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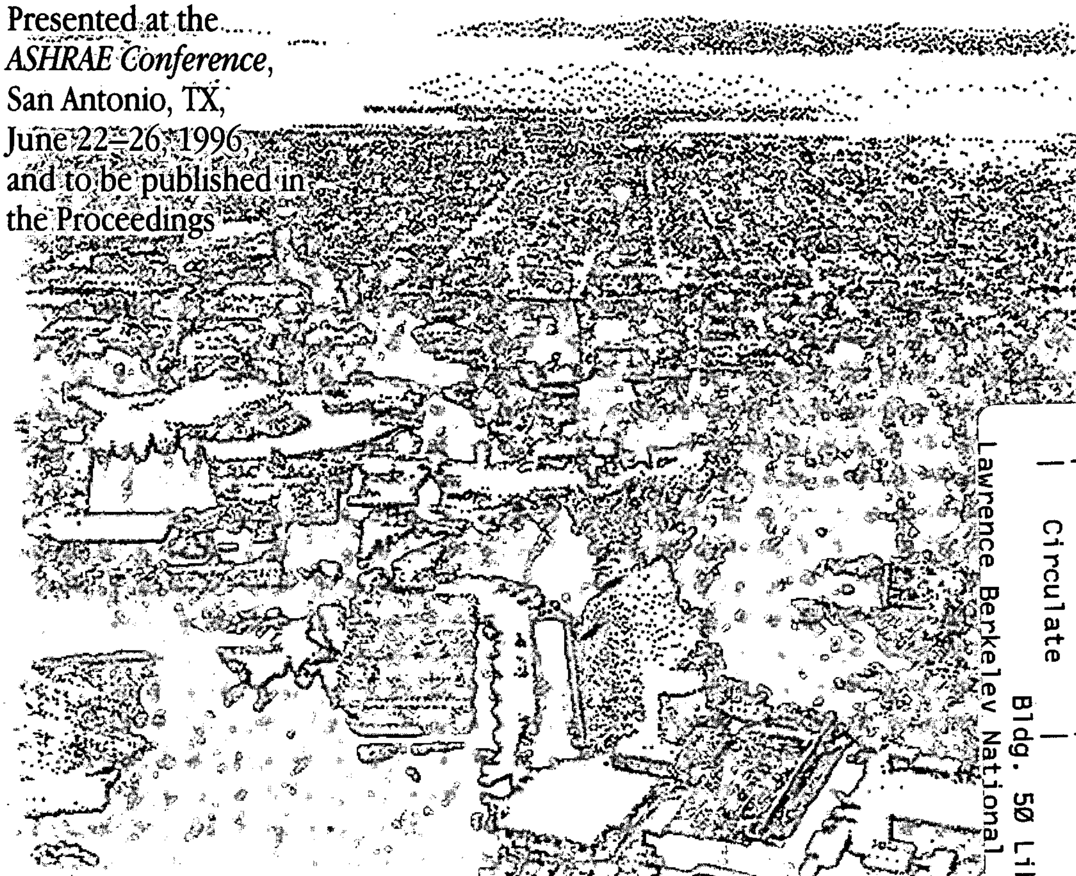

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ABSTRACT

One of the increasingly important mechanisms for profiting from energy efficiency in commercial buildings is energy savings performance contracting (ESPC). The key to this market-driven financing scheme is the ability to verify the savings. Although monitoring end-use energy consumption is not new, it is infrequently carried out and may not be cost-effective in many ESPC applications. Less expensive and less complex methods for determining savings may make this mechanism more frequently used. Protocols being developed by the Department of Energy (DOE), the energy service industry, and ASHRAE attempt to address this need. This paper describes these developmental efforts briefly and discusses the range of available evaluation methods entailed in them. It then discusses one particular monitoring technology, the use of in-place energy management and control systems (EMCS), to carry out this monitoring.

As one part of the protocol development effort, a case study of savings estimation in ESPC was carried out in an institutional building. In this project, a contractor installed retrofits and a fraction of the savings realized by the owner were paid to the contractor, who was responsible for monitoring the building and estimating the savings. The method for determining savings from the retrofits was clearly specified in the contract and included using the building's EMCS for monitoring. To verify the EMCS measurements, the owner installed independent submetering.

In this paper, the savings estimates resulting from these different monitoring methods will be compared, as will the different processes of collecting and analyzing data. The objective of the paper is to investigate the use of the EMCS to collect the data specified in the ESPC measurement and verification protocols and not to validate the savings estimates resulting from use of the protocols. Several inconveniences arose in using the EMCS for monitoring, but, on the whole, it was an adequate and inexpensive method of determining savings. The results of this comparison are recommendations on how EMCS can be used most effectively for the particular application of verifying ESPC savings and how EMCS results compare with other tools for calculating savings.

INTRODUCTION

Several works have investigated the use of in-place energy management and control systems (EMCS) to monitor the performance of buildings (Heinemeier 1995; Heinemeier and Akbari 1993; Heinemeier and Akbari 1992a, 1992b; Heinemeier et al. 1992) as a means of reducing the cost of building monitoring. The earlier works have 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 and Akbari 1992b).

One monitoring application of particular interest in the earlier work is remote monitoring to evaluate energy savings in energy savings performance contracting (ESPC). 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 important. The 1992 Energy Policy Act recommends the use of this kind of performance contract for federal buildings. The Department of Energy's Federal Energy Management Program (FEMP), which has responsibility for coordinating conservation programs in federal buildings, sought to encourage this performance approach as well. FEMP carried out a pilot study of ESPC on the campus of a national laboratory and the EMCS was used in the savings verification for this ESPC contract. Based upon the verification work in this pilot study (among other things), FEMP developed draft protocols for

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measurement and verification (M&V) of savings for an ESPC contract (FEMP 1996).

In addition to contributing to the development of the M&V protocols, this pilot study also created an ideal opportunity to evaluate the usefulness of EMCS in monitoring savings, serving as a more thorough demonstration of EMCS monitoring capabilities and identifying problems and advantages. This case study also serves as a detailed and quantitative comparison of EMCS and conventional monitoring techniques, according to the guidelines developed in the earlier work. This paper introduces the concept of different levels of monitoring savings for ESPC and presents an assessment of the use of EMCS for these levels of monitoring.

The site chosen for this project has an EMCS and is also monitored using dedicated monitoring instrumentation. This allows a side-by-side comparison. Thus, it is not intended to be representative of a standard-practice EMCS or the building stock. The purpose 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. It is also intended to investigate whether EMCS can provide the necessary data for ESPC M&V, given the framework proposed by the Department of Energy 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.

VERIFYING ENERGY SAVINGS

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. As with any contract, the services and equipment that are procured must meet the specifications contained in the contract. Unlike other contracts, payment for these services is contingent on proof of performance of the measures, based on energy cost savings, or the reduction in the cost of energy and related operation and maintenance expenses from a base cost established through a methodology of measurement and verification (M&V) set forth in the contract.

The basis of this methodology rests on the principle that energy savings are derived by comparing the energy use after the retrofit to what it would have been without the retrofit. Measuring the energy use after a retrofit ranges from trivial to nearly impossible; measuring what would have been without the retrofit is impossible. In fact, it can be reasonably stated that the actual energy savings cannot be measured. The term *actual energy savings* itself may be a misnomer, as it implies the existence of some true and accurate value that will be estimated, rather than a set of assumptions to which we are agreeing and verifying within a stated accuracy. The appropriate role of the energy-savings methodology in the contract, then, is to make clear the assumptions and responsibilities and to define the procedures for establishing the baseline, taking the post-retrofit measurements, and calculating the energy savings.

Protocols for Measurement and Verification

In the past several years all of the parties involved in this industry recognized the need to standardize these methods. Three recent protocol development efforts are relevant to this discussion:

- At the June 1993 ASHRAE meeting, a committee was formed to draft Guideline 14P, "Measurement of Energy and Demand Savings." This committee continues to work on the technical requirements for energy measurements. At some point in the future, it is expected that this work will be incorporated in the following protocols.
- In January 1995, the National Energy Monitoring and Verification Protocol (NEMVP) Committee was initiated by the Department of Energy and staffed with a group of volunteers representing the entire energy services industry with the goal of adopting a national measurement and verification guideline. The intention is to standardize the way the industry defines its business. The first draft of these protocols was released at the Governor's Conference in February 1996 (NEMVP 1996).
- In June 1995, work was begun on the FEMP M&V protocol, a specific guide to methods endorsed by DOE/FEMP for use in ESPC. These protocols were written so as to be consistent with the NEMVP document but with the rigors of the federal procurement process in mind. These protocols are currently out for review (FEMP 1996).

Methods for Measurement and Verification

The general approach taken in these three protocols (and, in fact, in any M&V effort) includes the following steps:

- accurately define baseline conditions and assumptions,
- confirm that the proper equipment/systems were installed and that they have the potential to generate the predicted energy savings, and
- estimate the energy savings achieved by the ECM.

Three methods have been defined for carrying out these steps: method A (short-term metering), method B (continuous measurement), and method C (whole-building monitoring and modeling). These methods are described below and summarized in Table 1.

Method A Experience with several pilot ESPC programs shifted the emphasis of measurement away from long-term metering of the systems toward spot and short-term metering before and after the retrofit. These methods focus the measurement on the areas in which the contractor has control: the installation of the correct measure (equipment, systems, devices, or procedures) and assurance of its performance in the facility. The long-term operation of the measure is stipulated over the life of the contract, and the owner takes responsibility for any deviations from this stipulated operation. Note that the energy savings is verified but not quantified—that is, the exact value of the

TABLE 1 M&V Methods Summary

M &V Option	Verification of Potential to Perform (and generate savings)	Verification of Performance (savings)	Performance Verification Techniques
Option A Verifying that the measure has the potential to perform and to generate savings.	Yes	Stipulated	Engineering calculations (possibly including spot measurements) with stipulated values.
Option B Verifying that the measure has the potential to perform and verifying actual performance by end use.	Yes	Yes	Engineering calculations with metering and monitoring throughout term of contract.
Option C Verifying that the measure has the potential to perform and verifying actual performance (whole building analysis).	Yes	Yes	Utility meter billing analysis, possibly with computer simulation.

source: NEMVP 1996

savings is not known, but it is known that the contractor did his or her job correctly and the estimated savings can be realized.

Method A involves procedures for verifying that

- baseline conditions have been properly defined;
- the measures that were contracted to be installed have been installed;
- the installed measure components or systems meet the specifications of the contract in terms of quantity, quality, and rating;
- the installed measure is operating and performing in accordance with the specifications in the contract and meeting all functional tests; and
- the installed measure components or systems continue, during the term of the contract, to meet the specifications of the contract in terms of quantity, quality and rating, and operation and functional performance.

Method B Procedures that call for continuous measurement of measures are contained in "method B" methods. Method B involves procedures for verifying the same items as method A plus verifying achieved energy savings during the term of the contract. Performance verification techniques involve engineering calculations with metering and monitoring to determine an energy (and cost) savings value using measured data taken throughout the term of the contract.

Method C Procedures that attempt to determine energy savings by using whole-building data such as utility bills are defined as "method C" methods. Method C is identical to method B in intent, although it involves using whole-building meter analysis and/or use of regression models or engineering-based simulation models calibrated with utility billing data. Method C would be used when there is a high degree of interaction between installed energy conservation systems and/or the measurement of individual component savings would be difficult.

All three of these methods require some form of measurement of actual performance at some point in the contract. Many different tools can be used for these measurements, ranging from single-use hand-held meters to sophisticated multipurpose dataloggers. One tool that can be used for this data collection is an existing 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. Earlier studies have suggested this use, and case studies validated that they can be used (see summary in Heinemeier [1995]). A more detailed case study, verifying the usefulness for the particular case of ESPC M&V, was done, however, to increase confidence in the ability to use this tool for this application.

CASE STUDY OF EMCS MONITORING FOR ESPC MEASUREMENT AND VERIFICATION

As one step in the effort to develop the FEMP M&V protocols, DOE sponsored a pilot study of ESPC. This pilot study had a broad objective of gaining experience with many facets of ESPC in the federal sector. Although the ESPC process is 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 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.

The Case Study Site

The site chosen for the pilot was the campus of a national laboratory. There are more than 100 buildings at the laboratory, primarily scientific laboratories and office buildings, including auditoriums, cafeterias, and several large experimental facilities such as particle accelerators. The laboratory lies on a hill adjacent to a university campus and has a 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 ft^2 (5,200 m^2), 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 10-ton crane. The building houses the headquarters of the laboratory's materials and chemical sciences division and 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/ft^2 per year (540 kWh/m^2)—and about 100,000 therms (10,000 MJ) of natural gas—2 therms/ft^{2}per year (2,300 MJ/m^2)—for a total of about 700 kBtu/ft^{2}per year (7,900 MJ/m^2) 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 \$4/ft^2 per year (\$43/m^2). According to an instrumented survey performed in 1986, 39% of the consumption is due to heating, ventilating, and air conditioning (HVAC); 14% to lighting; and 47% to all other end-uses (LBL 1989).

The building has a chiller with chilled-water (CHW) pumps, a cooling tower with a fan and pump, two gas-fired boilers with pumps, one HVAC unit, a supply fan with a 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 1989, a contractor was selected in December 1989 to install and maintain conservation measures, and the contract was eventually issued in July 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-volume temperature 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 a 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 (4,300 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 2. 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-retrofit to pre-retrofit 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 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 8,760 hours per year before the retrofit and that after the retrofit, the kW remained the same. This is an example of method B 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.

TABLE 2 Methodology for Monthly Energy Savings Calculations for Shared Savings in a Controlled Case Study*

Method	End Use	Relevant ECM	Pre-Retrofit	Post-Retrofit
A	AHU	VSD	$kW_b \times \frac{8760\ hrs}{12mo}$	$kW_a \times \frac{8760\ hrs}{12mo}$
A	LCW Pump	Efficient motors	$kW_b \times \frac{8760\ hrs}{12mo}$	$kW_a \times \frac{8760\ hrs}{12mo}$
A	Lighting	Lighting mods.	$\frac{kWh/yr_b}{12mo/yr}$	$\frac{kWh/yr_b}{12mo/yr} \times \frac{kW_a}{kW_b}$
B	CHW pumps	EMCS	$kW_b \times \frac{8760\ hrs}{12mo}$	$kW_b \times \frac{(8760\ hrs - offhrs_a)^{\dagger}}{12mo}$
B	HV-2	EMCS	$kW_b \times \frac{8760\ hrs}{12mo}$	$kW_b \times \frac{(8760\ hrs - offhrs_a)^{\dagger}}{12mo}$
B	HV-3	EMCS	$kW_b \times \frac{8760\ hrs}{12mo}$	$kW_b \times \frac{(8760\ hrs - offhrs_a)^{\dagger}}{12mo}$
B/C	Chiller	EMCS	$b+(m_1 x HDD)+(m_2 x CDD)+(m_3 x INLOAD)^{\dagger}$	$kWh/mo_a^{\dagger}$
C	gas	EMCS Control repair Boiler Tune-up	$b+(m_1 x HDD)+(m_2 x CDD)$	$therms/mo_a$

NOTE:

b, m_1, m_2, and m_3	regression coefficients from historical monthly energy consumption;
INLOAD	mescellaneous energy consumption;
kW_b	one-time measurement of power before the retrofit;
kW_a	one-time measurement of power after the retrofit;
kWh/yr_b	measurement of annual end-use energy before the retrofit;
kWh/mo_a	measuremetn of monthly end-use enegy after the retorfit;
$offhrs_a$	measurement of logged off hours, after the retrofit; and
$therms/mo_a$	measurement of montly gas energy consumption after the retrofit.

* Savings from a retrofit is the difference between monthly "pre-" and "post-retrofit" consumption.

† Indicates that the source of the data is the ECMS.

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 (degree-days based on 65°F [18.3°C]). 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% to 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 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 one-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 under way. The EMCS was installed in building 62 in 1993. The overall architecture of the EMCS is illustrated in Figure 1. Each of the buildings connected to the EMCS has at least one primary controller and several local input/output (I/O) boxes. The primary controllers are connected together within one of several local area networks (LANs). Building 62 has two primary controllers and six local I/O boxes. The primary host computer is located in one building and an additional host computer is located in another. Once the input points are measured, they are stored momentarily at the local I/O box. The primary controller collects data from the local I/O boxes whenever requested by the host computer. The primary host computer constantly scans the primary controllers and obtains the most recent data possible.

The EMCS "host" runs on a compatible computer. Ordinarily, the host doesn't have to be running, but to collect data it is usually kept on 24 hours a day. The host software runs under a multi-tasking operating system. Remote connections are accomplished using a remote control program. The host scans the controller network to populate a database of current data on all points in the system. This scan can take several minutes to complete, so the most recent value of a data point may be up to several minutes out of date. All points within the system are recorded in the database and are summarized in several ways in a history facility. Once an hour, the one-minute database values are analyzed and the maximum, minimum, and average are calculated. Once a day, daily averages are calculated and once a month monthly averages are calculated. These data can then be viewed graphically or manually exported to a spreadsheet-ready disk file (ASCII, comma delimited, with headers).

There is also a mechanism to store these hourly data automatically for later analysis. A file is created on the host's hard disk, which includes the name of up to 40 points to be archived. An EMCS program then creates a file of "yesterday's" data for all of these points, with a name of the format MM-DD-YY.hd. This program can be run at any time or it can be initiated by the

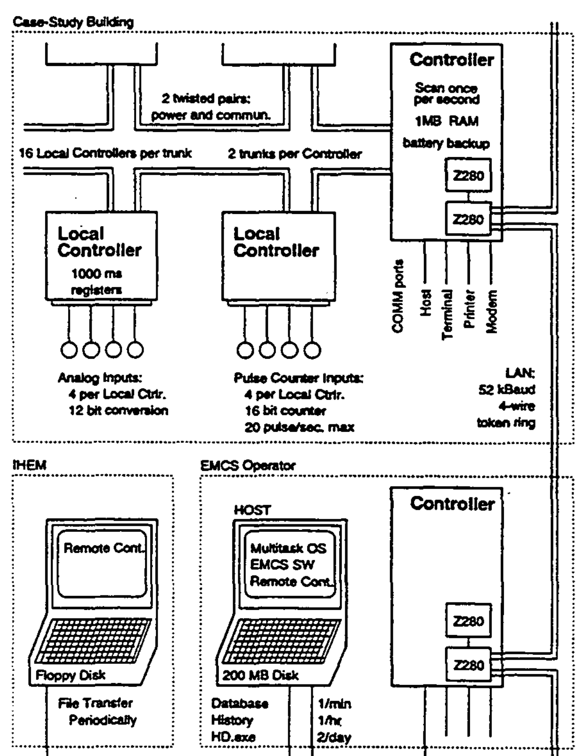

Figure 1 *Architecture of EMCS used in case study. This distributed control system, installed in several buildings at the laboratory site, was used to collect data needed to verify savings from ESPC contract.*

EMCS's supervisory controls program to be run automatically at a certain time every day.

Parallel Dedicated Monitoring

The contractor is responsible for monitoring the building, calculating the savings of the retrofits, and issuing invoices for its share of the savings. Since this is a pilot study, however, the laboratory's in-house energy management group (IHEM) is also monitoring the building to verify the savings estimates received from the contractor.

The equipment used for this monitoring is three power-monitoring dataloggers. This datalogger model is capable of monitoring up to 16 electrical channels (current, voltage, power, and power factor), up to 15 analog inputs, and up to 16 pulse-counter inputs. It has 26 kBytes of onboard memory and a lithium battery backup. It has a built-in modem, and the proprietary software can be run on a personal computer to download the data from the logger. This software can either manually interrogate the logger or can be set up to download data automatically—periodically or when the memory fills up. It has several different data formats from which to choose. The loggers are daisy-chained together so that one access can retrieve data from all three loggers. Hourly data for these points have been available since August 1993.

RESULTS OF EMCS-BASED MONITORING IN ESPC CASE STUDY

Savings Calculations

In accordance with the contract, the contractor accesses the EMCS once a month to retrieve the five values that are needed for savings calculations: three equipment off-time values and two kWh values. They then calculate the savings value and invoice the laboratory for their share of that savings. A laboratory analyst uses the five numbers provided by the contractor in a spreadsheet to calculate savings, reviews the contractor's invoice to verify the calculation of savings and amount due, and approves the invoice for payment. In early months of the contract, there were frequent discrepancies (such as the contractor inadvertently failing to share the savings and invoicing for the entire savings amount). Now that the procedure has become more routine, this entire review-and-approval process typically takes the analyst about one and one-half hours per month. The slowest part of this process is getting the weather data from NOAA, which introduces a two-month delay in this otherwise simple process.

Figure 2 shows the electricity savings that were invoiced in the first 20 months of the contract. As one expects, the method A measures (bottom three gray bars) show constant savings from month to month. The first year's savings are summarized in Table 3 by measure and fuel type. The total energy savings were about 145% of the initially estimated savings. This is due to several factors. For example, the installation of the VSD on the AHU (and removal of inlet vanes) reduced the pressure drop in the fan by a greater amount than

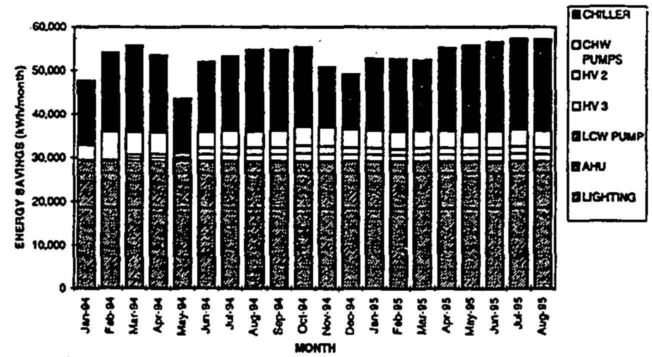

Figure 2 Savings estimates from ESPC contract. Savings for seven measures were calculated based upon methods specified in the contract. The M&V methods can be classified as "Method A" (cross-hatched bars), "Method B" (empty bars), or "Method C" (dark bars).

was originally estimated.[1] The gas savings (not shown) are negative in some months and, overall, the gas savings in the first year was only 22% of estimated savings. This is partly due to the interaction of the lighting retrofit and heating system.

The laboratory analyst does not routinely verify the five numbers provided by the contractor. However, in the first few months, these numbers were compared with the data obtained from the dedicated datalogger. Initially, there were several discrepancies between the two (described, in great detail, in the remaining sections of this paper). However, all major discrepancies were resolved, and the analyst does not now feel it is necessary to verify these numbers routinely. We compared the numbers for the most recent month for which data are available, August 1995, and found them to match to within ±5% for the kWh points and one off-hour point and to within ±10% for the remaining off-hours points. Some of this discrepancy may be due to different methods of hourly averaging and cutoff dates for monthly data.

Comparison of EMCS and Dedicated Datalogger: Data and Methods

As mentioned above, the remainder of this paper discusses the process of reconciling the data collected from the EMCS and the dedicated datalogger and evaluating the process of collecting data using both pieces of equipment.

Once a month, the IHEM computer was used to retrieve data from the dedicated monitoring. The same monthly averages were collected that the contractor uses for savings calculations.

[1] It is important to note that the method A savings value does indeed take this into account, as it does not use audit estimates but actual initial power readings as the basis for payments. Of course, if the performance of the VSD changes over time, these changes will not be reflected, but the actual measured performance of the VSD is the basis for payment, as one would desire.

TABLE 3 Savings from First Year of ESPC Contract

SAVINGS	Estimated kWh	Actual kWh	Estimated dollars	Actual dollars	Percent of Est.
Electricity	431,173	625,190	27,308	39,595	145%
Lighting	227,350	222,803	14,399	14,111	98%
EMCS	145,776	273,440	9,232	17,318	188%
AHU	44,075	96,360	2,791	6,103	219%
LCW	13,972	32,587	885	2,064	233%
	therms	therms	dollars	dollars	
Gas	9,197	8,860	582	561	96%

In addition, hourly data were collected to investigate the capabilities for carrying out more detailed hourly analysis. Also once a month, the IHEM EMCS computer was used to retrieve data from the EMCS. Data from both the dedicated monitoring and the EMCS were uploaded to a UNIX platform for analysis. This analysis and the methods of retrieving the data are presented and discussed in more detail.

The guidelines, developed earlier (Heinemeier and Akbari 1992b), provide a structure for evaluating the capabilities of the EMCS for monitoring and for comparing them with the dedicated monitoring. They were intended to address the reality that every EMCS model, and each EMCS installation, is different. It can be difficult simply to evaluate at a particular site whether or not the EMCS can be used for monitoring. It was found that defining guidelines to clearly communicate the requirements and provide methods for evaluating capabilities would greatly help in this evaluation process. Much more information is provided in Heinemeier (1995) to describe these guidelines, and they are simply presented here as a series of questions to be answered.

Data points: Are the physical attributes necessary for analysis measured?

According to the ESPC contract, the EMCS data needed to estimate the savings from the retrofits are energy consumption of the chiller and the 120-volt circuit ("miscellaneous" end-uses) and run-times of the pumps and two heating-ventilating units. These are fed into the agreed-upon formulas, shown in Table 2, to calculate monthly energy savings. If one were doing a more detailed savings assessment, however, whole-building electricity consumption would also be needed. To learn more about the operation of the building and verify the ongoing performance of the retrofits, one would also want to know the consumption of other end-uses, such as the air-handling units, lighting, pumps, and heating-ventilating units, and other data such as outdoor air temperature and other weather information, zone temperatures, equipment operating parameters (such as supply and return temperatures and flow rates), and setpoints.

The EMCS points include the five points required contractually for the evaluation of energy savings, as well as energy consumption for several end-uses and other operational data. The 88 EMCS points in this building include all types of points: inputs, outputs, setpoints, and virtual (calculated) points. Two important points that it does not include are whole-building electric and gas meters.

It does include potentially useful points such as timers for optimal stop/start operation, economizer percent (damper position), and a flag to indicate whether the building is in the occupied or unoccupied mode. Some of this other information could be used as a substitute for—or supplement to—energy consumption data in a number of different ways. The use of occupancy data, operational data, and proxies as a substitute for monitored energy data is described in greater detail in Heinemeier (1995). For each piece of equipment that is submetered by the dedicated monitoring, there is at least some operational data that could be monitored by the EMCS.

Data accuracy: Is the equipment sufficiently accurate to provide data needed to perform analysis?

The data accuracy needs for calculating savings in the ESPC program are not specified in the contract. The regression factors used in savings calculations are shown with eight significant figures in the contract, but there is no mention of required accuracy. In the calculation for estimating savings from the chiller, the audit stated that the baseline energy consumption could be estimated to within 2% to 3% (LBL 1989). If the post-retrofit energy consumption were measured to an uncertainty of 3%, then the resulting savings calculation would have an uncertainty of less than 5%.

The accuracy of the analog-to-digital conversion and any intermediate transducers must also be taken into account. The local I/O box has a 12-bit A/D conversion for analog inputs, which translates to a resolution of one value in 4,096, or about ±0.02% precision at full scale. Combined with the sensor accuracy, this should still meet accuracy requirements.

The local I/O box also has a 16-bit counter for pulse-count inputs. Power is measured by a watt-hour transducer. For the kWh meters, one pulse represents 0.33 kWh for the chiller, 0.16 kWh for the miscellaneous circuit, and 0.08 kWh for the lighting circuit. Given the range of demand by these end-uses, these correspond to roughly 3%, 1%, and 2% of the minimum values, respectively.

One means of assessing the accuracy of data is to look closely at the data and give it a reality check. As an example of this, there was a problem with the current transducers (CTs) on the EMCS. For the miscellaneous end-use channel, the CTs that were initially installed had a capacity that was too low for the power actually drawn. This caused the watt-hour transducer to malfunction and erroneous data were collected. After reviewing the data, this problem was pointed out to the EMCS operators, and the CTs were changed and the transducer replaced in mid-June 1994.

The CTs on the VFD were also problematic. IHEM looked closely at the savings from the VFD retrofit, as measured by the EMCS. They realized that the power readings of the VFD were smaller than what they expected. Further investigation showed that the CT had been installed on the wrong side of the VFD. Most watt-hour transducers assume that the power they are measuring is a smooth 60-Hz sine wave. Since the output of

VFDs is not at 60 Hz and not a smooth sine wave, they should only be measured on the input side. After moving the CT to the other side, the consumption was still surprisingly low, but it was determined with detailed one-time measurements that the data were correct and that the savings from the retrofit were actually greater than originally anticipated because of greater-than-anticipated reduction in airflow resistance.

Although the EMCS eventually provided data that appeared reasonable for all kWh channels, this took quite a bit of effort and about six months of time to achieve. At first, incorrect power value information was used, resulting in incorrect sizing of the CTs and watt-hour transducers and their immediate failure. After some time, equipment of the correct size was installed. However, this equipment never worked correctly either and a new model of watt-hour transducer was ordered. After installation of this new equipment, three of the channels appeared to be providing reasonable data, but the chiller channel was still not producing reasonable data. Inspection of the CTs on the chiller showed that one of the CTs had been installed with incorrect polarity. This was fixed and ultimately all four channels provided reasonable-looking data.

To check the accuracy of the EMCS kWh data, they were compared to the dedicated monitoring data. To compare the EMCS data with the dedicated monitoring authoritatively, a third set of monitoring equipment was installed for a short period on the two kWh channels that are needed for the contractual savings calculations. Two meters were used—the first meter collected data at a 15-minute interval and has an accuracy of ±0.8% of reading, or ±0.2% of full scale. There were problems with the paper tape used to collect data on the first meter, so the data were somewhat sporadic. However, they were sufficient to determine whether or not the meters were reading accurate data.

Figures 3 and 4 show a short period of data for the two kWh channels used in the savings calculations, along with the corresponding data from the dedicated monitoring and the verification monitoring. For the chiller in Figure 3, the data from the EMCS, the dedicated monitoring, and the verification monitoring were all fairly close. On an hourly basis, there was a 10% difference between any two of the three. On a daily basis, however, the differences between the EMCS and the verification and between the EMCS and dedicated monitoring were both about 2%.

For the miscellaneous end-use, the trends in the data were clearly the same as those found in the dedicated monitoring data (see Figure 4). However, the magnitude of the data was about three times greater than the dedicated monitoring. When the verification monitoring was installed on the panel, it was discovered that the EMCS CTs were in place and were the correct size but that two of the three dedicated-monitoring CTs had been removed. The third was still installed on one of the phases. Reviewing the data showed that the miscellaneous channel in the dedicated monitoring data dropped to one-third of its usual value on exactly the same day that the miscellaneous channel in the EMCS monitoring began registering good values. This drop in the dedicated logger miscellaneous data had not been a cause for

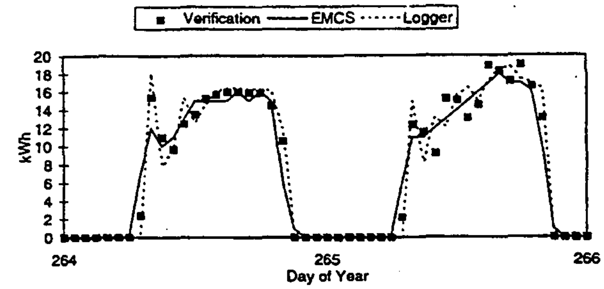

Figure 3 *Verification of EMCS and dedicated monitoring for chiller. A short-term datalogger was used to verify the data from the EMCS and the dedicated monitoring. The data from all three sources are very close.*

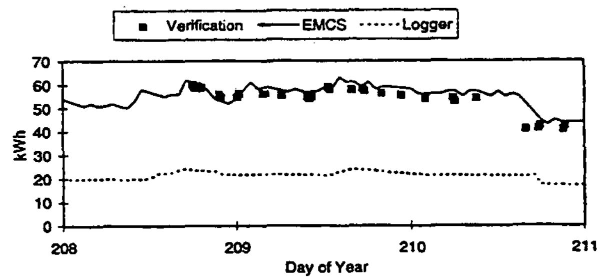

Figure 4 *Verification of EMCS and dedicated monitoring for miscellaneous loads. A short-term datalogger was used to verify the data from the EMCS and the dedicated monitoring. The EMCS provided more reliable data than the dedicated logger because two CT's had been removed from the dedicated equipment.*

concern earlier, since it occurred around the time of the EMCS retrofit, and it was erroneously assumed to be a large (66%) energy savings in the miscellaneous end uses. It was likely that the dedicated monitoring equipment was removed to make room for the EMCS equipment. The short-term monitoring confirms that the EMCS was reading roughly the correct value—less than a 10% difference on an hourly basis.

Accuracy and reliability are also important issues for the dedicated monitoring, as shown in the problem with the miscellaneous channel of the dedicated monitoring. Another problem with the dedicated monitoring was discovered after several months of monitoring. While some points were monitored with one CT on each of the three phases, others were intentionally monitored on only one phase to conserve CTs and channels. This was done by an IHEM engineer after short-term monitoring confirmed that the loads were balanced. However, this piece of information was not passed on to other IHEM engineers. The chilled water, cooling tower, and hot water pump data must be scaled upward by a factor of three to obtain the appropriate value.

In conclusion, the assessment according to the guidelines predicted that the sensors installed in the EMCS should be able to provide data that are accurate enough for the ESPC evaluation, as specified in the constraints assessment. Dedicated monitoring and a third set of monitoring data confirm that the data are accurate enough. There were problems with both EMCS and dedicated monitoring.

Sensor calibration: Are sensors in proper calibration?

The types of sensors typically most in need of calibration and recalibration are flow, temperature, dew point, and static pressure. For calculation of savings, the only important values are kWh and run-time (status). The accuracy and reliability of these points are more related to the choice of sensors and transducers than calibration and maintenance.

The watt-hour transducers were calibrated at the factory. According to the ESPC project manager, when the EMCS was installed, there were no explicit calibration procedures. Most of the sensors requiring calibration are calibrated at the factory. Where calibration factors are input then, they are obtained from sensor documentation. Correct functioning of the sensors is the responsibility of the contractor, and there was a requirement in the contract for the contractor to verify operation of the EMCS equipment. This verification took place on January 11, 1994, when the sequence of operations was tested. This verification did not include verification of accuracy or correct calibration of the sensors, however. The verification of the data carried out for this dissertation, described above, follows the guidelines for field calibration and confirms sensor calibration for the data used in the savings calculations.

Data recording: Do software and hardware permit recording of historical data?

Clearly, there is a need for the EMCS to be able to collect data in some way. The way in which it is done and the location at which the data are stored will relate to other guidelines, such as the need for adequate storage space and a method of accessing the data remotely without interrupting control functions. Since the contractor is operating the EMCS and the EMCS operators are aware of the monitoring efforts, it would probably not be a problem to share the data storage area.

The EMCS has four methods of recording historical data: host history files, trending, controller monitoring, and custom report formats. The first method was used to collect the hourly data in this study. The operator was given a list of the 40 points to be monitored and set up a supervisory routine to initiate hourly data collection four times a day—at 6 a.m., noon, 6 p.m., and midnight. This ensures that data will not be overwritten and lost, and that if any data are lost in the transmission, only six hours will be lost.

For the most part, data collection proceeded smoothly. One problem occurred when the system was rebooted, and for some reason hourly data collection was not re-enabled. This was discovered after one day, and one day of data was lost. No data were lost from the monthly values, however. Data space was shared with the building operators and no problems were encountered.

Dedicated monitoring has the advantage of relative simplicity. There are fewer elements in the system to break down. With the EMCS, if the network connection breaks down anywhere between the controller that is collecting the data and the host computer, the data will not be collected. If the connection between the dedicated datalogger and the polling computer breaks down, of course, data cannot be retrieved. However, this collection only takes place once a month, while it takes place roughly once a minute for the EMCS. About a year into the contract, there was a site-wide power failure, and when power was restored a power surge burned out both modems and part of the line between the dedicated monitoring logger and the polling computer. Data were then retrieved manually, once a month.

Data averaging: Are historical data recorded at intervals appropriate for analysis?

Data used for verification of the energy savings are all required on only a monthly basis. To better understand the building operation, however, daily or hourly data would be preferable. The five required variables—two kWh variables and three run-time variables—must all be reported as monthly or hourly averaged or totalized values.

As discussed in the previous section, data are collected at one-minute intervals and can be collapsed to hourly, daily, monthly, and yearly averages. Along with averages, minima, maxima, run-times, and totals can also be collected. With some systems, one can tell the difference between snapshots and average values by looking at the engineering units: kW vs. kWh, for example. With this system, however, the hourly average report simply lists the point name, which includes the point's engineering units, and does not refer to the averaging process.

For the kWh and run-time data, the points are cumulative, meaning that a counter is being constantly incremented. When the counter reaches a limit, it is reset to zero. Note that for the miscellaneous end-use, the reset limit is 1,000 kWh, and it is reset more than once a day. Another point—megawatt hours—was created to be incremented every time the kWh point is reset, so that the total amount of energy can be monitored. It is difficult to analyze the data during the hour that the counter is reset, and these points must be considered missing data. Therefore, several data points are lost every day due to this resetting.

For the chiller, the point is not reset. However, the precision of the data was originally not sufficient due to the way the point was programmed. Every time 30 pulses were accumulated, the software kWh variable was incremented by 10 kWh. Thus the energy consumption could not be known with more resolution than ±10 kWh. When it was changed so that the pulses themselves were monitored, rather than this software point, the precision was three times as great. Both methods provide the same monthly summaries, but hourly data differ.

Runtime data—used in evaluating savings from control of the pump and heating-ventilating units—are cumulative as well. A "minute" point is incremented for every minute that the equipment operates, and when the point passes 60 minutes, it is reset to zero and an "hour" point is incremented by one. Thus, the run-time should be known to ±1 minute. This is one part in 60 for hourly data, for an overall resolution of about 2%. However, when this minute point is averaged over an hour and then one subtracts each hour from the next, the data are incredibly difficult to interpret. For this reason, the minute points were ignored and only the hour points were used in any analysis. Again, there is sufficient resolution for monthly data but not for hourly data.

Data storage: Does the system have an available data storage capacity sufficient for monitoring applications?

The data storage requirements for the ESPC verification are minimal. Since, at a minimum, only monthly data are absolutely required and only five points are needed, very little space would be taken up by these data: less than 30 bytes. If storage space allows, hourly data and less essential operational data could also be collected. Data should reside on the hard disk until they are deleted by the monitoring personnel. Since they could conceivably be deleted as soon as they were downloaded, the amount of storage space required depends entirely on how often they will be downloaded. Invoices are prepared once a month, suggesting monthly downloading.

The EMCS has an absolute limit of 40 points for monitoring with the history method. Hourly data for one month for these 40 points should take about 200 kilobytes (40 × 24 × 30 × 6, assuming 6 bytes per value). Since the data are in a compact format, little space should be taken up by the data files.

Each file, with one day's worth of hourly data for 40 points, occupies about 8 or 9 kilobytes, so that each month of data occupies about 250 kilobytes. The stored data are contained on a 200-megabyte hard disk, so storage space is not a constraint with this method of data collection. Since disk space was not a limitation, data were downloaded approximately once a month.

Data format: Are data available in an easily processed format?

For the monthly data, data format is not crucial: information can be obtained from data files manually. When hourly data are collected, format becomes more important. Significant processing resources (computers, expertise) are probably not available, so format should be straightforward. Standardization of data format is also a benefit if many other buildings are being monitored. The coding of missing values would be important.

The EMCS data format is reasonably concise. Since the data are intended to be read with a spreadsheet, their format is predictable: ASCII data, each row represents an hour and each column represents a different point, all numbers are comma separated, there is one file per day, all text is in quotes, and missing data are indicated with the word "None." A header describes each point in a somewhat verbose format, but this is not a problem.

Data time stamping: Does the system record the time at which a piece of data was collected? For data with regular intervals, does it record data at specified times, not at specified intervals, so that it will begin collecting data at the correct time if the system is restarted?

Monthly data are needed and ideally they would correspond to calendar months since the savings calculations include a calculation involving degree-day data, which are available for calendar months. Any hourly data that are collected will have to be collected at specified times so that they can be compared with one another.

The hourly data report uses timestamps with the format: "09-10 p.m." This clearly indicates that the average represents data from the top of the hour to the bottom of the hour. With some other EMCSs, problems occurred when power was lost and restarted and data collection would restart at some time other than at the top of the hour. For this system, however, the system has a battery to back up the controller, and whenever power is lost, the battery should continue to keep the clock running so when power is restored, monitoring should be restored correctly.

The EMCS could reliably collect hourly and monthly data that were needed. As a comparison, the dedicated datalogger also has a backup battery, and will resume monitoring correctly when power is restored. The timestamps simply say hour "1," but since they run from 0 to 23, hour "0" must correspond to the hour from midnight to 1 a.m.

Remote connection: Can users connect to the EMCS remotely, using generic communications software?

The contractor is an outside entity in a contractual agreement with the laboratory to provide energy services. Since the contractor is essentially acting in the role of EMCS operator for this building, any way that they interfere with operation may affect themselves, but to the extent that it affects the conditions in the building or operation of other buildings at the laboratory, interference is not acceptable. It will be unacceptable for them to interfere with building operation or to require much assistance from the laboratory staff.

Since the contractor is located in Houston, it is important to be able to access the EMCS remotely. The potential for building operation to interfere with data collection is important for the contractor, since so much money is riding on a small amount of information. Proprietary software could be used, but the contractor has a large number of ESPC contracts, so it would be preferable to use more generic software.

It is possible to connect to the EMCS remotely. The mechanism for connecting to this system, whether using the network or using a telephone line and modem, uses a remote control program. The EMCS operator initiates the remote control program within a window. In another window, the EMCS program can be run. Hence, to transfer hourly data, one can connect to the remote control program and transfer the file without ever interacting with the EMCS software. The remote monitoring computer must use the same remote control software that the EMCS is running to transfer the file, but this software is fairly common and not specific to a single EMCS maker.

Since the laboratory uses a digital phone system, it is difficult to have a direct phone line to an EMCS computer and modem. It should be possible to call into the one EMCS computer that has a standard analog phone line dedicated to it. This phone line was installed so that maintenance personnel could call into the system from home, when necessary, and was used by the contractor in Houston for monitoring.

Remote data transfer: Is there a mechanism either to display a trend report on the screen of a remote computer that is running generic communications software or to transmit an ASCII file from the host computer disk directly to the disk of the remote computer?

Since the monitoring done by the contractor requires obtaining only five values per month, it can be done with no actual electronic transfer of data. When the data are brought on the screen remotely, they can be written down manually.

For more extensive data collection, of course, remote transfer is as important as remote connection. Either screen-display or file-transfer methods would be sufficient (see Heinemeier [1995] for more description of these and other methods for transferring data). Once the remote control connection is made, it is a simple matter to transfer the data files that have been stored on the disk. The remote computer instructs the host computer to transfer the data files in a specified directory on its disk to a specified directory on the remote computer's disk. Note that although the remote control program does allow the remote computer to "log on" to the EMCS computer by running its software, this log-on is not really necessary to collect the hourly data. Once the connection between the remote and EMCS computers has been made, the files can be simply transferred from one disk to another without running EMCS software. Since the EMCS software is password protected, this can prevent the monitoring staff from using the EMCS software to alter building operation. This should be a good method of transferring data.

Again, since the contractor is located in Houston and is essentially responsible for EMCS operation at this site, they must access the system frequently. Communications traffic throughout the EMCS is an important issue. While one is connected to the system and looking at current data on the controllers, none of the other network communications can take place. This means that alarms are not transmitted. Retrieving data from the hard disk of the host, however, did not create this problem, so normal data collection was not a problem.

One problem that occurred fairly late in the monitoring was that additional buildings were added to the system, so that the host computer memory was increasingly taxed. Simply having extra open windows caused the memory to overflow and additional tasks could not be performed. When this problem was detected and the EMCS operator looked for unnecessary processes that could be shut down, he disabled the hourly data collection. Several days of data were lost, until he was asked how monitoring was going. When he was told that monitoring would only last a short period longer, he agreed to run the program manually once a day for the duration. Had the monitoring been planned for a longer period, however, he would have reconfigured the windows to allow monitoring to continue without causing memory problems.

Simple process: Can users request historical data with a simple command?

If the contractor has a large number of ESPC contracts, they would need simple and quick methods of retrieving data. The contractor probably will not need to automate the data collection process, so the process should be as user-friendly as possible. This is particularly true if they will be monitoring several other buildings.

The method of transferring data described in the previous section is simple to perform by hand. It consists of making about 14 menu choices. Since it is menu oriented and occasionally requires hitting a space bar to "wake the system up," it would be difficult to automate. One has to be given instructions on how to transfer the data.

Although the method for transferring files from the EMCS is fairly simple and relatively user-friendly, a simple command-line command would be much preferable. The data transfer process using remote control software can be automated.

Although the process could be automated, this capability was not tested for this study. As a comparison, the methods used by IHEM for retrieving data from the dedicated datalogger are fairly simple, and also menu oriented, but again require instruction. The fact that the logger would be likely to be used in several different buildings allows one to become proficient at the transfer process and apply that proficiency in several buildings, however. There is a mechanism in the datalogger software to automate the transfer process, but it is not being used at this time.

Rapid process: Is the time required to transmit the data short?

Since the amount of monthly data is so small, the speed of the transmission is not essential. If hourly data were needed, however, the contractor would need fairly quick methods of retrieving data. Since the contractor is in Houston, the cost of the telephone call could impose an additional need for a speedy transmission.

Partly because the data files are relatively compact, the transfer process should be fairly quick. The baud rate of this network connection is 9,600. Using the formula presented in the guidelines, an ideal data transfer should require about two and a half minutes for this amount of data. The actual transfer required four times as much time as the ideal data transfer. This is fairly efficient. Using an EMCS on the network, it took about 10 minutes to transfer one month of hourly data for 40 points.

With the dedicated monitoring, transferring a month of hourly data for 16 end-uses typically takes up to an hour. This is partly because the file contains a lot more information and partly because of the relatively slow 1,200-baud transmission rate. It includes monthly cumulative energy consumption and hourly average reactive power as well as real power.

Transmission error detection: Are data transmission errors automatically detected and corrected?

As with any monitoring project, transmission errors must be avoided. Since so much money is riding on only five numbers monitored by the EMCS, ensuring that there are no errors in those five numbers is important. Since there are only five of them, however, it is a simple matter to check and recheck that the correct number was received. For hourly data, fewer redundant data can be collected, so some means of error checking should ideally be built into the transfer mechanism.

The remote control software carries out error checking as the files are transferred. This error checking is optional and can be turned off or can be set to a higher level. According to the remote control software documentation, setting the error checking to a higher level significantly slows down communications.

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 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; 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 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.

EMCS 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.

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