Measurement and Verification of Energy Savings: Applications of Monitored Data to Energy Services Project Development and Implementation

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This paper reports on measurement and verification (M&V) activities at an energy-services subsidiary of a large electric utility. Engineering estimates of energy savings for the proposed measures were examined, and uncertainties were assigned to each savings estimate. M&V resources were prioritized by focusing on the measures with the highest savings at risk. The overall M&V plan included billing analysis, engineering calculation review, short-term pre/post measurements on selected equipment, and long-term post-construction energy consumption monitoring of selected large equipment. Pre-construction monitoring was used to establish baseline energy consumption, identify additional savings opportunities, and improve engineering design. Post construction monitoring provided valuable feedback to the commissioning process, as well as providing performance information for savings verification reporting. The role of integrating M&V data collection with engineering feasibility, new equipment commissioning, and on-going operations and maintenance is discussed. The use of baseline performance data to improve engineering estimates for future projects is also discussed.

INTRODUCTION

The development of successful energy services projects relies on accurate building-specific information during all phases of the project. As a project progresses from initial prospecting to engineering design, baselining, commissioning, and savings verification; the availability of accurate building and measure performance data can reduce risk and enhance customer satisfaction with the results of the project. Data gathering activities conducted during each phase of the project can be leveraged to improve up-front engineering estimates of savings, improve engineering design of new energy systems, identify low-cost/high value savings from improved operation and maintenance practices, commission the new equipment, and provide on-going savings verification data.

Energy services contracts can be structured in a number of ways, including shared savings, guaranteed savings, and straight financing arrangements based on up-front estimates of savings. With each of these arrangements, the service provider and the customer assume varying levels of risk. Under shared savings and guaranteed savings contracts, measurement and verification activities are used as the basis for determining payments. Under a straight financing arrangement, the M&V results are provided to the customer as a value added service, but the results do not affect the payment schedule. Regardless of the scenario, M&V results are tightly linked to project financial success and customer satisfaction. Unlike utility program impact evaluations, which often apply detailed analysis to a sample of customers, M&V activities are applied at some level to virtually all participating facilities. Due to the need for broad application, M&V analysis can be somewhat simplistic, providing little insight when a project performs below expectations.

This paper describes the M&V activities on a multi-building project for a municipal client. A combination of HVAC and lighting system upgrades were supplied to eleven facilities. At this time, the project is nearing completion, thus only energy consumption baseline definition activities have been completed. However, the data gathered thus far provides some interesting insights into the role of measurement and verification in the overall project design and execution process. Although lighting and HVAC measures were installed under the project, the discussion will focus on measurement and verification of HVAC system savings. HVAC upgrades were applied to five buildings, as described in Table 1.

METHODOLOGY

The overall M&V approach utilizes billing data analysis, engineering analysis and selected short- and long-term equipment monitoring to verify project energy savings estimates. Since the energy bill is the primary interface between the utility and the customer, billing analysis will be done for all sites. The whole-building approach to savings verification can be a viable approach when the impact of the energy efficiency improvements are expected to be a reasonable percentage of the annual energy consumption. Problems can arise when the savings estimates from the billing analysis do not match initial project expectations. In situations where

Table 1. HVAC Measure Summary

Building	Type	HVAC Measures Installed
1	Office	A majority of the HVAC systems serving the building were modernized. Thirty eight packaged rooftop and split systems, representing 120 tons of cooling capacity were replaced with high-efficiency units. Existing multi-zone air handling units (AHUs) were converted to a variable air volume (VAV) reheat system by installing variable frequency drives (VFD) on the supply fans of two roof-mounted air handlers. The existing gas boiler and air-cooled chiller were replaced with high-efficiency units. The existing air-side economizer was repaired. A new direct digital control (DDC) energy management system (EMS) was installed to control the central plant and the new packaged rooftop units.
2	Assembly	Chilled water coils in the main auditorium air handlers were replaced to improve the cooling capacity and efficiency of the system. Direct digital controls were added to the system.
3	Recreation	Two existing pool pump motors were replaced with energy-efficient motors. Two existing gas boilers that heat the pool water were replaced with high efficiency gas boilers.
4	Library	Two existing 12 ton rooftop units serving the main floor were replaced with one 15 ton energy-efficient unit. The badly-corroded condenser coil on the rooftop unit serving the basement were replaced. A new DDC system was installed to control all units.
5	Library	Four existing window-mounted air conditioners were removed, and a split DX air conditioning system was installed to provide central cooling via the existing heating system ductwork to the main library area. An existing rooftop system was replaced with an energy-efficient unit.

the energy consumption of the building is highly variable, and/or the savings are a small fraction of the billing data, a component-based approach is required. Even in buildings with large expected savings, component-based measurements are valuable to help provide an explanation if billing-based savings estimates are below project expectations. This paper focuses on the details of the component-based measurement approach.

Prioritizing M&V Activities

In order to prioritize the M&V activities, resources were directed at the buildings with the largest savings at risk. The engineering calculations of energy savings were reviewed. For example, the HVAC energy savings for equipment replacements were calculated as shown in equation 1:

$$\Delta \text{kWh} = \text{ton} \times \left[\left(\frac{12}{\text{EER}} \right)_{\text{pre}} - \left(\frac{12}{\text{EER}} \right)_{\text{post}} \right] \times \text{FLH} \quad (1)$$

where:

ΔkWh = cooling energy savings
ton = cooling equipment size (ton)
EER = equipment efficiency (Btu/hr-watt)
FLH = cooling annual equivalent full-load hours

The uncertainty in the energy savings calculation was estimated based on a subjective assessment of the uncertainty in the engineering parameters. The overall uncertainty was calculated using a propagation of error analysis (Violette, et al., 1993). The projects were then ranked according to their relative contribution to overall uncertainty, as shown in Table 2. Based on this analysis, HVAC M&V activities were primarily focused on Buildings 1 and 2. The overall approach adopted for HVAC savings measurement and verification for each building in the project is summarized in Table 3.

Component-based approach

In order to provide sufficient insight into building systems performance, component-level measurements were made at the high-priority sites. Since it was impractical to monitor every packaged HVAC unit on these buildings, a sample of units was selected for short-term monitoring. Monitored data from the sampled units were used to develop a ''calibration factor'' or ''ratio estimator'' for the original engineering estimates (Wright, et al., 1994). The calibration factor developed from the monitoring activities was applied to all units, thus providing an improved estimate of baseline cooling consumption.

Table 2. ***HVAC Savings Risk Assessment***

Site	Building Type	Percent Total HVAC Savings	Estimated Uncertainty	Percent Total Uncertainty	Notes
1	Office	69.6%	20%	66.7%	System operation variable, due to occupant controls
2	Assembly	8.6%	30%	12.3%	Building energy consumption is driven by event bookings, which are highly variable.
3	Recreation	11.9%	20%	11.4%	Continuous operation
4	Library	8.5%	20%	8.2%	Operating schedule well-defined
5	Library	1.5%	20%	1.4%	Operating schedule well-defined

The component-based energy use baseline for HVAC equipment was established from short-term measurements of equipment energy consumption and outdoor temperature data. A component-based baseline equation for HVAC systems was established from a linear regression model of kWh/day vs. daily average temperature (Katipamula, et al., 1995), as shown in equation 2.

$$kWh / day = a + b \times T_{amb} \tag{2}$$

where:

a = non-weather-sensitive consumption (kWh/day)
b = weather sensitive consumption (kWh/day-degree)
T_{amb} = daily average outdoor temperature

Separate equations were developed for occupied and unoccupied days. HVAC system operation was controlled by the occupants. For certain systems, hours of operation varied significantly over the monitoring period. For these systems, the consumption data were normalized per hour of operation and the temperature data were averaged over the period of operation. The daily HVAC consumption model was then combined with daily bin data to calculate the annual cooling consumption. Additional measurements, such as cooling supply temperatures and outdoor air fraction measurements were made on the equipment to confirm initial engineering assumptions and better understand equipment condition and operation.

RESULTS

As the project is still under construction, baseline performance results are reported. Results for buildings 1 and 2 are described.

Building 1

Pre-construction measurements were made on a sample of rooftop HVAC units in Building 1. Typical units were selected from four basic occupancies:

(1) Normal business hours

(2) Extended work hours

(3) Large meeting room

(4) 24 hour/day operation

Short-term measurements (about 4 weeks) of equipment performance and ambient temperature were made on the selected HVAC systems, including one-time measurements of true electric power and current, coupled with time series measurements of current, supply temperature, return temperature, and mixed air temperature. A series of small, battery-powered dataloggers were used to make the short-term measurements. These data were used to assess overall system condition and develop a model to predict baseline energy consumption. Time-series values of unit current were combined with spot measurements of power vs. current to provided an estimate of daily energy consumption. A regression model was developed from the daily cooling energy consumption and ambient temperature data. A sample regression equation is shown in Figure 1.

The regression models were applied to annual daily average bin temperature data. An estimate of the annual energy consumption for each unit was calculated, and compared to the

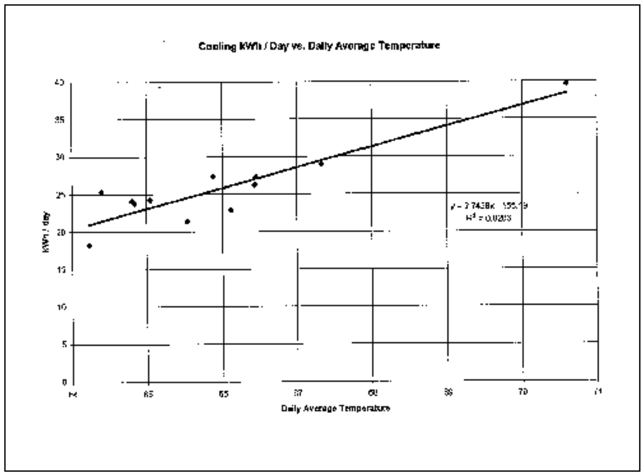
Table 3. *Summary of M&V Approach*

Site	Approach
1	• Make short-term measurements with portable data loggers on a sample of existing packaged rooftop units to establish a baseline performance model. • Make short-term measurements with portable data loggers on the new packaged rooftop units that replace the units monitored above to establish a performance model for the new equipment. • Periodically check EMS for run schedules on all packaged units to adjust savings estimates for system schedule. • Make one-time power measurements on AHU fans and make short-term measurements with portable data loggers on the existing chiller to establish a baseline performance model. • Install watt transducers on the new chiller and VFD drives. Log energy consumption with the EMS.
2	• Make short-term measurements with portable data loggers on chillers and AHUs before repairs are undertaken to establish a baseline performance model. • Make short-term measurements with portable data loggers on the chillers and AHUs after repairs are undertaken establish a performance model for the improved system. • Use the EMS to log chiller run hours.
3	• Make one-time spot-watt measurements on the pool pump motors before and after the motor retrofit. • Survey pool personnel on pump operating hours. • Estimate gas savings from boiler retrofit with a gas billing analysis.
4	• Calculate HVAC savings with a billing analysis.
5	• Calculate HVAC savings with a billing analysis.

original engineering estimates of baseline energy consumption. The results of the comparison are shown in Table 4.

In all cases, the baseline cooling energy estimated from the short-term monitoring was less than the original engineering calculations. The original engineering calculations were based on a uniform assumption of annual cooling full-load hours for all systems in the facility. The cooling full-load hour assumption was based on a rule of thumb number that was inappropriate for the coastal location of the facility. The varying occupancy of the spaces served by the systems was also not considered in the original engineering analysis. For example, the meeting room, while served by a fairly large unit, is occupied only a few hours per week. Thus, the baseline energy consumption estimates for the meeting room system vary significantly from the original engineering calculations.

Figure 1. *Building 1 Typical Packaged Unit Baseline Performance Model*



The implication of reduced baseline consumption is reduced energy savings, since the savings are based on an incremental improvement to system efficiency. Applying the ratio estimators derived from baseline measurements to the energy savings calculations results in a revised estimate of savings, as shown in Figure 2. Note that post-construction measurements, when available, will be used to calculate actual savings.

In addition to the measurements made to calculate baseline energy consumption, additional data collection provided information on the operating strategies and overall condition of the equipment. The results are summarized in Table 5.

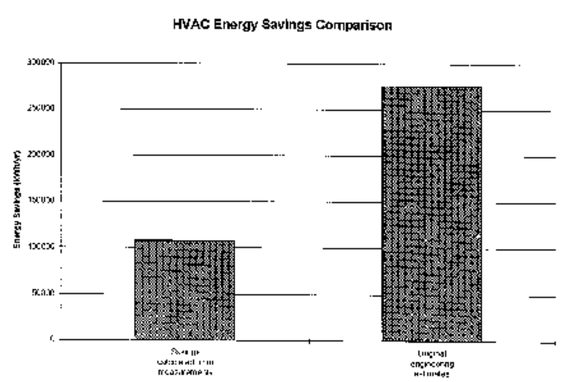
Building 2

Short-term measurements (about 4 weeks) of equipment performance and outdoor temperature were also made in Building 2. Measurement were made on two chillers and air handlers that serve the majority of the space. These measurements included one-time measurements of true electric power and current, coupled with time series measurements of compressor current, supply air temperature, mixed-air temperature, chilled water temperature, and condenser water temperature. These data were used to assess overall

Table 4. ***Summary of Short-Term Monitoring Results for Packaged Units***

Unit	Size (ton)	Operating Schedule	Annual Cooling kWh from Engineering Calculations	Annual Cooling kWh from Monitoring	Ratio
1	5	1	14,340	5,881	0.41
2	3	1	8,604	3,639	0.42
3	5	2	14,340	10,200	0.71
4	17	3	48,756	1,890	0.04
5	3.5	4	36,792	13,765	0.37
6	65.5	4	688,536	185,889	0.27

Figure 2. *Building 1 HVAC Energy Savings Comparison*



coils are repaired, more heat will be extracted from the building, causing the second chiller to operate. The repairs, while improving comfort to the space, will likely increase energy consumption.

CONCLUSIONS

Measurement and verification expenditures do not contribute directly to energy savings, thereby decreasing the overall cost-effectiveness of an energy services project. There is a tendency to reduce M&V expenditures to the lowest possible level consistent with contractual obligations, especially on projects with marginal pay-back. However, there are several valuable roles for M&V activities beyond the traditional role of contract fulfillment.

system condition and develop a model to predict baseline energy consumption. Similar to the process used for building 1, a regression model was developed from the chiller energy consumption and ambient temperature data. Chiller plant kWh per hour of operation data were plotted against outdoor temperature averaged over the operating period to produce a baseline energy consumption equation normalized to building operating hours.

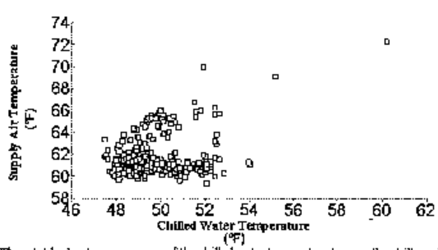
An examination of the short-term monitored data on the chilled water system yields some important insights into the condition of the system. Chilled water temperature is plotted against supply air temperature in Figure 3. The design chilled water temperature was easily maintained by the chiller plant, yet the air handlers could not supply sufficiently cool air to satisfy space cooling needs. A time-series plot of chiller operation shows that only one of the chillers is operating during this period, as shown in Figure 4. Once the cooling

Data collected during the measurement and verification process can be of significant value to the overall project execution process. For example, baseline data collection for M&V purposes can provide significant value to the engineering feasibility and design activities. Greater attention paid to the up-front engineering calculations during the project feasibility stage will reduce ESCO risk and improve customer satisfaction with the project. Engineering and M&V baseline measurement activities should be integrated in order to receive the maximum benefit. Short-term component-based measurements made on a sample of equipment can provide key information to the design and feasibility process at a reasonable cost. The expenditures are justified when the reduction in the savings at risk is greater than the cost of the additional baseline activities. Engineering parameters derived from measurements made over several projects can be used in future projects to improve up-front engineering calculations.

Table 5. Summary of Observed Baseline Unit Operation and Condition

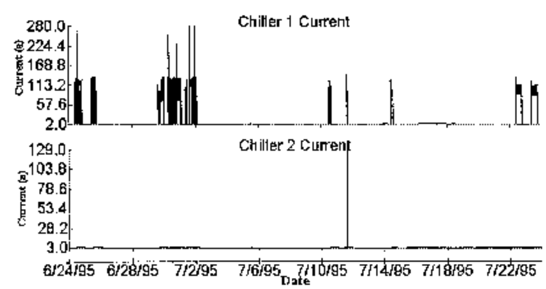
Unit	Size (ton)	Cooling Supply Temperature (deg F)	Economizer operable?	Notes
1	4	50–55	No	System runs 24 hr/day
2	3	50–55	No	System operation follows occupancy schedule.
3	5	50–55	Not equipped	System runs 24 hr/day
4	17	57–63	No	System runs about 16 hr per week, seems to be losing refrigerant charge
5	3.5	N/A	Not equipped	Split heat pump. Air-side measurements not made
6	65.5	47–52	N/A	Measurements made on chiller only. Chilled water temperature control malfunctioned during latter portion of monitoring period

Figure 3. *Building 2 Air Handler Performance*



This plot looks at a comparison of the chilled water temperature leaving the chiller with the supply air temperature at the east air handler. Note that the single chiller maintains chilled water temperature within a reasonable range (49°F to 52°F), but the chilled water coils in the air handlers cannot hold a reasonable supply air temperature. The supply air temperature in the east air handler generally ranges from 59°F to 64°F (The outlier points represent transient startup conditions, and can be ignored)

Figure 4. *Building 2 Chiller Operation*



Compressor current measurements for the two chillers over the four week monitoring period. Note that the second chiller only came on for a brief time during the monitoring period. The chillers are turned on only when an event is scheduled.

Similarly, post-construction data collection can provide much useful information to the commissioning process. Field inspections of new equipment installations, functional performance testing, and short-term component-based measurements are all steps in the commissioning process (Arney and Frey, 1995). The data requirements for commissioning and post-construction M&V data acquisition overlap significantly. These activities should be leveraged to obtain the maximum benefit to the project.

Component-based measurements play a key role in improving up-front engineering calculations of savings, establishing baseline performance, commissioning equipment, and estimating project savings. The cost of providing this service is justified in terms of reducing risk and improving customer satisfaction with the project. M&V activities should be planned and coordinated with all phases of ESCO project execution to obtain the maximum benefit.

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