

# Tracking the Benefits of Retro-Commissioning: an Integrated Measurement and Verification Approach

**David Jump, Ph.D., P.E.**

**Kris Kinney**

**Matt Denny**

*Quantum Energy Services and Technologies, Inc.*

**Raul Abesamis**

*Physical Plant-Campus Services*

*University of California, Berkeley*

## Synopsis

This paper discusses the advantages of integrating measurement and verification procedures in retrocommissioning projects. An example M&V plan developed for a monitoring-based commissioning project at UC Berkeley's Soda Hall is presented. Baseline data has been collected, and energy baselines are presented.

## About the Authors

David Jump is QuEST's Director of Engineering. He currently leads a team of eight engineers in providing commissioning and energy project development. He has developed and helped implement public-goods funded retro commissioning programs since 2002 in the City of Oakland, SCE, and PG&E territories. His experience with data acquisition and analysis techniques and tools has enabled him to author chapters in M&V guidelines, and develop tools for assessing measurement protocol cost effectiveness. He received a Ph.D. in Mechanical Engineering from the University of California, Santa Barbara and has over ten years experience in the energy-engineering field.

Kris Kinney is a Senior Project Manager at QuEST. He has experience conducting energy assessments of both commercial and industrial facilities in the US, Singapore, and Hong Kong. He has a bachelor's degree in Architectural Engineering, which focused on HVAC, Design and Energy Efficiency. He has particular expertise expanding building automation systems to include performance monitoring. His expertise in system evaluation and modeling, energy savings calculations, data logging, and controls has resulted in several presentations at national conferences.

Matt Denny is an engineer at QuEST. He has a B.S. in Mechanical Engineering from San Francisco State University. Mr. Denny is expert with multiple data collection systems and analysis tools, which he uses to optimize building systems operation. Mr. Denny is also currently implementing a mobile wireless data acquisition network with remote access capability.

Raul Abesamis has a B.S. in Industrial Engineering and is currently an Energy Engineer at the University of California at Berkeley Physical Plant-Campus Services department. He has developed and implemented energy conservation projects at the University with focus on improving energy efficiency through lighting retrofits and HVAC and controls systems automation. Mr. Abesamis is the campus project manager for the implementation of the monitoring based commissioning and retrofits programs under the UC/CSU/IOU Partnership Program.

## Introduction

A need to establish more robust measurement and verification (M&V) practices to demonstrate savings in retrocommissioning (RCx) projects has emerged. This paper discusses various needs and advantages to incorporate M&V into RCx projects and provides one approach currently being implemented under the University of California / California State University / Investor-Owned Utility (UC/CSU/IOU) Partnership Program.

### ***Need for M&V***

Retrocommissioning, tune-ups, and building optimization projects are effective means to tap the energy savings potential often found in commercial buildings. Several owners in the commercial building sector, including office buildings, hotels, retail chains, and others have completed RCx projects and realized savings. Most projects *recommend* measures based on *estimated* energy savings and costs, yet few projects include follow-up to demonstrate actual savings within an industry-standard M&V framework<sup>1</sup>. Demonstrated savings would provide solid evidence to help owners understand the benefits of RCx, help practitioners improve their services, and generally help promote the industry.

In recent years, utility and other entities supported through public-goods funds have administered RCx programs<sup>2</sup> focusing on energy savings. These programs require an evaluation, measurement, and verification (EM&V) process be carried out to determine societal benefits. Typically, the approach is for a third party to review the collected data and analysis, visit the site and verify the savings. To lower costs, a sample of program sites or individual measures may be reviewed. Results may be reported program-wide, and not on an individual building basis. Problems with limited third party review include: EM&V reviewers not being intimately familiar with each building, inadequate budgets to fully understand the systems and measures, and seasonal timing of verifications. Integrating a standardized M&V approach into the program RCx process would greatly facilitate EM&V of these programs.

---

<sup>1</sup> Such as the International Performance Measurement and Verification Protocol (IPMVP), and the American Society of Heating, Refrigeration, and Air-conditioning Engineers's (ASHRAE) Guideline 14.

<sup>2</sup>Programs include: The Building Tune-Up Program ([www.buildingtuneup.com](http://www.buildingtuneup.com)), The San Diego RetroCommissioning Program, Xcel Energy's RetroCommissioning program, NEEA's Building Performance Services program, as well as programs in Texas, New York, and Wisconsin.

Improved M&V would also help answer one of the lingering questions about the benefits of RCx - how long the savings last. Many of the low-cost measures touted by program marketers and service providers are “soft” in nature, such as simple adjustments to control system set points and schedules, or minor programming changes. These measures can easily be defeated, and savings lost. A properly designed M&V program would help building operators understand whether their savings are persisting over time, and help find the root causes when savings diminish.

## **Integrating M&V in RCx Projects**

Most RCx services in commercial buildings rely on extensive data collection and functional testing to detect flaws in system operation and performance. Monitoring plans are implemented, with schedules of points to trend from the building’s energy management system (EMS), and data collected with independent loggers and measurement instruments. Most EMSs provide supervisory control, not energy reporting, and therefore lack the necessary points to monitor electric energy consumption, and air and water flows. These points represent significant additional cost. The points needed for energy monitoring are usually collected independently of the EMS using data loggers.

Once tests are completed and data is collected, data visualization and analysis tools may be used to identify performance deficiencies and estimate savings. Costs are estimated and recommendations are made.

The data used to identify and estimate savings is the same data that can be used to verify actual savings. However, once the installations are complete, the RCx providers may not be engaged to verify savings, and therefore post-installation energy data is often not collected and analyzed. This leaves the task of verifying savings to the building operators, and because of busy schedules or lack of familiarity with the procedures, savings verification is seldom completed.

A method QuEST is currently pursuing under the UC/CSU/IOU Partnership’s Monitoring-Based Commissioning (MBCx) Program, is to enhance monitoring systems in order that diagnostics and M&V are integrated with the retrocommissioning process. Under this program, the EMS’ capabilities are expanded through addition of points, control system hardware, and programming, to provide operators with tools to better understand the day-to-day energy performance of their systems<sup>3</sup>. An example M&V plan for UC Berkeley’s Soda Hall MBCx project is described in order to demonstrate these integration concepts.

### ***Practical Application***

Soda Hall houses the computer science department and has several computer rooms. Its two main utilities are electricity, and steam from the campus’ cogeneration plant. It has a very high-

---

<sup>3</sup>The M&V approach used is partially based on those found in “Specifications Guide for Performance Monitoring Systems,” a guide developed as part of a jointly funded CEC PIER-DOE project, available at <http://cbs.lbl.gov/performance-monitoring/specifications/>, Philip Haves, principal investigator, Lawrence Berkeley National Laboratory.

energy use intensity of 172 kBtu/ft<sup>2</sup>-yr. The goal of the project is to achieve 5% or more savings in both electricity and steam consumption, while maintaining or improving building services such as thermal comfort, indoor air quality, and system maintainability and reliability. Savings are to be obtained primarily through corrections to operational flaws in the building’s mechanical and electrical systems. Table 1 shows the 5 and 10% savings targets for Soda Hall.

**Table 1: Soda Hall Energy Consumption and Savings Targets**

UCB MBCx Target Savings - Soda Hall			
		5% Savings	10% Savings
Average Annual kWh Use	4,135,500	206,775	413,550
Steam Use - lbs	5,325,700	266,285	532,570
Average Annual kWh Cost*	\$454,900	\$22,745	\$45,490
Average Annual Steam Cost**	\$69,200	\$3,460	\$6,920
Total	\$524,100	\$26,205	\$52,410

\* assumed electric cost is \$0.11/kWh

\*\* assumed steam cost is \$13/1,000lb

RCx investigations have identified several issues with the air distribution, chilled, and condenser water systems. These issues include variable-speed fans and pumps operating in bypass mode, chiller scheduling, and high minimum damper positions in terminal boxes. Correcting these issues will provide significant savings.

### **M&V Approach**

The International Performance Measurement and Verification Protocol (IPMVP), usually cited as the guiding M&V protocol for energy savings projects, defines four M&V Options. In general, Options A and B are retrofit-isolation approaches, and focus on the equipment and systems affected by the improvements. Options C and D focus on the whole-building level, with Option C describing a utility-bill approach, and Option D describing how whole-building energy simulations can be applied. The IPMVP allows the options to be combined, as appropriate. For example, energy simulation methods can be applied to individual systems.

The Option A and B approaches require isolation of the specific system where the energy intervention will be made, accounting for all energy consumed and influencing parameters in the system, and monitored data in the post-installation period to determine energy savings. Option B requires continuous monitoring. Option A is slightly less rigorous, allowing values of certain factors to be mutually agreed upon by the owner and provider (called stipulation).

Generally, whole-building approaches are used when the savings will be large enough to distinguish them from normal variations and uncertainties in the building’s energy use. Fifteen to twenty percent savings is often cited in the literature. This is not generally true of RCx projects, which typically recommend and implement a large number of energy “tune-ups” as opposed to major equipment retrofits.

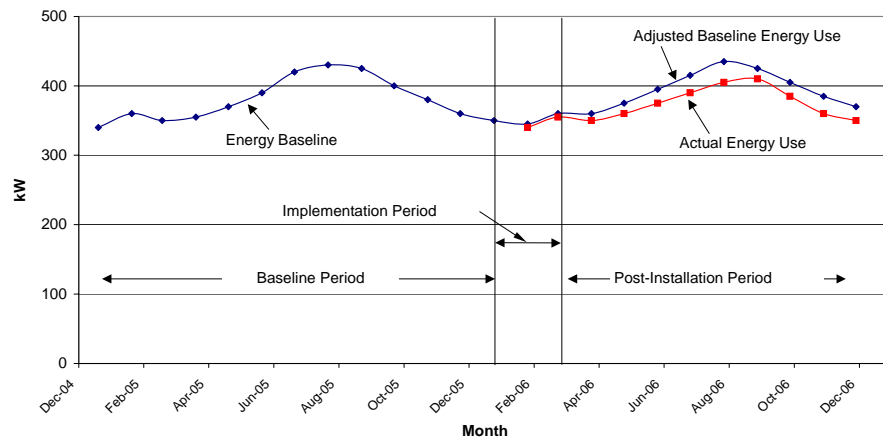
For each option, the principal of calculating savings is the same. The IPMVP recommends that a model of the baseline energy characteristics of the system be developed, and dependent variables

(usually energy) and independent variables (usually outdoor air temperature, building and equipment schedules, temperature set-points, etc.) be identified. The models are based on application of engineering principals, or can be derived through statistical techniques.

Enough data to properly characterize the baseline must be collected before the measures can be implemented. After implementation, the dependent and independent variable data are again collected. The savings are calculated as follows:

$$\text{Energy Savings} = \text{Adjusted Baseline Energy Use (modeled)} - \text{Actual Energy Use (measured)}.$$

The adjusted baseline is the amount of energy the system would have used, without the improvements, under the post-installation conditions. The actual energy use is measured in the post-installation period. These concepts are illustrated in Figure 1.



**Figure 1: Energy Savings from Baseline Through Post-Installation Periods**

For Soda Hall, the M&V will be performed on the systems level, using an Option B approach. This approach magnifies the energy savings as a proportion of system usage, so that the benefits can be more easily tracked. In addition, the impact of numerous tune-up measures associated with each system will be accounted for with far more accuracy than if the savings were to be tracked at the whole building level.

The systems are defined in Table 2. The M&V procedure will be similar for each system. Daily totals of each system's energy consumption (kWh, kW, and lbs of steam) in both the baseline and post-installation periods will be tracked. As will be demonstrated, the total energy consumption in each system will be calculated based on data available through the EMS and independently measured using power loggers and meters.

Using the baseline period data, a functional relationship between the daily energy use and an independent variable (such as an average daily outside dry-bulb temperature, or daily peak temperature, etc.) will be developed. Purposely, we'll look for relationships with variables that are among the existing points in the EMS. This will keep the number of independent variables to

a minimum, and eliminate cumbersome data entry steps. Such manual tasks reduce the likelihood of this procedure's success as an integrated process. Preliminary results are presented in this paper.

In the post-installation period, all dependent and independent variable data will be continuously monitored. The adjusted baseline will be determined for each system and compared to the measured consumption of the equipment operating under the improved conditions. The analysis will be automated, and the results can be viewed graphically. This enables the operations staff to view, for example, bar charts each week of the daily energy consumptions. This has the potential to be not only a powerful and robust M&V procedure, but also provides the operators with immediate feedback on the daily energy performance of their systems. This information has multiple uses, among them are:

- Helping operators and service providers track savings,
- Identifying when energy performance is degrading, enabling the problems to be identified and addressed (improving savings persistence),
- Establishing new baselines from which new projects can be evaluated,
- Providing operators with means to demonstrate their excellence, and
- Providing owners and managers with insight into the energy performance of their buildings.

UC Berkeley has extensive resources in place to facilitate M&V for this project. Its campus-wide EMS has numerous monitoring points in Soda Hall. Further, each point is trended at 1-minute intervals and 6 months of trended data is stored and available for use. For the baseline period, data loggers and power measurement instruments have been used to collect the necessary energy data. New data points have been added to facilitate energy calculations for the systems in the post-installation period. The M&V procedure will make extensive use of the established data collection activities, and establish simple procedures for pulling data and performing the required analysis and reporting. The following is a description of elements of the M&V plan.

## **Identify Systems to be Monitored**

Table 2 lists the systems defined for this project. The points available to help quantify energy use within each system are also shown.

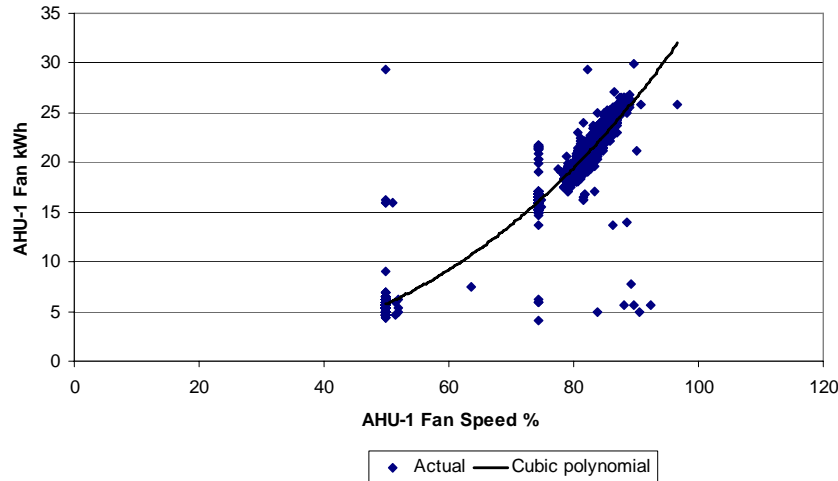
## **Define the Baseline Period**

The baseline period has been defined as the year prior to implementation of the RCx measures. Eight months of EMS data has been collected, as well as independently logged data, and spot measurements have been used to determine the energy consumption of each component in each system. Whole building power and steam consumption, as well as both chiller's kW and chilled water flow data are existing points on the EMS. The remaining pumps, fans, and other energy-consuming equipment's energy consumption were quantified as follows:

- Each variable speed item's equipment (secondary chilled water pumps P-3 and P-4, condenser water pumps P-9 and P-10, hot water pumps, and AHU-1, 3, and 4 fans) power was logged, and a relationship between the logged power and the trended speed was developed. The resulting regression relationship was used with the equipment's trended speed to calculate power and energy consumption for each trended data interval. Figure 2 shows the regression relationship developed between AHU-1 kWh and fan speed. A cubic relationship fit the data well, as would be expected.
- Each constant speed equipment's (primary chilled water pump P-5 and P-6, condenser water pumps P-7 and P-8, cooling tower fans, AHU-2 and 5 fans, chiller room and exhaust fans, and AC units) power was measured over a short time interval. In some cases, it was logged, and an average of the logged measurements was used to characterize the power consumed by that equipment. Using the equipment's status signal, the energy consumption for each trended data interval was calculated.

**Table 2: Systems and Equipment Selected for Monitoring**

System	Equipment	Available Points
Whole Building	Main Electric Meter	kW
	Main Steam Meter	lb
Chilled Water System	Chillers 1 and 2	kW
	Primary Chilled Water Pumps P-5, P-6	Status
	Secondary Chilled Water Pumps, P-3, P-4	VFD speed
Condenser Water System	Cooling Towers	High/Low Status
	Condenser Water Pumps P-9, P-10	VFD speed
	Condenser Water Pumps P-7, P-8	Status
Air Distribution System	AHU-1, SF-11, EF-12, EF-13	VFD speed
	AHU-2, SF-14, EF-15	Status
	AHU-3, SF-16, SF-17	VFD speed
	AHU-4, SF-18, SF-19	VFD speed
	AHU-5, SF-20	Status
Chiller Room Fans	Chiller Room 183, SF-1, EF-3	Status
	Chiller Room 181, SF-2, EF-2	Status
	Chiller Room 179, SF-3A, SF-3B, EF-1A, EF-1B	Status
AC Units	AC-31 through AC-41	Status
Hot Water System	Hot Water Pumps P-1, P-2	VFD Speed



**Figure 2: Regression Relationship for AHU-1 Power and Fan Speed**

Figure 3 shows the results for the chilled water system. This figure shows the cumulative daily total of the energy consumption for each component piece of equipment in the system as defined in Table 2. The average daily dry-bulb temperature is also shown on the figure. Note the strong relationship with the daily averaged outside air temperature. Based on a linear regression between these variables, the adjusted baseline model for the chilled water system daily kWh was determined to be:

$$\text{Chilled Water System Daily kWh} = 60.85 \times (\text{Avg. Daily DB Temperature}) - 2,392$$

This relationship is valid between the maximum and minimum temperature values of 56 and 72 °F. It also has an  $R^2$  value 0.86, which is close to 1.0, meaning that the derived relationship with average daily DB temperature is a good predictor of the kWh. Note also that the entire year of data does not need to be captured in order to have a valid baseline. What is important is that most (generally >70%) of the range of data, for both kWh and average daily ambient temperature, should be captured in order to avoid excessive extrapolations beyond valid limits.

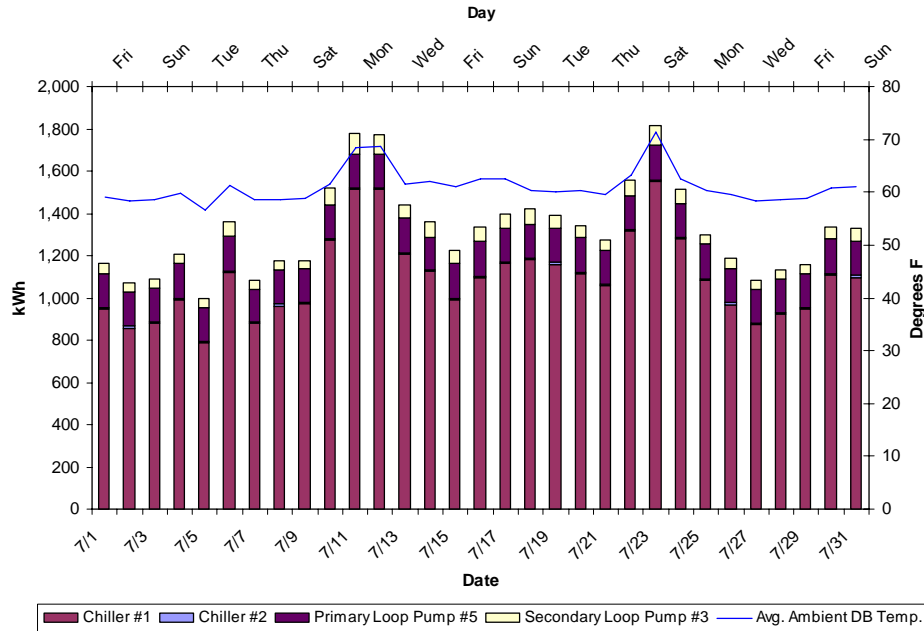
Figure 4 shows results for Air Handling System #1. This is a single-duct VAV system with VFDs on the supply and return fans, however, the return fan VFDs are malfunctioning so that they are constantly running in bypass mode at 100% speed. The supply fan shows modest modulation. The adjusted baseline for this system will be a constant represented by the average of the daily values.

## Install Measures

As data is collected in the baseline period, the detailed investigation is concluded and measures are recommended that improve operations and generate savings. These recommended measures include:

- Repair of several AHU VFDs that enables:

- Placing the fans back under scheduled control,
- Re-enabling VAV operation under the scheduled operation, and
- Re-instituting a supply air reset strategy for AHU-1;
- Raising supply air temperature set points to eliminate excessive use of reheat,
- Reducing minimum VAV box air flows,
- Eliminating nightly chiller operation,
- Re-establishing chilled water supply temperature reset control.



**Figure 3: Chilled Water System Daily kWh for July, 2005**

Some of these measures will have impacts on more than one system, for example we expect savings from both the air handlers and the chilled water system for the repair of the AHU VFDs, and savings from both the chilled water plant and hot water system for reducing the minimum air flow in the VAV boxes (thereby reducing excessive reheat). When more than one system is impacted by the measure, the isolated system should be expanded to include each impacted system. The adjusted baseline model becomes the sum of each adjusted baseline model for each individual system, and similarly, the measured post-installation use for each system is summed. All required independent variables are still measured and used in calculations.

### Collect and Analyze Post-Installation Data

The M&V plan for Soda Hall has been set up so that it will be integrated into normal facility O&M activities. The M&V algorithms have been kept simple so that they will not tax EMS resources. As data is collected and archived by the EMS, a simple routine can calculate the adjusted baseline consumption, and build up the system-by-system post-installation energy use. The calculations can be run on a weekly or bi-weekly basis, frequently enough to note when excessive consumption or other problems arise, and enable the causes to be found and corrected.

In this respect, the M&V process serves as fault detection, providing early indications of performance deficiencies in a system.

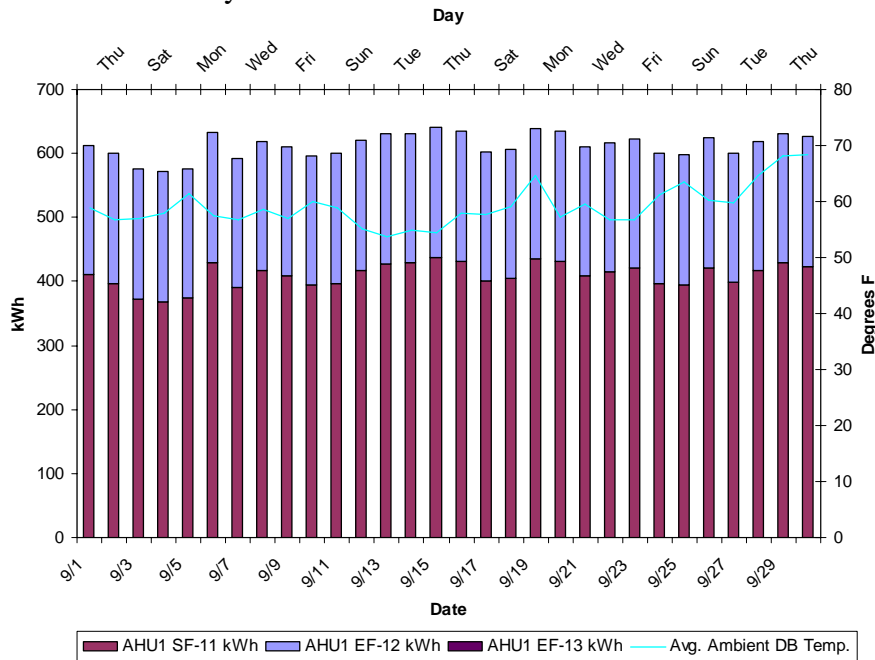


Figure 4: Air Handler 1 Daily kWh for September

### Notes on Cost and Uncertainty

Under this Option B approach, we must account for energy consumption in two fundamental types of equipment – constant and variable speed. Various techniques were assessed, based on their estimated costs and uncertainties. The IPMVP recommends that some assessment of the M&V method’s resulting savings uncertainty be made<sup>4</sup>. Below is a discussion of the techniques we considered. Table 3 provides per-point estimates of costs and uncertainties for these techniques. At Soda Hall, where there was an abundance of useful EMS points, we relied on the first two techniques.

- Constant load equipment – equipment ON/OFF status signal to track time-of-use, combined with independent measurements of equipment power.
  - Depending on how “constant” the load is, spot measurements or short-term data logging is used to determine actual equipment power. For example, a “constant” speed supply fan will “ride the fan curve” depending on the dynamically changing flow resistance caused by opening and closing of terminal unit dampers. Data logging of a week or more is recommended for this system. An average of the power readings is used.
  - Status signal is interval data, not change of value.

<sup>4</sup>ASHRAE’s Guideline 14 goes further and requires a complete statement of uncertainty and confidence limits be included with the calculated savings result.

- There are no material costs for adding points to the EMS, only labor for taking spot measurements, setting up and collecting trends, and programming analysis routines.
- The instrument's measurement uncertainty is combined with the standard error of the average (standard deviation), and combined with the uncertainty of daily the time-of-use to arrive at an estimate of the uncertainty in the daily energy use. Note that the uncertainties can only be combined when they have the same confidence limits. Several references provide details on uncertainty propagation.<sup>5</sup>
- Variable load equipment – percent load variable on EMS to indicate load and time-of-use, independent equipment power monitoring.
  - For variable load equipment – such as variable volume pumps and variable air volume air-handling systems, data loggers to monitor equipment power and the variable that represents equipment loading – such as VFD speed output, VFD amps output, axial vane position, discharge damper position, etc. are installed. The data is collected and an appropriate relationship is developed using regression techniques.
  - There are no material costs for adding points to the EMS, only labor for installing and removing data loggers, setting up and collecting trends, analyzing the data, and programming analysis routines.
  - The logger's measurement uncertainty is combined with the standard error of the regression, and combined with the uncertainty of the daily time-of-use to arrive at an estimate of the uncertainty in the daily energy use. The resulting relationship should not be extrapolated far beyond the maximum and minimum points of the load variable.
- Variable load equipment – variable speed drives.
  - Many variable speed drives can be programmed to provide the equipment's power over the communication line to the EMS.
  - Material costs include conduit or low voltage wire for adding the point to the EMS (assuming there are available I/O points), and labor costs for installation of communications, providing spot measurements for calibration purposes, and programming analysis routines.
  - The VFD's power measurement uncertainty is combined with the uncertainty of the daily time of use to arrive at an uncertainty in the daily energy use.
- Constant or variable load equipment.
  - Add a networked power meter to the EMS to monitor any equipment (but usually motors greater than 10 HP).

---

<sup>5</sup> See i) "M&V Value Tool Alpha Specifications, D. Jump, et.al., available at [ateam.poet.lbl.gov](http://ateam.poet.lbl.gov), or at [www.cacx.org](http://www.cacx.org).

ii) Reddy, T.A., Kissok, J.K., and D.K. Ruch, 1998, "Uncertainty in Baseline Regression Modeling and in Determination of Retrofit Savings," *Journal of Solar Energy Engineering*, p. 185 – 192, Vol 120, August, 1998.

iii) ASHRAE Guideline 2-1986 (RA 96), 1996, "Engineering Analysis of Experimental Data," American Society of Heating Refrigeration and Air-conditioning Engineers, Inc., 1791 Tullie Circle, NE, Atlanta, GA 30329-2305

iv) Brandemuehl, M.J., Krarti, M., and J. Phelan, 1996, "Methodology Development to Measure In-Situ Chiller, Fan, and Pump Performance," ASHRAE Research Project 827-RP, Volume 1: Final Report.

- Material costs include the cost of the meter and communications wire & conduit (assuming there are available I/O points), labor costs include labor for running wire, programming the EMS, adding trends, and calibrations.
- The power meter's measurement uncertainty is combined with the uncertainty of the daily time of use to arrive at an uncertainty in the daily energy use.

**Table 3: Estimated Costs and Uncertainties for Monitoring Techniques**

Technique	Costs		Total Cost per Point	Uncertainty Range
	Material	Labor*		
1	\$ 60	\$ 1,010	\$ 1,070	5 - 15%
2	\$ 60	\$ 1,370	\$ 1,430	10 - 20%
3	\$ 510	\$ 1,170	\$ 1,680	3 - 8%
4	\$ 1,010	\$ 1,340	\$ 2,350	1 - 5%

\*assuming \$110/hr labor

## Conclusion

Most retrocommissioning projects are undertaken to improve the energy performance of existing systems and equipment, yet seldom are industry-accepted M&V practices used to provide savings verification. Because of their data-rich approach, RCx projects provide a unique opportunity to integrate M&V into the process, and provide building operators and owners with valuable tools to track and manage their systems. An M&V plan, developed under the UC/CSU/IOU Monitoring-Based Commissioning Program at UC Berkeley's Soda Hall, is outlined to demonstrate how M&V procedures may be employed in RCx projects. As post-installation data becomes available, we will show how the RCx benefits can be tracked by this approach.