Measuring Savings in Energy Savings Performance Contracts Using In-Place Energy Management Systems—A Case Study

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Energy Management Control Systems (EMCSs) have been used in many projects as a monitoring device to provide information necessary for estimating savings from efficiency measures. This paper discusses a case study that looked in great depth at that use for evaluating savings in Energy Savings Performance Contracting (ESPC).

ESPC is one of the increasingly important mechanisms for profiting from energy efficiency in commercial buildings. With ESPC, a contractor finances and installs energy-conservation measures, and the resulting savings in energy bills are shared between the contractor and the building owner. Hence, the method used for determining savings is key to the success of this financing scheme. As a part of their effort to establish measurement and verification methods, the Federal Energy Management Program (FEMP) carried out a pilot study of ESPC, and the EMCS was used in the savings verification for this ESPC contract. This case study also serves as a detailed and quantitative comparison of EMCS and conventional monitoring techniques, according to the guidelines developed in earlier work. This paper discusses the concept of different levels of monitoring savings for ESPC and presents an assessment of the use of EMCS for these levels of monitoring.

INTRODUCTION

ESPC is a means of procuring energy saving equipment and services (Energy Conservation Measures, or ECMs), and paying for the purchases out of future savings. Since substantial cash payments are based on savings, it is important to be able to measure or estimate the savings actually resulting from the project. Three efforts have been aimed at developing protocols for determining these savings, sponsored by the American Society for Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), by the Department of Energy (the Federal Energy Management Program, or FEMP), and by the National Association of Energy Service Companies (in their North America Energy Measurement and Verification Protocol) (see NEMVP 1996 and FEMP 1996). All three of these protocols for Measurement and Verification (M&V) are considering a range of monitoring methods, from *verifying the operation* of the measure over its lifetime (referred to as Method A in the FEMP document), to *measurement* of conservation measures (Method B), to measurement of whole-building energy performance (Method C).

All three of these types of methods require some level of monitoring. One tool which can be used for ESPC M&V data collection is an existing Energy Management and Control System (EMCS). Making use of pre-existing equipment can be advantageous in terms of the cost and time required for M&V efforts. However, the EMCS hardware is typically not designed for this particular application, and its applicability must be demonstrated before it can be used with confidence. Several earlier works have investigated the use of in-place EMCSs to monitor the performance of buildings (see Heinemeier 1995; Heinemeier et al. 1992, 1993; Heinemeier & Akbari 1992a, 1992b), as a means of reducing the cost of building monitoring. The earlier works created a general framework for the process of monitoring-project planning, through exploratory case studies to investigate the effectiveness of EMCS monitoring. In those studies, there was an emphasis on identifying the kinds of problems that could occur, and categorizing those problems to define important issues. These issues were formalized into guidelines to provide a procedure for evaluating an EMCS for monitoring applications (Heinemeier & Akbari 1992b).

A more detailed final case study, verifying the usefulness for the particular case of ESPC M&V, was done to increase confidence in the ability to use this tool for this application. The case study was carried out in conjunction with a FEMP case study in ESPC. This pilot study had a broad objective of gaining experience with many facets of ESPC in the federal sector. Although the ESPC process was straightforward in concept, the actual details of the contracting and the process of verifying savings can be complex, and the pilot study was completed to determine ways to simplify the process (Rhea 1993).

This was also a good case study for EMCS-based monitoring, since it also used more traditional dedicated monitoring equipment, and allowed a detailed comparison of the two methods. This case study is not intended to be representative of a standard-practice EMCS or the building stock. The purpose of this paper is not to prove that EMCS monitoring will be effective in every case, but rather to provide a side-by-side comparison of dedicated monitoring and EMCS-based monitoring. The paper is also intended to investigate if EMCSs can provide the necessary data for ESPC M&V, *given* the framework proposed by DOE and others. It is not intended to validate that framework, and the effectiveness of the methods in these protocols, compared to other methods of determining savings, is not addressed.

This section describes the building used as the case study, the retrofits that were installed, the ESPC savings methodology, and the data collection equipment (EMCS and dedicated). The next section describes the results of the savings calculations, and evaluates the use of the EMCS in the M&V effort.

CASE STUDY OF EMCS MONITORING FOR ESPC MEASUREMENT AND VERIFICATION

The site chosen for the pilot was the campus of a National Laboratory. There are over 100 buildings at the laboratory, primarily scientific laboratories and office buildings, and including auditoriums, cafeterias, and several large experimental facilities such as particle accelerators. The laboratory lies on a hill adjacent to the University of California campus in Berkeley, and has a very mild climate.

The building that was the subject of the ESPC contract was Building 62, the Inorganic Materials Laboratory. Building 62 was built in 1965 with approximately 56,000 gross square feet (5200 square meters), and houses 110 employees. The building has two sections: the first is three stories composed of 56 offices, 56 laboratories, an auditorium, a mechanics shop, and a small library. The second section is a high-bay space with a ten ton crane. The building has the headquarters of the laboratory's Materials and Chemical Sciences Division and houses several chemistry, chemical engineering, nuclear engineering, ceramics, solid-state physics, and metallurgy research groups.

Before the retrofit, the building annually consumed about 3 million kWh in electricity,—50 kWh/square-foot per year (540 kWh per square meter)—and about 100,000 therms (10,000 MJ) of natural gas—2 therms/square-foot per year (2300 MJ per square meter)—for a total of about 700 kBtu/square foot per year (7900 MJ per square meter) in primary energy, (which reflects the relative inefficiency of electricity as a fuel). Annual energy costs were about $190,000 for electricity and $40,000 for gas—for a total of $230,000 or about four dollars per square-foot per year ($43 per square meter). According to an instrumented survey performed in 1986, 39% of the consumption is due to HVAC, 14% to lighting, and 47% to all other end uses (LBL 1989).

The building has a chiller with chilled water (CHW) pumps, cooling tower with fan and pump, two gas-fired boilers with pumps, supply fan with return fan, exhaust fans, a pump for low-conductivity water (LCW—for laboratory experiments), lighting, 120-volt circuits (including task lighting), and an emergency lighting panel. The high-bay section of the building has two heating and ventilating (HV) units. The building has a constant-volume air distribution system, with zone reheat. The power supplied to the building also serves two other buildings. (Note that the total energy consumption reported above does not include this exported energy).

Retrofits

An instrumented building audit was performed in 1986. In 1988, a more detailed end-use monitoring study was undertaken to identify baseline consumption patterns and to identify potential conservation measures. A Request-For-Proposals was issued in June of 1989, a contractor was selected in December of 1989 to install and maintain conservation measures, and the contract was eventually issued in July of 1991. The procurement process was somewhat difficult and lengthy, and resulted in many recommendations on how this process could be improved for use in other federal facilities (Rhea 1993). The work of installing the conservation measures began in June, 1993, and was completed in January, 1994.

The ECMs include several lighting measures, installation of a Variable-Frequency-Drive (VFD) on the air handling unit (AHU) (to replace the inefficient inlet-vane control needed to reduce flow from an oversized fan, not to carry out variable-air-volume control), temperature control repairs on the boiler, high-efficiency motors on the LCW pumps, a tune-up of the boiler, and an EMCS to control the chiller, air-handling units and HVAC system. The total installation cost was estimated at about $274,500 and the projected annual savings were about $28,500 from electricity and $16,000 from gas, for at total of about $44,500. This corresponds to a simple payback time of about six years. The projected annual energy savings were 430,000 kWh, and 41,000 therms (4300 GJ). The contractor paid for the construction costs and is being repaid by the laboratory from the savings.

Savings estimation methods in contract

The formulas for estimating savings were agreed upon and stipulated in the contract. These formulas are summarized in Table 1. These methods of estimating savings were developed for this particular project, and were developmental versions of the later FEMP ESPC M&V protocols. All savings estimates are based solely on energy savings, although the laboratory is billed for demand as well as energy consumption. The most difficult part of any savings calculation is determining the baseline: how much energy the building and end uses would have used if the retrofits had not been performed. The following sections discuss the baseline calculations for each end use.

Method A.

- *LCW pump and AHU:* Since this equipment operates 24 hours a day, 365 days a year, and its load is constant, simple one-time measurements of power taken before and after the retrofit are used to determine savings.

- *Lighting*: Since there are no expected changes in lighting operation patterns, lighting savings are estimated from pre- and post-retrofit one-time kW readings (taken with all the lights in the building turned on). The ratio of the post- to the pre- readings was used to scale down the pre-retrofit annual lighting consumption, taken from the end-use monitoring. Another way of thinking of this is that the ratio of the annual pre-retrofit lighting consumption and the pre-retrofit one-time kW reading is the equivalent full-load hours for lighting. This is used with the post-retrofit kW reading to estimate post-retrofit annual consumption. Note that any reductions in cooling

Table 1. *Methodology for Monthly Energy Savings Calculations for Shared Savings in Case Study*

Method	End Use	Relevant ECM	Pre-Retrofit	Post-Retrofit
A	AHU	VSD	$\mathbf{kW_b} \times \frac{8760\text{hrs}}{12\text{mo}}$	$\mathbf{kW_a} \times \frac{8760\text{hrs}}{12\text{mo}}$
A	LCW Pump	Efficient Motors	$\mathbf{kW_b} \times \frac{8760\text{hrs}}{12\text{mo}}$	$\mathbf{kW_a} \times \frac{8760\text{hrs}}{12\text{mo}}$
A	Lighting	Lighting Modifications	$\frac{\mathbf{kWh/yr_b}}{12\text{mo/yr}}$	$\frac{\mathbf{kWh/yr_b}}{12\text{mo/yr}} \times \frac{\mathbf{kW_a}}{\mathbf{kW_b}}$
B	CHW Pumps	EMCS	$\mathbf{kW_b} \times \frac{8760\text{hrs}}{12\text{mo}}$	$\mathbf{kW_b} \times \frac{8760\text{hrs-}\mathbf{offhrs_a*}}{12\text{mo}}$
B	HV-2	EMCS	$\mathbf{kW_b} \times \frac{8760\text{hrs}}{12\text{mo}}$	$\mathbf{kW_b} \times \frac{8760\text{hrs-}\mathbf{offhrs_a*}}{12\text{mo}}$
B	HV-3	EMCS	$\mathbf{kW_b} \times \frac{8760\text{hrs}}{12\text{mo}}$	$\mathbf{kW_b} \times \frac{8760\text{hrs-}\mathbf{offhrs_a*}}{12\text{mo}}$
B/C	Chiller	EMCS	$\mathbf{b} + (\mathbf{m_1} \times \text{HDD}) + (\mathbf{m_2} \times \text{CCD}) + (\mathbf{m_3} \times \mathbf{INLOAD*})$	$\mathbf{kWh/mo_a*}$
C	Gas	EMCS Control Repair Boiler Tune-up	$\mathbf{b} + (\mathbf{m_1} \times \text{HDD}) + (\mathbf{m_2} \times \text{CCD})$	$\mathbf{therms/mo_a}$

Notes: $\mathbf{b}$, $\mathbf{m_1}$, $\mathbf{m_2}$, and $\mathbf{m_3}$ are regression coefficients from historical monthly energy consumption;
INLOAD is the miscellaneous energy consumption:
$\mathbf{kW_b}$ is a one-time measurement of power before the retrofit;
$\mathbf{kW_a}$ is a one-time measurement of power after the retrofit;
$\mathbf{kWh/yr_b}$ is a measurement of annual end-use energy before the retrofit;
$\mathbf{kWh/mo_a}$ is a measurement of monthly end-use after the retrofit;
$\mathbf{offhrs_a}$ is a measurement of logged off hours, after the retrofit; and
$\mathbf{therms/mo_a}$ is a measurement of monthly gas energy consumption after the retrofit.
*indicates that the source of data is the EMCS.

load or increases in heating loads are not accounted for in this estimation.

Method B.

- *CHW pumps and HV units:* These units previously operated 24 hours a day, but in the EMCS retrofit, they are turned off at night and when they are not needed. Thus, the savings estimates consist of one-time kW measurement before the retrofit, and monitoring of the amount of time the units are turned off after the retrofit. This off-time monitoring is carried out by the EMCS. This assumes that the units operated for 8760 hours per year before the retrofit, and that after the retrofit the kW remained the same. This is an example of ''B'' method M&V, since it continuously monitors the operation of the building and equipment, and doesn't simply take a snapshot of the performance of the retrofit as installed.

Method C.

- *Chiller:* Chiller savings come from EMCS control, including supply temperature reset and reduction of nighttime operation with an optimal-start routine. The 1988 end-use monitoring was used to establish the chiller baseline. Daily data were originally considered as the basis for baseline and savings estimates, but they were considered to be too burdensome, and monthly data were decided upon as the basis for savings calculations. The end-use monitoring determined that the end uses fell into three categories: constant, independent, and weather-dependent. All the baseloads were constant with the exception of miscellaneous end uses (independent) and the chiller (weather-dependent). It was also determined that the chiller load was correlated with the independent miscellaneous load, in addition to being correlated with weather. The weather data used for this correlation were cooling degree days (CDD) and heating degree days (HDD) published by the National Oceanic and Atmospheric Administration (NOAA) for San Francisco Airport. By using a fixed value for the constant loads (averages based upon the monitored data), monitoring the independent loads, and using the independent load and weather to correlate the chiller load, the auditors were able to estimate historical monthly chiller energy consumption to within 2–3% (LBL 1989).

  The method for estimating chiller savings, then, is to monitor the independent miscellaneous end use, and use this with CDD and HDD data from NOAA to calculate the baseline chiller consumption (i.e., how much the chiller would have consumed—given the internal loads and weather—had the retrofit not taken place). The actual post-retrofit consumption is monitored, and the difference between the two is the savings. Monitoring of the post-retrofit chiller consumption and the miscellaneous end use consumption is carried out by the EMCS.

  This is similar to Method C, since it builds and applies a pre-retrofit model of equipment performance and monitors the performance throughout the life of the contract. However, since it does not monitor whole-building consumption, it is something of a ''Hybrid'' B/C Method.

- *Gas:* Savings from the boiler tune-up and the repair of radiator thermostats are evaluated together, in natural gas savings. Just as was done for the chiller, a pre-retrofit model was created, and consumption is expressed as a function of heating- and cooling-degree days. Post-retrofit actual consumption (from the utility bill) is compared with baseline consumption (result of the pre-retrofit model, using the actual, post-retrofit weather). This is a true Method C methodology, since it uses the whole-building consumption. This shows the advantages of Method C: lighting retrofits will increase the need for heating in the building, although the Method A methodology for expressing lighting savings does not take this into account. This interactive effect is taken into account in the gas savings calculation: some months may show negative savings for gas, if the increased efficiency of the boiler and distribution system is outweighed by an increased need for heating.

EMCS monitoring

After lighting modifications, the measure with the greatest anticipated savings was installation of an EMCS. Estimated savings from the EMCS are $9,500 in electricity and $3,500 in gas, for a total savings of about $13,000. The installation cost was $72,000, for a simple payback time of five and a half years. Savings are achieved from hot- and cold-water outdoor-air temperature reset; control of the VFD on the AHU to maintain static pressure; night setback; economizer; optimal stop and start on HV units, chiller, and boiler; nighttime shutoff of chilled-water pumps; temperature control of the cooling-tower fan; and nighttime lockout of the domestic and industrial hot-water valves.

The EMCS in the case study building is the system currently used in many of the laboratory's buildings, and a site-wide building automation expansion project is underway. The EMCS was installed in Building 62 in 1993. The overall

- The *process* of collecting data from the EMCS was very comparable to the dedicated monitoring, and in some cases more convenient and quicker.

DISCUSSION

In all of the case studies that have been carried out, using existing in-place EMCSs had several limitations in meeting the requirements. The specific problems that occurred in

- change-of-value (COV) levels were set too high, resulting in insufficient resolution;

- when capturing data reports from a screen, the data format was difficult to process (no line feeds, a status line occurred frequently, data were not in columnar format);

- COV cumulative data, combined with hourly averaging, made interpretation of some of the data difficult; and

- when system was rebooted, data collection sometimes

Quality control

- A sensor was in the wrong location: on a recirculating rather than a supply pipe, or on the output rather than the input side of a VFD;
- a CT was incorrectly sized;
- a kWh calibration factor was incorrect, by a factor of two;
- the wrong units were specified for a point; and
- a CT was installed backwards.

Fundamental problems

- Each site had unique problems, required unique procedures, and had to be evaluated individually;
- it was not straightforward to evaluate capabilities at a site; and
- significant assistance by the EMCS operator was required.

Solving the problems

It is important to note that for each problem that occurred at a site, there were other sites where the problem did not occur, so that none of the problems should be considered universal or insoluble. Since the application of EMCSs to monitoring has significant promise, it is useful to discuss how its problems might be solved, so that the tool can be more appropriate in future efforts.

Some of the stated problems can be easily solved in existing systems. For those systems that are not well suited to monitoring, the limitation is frequently in the software and not in the hardware. That is, the EMCS could log the necessary data, but it has not been programmed to do so. In these cases, data monitoring should be fairly simple to implement. The problem of insufficient storage space can sometimes be solved by judicious choice of which data to store. For example, it might be impossible, because of storage limitations, to store short-interval end-use demand or status data for a long period of time. However, if an average weekday profile is constantly updated (e.g., just 24 hourly averages and their corresponding statistical variation), the necessary statistical information on hourly changes will take up a minimal amount of space. (Also, additional memory or a permanent storage device might be added to a system at a cost that is small relative to the cost of the original EMCS or of submetering.) While it may be difficult to increase the reliability of sensors, some indicator of whether or not a given piece of data is reliable—such as the indicator of down time in one of the case studies—would be sufficient to prevent false conclusions. The problem of tying up phone lines or interfering with control activities while getting data would be less serious if the transfer of data could occur more quickly, which would be possible if the data were transferred in compact format, rather than buried in bulky reports with unnecessary headings and descriptions.

Other problems can be solved with minor modifications to system design. Relatively minor modifications to the available EMCS software could greatly improve this method of collecting data. In particular, EMCS software could be modified to:

- allow data to be averaged over an hourly interval;
- reliably report data at the end of each hour;
- create concise and standardized formats for requesting data;
- create concise and standardized formats for reporting data;
- create some simple means of rapidly and reliably displaying or transmitting the data;
- allow a ‘‘read-only’’ access mode; and
- create a data collection facility that requires a special password to alter or delete data.

Some problems will require major modifications to system design. A system designed with energy performance monitoring in mind would probably have some fundamental differences. For example, the simplest way to gain access to the data in these existing cases was to have the data displayed on the screen and captured into a log file. However, this is not the most appropriate method, due to the inability to perform error detection and correction, and the time it takes to transmit and process the report. There is also a potential for energy monitoring to interfere with EMCS control operations, and for control operations to interfere with energy monitoring. Ideally, controls manufacturers should incorporate into their basic software a procedure for transmitting data files to a remote, dial-in terminal, using non-proprietary communications software and a standard file transfer protocol that is capable of transmission error detection and correction. It should also have a separate energy monitoring procedure, which would allow monitoring to take place without either interrupting or being interrupted by control procedures.

Other problems may be more difficult to solve. Installation, programming, and commissioning problems are quite common in EMCS applications. Quality control is always a serious concern. Contributors to this problem are the need to minimize installation costs to be competitive, and the complexity of most systems. This type of problem is not easy to solve; entire conferences have been devoted to discussion the causes and possible solutions to building quality control problems. It is important to remember at the same time that the quality of specification and installation should also be considered serious issues for conventional monitoring. For example, most of the types of problems that occurred in the EMCSs in the case studies have occurred with conventional monitoring systems in other programs (see, for example, O'Neal et al. 1992). However, an important distinction is that quality control is ultimately under the control of the monitoring professional, while that is not the case when the building's EMCS is being used. Until progress is made on ensuring the quality of EMCS installations, it is important that EMCS systems are designed to facilitate recalibration of sensors and provide redundancy in data collection.

Implementation

Given that the use of EMCSs for monitoring has promise, that it currently does not meet some of its objectives in many cases, and that many of the problems are soluble, what will it take to make these solutions come about? This requires an understanding of what the current barriers are. One of the major barriers is a lack of protocols for carrying out this type of monitoring. These are needed to solve the problems that were classified as ''fundamental'' above: the difficulty in assessing capabilities when no such protocols are in place, and the difficulty in integrating EMCS-monitoring into programs when many different procedures are required for different models. Protocols would include specification of data formats, and definition of what is meant by a ''monitoring-ready'' system, so that it does not have to be assessed on a case-by-case basis. Hopefully, the guidelines presented in earlier work will provide a basis for construction of such protocols.

The second barrier is the perceived lack of a market for such capabilities. This can be overcome in several ways. The first is for entities carrying out conservation programs to include a requirement for monitoring capabilities in their requirements for participation in the program. Utility DSM programs and the Environmental Protection Agency's Energy Star Building program are two examples of the types of programs that could include this type of requirement. If such requirements were in place, EMCS manufacturers could be assured that enough customers will request such capabilities to be worthwhile for them to create these capabilities. Program planners would also be assured that the systems installed will be usable for monitoring. Another means of implementation would be for major customers to specify that ''monitoring-ready'' EMCSs shall be installed. Examples of major customers that could exercise this type of market pull would be government buildings, large chains, major developers, or property management firms. A final example of a means to ensure implementation of this technology would be standards. This could either be standards set by the controls or buildings industries to assure quality in their products, or building standards imposed by states or localities.

CONCLUSIONS

This study successfully demonstrated at one case-study site the use of an in-place EMCS to collect the data needed for measurement and verification of savings in an ESPC contract, using several different methods of M&V. In terms of the data collected and the process of collecting data, the EMCS compared favorably to the dedicated monitoring installed at the same site for the simplified data required using this M&V methodology. However—as with any monitoring project—problems did occur.

Accuracy and reliability problems were quite frequently encountered. In one case, the CTs installed were the wrong size, or installed on the wrong side of a VFD. Insufficient resolution (due to programming, not hardware), programming for pulse counter incrementing, CT polarity problems, and faulty watt-hour transducers, all led to delays in obtaining accurate data. It was difficult to determine what the problems were, and to convince the building and EMCS personnel to fix the problems. On the other hand, eventually all the kWh points did provide acceptable data. In fact, one of the points was used to identify a problem with the dedicated monitoring data: CTs had been removed from two of the three phases on one of the channels, and the drop in consumption was attributed to a retrofit, rather than faulty metering.

There were problems with both EMCS and dedicated equipment, and it is concluded that quality control is an essential factor for both types of monitoring. In fact, the literature on dedicated monitoring is filled with notations of problems of the type that were found in this EMCS (see, for example, O'Neal et al. 1992; and ASHRAE 1995). With significant effort, it was possible to resolve all data problems, just as it is usually possible to address hardware and software problems in dedicated monitoring efforts. However, since addressing the problems necessarily involved the assistance and interest of the EMCS operator, ESPC program manager, retrofit contractor, EMCS vendor, and instrumentation subcontractors, it was quite difficult.

While there were several significant problems with hardware and software, data needed for the savings calculations were successfully collected from the EMCS and, once problems with the data were ironed out, the process was fairly simple. Data storage and access to data were very robust. The process for collecting the data from the EMCS was slightly simpler and quicker than collecting data from the dedicated monitoring. Operational data from the EMCS provided a wealth of information on building operation that would have been difficult to infer from end-use monitoring.

EMCSs can play an important role in the expanding market for energy savings performance contracts. Beyond simply measuring the savings, the EMCS can provide more detailed information on the operation of the building, equipment, and efficiency measures. It can play an important role in initially ensuring and measuring ECM performance (commissioning), and monitoring the operation and performance of the measures throughout their lives. Taken together with results of earlier studies, it can be concluded that many of the problems with EMCS monitoring can be solved. Some can be solved with careful attention at individual sites. Others will require minor or major modifications to system design. Quality control, however, is the primary source of problems in EMCS monitoring, and—just as with dedicated monitoring—attention to quality control can make the difference between an accurate estimate of energy savings and suspect data that will make energy savings estimates meaningless.

EMCS monitoring capabilities must be further developed to meet all of the needs for monitoring and to be considered a universally reliable and appropriate tool. However, the potential advantages are significant, and when this development takes place, EMCSs are expected to become very important tools in ensuring that energy conservation is an effective and viable alternative to increased energy consumption.

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