

# Improving standards and labels with IPMVP and Six Sigma strategies

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## Abstract

Efforts to improve energy efficiency and mitigate global warming through equipment and appliance standards and labels have been somewhat hampered by differences in energy consumption between actual and labeled energy use. In some cases actual energy use is 50 to 200 % greater than labeled energy use. The International Performance Measurement and Verification Protocol (IPMVP) can be used to evaluate standards and labels to improve performance. 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. Greenhouse gas trading policy encourages rigorous EM&V by applying savings discount factors tied to IPMVP Options. Efforts to increase customer satisfaction, resource efficiency, and improve profitability have 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. Companies implementing Six Sigma find that 70 to 80 percent of the total cost of a product or service is determined in the design stage. The higher the quality of energy efficiency designed into a product, the lower its lifecycle costs. IPMVP and Six Sigma share similar objectives with respect to reducing lifecycle costs and improving performance through measurement and verification of quality and efficiency improvements. IPMVP provides a framework to

measure and verify energy efficiency performance. 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 appliance standards and labels will improve reliability and ensure that labeled energy use is closer to actual energy use.

## Introduction

Equipment and appliance standards and labels offer significant and cost-effective opportunities for industrialized and developing countries to reduce the financial, health, and environmental costs associated with burning fossil fuels and mitigate global warming (CLASP 2007, USDOE 2002).<sup>1</sup> Available cost-effective global investments in energy and water efficiency are estimated to be tens of billions of dollars per year. Customers, businesses, utilities, and government agencies need to know how much energy will be saved and how long the savings will last from appliance standards and labels programs.

The International Performance Measurement and Verification Protocol (IPMVP) has become a worldwide standard for evaluation, measurement, and verification (EM&V) of energy savings. The California Public Utilities Commission, NYSERDA, the World Bank, and many government agencies require adherence to IPMVP. The World Resources Institute is recom-

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1. Since 1999, the Collaborative Labeling and Appliance Standards Program (CLASP) has assisted with the implementation of 21 new minimum energy performance standards, energy efficiency endorsement labels, and energy information labels that will save 250 megatonnes of CO<sub>2</sub> by 2014. CLASP's goal is to support S&L programs that reduce total anthropogenic CO<sub>2</sub> emissions by 3 % by 2030.

mending 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 and Schroeder 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 appliance standards and labels programs will improve reliability and ensure that labeled energy use is closer to actual energy use.

## IPMVP

The IPMVP is a resource savings-verification tool applicable to residential and non-residential energy efficiency projects and programs. It is also applicable to equipment and appliance standards and labels. The IPMVP defines four options to quantify energy savings (**Table 1**). IPMVP Options A and B are applicable to evaluating the performance of standards and labels.

None of the four IPMVP options allow exclusive use of stipulated values. According to IPMVP, whenever a parameter is not measured, it is stipulated. Unreasonable stipulations create risks and uncertainties especially when standards and labels are based on uncalibrated computer simulations or one-time measurements of pre-production equipment or appliance prototype.

The IPMVP has been used for energy efficiency program evaluation in California since 2000 when the California Public Utilities Commission required measurement and verification (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 NYSERDA use IPMVP. The US Green Building Council Leadership in Energy and Environmental Design requires IPMVP.

The costs of evaluating energy and peak demand savings will depend on the overall accuracy and precision goals of the analysis as defined in the evaluation plan (Hall et al. 2004). In general, IPMVP Option A is the least accurate and least costly option. IPMVP Options B or D, are generally the most accu-

rate and most costly options depending on the measure. 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%.<sup>2</sup> Selection of the IPMVP Option is a balance between accuracy and cost. Approaches for striking this balance vary. For example, ASHRAE Guideline 14 takes a quantitative approach, where the risk in the uncertainty is calculated from the energy value of the difference between the savings estimates at the upper and lower ends of the confidence interval (ASHRAE 2002). Improvements to the EM&V approach are introduced iteratively, with the incremental M&V costs compared to the reduction in savings risk. The literature on greenhouse gas trading policy encourages rigorous EM&V by applying savings discount factors tied to the EM&V option.<sup>3</sup> The USEPA Conservation Verification Protocols direct the evaluator to report verified savings at the low end of the confidence interval, thus encouraging more precise estimates.<sup>4</sup>

## 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 have greater opportunities for defects especially with respect when energy efficiency performance 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). The following Six Sigma strategies are relevant to improving standards and labels programs.<sup>5</sup> The first strategy is measuring the frequency of defects. There are three obstacles to measuring: the first is what to measure and when to measure, the second is how to measure, and 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 guidelines identified in the National Energy Efficiency Best Practices Study (Rufo 2004). The second strategy is analyzing gaps between actual and labeled energy use. Analyzing gaps is accomplished by continually measuring performance metrics and linking these measurements to process improvements. The third strategy is improving system elements to achieve

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

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

5. Six Sigma includes eight strategies (see Harry and Schroeder 2000).

Table 1. IPMVP Options

IPMVP Option	Savings Calculation	Typical Applications
<b>Option A. Partial Measured Retrofit Isolation</b> 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.	Appliance where power draw is measured periodically. Operating hours are measured with loggers.
<b>Option B. Retrofit Isolation</b> Savings are determined by short-term or continuous measurements of energy use.	Engineering calculations using short term or continuous measurements.	Appliances or equipment where electricity use is measured and compared to labeled energy use.
<b>Option C. Whole Facility</b> 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.
<b>Option D. Calibrated Simulation</b> 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

Table 2. IPMVP and Six Sigma Strategies

1) <b>Measure</b> labeled energy use following an Evaluation, Measurement, and Verification (EM&V) plan consistent with IPMVP, measure frequency of defects and Critical to Quality (CTQ) Characteristics, define performance standards, and validate systems.
2) <b>Analyze</b> energy efficiency performance, gaps in performance, when and where CTQ defects occur. Define performance objectives and sources of variation.
3) <b>Improve</b> systems to achieve performance goals based on process evaluation results. Establish potential causes, variable relationships, and operating tolerances.
4) <b>Control</b> or verify system-level CTQ characteristics so process and product energy efficiency performance stays fixed. Validate measurement system, determine process capability, and implement controls. Standardize and adopt best-in-class systems.

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. The fourth strategy is controlling CTQ characteristics to achieve the labeled energy efficiency performance goal. Regular 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. The application of these strategies will improve the reliability of existing programs and lead to the development of improved standards and labels programs.

Companies implementing Six Sigma find that 70 to 80 percent of the total cost of a product or service is determined in the design stage (Harry 2000). The higher the quality of energy efficiency designed into a product, the lower its lifecycle cost. In order to ensure that energy efficiency is incorporated into improved designs of products, marketing and engineering need to compile rigorous data about field performance of energy efficiency. Businesses that achieve significant energy efficiency quality improvements earn higher prices and are more profitable compared to companies with inferior energy efficiency.

### 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). The four strategies are summarized in Table 2.

The EM&V protocols in California require adherence to the IPMVP to obtain more rigorous load impact evaluations (Hall et al. 2005b, Hall et al. 2005). Incorporating IPMVP and Six Sigma strategies in standards and labels programs will yield more reliable and cost effective energy and peak demand savings. The ultimate goal of standards and labels is to help customers make informed purchasing decisions with respect to energy use. This goal can be achieved by incorporating IPMVP and Six Sigma strategies into standards and labels programs to improve reliability and help consumers, corporations, and government agencies better understand the value of energy efficiency.

IPMVP and Six Sigma strategies can improve laboratory testing methods used to establish energy efficiency performance standards and labels. Energy efficiency labels are currently unreliable due to lack of similitude between field and laboratory testing conditions, manufacturing defects, improper

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

Site	Rated EER	Rated Capacity kW	Measured Cooling Capacity Post kW	Average Outdoor, Indoor Dry/Wet Bulb °C	AC Unit Airflow litre/s	Duct Leak Litre/s @ 25 Pa	Bldg. Infil. litre/s @ 50 Pa	Pre EER	Post EER	Service Adjust kg	Charge Adjust per Factory Charge
#1	2.93	14.94	11.28	41/27/18	770	19 %	863.8	1.2	1.9	+2.78	+49.4 %
#2	2.93	14.94	12.19	41/25/18	818	12 %	725.5	1.6	1.9	+0.35	+6.3 %

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

installation, and maintenance (Mowris et al. 2004, Mowris et al. 2005, Tsurusaki et al. 2006).<sup>6</sup> 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 25.56°C (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.<sup>7</sup> 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., 1.9 EER versus 2.93 EER) compared ARI ratings (Table 3).

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 1.9 or 35 percent less than the 2.93 EER rating.<sup>8</sup> 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. A recent EM&V study prepared for the US Environmen-

tal Protection Agency (EPA) Installation Pilot Commissioning Project found that cooling equipment was oversized by  $63 \pm 29$  percent and the heating equipment was oversized by  $117 \pm 48$  percent (Mowris 2006). The potential peak demand savings from properly sizing air conditioners are estimated to be approximately  $0.95 \pm 0.4$  kW per site. These findings are consistent with published studies of peak demand savings ranging from  $1 \pm 0.6$  kW from proper sizing (Sonne and Parker 2006).

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. 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).

Field measurements of a new high efficiency 35.16 kW 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 0.426 kilograms (kg) or 7.1 percent of the factory charge of 6 kg. 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 1.67 EER, and average power usage was 13 kW. After performing the AC tune-up, the efficiency improved to 3.02 EER, and the average power usage was reduced to 9.5 kW. This is consistent with the ARI rating of 3.02 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 became 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 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.

For refrigerators and freezers, the DOE Test Method uses an ambient temperature of 32.2°C with no cabinets or walls immediately adjacent to the units (AHAM 1995). Typical installations especially with larger units have cabinets surrounding the

6. 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 similarity.

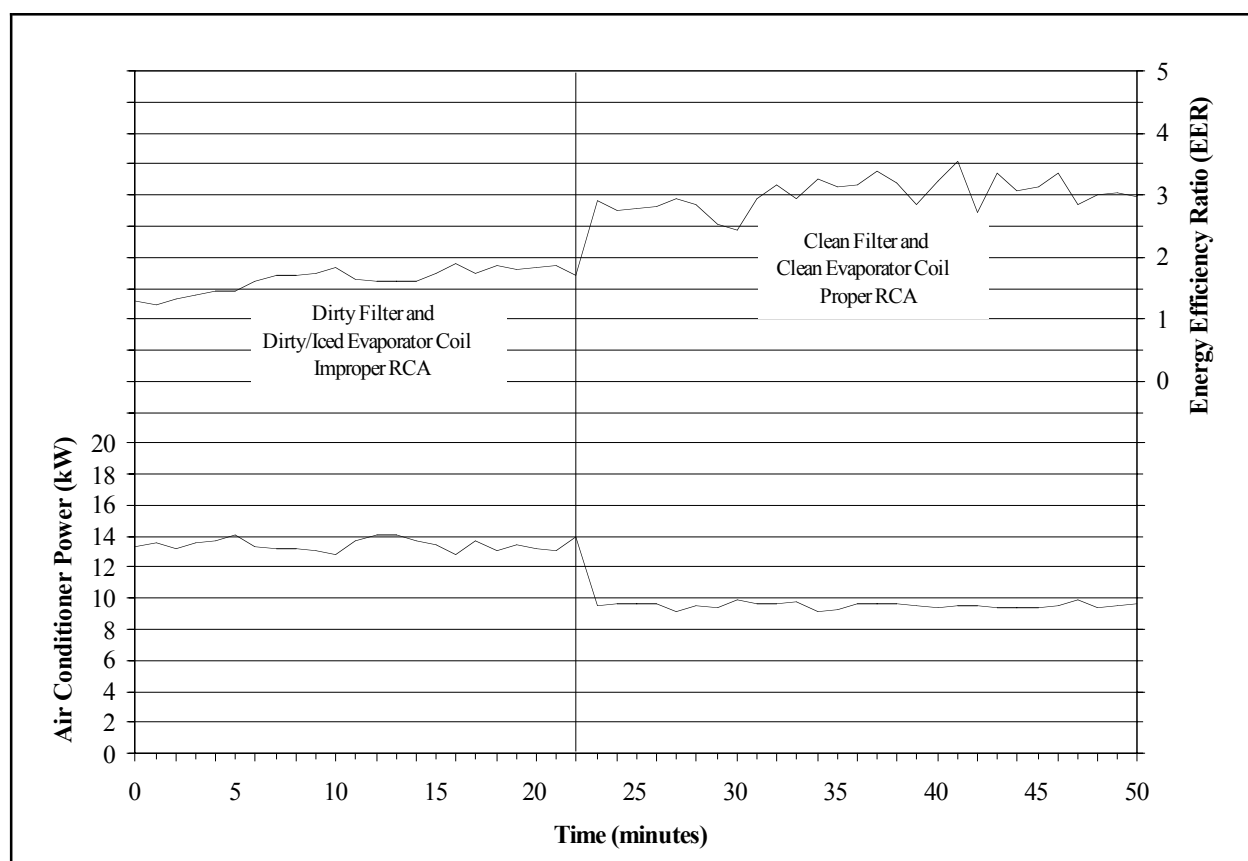
7. In the United States the SEER and EER are defined as the cooling capacity in British thermal units (Btu) per hour divided by total air conditioner electric power input (kW) including indoor fan, outdoor condensing fan, compressor, and controls. The Btu is the energy required to raise one pound of 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 indoor evaporator return temperatures of 26.7°C drybulb and 19.4°C wet bulb (ARI 2003). 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.

8. 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.

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

Site	kW	Factory Charge kg	Charge Adjust +Add -Remove	Rated SEER/ EER	Pre-EER	Post-EER	Relative Efficiency Gain	Average Outdoor Temp °C	Airflow litre/s-kW	Notes
1	35.2	9.2	Okay	3.2	3.0	3.0	n/a	28.3	37.6	New Unit
2	35.2	5.7	-7.1 %	3.0	1.7	3.0	80.7 %	33.3	51.5	Iced Coil
3	17.6	5.4	+13.8 %	3.8	2.6	3.0	12.2 %	41.7	39.8	New Unit
4	7.0	2.4	-3.5 %	3.5	2.7	2.8	3.3 %	40.0	55.0	New Unit
5	17.6	4.4	Okay	3.8	3.2	3.2	n/a	26.1	49.2	New Unit
6	17.6	4.4	Okay	3.8	3.2	3.2	n/a	26.1	43.9	New Unit
7	52.7	n/a	Okay	3.2	n/a	n/a	n/a	26.1	n/a	New Unit
8	14.1	4.7	-9.4 %	3.2	2.5	2.7	8.1 %	26.1	34.3	New Unit
9	17.6	3.6	+13.7 %	n/a	1.8	2.1	12.9 %	27.2	38.8	Old Unit
10	35.2	7.1	+13.8 %	n/a	1.6	1.9	16.1 %	27.2	49.2	Old Unit
<b>Ave</b>	<b>25.0</b>	<b>5.2</b>	<b>9.5 %</b>	<b>3.5</b>	<b>2.5</b>	<b>2.8</b>	<b>22.2 %</b>	<b>30.2</b>	<b>44.4</b>	

Source: Mowris et al. 2005

**Figure 1. Measurements of a New 35.2 kW Packaged Unit with and without Proper RCA. Source: Mowris 2005.**

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. Refrigerators are not verified per IPMVP or Six Sigma for compliance with the FTC Energy Guide yellow label. Field studies of refrigerators and freezers indicate energy use can be 80 to 135 % greater than the DOE Test Method as shown in **Figure 2**. In Japan from 1999 to 2004, the labeled annual electricity consumption of refrigerator-freezers was reduced to 290 kWh/year or 55 % less than the base 1999 year (Tsurusaki et al. 2006). However actual electricity consumption was 100 to 200 percent greater than labeled values (based on tests conducted from 2001-04 by the Consumer Associa-

tion and National Consumer Affairs Center of Japan). Japan is adopting the 4th refrigerator-freezer standard in 2006 (JIS C9801-revised) to develop more accurate labels (i.e., multiple settings, more door openings, closer to walls, greater ambient temperatures, etc.).

For boilers, the ANSI Z21.13-2000 test procedure uses a  $26.7 \pm 1.67^\circ\text{C}$  inlet temperature and  $82.2 \pm 0.91^\circ\text{C}$  outlet temperature (ANSI 2000). Boiler efficiencies and average inlet/outlet temperatures were evaluated for a natural gas boiler efficiency program in California following IPMVP Option B.<sup>9</sup> The first-

9. Field measurements of boiler thermal efficiencies were made using a combustion efficiency analyzer. Hours of operation were evaluated using motor loggers installed on the blower fan which turns on every time the boiler fires. Boiler efficiency measurements were made consistent with the American National Standards

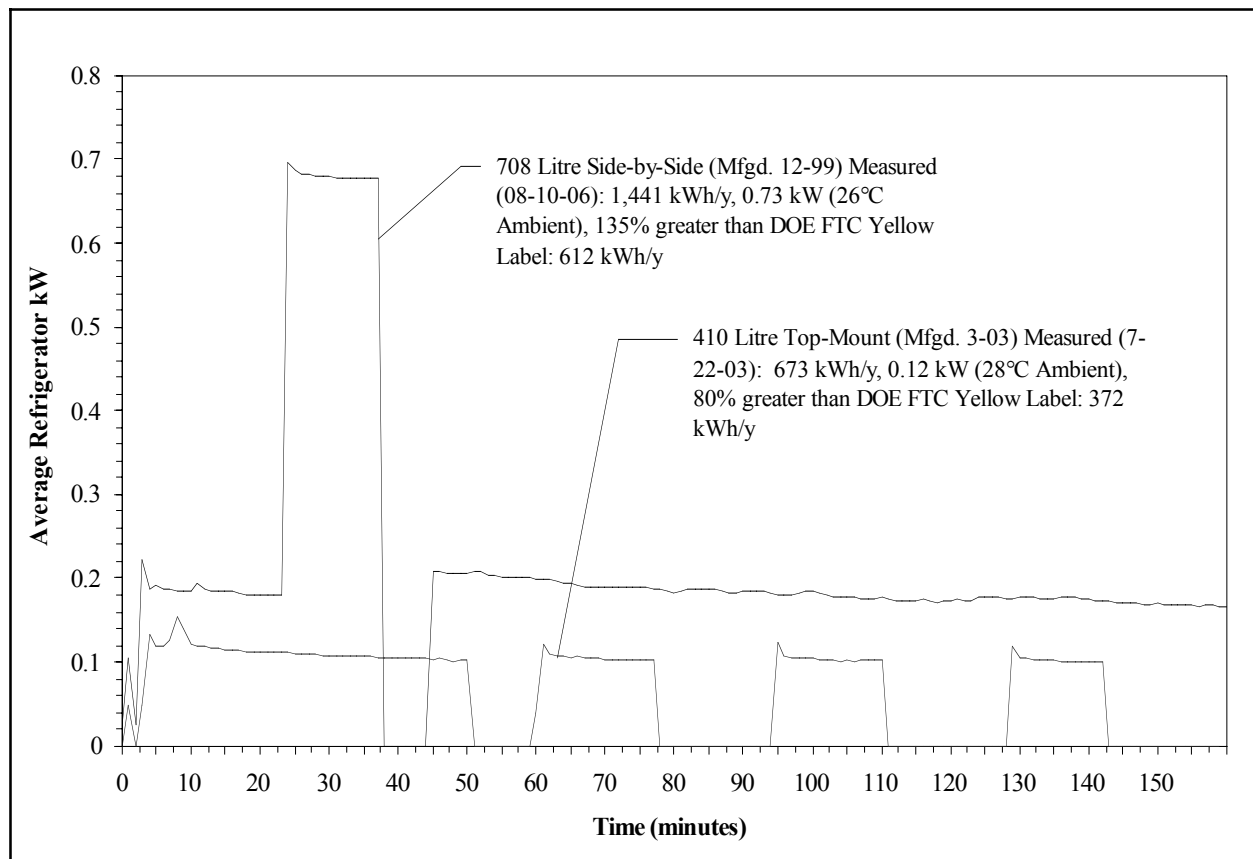


Figure 2. Measurements of 708 Litre Side-by-Side and 410 Litre Top-Mount Refrigerator Freezers

year net realization rate was  $0.87 \pm 0.10$ . This was due to field measured efficiencies and full load operating hours being less than ex ante values. The study found average inlet temperatures of  $46.1 \pm 4.4^\circ\text{C}$  and outlet temperatures of  $63.3 \pm 4.7^\circ\text{C}$ . Field measured boiler efficiencies were generally found to be 4 to 12 percent lower than manufacturer ratings due to higher inlet and lower outlet temperature conditions as shown in Figure 3 (Mowris et al. 2004b). The highest measured efficiency for all boilers tested was 89 % including boilers with rated efficiencies of 98 %. The United Kingdom boiler efficiency database includes units with SEDBUK efficiency ratings in excess of 91 % (DEFRA 2007).<sup>10</sup> Measured efficiencies were generally closer to rated efficiencies for lower efficiency boilers with a 3.3 % difference. The difference was 7.7 % for medium efficiency, and 7.5 % for high efficiency boilers. Based on field measurements, the average medium efficiency boiler was 0.1 % more efficient than low efficiency, and high efficiency was 6.2 % more efficient than medium efficiency.

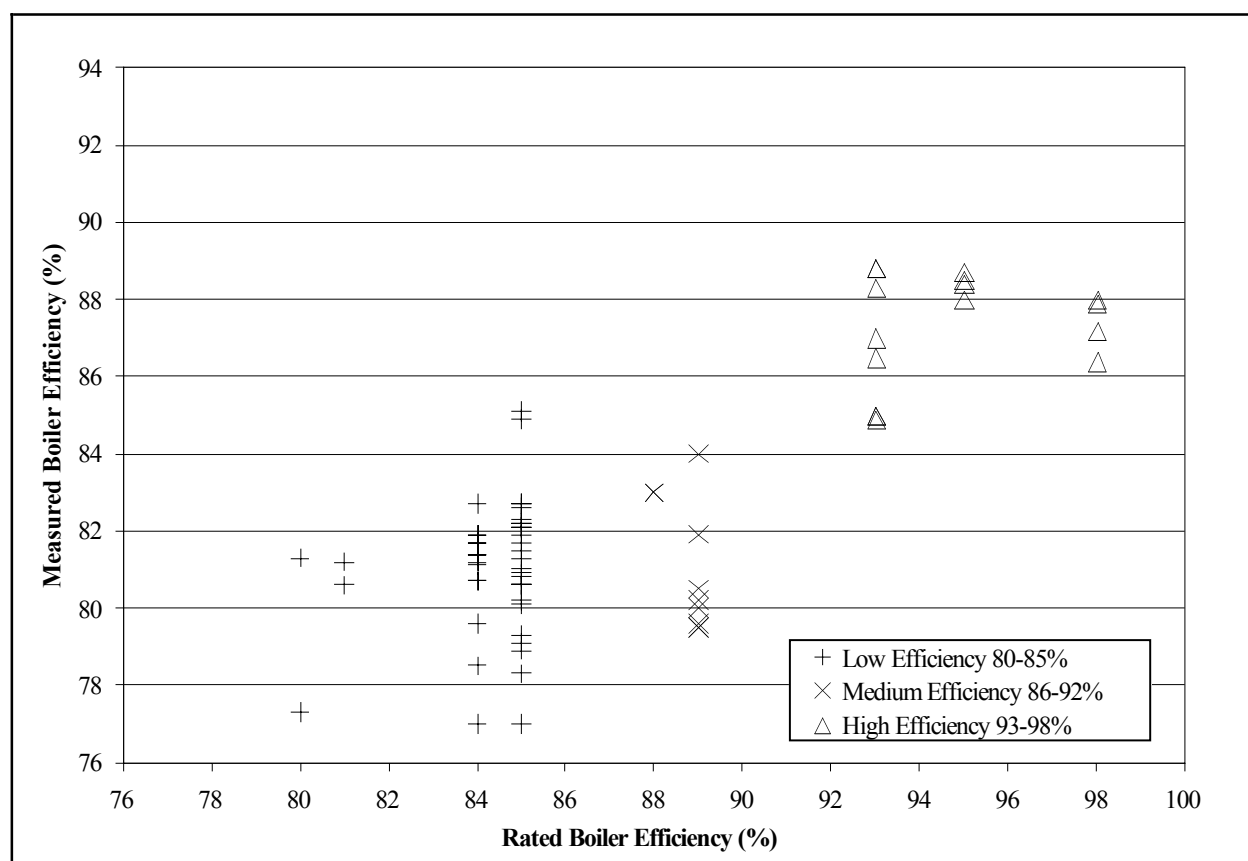
For showerheads, the ASME A112.18.1M-1996 test procedure is used to limit maximum flow rates to 9.5 litres per minute (lpm) at a flowing pressure of 551.58 kilopascals (kPa)

(ASME 1996). Many showerheads do not have pressure-compensating valves to allow 9.5 lpm 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. This problem is being addressed in California where a new showerhead testing protocol is being developed for measuring the performance of showerheads to include flow rates at multiple pressures (i.e., 68.94 to 758.42 kPa), quality of the flow rate pertaining to force or impact, and flow radius (Mowris 2007). Additionally, the new test protocol will address thermal shock and the potential for scalding with non-thermostatic mixing and thermostatic mixing valve technologies.

Standards and labels should require random field measurements of performance consistent with IPMVP and Six Sigma to compare in-situ performance with laboratory performance. Equipment and appliances 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. Standards and labels with evaluation, measurement, and verification requirements that adhere to IPMVP and Six Sigma will help in understanding failure mechanisms, laboratory-testing procedures, design/manufacturing/installation defects, and CTQ characteristics.

Institute (ANSI) procedures except for the inlet and outlet temperatures where in-situ values were used for the application. See ANSI Z21.13-2000, Gas-Fired Low Pressure Steam and Hot Water Boilers. Combustion efficiency measurement procedures are discussed in 10 CFR Part 431, Docket No. EE-RM/TP-99-470, Federal Register, Vol. 65, No. 154, Wednesday, August 9, 2000, Proposed Rules. [http://www.eere.energy.gov/buildings/appliance\\_standards/commercial/pdfs/boilers\\_nopr\\_080900.pdf](http://www.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/boilers_nopr_080900.pdf).

10. Seasonal Efficiency of Domestic Boilers in the UK (SEDBUK) is available online at <http://www.sedbuk.com/>.



Source: Mowris et al. 2004b.

Figure 3. Measurements of Low, Medium, and High Efficiency Boilers.

## Conclusions

Efforts to improve energy efficiency and mitigate global warming through equipment and appliance standards and labels have been somewhat hampered by significant differences in energy consumption between actual and labelled energy use. In some cases actual energy use is 50 to 200 % greater than labelled energy use, and this has damaged consumer confidence. The IPMVP can be used to evaluate standards and labels to improve performance and consumer confidence. 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. Greenhouse gas trading policy encourages rigorous EM&V by applying savings discount factors tied to the IPMVP Option. 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 most costly options. The USEPA Conservation Verification Protocols direct evaluators to report verified savings at the low end of the confidence interval to encourage more precise estimates.

Efforts to increase customer satisfaction, resource efficiency, and improve profitability have 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. Companies implementing Six Sigma find that 70 to 80 percent of the total cost of a product or service is determined

in the design stage. The higher the quality of energy efficiency designed into a product, the lower its lifecycle costs. IPMVP and Six Sigma share similar objectives with respect to reducing lifecycle costs and improving performance through measurement and verification of quality and efficiency improvements. IPMVP provides a framework to measure and verify energy efficiency performance. 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 appliance standards and labels will improve reliability and ensure that labeled energy use is closer to actual energy use.

Standards and labels should require random field measurements of performance consistent with IPMVP and Six Sigma to compare in-situ performance with laboratory performance. Equipment and appliances 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. Standards and labels with evaluation, measurement, and verification requirements that adhere to IPMVP and Six Sigma will help in understanding failure mechanisms, laboratory-testing procedures, and design, manufacturing, and installation defects.

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 for standards and labels. This

will motivate consumers, manufacturers, and government agencies to value energy efficiency on the same level as other investments and reduce market barriers. The ultimate goal of standards and labels is to help customers make informed purchasing decisions with respect to energy use. This goal can be achieved by incorporating IPMVP and Six Sigma strategies into standards and labels programs to improve reliability and help consumers, corporations, and government agencies better understand the value of energy efficiency.

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