total number of measures across all strata in program category.

The variance, s_h^2 , of the sample mean for a utility program stratum within a program category is calculated using **Equation 3**.

$$\text{Eq. 3} \quad s_h^2 = \frac{\sum_{k=1}^n (y_k - \bar{y}_h)^2}{N_h - 1}$$

The coefficient of variation (Cv) provides a relative measure of the sample size required to satisfy the 90/10 criteria (or 80/20 criteria) for estimating the mean of the population. The sample Cv for the utility program stratum is calculated using **Equation 4**.

$$\text{Eq. 4} \quad \text{Sample Coefficient of Variation} = Cv_h = \frac{s_h}{\bar{y}_h}$$

Where,

$$s_h = \sqrt{s_h^2} = \text{Standard deviation of the sample mean savings in stratum "h."}$$

The sample size necessary to obtain a desired level of relative precision for the utility program stratum mean savings estimate is calculated using **Equation 5**.

$$\text{Eq. 5} \quad \text{Utility Program Stratum Sample Size} = n_h = \frac{t_o^2 Cv_h^2}{r_h^2}$$

Where,

n_h = Sample size of the utility program stratum.

r_h = Desired relative precision for the utility program stratum.

For small populations, the sample size is corrected using the finite population correction (FPC) equation as follows.

$$\text{Eq. 6} \quad \text{FPC Sample Size} = n_{FPC_h} = \frac{n_h}{1 + (n_h - 1)/N_h}$$

Where,

n_{FPC_h} = Sample size for stratum with finite population correction.

The utility program stratum error bound of \bar{y}_h as an estimator of the mean value at the 90% level of confidence is calculated using **Equation 7**.

$$\text{Eq. 7} \quad \text{Stratum Error Bound} = Eb(\bar{y}_h) = t_o \frac{s_h}{\sqrt{n_h}}$$

Where,

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

n_h = Number of units in sample in stratum h.

An unbiased estimate of the program category variance is calculated using **Equation 8**.

$$\text{Eq. 8} \quad s_p^2 = \sum_{h=1}^L \frac{W_h^2 s_h^2}{n_h} - \sum_{h=1}^L \frac{W_h s_h^2}{N_p}$$

Where,

s_p^2 = Variance of the program category mean savings estimate, \bar{y}_p .

The Cv for the program category is calculated using **Equation 9**.

$$\text{Eq. 9} \quad \text{Program Category Coefficient of Variation} = Cv_p = \frac{s_p}{\bar{y}_p}$$

Where,

$s_p = \sqrt{s_p^2}$ = Standard deviation of the mean savings in the program category.

Statistical analysis is used to extrapolate M&V ex post kW and kWh savings at the sample level for a utility program (stratum) to the program category level and finally for the portfolio. This step includes an assessment of the error bounds and relative precision of program-level kW and kWh savings. The program category savings estimate is calculated as the sum of the number of measures for the utility program stratum times the M&V gross ex post sample mean savings as shown in **Equation 10**.

$$\text{Eq. 10} \quad \hat{Y}_p = \text{M\&V Gross Ex Post Program Category Savings} \\ = \sum_{h=1}^L [N_h \times \bar{y}_h]$$

Where,

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

The M&V Average Gross Realization Rates (AGRR) for kW and kWh savings are calculated using **Equation 11**.

$$\text{Eq. 11} \quad AGRR_h = \frac{\hat{Y}_h}{\hat{X}_h}$$

Where,

$AGRR_h$ = Average Gross Realization Rate for kW or kWh savings defined as the sum of M&V kW savings for measures in program stratum "h" divided by the ex ante kW savings.

\hat{Y}_h = Ex post program stratum "h" savings (kW or kWh).

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

The error bound for the program category is the square root of the sum of the squared error bounds for each of the utility program stratum and is calculated using **Equation 12**.

$$\text{Eq. 12 } \hat{Eb}(\bar{y}_p) = \sqrt{\sum_{i=1}^m [Eb(\bar{y}_h)]^2}$$

The AGRR is combined with the Net-to-Gross Ratio (NTGR) to develop the Net Realization Rate (NRR) relative to planning using **Equation 13**.

$$\text{Eq. 13 } NRR_h = NTGR_h \times AGRR_h$$

Where,

NRR_h = Net Realization Rate for kW or kWh savings in program stratum "h."

$NTGR_h$ = Net to Gross Ratio defined as the number of units that would not have been installed without the program divided by the total number of units installed through the program (kW or kWh).

Gross M&V program evaluation savings (i.e., kWh/yr and kW) are based on sample mean savings developed from billing data analysis of 50 air conditioners. Gross program kW savings are based on sample mean savings estimates and field measurements of 14 new high efficiency air conditioners and 7 existing air conditioners. Gross kW savings for the sampled units are compared to kW savings based on manufacturer kW ratings for similar indoor and outdoor temperature conditions. Net program evaluation savings are based on the participant decision-maker survey results that are analyzed to develop net-to-gross ratios for kWh and kW savings (see **Table 11**). The gross and net savings estimates obtained at the participant level are extrapolated to the population of program participants using statistical methods.

Ex ante program savings are summarized in **Table 12**, and ex post M&V savings are summarized in **Table 13**.

The ex ante program savings are 1,400,210 kWh/yr and 1,568 kW. The net program evaluation savings are 738,495 ± 134,319 kWh/yr and 909 ± 61 kW at the 90 percent confidence level. The net ex post lifecycle savings are 11,077,425 ± 2,014,790 kWh based on the effective useful lifetime for air

conditioners of 15 years (CPUC 2003). The M&V net ex post savings per unit are 408 ± 74 kWh/yr and 0.50 ± 0.34 kW. The net realization rates are 0.53 ± 0.1 for kWh and 0.58 ± 0.04 for kW. Net ex post savings and net realization rates are lower than anticipated due to lower baseline usage, lower net-to-gross ratios, and lower ex post savings. Findings for the residential air conditioner programs underscore the importance of measuring performance and not over promising results. These findings also provide information to improve the residential air conditioner incentive programs.

Conclusions

The examples provided in this paper demonstrate how the IPMVP framework and Six Sigma strategies can be incorporated into monitoring and evaluation of energy efficiency programs and business systems. The net realization rates for the four residential air conditioner rebate programs are 0.53 ± 0.1 for kWh and 0.58 ± 0.04 for kW. The net realization rates are lower than anticipated due to lower baseline usage, lower net-to-gross ratios, and lower ex post savings. The utilities haven't previously conducted evaluations and were unfamiliar with tracking accomplishments and measuring results. Future evaluations should include the following requirements: tracking database, net savings including precision and error bounds, process evaluation, independent study management, adequate time, and evaluation contractors experienced with IPMVP measurement procedures. Findings for the four utility programs underscore the importance of measuring performance and not over promising results.

Increased emphasis on energy efficiency to reduce energy use and mitigate global warming requires rigorous evaluations based on the IPMVP. The California Public Utilities Commission, the World Bank, and many state and federal agencies require adherence to IPMVP. The World Resources Institute is recommending evaluation standards such as IPMVP for the Kyoto Protocol. Increased emphasis on customer satisfaction and resource efficiency to improve profitability has motivated businesses worldwide to adopt Six Sigma strategies. Motorola, General Electric, Allied Signal, Sony, Honda, Toyota, Maytag, and many other companies have adopted Six Sigma strategies to decrease costs, grow profit margins, and increase market share.

The objectives of IPMVP and Six Sigma are similar to IEA Annex 40 which provides tools, guidelines, and recommendations for commissioning HVAC systems to optimize building energy efficiency. IPMVP provides a framework to measure, verify, and commission energy efficiency and renewable energy savings. Six Sigma provides a framework to measure and

Table 12. Ex Ante Savings for Residential HVAC Rebate Programs

NCPA Utility	Qty.	Gross Ex Ante Unit Savings kWh/yr	Gross Ex Ante Unit Savings kW	Ex Ante Net-to-Gross Ratio kWh/y	Ex Ante Net-to-Gross Ratio kW	Ex Ante Program Savings kWh/y	Ex Ante Program Savings KW
MID	316	350	0.64	1	1	110,645	201.2
Redding	704	666	0.76	1	1	469,104	536.3
Roseville	134	2,594	2.59	1	1	347,616	347.6
TID	656	721	0.74	1	1	472,845	483.2
Total or Average	1,810	801	0.87	1.00	1.00	1,400,210	1,568

Table 13. M&V Ex Post Savings for Residential HVAC Rebate Programs

NCPA Utility	Qty.	Gross Ex Post Savings kWh/y	Gross Ex Post Savings kW	Net-to-Gross Ratio kWh/y	Net-to-Gross Ratio kW	Net Ex Post Savings kWh/y	Net Ex Post Savings kW
MID	316	446	0.52	0.82	0.82	115,513	135.8
Redding	704	561	0.71	0.83	0.83	327,658	413.2
Roseville	134	581	0.79	0.86	0.86	67,011	91.2
TID	656	430	0.51	0.81	0.81	228,313	268.4
Total or Average	1,810	495	0.61	0.83	0.82	738,495	908.6

verify energy efficiency performance metrics at critical steps in the market chain (i.e., design, manufacturing, installation, and service). IPMVP and Six Sigma offer similar strategies to measure and analyze performance gaps, improve systems, control system-level critical-to-quality characteristics, standardize systems that prove to best-in-class, and integrate best-in-class systems into strategic planning. Incorporating IPMVP and Six Sigma strategies into monitoring and evaluation will help program implementers, utilities, consumers, corporations, and government agencies better understand the value of energy efficiency to reduce global warming.

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