Incorporating IPMVP and Six Sigma Strategies into Energy Efficiency Program Design, Implementation, and Evaluation

Robert J. Mowris, Ean Jones, and Anne Jones, Robert Mowris & Associates

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. The California Public Utilities Commission, NYSERDA, 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, Sony, Honda, Toyota and many other companies have adopted Six Sigma to decrease costs and increase profitability and market share.

IPMVP and Six Sigma have similar objectives with respect to improving performance through measurement and verification of quality and efficiency improvements. IPMVP provides a framework to measure and verify energy efficiency and renewable energy savings. Six Sigma strategies provide 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). Incorporating IPMVP and Six Sigma into program design, implementation, and evaluation will improve reliability and cost effectiveness.

The goal of publicly-funded energy efficiency programs is to transform the market so the societal cost to deliver energy efficiency products and services is included within transactions costs and market intervention is no longer necessary. This goal can be achieved by incorporating IPMVP and Six Sigma into program design, implementation, and evaluation to help consumers, corporations, and government agencies better understand the value of energy efficiency.

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 the savings will last when they invest in energy efficiency projects or programs.

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, 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. 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).

This report provides the historical background, purpose, and objectives of IPMVP and Six Sigma. IPMVP and Six Sigma offer similar approaches to measure and verify performance. 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 program design, implementation, and evaluation will improve reliability and reduce the cost to achieve energy savings.

What Is 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.

Table 1. IPMVP Options

M&V Option	Savings Calculation	Typical Applications
Option A. Partial Measured Retrofit Isolation Savings are determined by short-term or continuous field measurements of energy use, separate from facility energy use. Partial measurement means some parameters may be stipulated.	Engineering calculations using short term or continuous post-retrofit measurements and stipulations.	Lighting retrofit where power draw is measured periodically. Operating hours of the lights 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 of ECM, separate from the energy use of the rest of the facility.	Engineering calculations using short term or continuous measurements	Variable speed drive used on a constant speed fan. Fan motor electricity use is measured with and without the variable speed drive.
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

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. Stipulations based on reasonable assumptions or historical data can be used along with partial field measurements to reduce EM&V costs for some ECMs. 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 conducting evaluations.

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 resulting from implementation of ECMs (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), critical-to-quality (CTQ) characteristics, and cost effectiveness.[1, 2]
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 process improvements for the sample and the population consistent with the EM&V plan.

History of IPMVP

In 1994, the United States Department of Energy (USDOE) started a market transformation initiative to help secure low-interest loans from financial institutions for energy efficiency investments. USDOE envisioned achieving this by developing industry consensus and standard methods to measure and verify energy savings resulting from ECMs. USDOE worked with hundreds of industry experts from the United States, Canada, and Mexico to develop a consensus approach to measuring and verifying energy efficiency investments. The IPMVP was first published in 1996. In 1997, twenty national organizations from a dozen countries worked together to revise, extend, and publish a second version of the IPMVP. The second version was widely adopted internationally, and became the standard EM&V document throughout the world. In 2002, a third edition was published and expanded to include national organizations from 16 countries and hundreds of individual experts from more than 25 nations. The financial advisory subcommittee helped ensure that the third edition is valuable to the financial community in facilitating and enhancing efficiency investment financing. The IPMVP has been translated into Bulgarian, Chinese, Czech, Japanese, Korean, Polish, Portuguese, Romanian, Russian, Spanish, French, and Ukrainian (translated versions are available online at www.ipmvp.org). A fourth edition is being developed for publication in 2006.

The IPMVP has been used for energy efficiency program evaluation in California since 2000 when the California Public Utilities Commission required measurement and verification

[1] 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.
[2] 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).

(M&V) plans "… adhere to the guidelines in the International Performance Measurement and Verification Protocol" for energy efficiency program evaluations (CPUC 2001). The CPUC extended this requirement through 2008 with its *2005 Energy Efficiency Evaluation Protocols* stating that "M&V projects conducted under this protocol shall adhere to the International Performance Measurement and Verification Protocol" (Hall et al. 2005). IPMVP is also required by many state and federal agencies and the World Bank (USDOE 2002). The World Resources Institute is recommending evaluation standards such as IPMVP for the Kyoto Protocol. The US-DOE Federal Energy Management Program and the NYSERDA use IPMVP. The US Green Building Council Leadership in Energy and Environmental Design requires IPMVP.

The Purpose of IPMVP

The purpose of IPMVP is to increase investments in energy efficiency and renewable energy through measurement and verification of energy savings with the following six strategies.

1. **Increase energy savings.** IPMVP provides valuable feedback to increase energy savings, persistence, and reliability (Kats et al. 1997, Haberl et al. 1996).
2. **Reduce cost of financing projects.** Widespread adoption of the IPMVP has made efficiency investments more reliable and profitable and reduced the cost of financing projects.
3. **Encourage best practices engineering.** Incorporating IPMVP into EM&V studies encourages best practices engineering and implementation. Best energy management practices help reduce maintenance problems and increase energy efficiency.
4. **Help demonstrate and capture the value of reduced emissions from energy efficiency and renewable energy investments.** Emissions reductions include CO_2, SO_2, NO_X, and mercury. Failure to include the costs of these emissions has distorted prices and prevented rational and cost-effective energy investment strategies around the world (Kats 1999).
5. **IPMVP increases understanding of energy efficiency benefits as a policy tool.** Benefits include energy savings, employment, community health, and environmental protection.
6. **Help national and industry organizations promote and achieve resource efficiency and environmental objectives.** The IPMVP has been widely adopted by government agencies, industry, and trade organizations to increase investment in energy efficiency. Program evaluations adhering to IPMVP realize greater credibility and reliability.

What Is Six Sigma?

Six Sigma is a performance target that applies to a single critical-to-quality (CTQ) characteristic and focuses on nonconformance within a product or process. It does not refer to the product itself. Products or processes that are complex, such as air conditioners, have greater opportunities for defects especially with respect to their energy efficiency performance that is dependent upon installation quality by air conditioner dealers. 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 1,500 square-foot home were cleaned to a 3.5 sigma level, about 34 square feet of carpet would be left dirty. If the same carpet were cleaned to Six Sigma, the dirty carpet area would be less than ½ square inch.

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). The first strategy is *recognizing* the true states of the business.[3] The second strategy is *defining* what plans must be in place to realize improvement. The third strategy is *measuring* the business system that supports the plans. The fourth strategy is *analyzing* gaps in system performance benchmarks. The fifth strategy is *improving* system elements to achieve performance goals. The sixth strategy is *validating* measurement systems and *controlling* the process. The seventh strategy is *standardizing* systems that prove to be "best-in-class" and transfer this knowledge to all relevant sectors in the business. The eighth strategy is *integrating* best-in-class systems into business operations through recognition and rewards.

Companies operating below a three sigma level usually don't survive because the cost of quality below a three sigma level is roughly 25 to 40% of sales revenue. At a Six Sigma level, the cost of quality declines to less than 1% of sales revenue. When General Electric reduced its cost of 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 corporations are adopting Six Sigma strategies and why Six Sigma strategies should be incorporated into energy efficiency program design, implementation, and evaluation.

History of Six Sigma

Six Sigma was conceived at Motorola in 1979 when executive Art Sundry stood up at a management meeting and proclaimed, "The real problem at Motorola is that our quality stinks!" Sundry's proclamation started a new era at Motorola and led to the discovery of the crucial correlation between higher quality and lower development costs in manufacturing products. At a time when most American companies believed that quality cost more money, Motorola realized that done right, improving quality would actually improve production efficiency and reduce costs. They believed that high-quality products should cost less to produce, not more, and that the highest-quality producer should be the lowest-cost producer. At the time, Motorola was spending 5 to 10 percent of annual revenues, and in some cases 20 percent of revenues, correcting poor quality. This was costing $800 million to $900 million each year, money that with higher-quality processes could be returned directly to their bottom line.

As Motorola executives began looking for ways to cut waste, Bill Smith, an engineer in the communications sector, was quietly working behind the scenes studying the correlation between a product's life and how often the product had been repaired during the manufacturing process. In 1985, Smith published a paper showing that if a product was found defective and corrected during the production process, other defects were bound to be missed and found later by the customer during early use of the product. However, when the product was manufactured error-free, it rarely failed during early use by the consumer. Smith's findings triggered a debate in Motorola. Was the effort to achieve quality dependent on detecting and finding defects? Or could quality be achieved by preventing defects in the first place through better product design

[3] Business states are inseparable from business systems. For example, delivery of a defect-free product or service depends on how the business measures quality. On-time delivery requires reliable material acquisition and scheduling systems. Delivery at the lowest cost requires good accounting and management systems.

and manufacturing controls? Detecting and fixing defects (i.e., total quality management programs) led Motorola to only four sigma (6,210 defects per million opportunities) – placing it slightly ahead of the average American company. At the same time, foreign competitors were making products that required no repair or rework during the production process.

If hidden defects caused product failure shortly after the consumer began using it, something had to be done to improve the product design and manufacturing process. Motorola began its quest to improve quality and simultaneously reduce production time and costs by focusing on how a product is designed and made. It was this link between higher quality and lower cost that led to the development of Six Sigma – an initiative that at first focused on improving quality through the use of exact measurements to anticipate problems and not just to react to quality issues. Six Sigma strategies allowed Motorola executives to be proactive, rather than reactive, to quality issues. The difference between previous total quality management approaches (TQM) and Six Sigma is that TQM focuses on improvements in individual operations with unrelated processes taking many years before all operations within a process are improved. Six Sigma focuses on making improvements in all operations with a process producing results far more rapidly and effectively.

A quantum leap in manufacturing technology occurred when Motorola applied Six Sigma to developing its Bandit pager. Motorola's engineers designed a pager that could be produced in an automated factory in Florida. Pagers could be ordered with various options and custom-built for customers within seventy-two minutes from the time an order was placed by computer from any Motorola sales office. The Bandit pager's superior design and manufacturing process resulted in a product that was virtually defect-free with an average life expectancy of 150 years.

The Purpose of Six Sigma

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.** A business state describes conditions created by systems used to guide and manage. Companies and programs cannot improve what they do not measure. When measurement is "fuzzy," so is improvement.
2. **Define what plans must be in place to realize improvements of each state.** Once companies have defined and characterized their business states, they can begin to creatively think about how to achieve a higher level of performance. They 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. The first is what to measure and when to measure. The second is how to measure. The third is gaining approval to go after the right measurements. 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 the gaps in system performance benchmarks helps to understand energy efficiency performance and savings. Program implementers can diagnose and assess performance gaps by continually measuring performance metrics (i.e., savings) and linking these measurements to 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 CTQ characteristics. Elements used to create solutions must be monitored and analyzed to identify and control system-level CTQ characteristics.
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 best practices and transfer the knowledge to all relevant sectors in the business or program.
8. **Integrate best-in-class systems into the strategic planning framework**. Organizations have difficulty adopting, standardizing, and integrating 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.

IPMVP and Six Sigma Objectives

IPMVP and Six Sigma have similar objectives with respect to improving performance through measurement and verification of quality and efficiency improvements. IPMVP provides a rigorous framework to measure and verify energy efficiency and renewable energy savings. Six Sigma strategies provide 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 approaches to measure and verify performance (**Table 2**).

Table 2. IPMVP and Six Sigma Strategies

IPMVP	Six Sigma Strategies
1) **Recognize or Select** IPMVP Option(s) consistent with the energy conservation measures in the project or program.	1) **Recognize** the true states of the business and systems of delivering: 1) defect-free products or services, 2) on-time/schedule, 3) lowest cost.
2) **Define** the boundaries and gather relevant energy and operating data for base year.	2) **Define** what plans must be in place to realize improvement.
3) **Measure** or evaluate ex ante program assumptions, measures, percent savings, CTQ characteristics and upper limit of savings.	3) **Measure** the business system that supports the plans and frequency of defects. Select CTQ characteristics, define performance standards, and validate systems.
4) **Prepare** a Measurement and Verification Plan. The M&V plan is used to **analyze** savings or gaps in savings for each project or program.	4) **Analyze** gaps in performance when and where CTQ defects occur. Establish product capability, define performance objectives, and identify variation sources.
5) **Design**, **install, and test** measurement equipment needed for the M&V plan.	5) **Improve** systems to achieve performance goals. Establish causes, variable relationships, and operating tolerances.
6) **Verify or Commission** as programs are implemented, inspect installed measures and operations to ensure compliance with EM&V plan.	6) **Control** or verify system-level CTQ characteristics so process stays fixed. Validate measurement system, determine process capability, and implement controls.
7) **Gather energy and operating data** from post-retrofit period consistent with M&V plan.	7) **Standardize** and adopt systems that prove to be best-in-class.
8) **Compute and report savings** and process evaluation recommendations based on findings.	8) **Integrate** best-in-class systems into products, services, policies, procedures, programs, and portfolios.

EM&V studies 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 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, and evaluation.

IPMVP and Six Sigma strategies can improve laboratory testing methods used to establish energy efficiency performance labels and standards. Energy efficiency labels are unreliable due to lack of similitude between field and laboratory testing conditions, manufacturing defects, improper installation, and maintenance.[4] Random testing of energy efficiency performance is not required under Federal energy efficiency standards for boilers, air conditioners, refrigerators, freezers, showerheads, and other products. Instead energy efficiency performance testing is conducted once on a prototype or early production model in a laboratory environment where the test procedure is dissimilar to typical field conditions. Field measurements of rated products indicate efficiency performance problems due to design, manufacturing, and installation defects.

For air conditioners, the American Refrigeration Institute (ARI) laboratory test procedure is required for original equipment manufacturers (OEM). The ARI test requires locating the evaporator coil in conditioned space at 78°F (ARI 2003). Most air conditioner evaporator coils are located in unconditioned spaces such as hot attics (Mowris et al. 2004). The ARI laboratory test procedure yields higher seasonal energy efficiency ratios (SEER) and energy efficiency ratios (EER) than would be possible under typical field conditions.[5] In hot climates SEER ratings over-predict efficiency performance by approximately 30% (Hirsch 2004). Independent Coil Manufacturers (ICM) develop ARI ratings for their coils using computer simulations. Field measurements of ICM evaporators with OEM condensers indicate up to 35% lower EER values (i.e., 6.5 EER versus 10 EER) compared ARI ratings (**Table 3**).

Table 3. Field Measurements for Two New Split-System Air Conditioners

Site	Rated EER	Rated Capacity MBtuh	Measured Cooling Capacity Post MBtuh	Average Outdoor, Indoor Dry/Wet Bulb °F	Airflow (cfm)	Duct Leak cfm @ 25 Pa	Infil. cfm @ 50 Pa	Pre EER	Post EER	Service Adjust Oz.	Charge Adjust per Factory Charge
#1	10	51	38.5	105/81/65	1631	19%	1830	3.9	6.5	+98.2	+49.4%
#2	10	51	41.6	105/80/64	1734	12%	1537	5.5	6.5	+12.5	+6.3%

Note: Rated EER values are based on OEM data. Source: Mowris et al. 2004a

[4] Similitude is used in the testing of engineering models and performance. A model has similitude with the in-situ application if the two share geometric kinematic, dynamic, or thermodynamic silimarity.

[5] SEER is an adjusted rating based on steady-state EER measured at standard conditions of 82°F outdoor and 80°F drybulb/67°F wet bulb indoor temperature multiplied by 0.875 Part Load Factor (ARI 2003). EER is the cooling capacity in thousand British Thermal Units per hour (MBtuh) divided by total air conditioner electric power (kW). The Btu is the energy required to raise one pound of water one degree Fahrenheit. EER is typically measured in a laboratory at 95°F condenser entering air and 80°F dry bulb and 67°F wet bulb evaporator entering air.

Pre-EER values were measured with improper refrigerant charge and airflow (RCA), and post-EER values were measured after correcting RCA. The post-EER is 6.5 or 35 percent less than the 10 EER rating.[6] Most new homes in California receive ICM evaporator coils. Condensing coil manufacturers cannot guarantee rated efficiency per the ARI SEER/EER ratings when OEM condensers are matched with ICM evaporator coils.

Approximately six million new residential and small commercial air conditioners are installed in the United States each year (ARI 2004). Approximately 50 to 67 percent of these systems are installed with improper RCA causing them to operate 10 to 20 percent less efficiently than if they were properly installed (Mowris et al. 2004, Neme 1998). This represents a 2.1 sigma level. The relative efficiency gains due to proper RCA for a random sample of ten commercial air conditioners are shown in **Table 4**.[7] The average efficiency gain is 22.2 percent. Relative efficiency gains are applicable to normal operating conditions since the change in EER as a function of RCA is independent of operating conditions (O'Neal 1990).

Table 4. Measurements of Efficiency Gain for Commercial Packaged Air Conditioners

Site	Tons	Factory Charge oz.	Charge Adjust +Add -Remove	Rated SEER/ EER	Pre-EER	Post-EER	Relative Efficiency Gain	Average Outdoor Temp °F	Airflow cfm/ton	Notes
1	10	323	Okay	11	10.4	10.4	n/a	74	280	New Unit
2	10	200	-7.1%	10.3	5.7	10.3	80.7%	83	383	New Iced Coil
3	5	192	+13.8%	13	9	10.1	12.2%	98	296	New Unit
4	2	85	-3.5%	12	9.1	9.4	3.3%	95	409	New Unit
5	5	156	Okay	13	11	11	n/a	70	366	New Unit
6	5	156	Okay	13	11	11	n/a	70	327	New Unit
7	15	n/a	Okay	10.8	n/a	n/a	n/a	70	n/a	New Unit
8	4	166	-9.4%	11	8.6	9.3	8.1%	70	255	New Unit
9	5	126	+13.7%	n/a	6.2	7	12.9%	72	289	Old Unit
10	10	250	+13.8%	n/a	5.6	6.5	16.1%	72	366	Old Unit
Ave	**7.1**	**183.8**	**9.5%**	**11.8**	**8.5**	**9.4**	**22.2%**	**77.4**	**330**	

Source: Mowris et al. 2005

Field measurements of a new high efficiency 10-ton packaged rooftop air conditioner are shown in **Figure 1**. The air filter and evaporator coil were dirty and covered with ice and the air conditioning unit was overcharged by 14.2 ounces or 7.1 percent of the factory charge of 200 ounces. The evaporator coil was de-iced and cleaned and new air filters were installed. Prior to performing the AC tune-up, the average efficiency was 5.7 EER, and average power usage was 13 kW. After performing the AC tune-up, the efficiency improved to 10.3 EER, and the average power usage was reduced to 9.5 kW. This is consistent with the ARI rating of 10.3 EER.

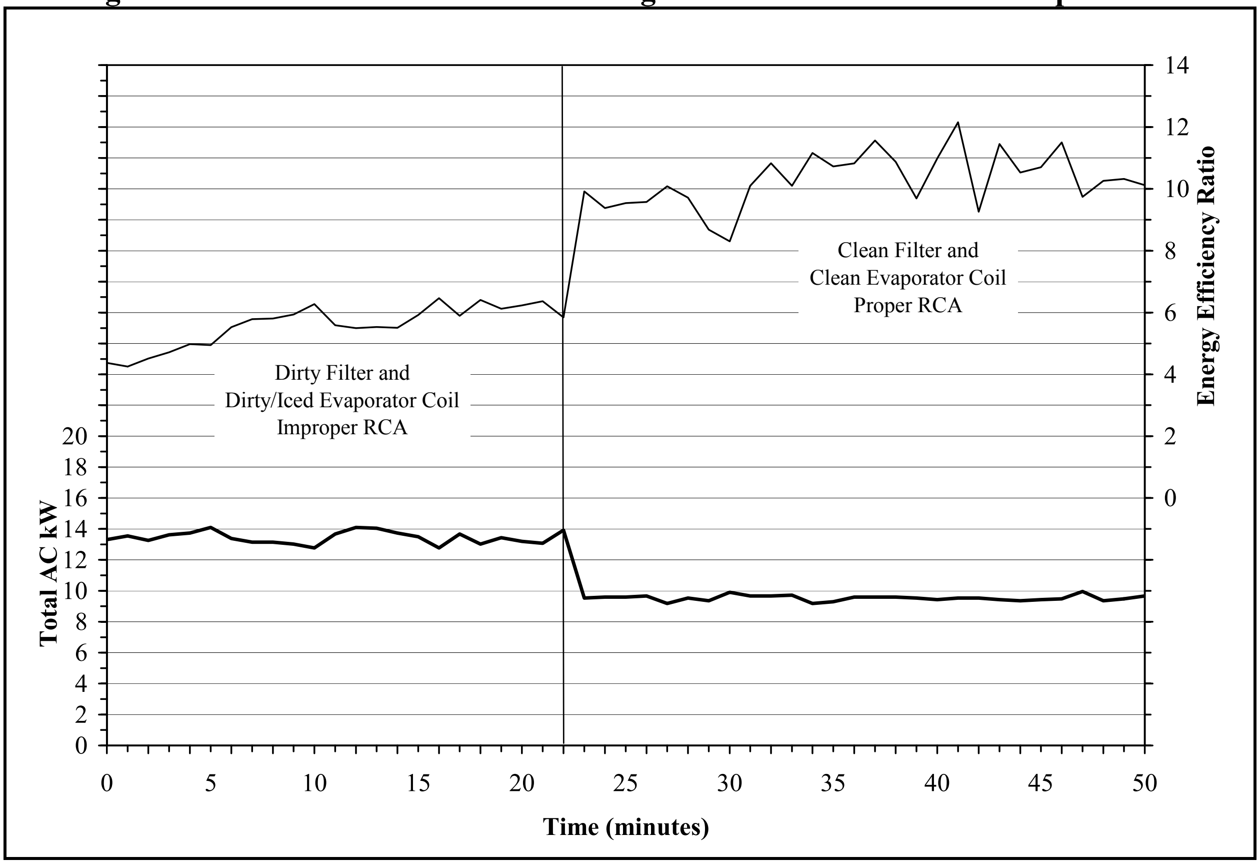
One of the most important problems affecting the performance of this packaged air conditioner (and similar units) was the air filter being too close to the evaporator coil. When the filter got dirty, the airflow decreased and the pressure increased causing the filter to impinge on the evaporator coil. This caused water to condense onto the cold evaporator coil and ice formation which eventually covered the filter, evaporator coil, suction line, and compressor. Besides increasing power consumption and decreasing energy efficiency, refrigerant

[6] EER field measurements were made at non-standard temperature conditions (i.e., not at 95°F outdoor temperature or 80°F dry-bulb/67°F wet-bulb inlet conditions). EER field measurements are not directly comparable to laboratory measurements at standard conditions where airflow, return air, and condenser air temperatures are controlled.

[7] Cooling capacity is provided in tons. The "ton" is defined as 12,000 Btu per hour of cooling capacity or the latent heat extraction rate to produce one short ton of ice (i.e., 144 Btu per pound) from water at the same temperature.

overcharging and dirty/iced evaporator coils also cause a phenomenon known as "slugging" where liquid refrigerant enters the compressor cylinders. Slugging will reduce the effective useful lifetime of the compressor by causing broken valves and other major compressor damage.

Figure 1. Measurements of 10-Ton Packaged Unit with and without Proper RCA



Source: Mowris et al. 2005

For refrigerators and freezers, the DOE Test Method uses an ambient temperature of 90°F with no cabinets or walls immediately adjacent to the units (AHAM 1995). Typical installations especially with larger units have cabinets surrounding the sides and top and a wall in the back. Having surfaces immediately adjacent to the unit creates different operating conditions and heat transfer compared to the DOE Test Method. Improper refrigerant charge and manufacturing defects can also cause reduced efficiency. Field studies of refrigerators and freezers indicate energy use can be 15 to 65% greater than the DOE Test Method (Mowris et al. 2005).

For boilers, the ANSI Z21.13-2000 test procedure uses an 80°F inlet temperature and 180°F outlet temperature. These inlet/outlet temperatures are not typical of normal field conditions where average inlet temperatures are 115°F and average outlet temperatures are 146°F. This causes boiler efficiency ratings to be 3 to 11 percent higher than field-measured efficiencies (Mowris et al. 2004b).

For showerheads, the ASME A112.18.1M-1996 test procedure is used to limit maximum flow rates to 2.5 gallons per minute (gpm) at a flowing pressure of 80 pounds per square inch (psi) (ASME 1996). Many showerheads do not have pressure-compensating valves to allow 2.5 gpm at lower flowing pressures (Mowris et al. 2004c). Consequently, many consumers and hospitality businesses have installed multiple showerheads or are disabling flow restrictors to increase water flow rates by 100 percent or more causing increased water and energy usage. The difference between a qualifying showerhead and pressure-compensating showerhead is important to realize energy and water savings and improve retention.

EM&V protocols should consider the importance of field measurements consistent with IPMVP and Six Sigma to benchmark in-situ performance against laboratory performance. Retention studies that only observe the presence of an energy efficiency product without field measurements might misunderstand and misreport the technical degradation of the product. Energy efficiency products are designed, manufactured, and installed with different specifications and procedures. Degradation of performance can occur in the first year and will not be fully understood without field measurements. Evaluation and retention studies that adhere to IPMVP and Six Sigma will better understand failure mechanisms, improper laboratory-testing procedures, design/manufacturing/installation defects, and CTQ characteristics.

Conclusions

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.

IPMVP and Six Sigma have similar objectives with respect to improving performance through measurement and verification of quality and efficiency improvements. IPMVP provides a framework to measure and verify energy efficiency and renewable energy savings. Six Sigma strategies provide 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). Incorporating IPMVP and Six Sigma into program design, implementation, and evaluation will improve reliability and cost effectiveness.

IPMVP and Six Sigma strategies can improve laboratory testing methods for energy efficiency by requiring similitude between field and laboratory testing conditions. IPMVP and Six Sigma can be used to establish random testing procedures of energy efficiency performance within future energy standards for new and existing buildings, equipment, and appliances. This will motivate consumers, corporations, and government agencies to value energy efficiency on the same level as other investments and reduce market barriers. The ultimate goal of publicly-funded energy efficiency programs is to transform the market so the societal cost to deliver energy efficiency products and services is included within transactions costs and market intervention is no longer necessary (i.e., exit strategy). This goal can be achieved by incorporating IPMVP and Six Sigma strategies into program design, implementation, and evaluation to help consumers, corporations, and government agencies better understand the value of energy efficiency.

References

American Refrigeration Institute (ARI). 2003. *2003 Standard for Unitary Air Conditioning and Air-Source Heat Pump Equipment.* ARI 210/240-2003. Arlington, Va.: American Refrigeration Institute. DOE Test Method as specified in 10 CFR, Section 430.23(b), 1995

American Refrigeration Institute (ARI). 2004. *ARI Statistical Release of Unitary Heating and Cooling Section's Reports of U.S. Manufacturers Shipments.* Arlington, Va.: American Refrigeration Institute. Available online: http://www.ari.org/sr/2003.

American Home Appliance Manufacturers (AHAM). 1998. *Method for Determining the Energy Consumption of Household Refrigerators*, Association of Home Appliance Manufacturers (AHAM), AHAM HRF-1-2001 (Revision of ANSI/AHAM HRF-1-1998).

American National Standards Institute (ANSI). 2000. Gas-Fired Low Pressure Steam and Hot Water Boilers. ANSI Z21.13-2000.

American Society of Mechanical Engineers (ASME). 1996. *Plumbing Fixture Fittings: An American National Standard.* ASME A112.18.1M-1996. Revision of ASME A112.18.1M-1994. New York, New York: American Society of Mechanical Engineers.

California Public Utilities Commission (CPUC), 2001. Energy Efficiency Policy Manual, prepared by the Energy Division. San Francisco, Calif: Available online: www.cpuc.ca.gov/.

Haberl, J., Readdy, A., Claridge, D., Turner, D., O'Neal, D., Heffington, W. 1996. Measuring Energy-Savings Retrofits: Experience from the Texas LoanSTAR Program. Oak Ridge National Laboratory Report No. ORNA/Sub/93-SP090/1.

Hall, N., Barata, S., Chernick, P., Jacobs, P., Keating, K., Kushler, M., Migdal, L., Nadel, S., Prahl, R., Reed, J., Vine, E., Waterbury, S., Wright, R. 2004. *The California Evaluation Framework,* San Francisco, Calif.: California Public Utilities Commission. Available online: http://www.cpuc.ca.gov/.

Hall, N., Barata, S., Jacobs, P., Keating, K., Kromer, S., Megdal, L., Peters, J., Ridge, R., Trottier, F., Vine, E. 2005. *The 2005 California Energy Efficiency Evaluation Protocols*. page 44. San Francisco, Calif.: CPUC. Available online: http://www.cpuc.ca.gov/.

Hall, N., P., Jacobs, Best, C., Migdal, L., 2005b. *California 2002-2003 Portfolio Energy Efficiency Program Effects and Evaluation Summary Report.* San Francisco, Calif.: California Public Utilities Commission. Available online: http://www.cpuc.ca.gov/.

Harry, M., Schroeder, R. 2000. *Six Sigma.* New York, New York: Doubleday.

Hirsch, J. 2004. EER & SEER as Predictors of Seasonal Cooling Performance: Summary Research. Prepared for Southern California Edison Company. Irwindale, Calif.

Kats, G., Rosenfeld, A., McGaraghan, S. 1997. *Energy Efficiency as a Commodity: The Emergence of an Efficiency Secondary Market for Savings in Commercial Buildings*. Proceedings if the ECEEE 1997 Summer Study, Vol. 1, Panel 2.

Kats, G., Kumar, S., Rosenfeld, A., 1999. *The Role for an International Measurement & Verification Standard in Reducing Pollution*. Proceedings if the ECEEE 1999 Summer Study, Vol. 1, Panel 1.

Mowris, R., Blankenship, A., Jones, E. 2004. *Field Measurements of Air Conditioners with and without TXVs.* In Proceedings of 2004 ACEEE Summer Study on Energy Efficiency in Buildings, Washington, D.C.: American Council for an Energy-Efficient Economy.

Mowris, R., Blankenship, A., Jones, E. 2004a. *EM&V Report for the Residential Ground Source Heat Pump Program.* prepared for Redding Electric Company, Redding, Calif.

Mowris, R., Blankenship, A., Jones, E. 2004b. *EM&V Report for the Local Small Commercial Energy Efficiency & Market Transformation Program #208-02,* prepared for Energx Controls, Inc., Cypress, Calif. Available online: www.calmac.org.

Mowris, R., Blankenship, A., Jones, E. 2004c. *Evaluation, Measurement, and Verification Report for the Local Gas-Only Multifamily Efficiency Program #197-02*, prepared for SESCO, Inc, Lake Hopatcong, New Jersey. Available online: www.calmac.org.

Mowris, R., Blankenship, A., Jones, E., Noack, R. 2005. Measurement & Verification Load Impact Study for NCPA Senate Bill 5X Programs, prepared for Northern California Power Agency and the California Energy Commission. Olympic Valley, Calif.: Robert Mowris & Associates. Available online: http://www.calmac.org.

Neme, C., Nadel, S., and Proctor, J. 1998. *National Energy Savings Potential from Addressing HVAC Installation Problems*, Vermont Energy Investment Corporation, prepared for US Environmental Protection Agency.

O'Neal, D., Farzad, M. 1990. "The Effect of Improper Refrigerant Charging on Performance of an Air Conditioner with Capillary Tube Expansion." *Energy and Buildings* 14: 363-371.

Rufo, M. 2004. The National Energy Efficiency Best Practices Study. Berkeley, Calif: Quantum Consulting, Inc. Available online: www.eebestpractices.com).

United States Department of Energy (USDOE). 2002. International Performance Measurement & Verification Protocols: Concepts and Options for Determining Energy and Water Savings. Volume I. DOE/GO-102000-1132. Washington, D.C.: United States Department of Energy. Available online: www.ipmvp.org.