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THE USE OF ENERGY MANAGEMENT AND CONTROL SYSTEMS TO MONITOR THE ENERGY PERFORMANCE OF COMMERCIAL BUILDINGS

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ABSTRACT

Monitored data play a very important part in the implementation and evaluation of energy conservation technologies and programs. However, these data can be expensive to collect, so there is a need for lower-cost alternatives. In many situations, using the computerized Energy Management and Control Systems (EMCSs)—already installed in many buildings—to collect these commercial building performance data has advantages over more conventional methods. This method provides data without installing incremental hardware, and the large amounts of available operational data can be a very rich resource for understanding building performance.

EMCSs are not typically considered in selecting tools for monitoring. They are considered untried, and have never been adequately evaluated as an alternative. EMCS monitoring does not fit into the conventional monitoring paradigm: the methods, limitations, resulting data, and analysis possibilities will all be different. Thus, assessing its appropriateness for an application will also require different methods, which have never been spelled out.

This dissertation addresses several of these issues. One specific objective is to describe a monitoring-project planning process that includes definition of objectives, constraints, resources and approaches for the monitoring. The choice of tools is an important part of this process. The dissertation goes on to demonstrate, through eight case studies, that EMCS monitoring is possible, and to identify and categorize the problems and issues that can be encountered. These issues lead to the creation, use, and testing of a set of methods for evaluation of EMCS monitoring, in the form of guidelines. Finally, EMCS monitoring is demonstrated and compared with conventional monitoring more methodically in a detailed case study.

The guidelines were found to be a useful tool in assessing EMCSs for monitoring. Fundamental differences were found between EMCS and dedicated monitoring: with dedicated monitoring, for example, quality control is ultimately under the control of the monitoring professional, while that is not the case when a building's EMCS is used. In many cases, however, EMCS monitoring is an adequate substitute for dedicated monitoring.

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I. INTRODUCTION

1. Background

Reduction of energy consumption is essential to maintaining global environmental quality and national economic stability. Buildings are one of the largest consumers of energy (about 36% of all US energy consumption, EIA 1992), and have a large potential for savings. Performance monitoring allows energy conservation to compete fairly with expanding energy supply, by ensuring that these conservation resources can be measured just as energy supply resources are. Combined with analysis, monitoring helps ensure that energy savings that are paid for materializes, and provides feedback on technology performance to improve that performance. Thus, collecting and analyzing building data can lead to improvement in the performance of conservation technologies and give greater confidence in them, leading to greater penetration and increased energy savings.

Other examples of the important roles monitoring can play in conservation programs and technologies include:

- Satisfying the verification requirements in third-party financing, shared savings, and demand-side resource auction contracts.
- Providing short-term diagnostic feedback to building operations staff during commissioning of buildings or conservation measures.
- Providing longer-term operational feedback to building operations staff over the lifetime of a building or conservation measure, in order to improve operational control.
- Optimizing the use of energy in response to changing financial, climatic, and operational environments.
- Identifying potential conservation measures.
- Providing a "reality check" in almost any type of energy conservation measure technology assessment.
- Demonstrating the performance and potential of energy conservation measures.
- Providing a detailed baseline for use in energy forecasting and program planning.
- Tracking the energy consumption of a building or portfolio of buildings to identify buildings performing poorly.
- Metering the consumption of buildings for utility revenue purposes.

Depending on the application, however, effective monitoring can be quite expensive, costing from three to ten thousand dollars for each site, for equipment (sensors, wiring, dataloggers), installation, and testing of the data acquisition system (EPRI 1989b). In some applications, the cost may be even higher. Much of this same type of equipment is likely to be present at a large commercial or industrial site in the form of an Energy Management and Control System (EMCS). An EMCS is a computerized control system used to control a building, or some subset of the energy-using equipment in a building, such as Heating, Ventilation, and Air Conditioning (HVAC) equipment. If the equipment required for monitoring already resides in a building, in the form of an EMCS, it would be advantageous to make use of it for any monitoring projects. In many situations, using in-place EMCSs to collect commercial building performance data may have advantages over installation of dedicated monitoring systems. Often, an EMCS can collect the same information that would be collected by a dedicated data acquisition system, but without having to install additional hardware. In addition to providing the monitoring capabilities of dedicated data acquisition systems, EMCS-based monitoring can offer different data and computing capabilities. Hundreds or thousands of data points are typically accessible in an EMCS. The EMCS also accesses a different type of data—operational data—since it is controlling the building. These data may be a rich resource for understanding building performance. Since an EMCS often contains a microcomputer, it could be used not only as a source of raw data, but as a data analysis tool.

The attractiveness of using the existing EMCS equipment to carry out tasks that would otherwise have to be paid for seems intuitive. However, there are many complications that one might anticipate:

- One of the most significant concerns is that the monitoring team will not have control over what is being monitored or the integrity of the data: the system will not necessarily measure the points that are desired; the sensors that are already installed will not necessarily be well maintained, well calibrated, or well placed; their reliability and accuracy are likely to be unknown and possibly unacceptably low; and sensors may have to be added (possibly through the EMCS supplier).
- Since collection of energy-use data is a secondary function, the appropriateness of an EMCS is not guaranteed. Capabilities vary widely, and special consideration will have to be made for each model, making it difficult to assess these capabilities. This is also problematic because many conservation programs may require the use of standardized monitoring equipment.
- Another concern is that, for certain methods, there will be a need to decipher proprietary data communications protocols, and proprietary software may have to be used, causing the potential appearance of bias or of promoting a single supplier. Using many different EMCS models in a program would also require more training effort.
- Access to the system is also a concern. Permission will have to be given to connect to the system, and there is a potential to interfere with EMCS control functions.
- Finally, there is a conceptual problem when the EMCS monitors energy savings from the installation of the EMCS: can a device monitor itself?

Is the EMCS an appropriate tool for building monitoring? This is not a simple matter to assess. Although it has been used informally in several different applications, there is little standardization of methods used or documentation of this use, and it is not yet considered to be a "tried and tested" alternative to standard energy-use monitoring systems. Little work has been done methodically to distinguish monitoring applications in which EMCSs might be a good choice from those in which in which it might not. Assessing the use for monitoring in an application requires addressing two distinct issues: the needs for monitoring tools in that application, and the characteristics of the EMCS in question.

In designing appropriate new tools or assessing the appropriateness of old tools for a new application, one needs to assess the objectives of the effort, the basic qualities that a monitoring tool must possess, the full range of resources available to the effort, and the alternative approaches to achieving the objectives. For monitoring projects in general, this means understanding the question the monitoring is attempting to answer and exactly how it will be answered, the concrete and abstract characteristics monitoring tools will have to have to be successful in achieving the objectives, the financial and other resources can be brought to bear on the project, and the potential monitoring and data analysis approaches.

This all assumes that one knows how to assess the available resources. In the case of EMCS monitoring, however, the tool does not achieve project objectives in the same way as more conventional monitoring methods. It requires using different techniques for initiating and carrying out data collection; the limitations may lie more in logistical or people-related issues than in technical ones; and it may provide new types of data—such as operational data—requiring unique forms of analysis. So, assessing its appropriateness is not a simple matter of comparing specifications on a "spec sheet"—it requires new methods. These methods have never been spelled out. Therefore, there is a need for methods for determining if EMCS monitoring is appropriate for an application, a demonstration of its effectiveness, identification of its shortcomings, and suggestion of ways to maximize its effectiveness.

2. Objectives

This dissertation addresses the gaps identified above by posing the following hypothesis: that an in-place EMCS can serve as an adequate alternative for long-term, remote, third-party monitoring for evaluation of energy savings from HVAC retrofits in commercial buildings. This hypothesis is tested by meeting several objectives. The first objective is to provide a framework for assessing needs for monitoring tools. While this framework is particularly necessary in assessing the use of EMCSs as monitoring tools, it can be used by anyone planning monitoring projects or designing potential monitoring tools. This framework systematically describes the process of planning monitoring projects. EMCS-based monitoring uses different methods and can provide different data, so assessing whether or not it makes sense in a given application requires critically reviewing the basic goals and objectives of the monitoring project, its constraints, the resources that are available to it, and possible approaches. By clearly describing this overall process, it is easier to understand where the assessment of EMCS monitoring fits in, and it becomes clear that methods for formally evaluating tools such as EMCS monitoring are needed.

The second objective is to provide methods for assessing particular EMCSs for monitoring. These methods will aid individuals who consider using an EMCS for monitoring, or EMCS designers who would like their systems to be more monitoring-friendly.

The third objective is to demonstrate the use of EMCSs for long-term, remote, third-party monitoring for the evaluation of energy savings. Some of these demonstrations provide evidence to define the methods, and others confirm and demonstrate the usefulness of the methods. They also identify aspects of EMCS monitoring that are problematic—suggesting areas that require further development, as well as aspects that work well—suggesting that this technology warrants further development.

3. Approach

This dissertation achieves these objectives in five separate steps:

- reviewing EMCS technology and available monitoring tools;
- analyzing different types of monitoring projects, and determining how their needs can be assessed;
- carrying out a progressive series of exploratory case studies of EMCS-based monitoring;
- defining methods for evaluating the capabilities of EMCSs for monitoring; and
- testing those methods in a detailed comparison of EMCS and conventional monitoring at one case study site.

These steps form the bases of five chapters in the dissertation. They are described below, providing an outline of the dissertation:

EMCS and Monitoring Technology

Chapter II of this dissertation looks in detail at the technologies for EMCSs and monitoring tools, as they are applied today. It defines categories of both types of systems, and discusses the technical and logistical characteristics of systems. It defines a "generic" EMCS and a "generic" monitoring system, describing the fundamental characteristics of such systems, the technologies in use, and the options available. It then goes on to compare the two and identify differences. This work is carried out through literature review and discussions with individuals involved in monitoring buildings, EMCS manufacturers, commercial building operators, individuals active in professional societies, and utility staff. Previous work addressing the use of EMCSs in different monitoring efforts is also reviewed in this chapter, along with the different methods that can be used for accomplishing EMCS monitoring.

Monitoring Projects

Chapter III develops a general framework for planning monitoring projects. It starts by analyzing the planning frameworks already in use, and judging their applicability to evaluation of EMCS monitoring. It then defines a sequence of procedures that should be undertaken early in the planning process. These procedures are: clearly defining overall project objectives, assessing the more abstract procedural requirements for monitoring tools, identifying all the resources that are potentially available to the project, and selecting potential approaches to the monitoring activity. Finally, an evaluation step must be undertaken to compare the needs and resources, and select appropriate approaches that will fulfill the project objectives effectively. This chapter is based upon experience with monitoring projects, review of monitoring literature, and discussions with professionals involved in building monitoring.

Exploratory Case Studies

To develop a set of methods for assessing EMCS monitoring, this chapter narrows the focus of the dissertation to the remote, long-term monitoring of buildings by a third party to evaluate energy savings from installation of HVAC energy-efficiency measures in commercial buildings. Three series of case studies are undertaken, and summarized in Chapter IV. The studies are taken from research projects with slightly differing objectives, although the overall research objective in each case includes the evaluation of EMCS monitoring capabilities. Eight sites with a range of EMCS capabilities are chosen, and the data collection capabilities are evaluated. In most cases, data are collected, and in some cases the data are analyzed to characterize energy consumption. As these case studies are evaluated, certain crucial issues become apparent. These issues are then categorized, and EMCS monitoring is evaluated according to these categories of issues. The case studies also serve as a demonstration of EMCS-based monitoring.

Guidelines

The case study results contribute to the establishment of methods for evaluating EMCS-monitoring, and construction of guidelines. These guidelines, defined and presented in Chapter V, include a detailed description of the technical or logistical requirements for using EMCSs for monitoring in a well bounded application, methods for assessing whether or not an EMCS meets these requirements, methods to improve or supplement capabilities, and alternatives or tradeoffs that can be made if requirements are not met. They range from what data are collected, to how the information is transmitted to a remote site.

Controlled Study

In Chapter VI, an additional field trial is conducted, using the methods developed in Chapter V. In this case, both EMCS and dedicated monitoring are assessed at one site, and compared according to each of the criteria established in the guidelines. The EMCS is used to collect energy-consumption and building-operation data, and these data are used to evaluate savings from several retrofits, and to confirm system operation. This serves as a demonstration of the use of the methods, a test of their use at one site, and a more quantitative trial of EMCS monitoring at one site.

Discussion

Finally, Chapter VII discusses the findings from the previous chapters. Further comment is made on a new understanding of the potential benefits and limitations of EMCS-based monitoring for savings evaluation programs. Its potential benefits for other types of programs are also discussed, based on the needs identified in Chapter III and the strengths and weeknesses found in the case studies. Recommendations are made both for making use of the current generation of systems as-is, and for changes that could be incorporated in future to enhance their capabilities. Finally, areas for future development are identified.

II. REVIEW OF EMCS TECHNOLOGY AND MONITORING TOOLS

One of the promising tools for monitoring building energy performance may be the EMCS. This promise must be evaluated both in general, and for specific situations. The first steps in a general evaluation are to investigate EMCS technology, to understand the EMCS characteristics that impact the ability to use it for monitoring, and to define the current state of the art in these characteristics.

This chapter begins by outlining the development and current state of EMCS and monitoring technology. This involves defining categories of EMCSs in terms of their goals, objectives, and strategies, and the characteristics of available EMCSs. The chapter also discusses the objectives and characteristics of dedicated monitoring systems, since the two will be compared. It goes on to generically discuss the fundamental elements that are common to the data-acquisition elements of both an EMCS and a dedicated monitoring system, and how the two technologies differ. Finally, it discusses what work has been done previously by others in using or investigating EMCS monitoring, and outlines methods for using EMCSs for monitoring. This review is based upon experience with EMCS and data acquisition technology, experience with monitoring projects, review of EMCS and monitoring literature, and discussions with professionals involved in building monitoring.

1. Characteristics of EMCSs

EMCSs are special-purpose computerized control systems, programmed to operate building equipment such as chillers, fans, boilers, pumps, dampers, valves, motors, and lighting systems. Lighting is often performed by more specialized lighting control systems, however, and this research focusses primarily on EMCSs that specialize in HVAC control. EMCSs are designed to control buildings more efficiently and effectively than human operators, and to assist in troubleshooting and maintaining buildings, and in managing energy consumption.

With advances in their technology, EMCSs have a growing presence in all building sectors. Industrial buildings use EMCSs to control building services, while the energy used by industrial processes is usually controlled by very specialized and process-specific control systems. In residential buildings, the technology for controlling building systems is typically referred to as "home automation," and is a promising technology. However, by far the most common application of EMCSs is in commercial buildings, and they are the subject of this review. Note that an EMCS is sometimes referred to as a "Building Automation System" (BAS) or "Energy Management System," (EMS), although the latter sometimes also refers to systems that carry out energy accounting and other more "managerial" energy management tasks, rather than feedback control of building systems.

Development of EMCSs

Because the technology for EMCSs has been developing quite rapidly (as have most technologies related to micro-electronics), it is important to discuss how EMCS technology has developed over time, and to define the state of development of the technology at the time of this writing. The research presented in this dissertation took place over several years, from 1986 to 1994. Thus the EMCSs that were investigated represent a range of the technologies available during that period.

Building controls have existed for quite a long time. Historically, the thermostat was the first element in the control of a building system. The first whole-building control systems operated with pneumatics: where compressed air is used to transmit control signals from the controller to another location within the building.

Centralized computerized controllers then evolved, at first acting in only a supervisory capacity and communicating with electric to pneumatic (E/P) transducers to translate electronic control signals to pneumatic signals that the rest of the building was equipped to respond to. Electronic actuators that responded to analog electrical control signals replaced pneumatic actuators in many cases (although pneumatic actuators can still be found in many installations).

Direct Digital Control (DDC) refers to the next step in the evolution, where supervisory digital control signals were sent to local controllers throughout the building. These local controllers collected analog information from sensors, and provided local control of the equipment, with only supervisory control from the main control unit. Fully decentralized control, such as this, is now the standard. Often, the local controllers and the main controller can be manufactured by different companies, and can communicate with one another in a rudimentary way, to exchange basic information.

With the current development of protocols for EMCS communication, more complex information will be shared by devices throughout the building, and more sophisticated control and optimization may be possible. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) is nearing completion of a national consensus standard for communication in building automation systems—Building Automation and Control Networks (BACnet). Some manufacturers have already begun to incorporate the protocol into their product lines, and are committed to making products that are BACnet compatible when the standard is finalized. At the time of this writing, the standard has just finished a second public review, and could be accepted soon. A consortium is also being formed to test the interoperability of BACnet products (EUN 1993). The future trends for EMCSs include a more standardized window-based interface, more powerful processors capable of handling larger amounts of data more quickly, a greater degree of decentralization, and vastly increased capabilities for communication.

EMCS Saturation

EMCSs for commercial buildings are readily available. There are over 150 EMCS manufacturers (EPRI 1986), and many manufacturer's representatives, vendors, and contractors in the market. According to a statistically significant national survey of the energy-using characteristics of commercial buildings, EMCSs exist in only a small fraction of commercial buildings: about five percent (EIA 1993). However, when this statistic is disaggregated, it can be seen that EMCSs have a much larger impact in large buildings, and in recently built buildings. 20% of the commercial floor area in the US is in buildings with EMCSs. About 50% of all buildings with a floor area over 500,000 square feet have an EMCS. For buildings built since 1992, almost 50% of the floor area is in buildings with EMCSs. ASHRAE/IES Standard 90.1-1989 suggests that all new buildings with a floor area of over 40,000 square feet should consider installing an EMCS (ASHRAE 1989a). This standard recommends that the EMCS should have several specific energy-management capabilities, and the ability to monitor energy consumption on a daily basis with weekly summaries.

EMCS Architecture

There are a variety of different types of EMCSs. Figure II-1 shows the architecture of a "generic" EMCS. Good summaries of EMCSs include EPRI (1986), and Akbari et al. (1989). EMCSs comprise a range of technologies for controlling building systems, and vary in complexity. The simplest EMCS might consist of a single function controller, used to perform one task, and controlling one or more building systems. A more complex EMCS utilizes a centralized computer to control systems throughout the building, implementing several different functions. The most commonly installed EMCSs today utilize a distributed architecture, in which controllers throughout the building—referred to as Remote Control Units (RCUs)—operate local control loops (for example, controlling a VAV box in a zone, based on input from the local thermostat). Often, these RCUs are application specific: for example, Johnson Controls has specific controllers for variable-air-volume boxes, central plant equipment, air-handling units, and lighting (Johnson Controls 1991). Landis & Gyr Powers also has a fume-hood controller (Landis & Gyr Powers 1992). The local controllers communicate with one another over a dedicated local area network. These controllers can then be supervised by a central, or "host" computer (for example, the host computer would determine an appropriate temperature setpoint, send this setpoint to the local-loop controller, which would implement control). The host computer can be used for many other tasks, such as graphic communication with the operators, data collection and analysis, and providing a more convenient environment for programming the local controllers. These high-end systems are sometimes integrated with security and fire-safety functions. An important figure used to describe the complexity of a system is the number of "points." These can be actual sensor inputs, (either analog, digital, or pulse counting), or actuator outputs (either analog or digital). However, it can also refer to virtual points (i.e., intermediary calculated points such as setpoints), or attributes (e.g., runtimes for a point, or calibration constants for an analog input).

EMCS Objectives

The capability of an EMCS to monitor energy performance is the primary focus of this dissertation. It is important to keep in mind, however, that EMCSs are not usually installed principally for this purpose. Rather, the objectives are:

- allow control over equipment operation from a central location,
- alert building operators to possible equipment malfunction or the need for maintenance,
- maintain comfortable conditions,
- permit simple software modification of control specifications
- monitor tenants' energy use for billing purposes, and
- save energy.

The primary energy-saving aspects of the EMCS are embodied in its particular energy management strategies. These strategies are described below.

Programmed Start and Stop: An on/off schedule is defined for the operation of each controlled device, and implemented by the EMCS. The schedule can vary by day of week, and can include contingencies, i.e., different ways to respond depending on conditions in the building such as operation of other end uses or past operation of this end use. Occupant and operator override, invoked from central or remote locations, (for example, by telephone or a local timer switch), ensure flexibility.

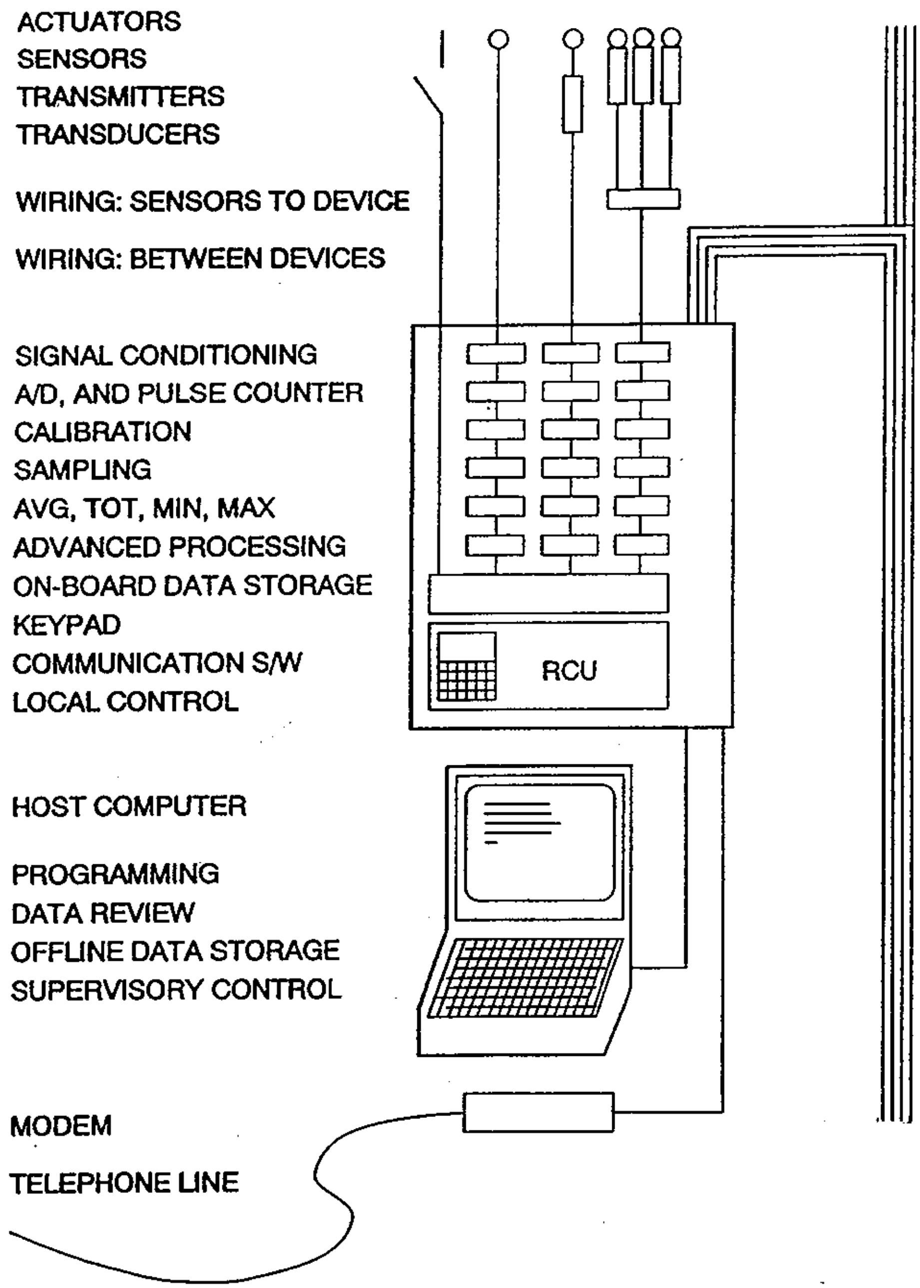

Figure II-1. Generic Architecture of an Energy Management and Control System. EMCSs vary, but most contain these basic elements.

Programmed start and stop is often responsible for most of the energy savings from an EMCS. To evaluate the savings, however, it must be compared with the alternative method of turning equipment on and off. For example, if a building has a dedicated operations staff who turn equipment on and off at the correct times, there will be no savings from this technique. One study estimated that the HVAC savings over and above those made possible by a seven-day time clock will be on the order of 5-20% (Guntermann, 1982). With most time clocks, it is possible to turn equipment on and off several times a day, and to have a separate schedule for each day of the week. However, an EMCS has the advantage that it can automatically adjust for daylight-savings time, and reduce operation during holiday periods. Time clocks are notorious for becoming out of synchronization with real time, (see, for example, Greely et al. 1990, where a timeclock was operating for many months set approximately twelve hours out of synchronization with the true time). Another advantage to a more comprehensive EMCS is that each end use can be controlled individually, and individual pieces of equipment can be started at different times. With a time clock, entire systems may begin operation at the same time, often creating a power spike. This has been found to be a problem for buildings on a demand charge, as that power spike can be the largest demand an building experiences (NCAEC 1987).

Optimal Start and Stop: Historical performance and outdoor temperature determine the latest possible time to begin conditioning each day, and the earliest time it can be turned off, so that the building will always be comfortable while occupied. Historical performance determines the response time of the building, which is used with indoor and outdoor temperatures to calculate the optimum times.

This may result in large savings, depending on the alternative means of control. One alternative is often to guess on an appropriate time to begin conditioning, and to set a time clock for that time. Often, complaints come in that the building is uncomfortable in the morning, the time will be moved earlier and earlier, until complaints stop coming in. That setting will then be used throughout the season, resulting in inefficient, "worst-case," scheduling.

Duty Cycling: Equipment is periodically switched on and off in order to reduce its average output. The fraction of the time that it is switched on is referred to as its "duty cycle." This is usually used for single speed equipment that has been oversized or sized for worst-case conditions. The duty cycle can be a fixed value, or proportional to zone temperature. To prevent equipment from turning on and off too rapidly, minimum on and off times are usually specified. For a single piece of equipment, this technique does not reduce building peak demand. However, when implemented in a coordinated way with several pieces of equipment, it can be configured so that there is always at least one piece of equipment off at any time, and demand can be reduced. This illustrates an advantage of integrated building operation, made possible by a whole-building EMCS.

One should note that such systems are usually only specified as a retrofit, since there are preferable ways to reduce equipment output in new buildings or when installing new equipment. More appropriate sizing or staging of the equipment would take advantage of higher efficiencies found when operating a piece of equipment closer to its full load. Also, adjustable speed equipment has a reduction in demand that is nominally proportional to the cube of the reduction in output. In fact, adjustable speed drives can be installed as a retrofit, and work very well in conjunction with EMCS control.

Economizer Control: Cooling energy can be minimized by monitoring the temperature (and possibly humidity) of return and outdoor air, and selecting a supply airstream with minimum temperature. This will vary anywhere from 100% fresh outdoor air on mild days, to a specified minimum amount of outdoor air on hotter days. Although this technique is common even in buildings without EMCSs, the EMCS can more closely control the system to optimize its performance. For example, while a standard economizer controller will typically be set to change over from outdoor air to mechanical cooling at a certain temperature, an EMCS that is controlling multiple zones with different conditioning requirements can more effectively modulate the amount of outdoor air to provide the optimum supply air temperature.

Another advantage of using an EMCS to implement economizer operation is that the EMCS can monitor the performance of the economizer, and can alert the operations personnel when it is failing to perform. Since economizers are prone to problems throughout their life cycle, this is an important benefit.

HVAC Optimization: The operation of the fans, chillers and boilers can be optimized in several ways. A few examples are resetting supply air and heating and cooling coil temperatures, efficiently combining several small chillers, adjusting the rate at which setpoints are approached, and monitoring the composition of furnace exhaust gasses to increase fuel-burning efficiency.

Demand Limiting: For buildings that are charged for peak demand as well as energy consumption, limiting building demand is an important means of controlling costs. An EMCS can limit demand by cutting back use of non-critical equipment when the building demand approaches a preset target. Equipment is turned off or reduced sequentially, according to a prioritized list. When demand is reduced to a sufficiently low level, end uses are restored, either in the same order they were shed (rotating load shed) or in the inverse order (priority load shed). An algorithm that predicts upcoming demand (by extrapolating past trends) allows the EMCS to prevent rather than respond to demand excesses. Demand limiting may reduce energy consumption, but it is primarily a load management strategy.

Diagnostics: EMCSs are capable of fairly sophisticated diagnostics algorithms, although this is usually not well developed. Most EMCSs implement simple diagnostics by issuing an alarm when the value of a point is beyond preset bounds. It is possible to do more complex range checking, such as time-sensitive checks (where the limits that would trigger an alarm depend on the time of day or year) or comparisons with the values of other variables (such as simultaneous calls for cooling and heating). One other diagnostic that is fairly common is monitoring the pressure drop across a filter to generate an alarm whenever the filter is clogged and in need of changing. Another is to require proof of operation of one piece of equipment (such as ensuring that a pump is operating by checking that the flowrate is above a certain level) before another piece of equipment is turned on. If the equipment is not proved to be on when it should be, an alarm can be generated.

Maintenance: Another category of EMCS algorithms is maintenance. Many systems monitor the amount of time major pieces of equipment have run since their last tune-up. In addition, this software can also generate work orders and purchase orders, and keep an equipment inventory including nameplate information and maintenance history.

Cost Effectiveness

EMCSs are almost always installed in order to save the building money. It is difficult to assess cost effectiveness in a generic way. There is a wide range in EMCS savings potential, because there are so many different energy management functions, and the basecase control strategies vary so much. There is also a wide range in system cost due to the range in complexity of the systems. For example, a simple and inexpensive controller can often be much more effective than a complex system that has not been implemented correctly, or is not operating correctly. In one survey of EMCSs carried out for the Electric Power Research Institute (EPRI), the minimum cost for single function controllers was from $300 to $8,000, depending on the complexity and number of controlled devices (EPRI 1986). The minimum cost for centralized systems was $10,000, and the minimum for distributed architecture systems was $18,000. In their survey, the average energy savings was about 15%. Although that study was carried out some time ago, and the costs are probably dated, they are still useful for comparison. One should also remember that EMCSs may reduce building operation and maintenance costs, and provide fire and security functions as well. Installation costs are highly dependent on the degree of complexity of the system, and the number of input and output channels. Installation of communications paths throughout the building is often a large part of the cost.

Several utilities offer incentives for installation of an EMCS (see EPRI 1989a, and PG&E 1993). In these programs, certain EMCS functions must be implemented, or an EMCS contractor must calculate estimated savings. Many of these programs are oriented much more towards load management than efficiency.

Installation and Maintenance

Systems are typically configured, installed, and commissioned by the vendor or a manufacturer's representative. Two essential and often overlooked steps in EMCS installation are making sure the system is doing what it was designed to do (commissioning), and making sure the operators understand and trust the system (training). A survey of EMCS users found that one EMCS in five had been disconnected by building personnel (Schwed 1988). With appropriate attention to commissioning and training, such problems can be avoided.

The computer portion of the EMCS should require little physical maintenance, as it consists primarily of solid-state electronics. However, it will still require significant "soft" maintenance such as periodic backups, and upgrades. Sensors and actuators will require periodic attention. Some energy-management functions, such as duty cycling of motor-driven devices, will cause additional wear on belts, motors, and electric starters, requiring more frequent maintenance.

2. Types of Monitoring Tools

Before going into technical details on EMCS technology, and then discussing how it can be applied for monitoring, the characteristics of the tools conventionally used for monitoring will be introduced. This section outlines the different types of systems used for monitoring energy use in buildings, and then the next section talks in more detail about the technology that is common to both EMCSs and dataloggers. The emphasis of this discussion is on tools used for longer-term monitoring, thus it does not stress hand-held tools or indicating but non-recording devices. There are several good references on data acquisition systems. ASHRAE (1989b) has a good glossary of important terms. EPRI (1992) has a very good summary of commercially available dataloggers and sensors. It summarizes the characteristics of some of the most common general-purpose data acquisition systems. Haberl et al. (1992b) have also developed a good primer on building monitoring and datalogger operation.

The equipment used for monitoring applications has also been a rapidly developing technology, and a wide variety of equipment is used in monitoring applications. Three general categories describe the overall architecture for this application: general-purpose dataloggers, micro-dataloggers, and—for the specific application of building energy performance monitoring—energy monitoring systems. While their characteristics vary, Figure II-2 illustrates the elements that are present in most monitoring equipment to some extent.

General purpose: General-purpose dataloggers are typically capable of monitoring the output of any kind of sensor that produces a voltage, current, pulse, or contact-switch closure. Some general-purpose dataloggers are stand-alone microprocessor-based systems that can collect data without connection to a computer; these often must use a computer for programming or data storage. Others are separate boxes that plug into a serial port on a computer, or have cards that are installed in the computer. Thus, the computer is an essential part of their operation. Some are geared towards permanent installation, while most are more portable. Some are designed specifically for very remote applications, and their capabilities focus on remote access of data, reliable operation, battery power, and a small power drain. Some can be used for all these applications. Weight and size vary, ranging from 1 to 66 pounds, and the dimensions range from 6 to 26 inches (EPRI 1992).

Micro-dataloggers: These systems are often referred to as "stick-on sensors" because of the fact that all of the equipment in the monitoring application—from the sensor to the communications port—is included in one small package. This datalogger can be smaller than a pack of cigarettes, and can often be magnetically attached to the device being monitored. Many of these monitor only one channel each, and have relatively low resolution (8-bit A/D, described later). Stick-on loggers are available to measure temperature, light intensity, relative humidity, current, voltage, and pressure, and there are general-purpose loggers to monitor analog inputs.

Energy monitoring: Since building performance monitoring is such an important application, there is a whole category of loggers dedicated to this type of monitoring. Their architecture is similar to that of the general purpose dataloggers, with the exception of the presence of an integral multi-channel watt-hour transducer (discussed later) and a common voltage transducer. For some models, the current transformers are built into the watt transducers. In this way, monitoring power simply requires installation of current transformers. Some of these systems also have control outputs, specifically for demand management.

3. Data Acquisition Fundamentals

With an overall idea of the types of EMCSs and monitoring tools available, the fundamentals of data-acquisition technology will now be discussed. The technology for acquiring data is essentially the same both for EMCSs and for dedicated monitoring systems. While there are slight differences between data-acquisition as implemented in an EMCS and that as implemented in a datalogger, the technology will first be discussed generically, and then the differences will be discussed.

The organization of the discussion of data-acquisition fundamentals parallels Figures II-1 and II-2: sensors and transducers, wiring from sensors to device, wiring between devices, signal and data processing, storage, operator interface, and communications. In many places, the discussion

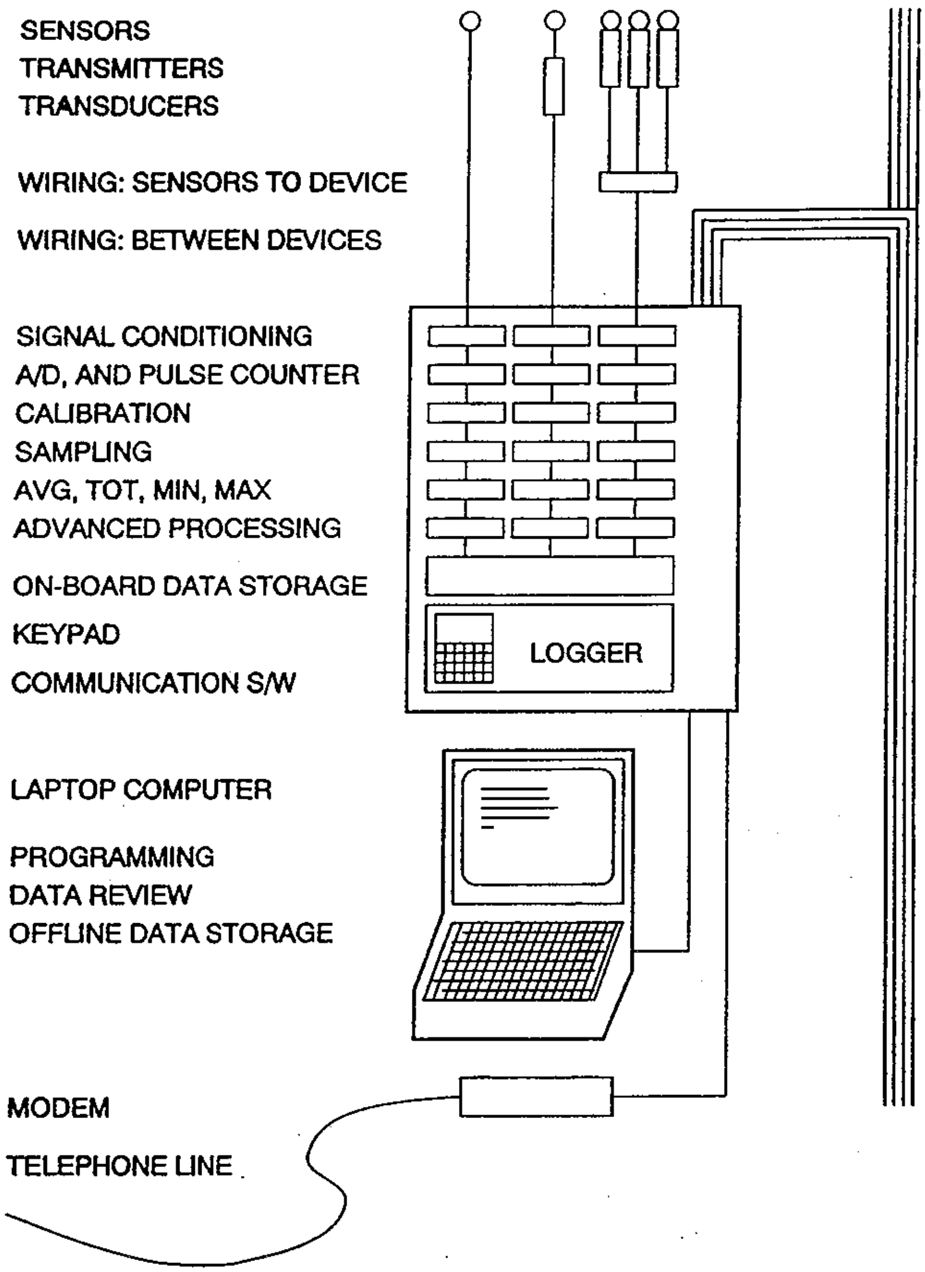

Figure II-2. Generic Architecture of a Dedicated Datalogger. Dataloggers vary, but most contain these basic elements. All of the elements present in dedicated dataloggers are present in a typical EMCS.

refers to a "device." This will refer to both the datalogger and to the EMCS host computer.

Sensors and Transducers

Sensors: One of the most important elements of a monitoring system is the sensor. Sensors are the primary elements used for taking measurements. Some sensors, due to the electrical nature of their mechanism of operation, output a very small current. Other sensors are designed to produce an output suitable for input to a data acquisition system. Some of these sensors require an "excitation voltage" in order to operate. The term sensor is often used interchangeably with the term transducer.

Transducers: A transducer is a device that converts something measurable into another form, often an electrical signal. There is a subtle distinction between transducers and sensors. For example, one might refer to a thermocouple junction as a sensor, but a device that includes a thermocouple as well as the circuitry to produce a more readily measurable output might be called a transducer. A *transmitter* is a device that translates the output of a sensor into a signal suitable for transmission to a site where it can be further processed. Transmitters must often be provided an excitation voltage (Omega 1990).

Sensors and transducers can have many different kinds of outputs. An analog output may be a voltage, typically varying from 0 to 10, or 0 to 5 volts DC. Or the output may be a current, for example, varying from 0 to 1 microamps, or 4-20 milliamps. A digital[1] output may be a switch or relay closure, or a TTL (Transistor-to-Transistor Logic value, where roughly 5 volts corresponds to a logical "yes"). The switch closure or TTL value may be repeated to comprise a pulse train, the pulse frequency of which carries the information. One important issue in measuring pulses is to differentiate between pulses and counts: for many transducers, each transition will constitute a count, so the rising and falling transitions associated with one *pulse* are registered as two *counts*. Another important consideration is that a pulse-generating relay should be debounced, so that spurious transitions are not registered as pulses or counts.

Energy measurement: There are three ways of measuring electrical power or energy.

- The first is with use of current transformers and watt transducers. This is the most commonly used technique in commercial building monitoring applications, and thus it deserves detailed description here. When an alternating current flows through a wire, a magnetic field is produced. If the iron core of a current transformer (CT) surrounds the wire, a current will be induced in the transformer secondary, and this (usually smaller) current can be measured. Thus, the transformer steps down the current and allows it to be sensed without physically being connected to the wire. CTs can either have a solid core—in which case the wire must be temporarily disconnected to be run through the hole in the CT—or a split core—in which case the CT can be slipped over the wire without interrupting it. Split core CTs are available as devices that must be bolted on, or devices that can be simply clamped in place. The latter are easier to maneuver in cramped and dangerous spots, but they are more expensive. Both types of split core CTs are more expensive than solid core CTs. Current measured in this way can be used as a proxy for power, for equipment with a fairly constant power factor. If the voltage is also measured, either directly or with use of a step-down voltage transformer, the instantaneous true power can be calculated. Watt

[1] Note that the term digital here refers to the fact that the value is either "yes" or "no," in contrast to other sorts of digital signals in which an analog value is encoded into a binary numerical representation.

transducers take input from line voltage and the CTs, and produce an output voltage or current that is proportional to instantaneous power.

Many watt-transducers are also capable of producing a pulse output to allow measurement of energy (as opposed to power), and each pulse corresponds to a given amount of energy. Such a transducer would be referred to as a watt-hour transducer. One can then either measure the number of pulses that are generated in a given time, or the amount of time between consecutive pulses—depending on the rate at which pulses are generated—to determine the average power or total energy consumed during the period.

Energy meters are often used to monitor whole-building or end-use energy consumption. End-use monitoring is greatly facilitated if all like loads—for example, all lighting circuits—are combined in a single electrical panel. (This is recommended by ASHRAE's Standard 90.1. This standard requires that separate circuits be made available for lighting and receptacles; heating, ventilating, and air conditioning (HVAC) equipment, and special uses. It also specifies that access provisions be made for eventual monitoring—particularly by an EMCS.) In such cases, it is possible to wire the CTs in series to monitor the combined load. It should be noted that one CT must be used for each wire of a 2- or 3-wire load, and their outputs or data summed. If the load is fairly balanced, it may be possible to estimate total consumption by measuring only one wire, and applying a multiplication factor to account for the other unmeasured wires. More than one wire should never be inserted into a single CT unless they are on the same phase. It should also be noted that the CT must not be installed backwards: if its polarity is reversed, the current flow will then be negative and it will be subtracted from the other CTs.

The specified size of the CTs, and the pulse rate of the watt-hour transducer are important determinants of the accuracy of a kWh measurement. The kWh consumption represented by each pulse depends on the product of the pulse factor and the CT ratio, where the pulse factor of the watt-hour transducer is selected when specifying the transducer, and the CT ratio is the ratio of primary and secondary amp ratings, which will depend on the application, and is specified when specifying the CTs. To measure anything with a pulse generator output to within 5% accuracy for a given period, one needs to collect at least 20 pulses in that period (20±1 is 5% accuracy). The lowest expected values of the variable then should be used when considering accuracy. On the other hand, one needs to ensure that the pulse rate will not be too high at hours of high demand. What constitutes "too high" is determined by the maximum pulse rate that can be read by the data acquisition system. Thus, a balance must be sought between accuracy and avoidance of overloading of the pulse counter.

- The second method of measuring electrical power is using a utility-type rotating disk watt-hour meter. With these meters, each revolution of the disk corresponds to a given number of watt hours (energy). The meter can be altered to generate electrical pulses for each revolution—again, a pulse corresponds to a given amount of energy and the time between pulses can be used to calculate average power.
- The final type of electrical meter uses a "Hall Effect Sensor." This sensor requires external power, and it senses the magnetic field due to the flow of current. It produces an output that is proportional to the product of the current and external voltage, and is thus a good way of measuring true power.

Other types of energy meters are gas consumption flow meters—although a correction must be made to account for changing gas pressure—and Btu meters which combine a differential temperature measurement with a flow measurement to determine the heat added to or subtracted from a fluid stream. Both types of meters output pulses.

Temperature measurement: There are four types of temperature measuring sensors: thermocouples, RTDs, thermistors, and IC sensors. A thermocouple is a temperature measuring device in which two junctions of dissimilar metals output a voltage proportional to the difference between the hot and the cold junction. The advantages of thermocouples are that they are self-powered, simple, rugged, inexpensive, and cover a wide range of temperatures (Omega 1990). However, they are non-linear, produce a low voltage, require a reference temperature, and are the least stable and sensitive of the four types. Resistance-temperature detectors (RTDs) rely on the fact that the resistance of many materials depend on their temperature. RTDs are stable and accurate, although they are expensive, require a current source, produce a small change in resistance and a low absolute resistance, and are self-heating (Omega 1990). Thermistors are also RTDs, although they are composed of a semiconductor material rather than a metal. Thermistors have an advantage in that they have a high output, produce a fast response, and require only a two-wire circuit; however, they are non-linear, operate over only a limited temperature range, are fragile, require a current source, and are self-heating (Omega 1990). Integrated-Circuit (IC) temperature sensors produce a voltage or current proportional to the temperature. Examples of these sensors are National Semiconductor LM34 and 35, Analog Devices AD590 and AD592 (National Semiconductor 1990, and Analog Devices 1992). These have advantages in that they are linear, produce a large output, and are inexpensive; however, they operate only for temperatures below about 400°F, require a power supply, have a slow response, are self-heating, and can be used only in limited configurations (Omega 1990).

Temperature sensors are used for a number of applications in building performance monitoring. They measure the temperatures of various air and liquid streams, and surfaces. There are specialized sensors for measuring temperature of air in ducts, the temperature of water in pipes, space temperatures, and outdoor air temperatures. These include special fittings such as "Pete's plugs" for inserting temperature sensors into pipes, thermocouple wells, coils for measuring average temperatures in ducts, attractive enclosures for room air temperatures, and solar radiation shields for measuring the temperature of outdoor air. There are also special sensors for measuring differential temperatures.

Flow measurement: Flow measurement is one of the most difficult areas of building monitoring. It is also often one of the most important: water flow is often measured as part of a load measurement to determine the load on a chiller or the amount of chilled or heated water supplied to a building. Flow measurement often requires devices that have complex moving parts, and measurement of fluids that may be corrosive or abrasive and may exert strong forces on the equipment.

Obstruction flow meters take advantage of the fact that an obstruction to the flow of a fluid causes a drop in pressure, and that drop is dependent on the fluid velocity. Obstruction flow meters include orifice plates, Venturi flow meters, and flow nozzles. In these devices, the flow downstream of the meter is affected by the meter. The distortion is the most for the orifice plate and the least for the Venturi. The orifice plate is also subject to wear and corrosion. These meters have the advantage of relative simplicity and the lack of moving parts. Another category of flow meters is rotating flow meters. This includes turbines and paddle wheels. For some rotating meters, rotation is sensed magnetically or ultrasonically. Insertion type meters can be installed without draining the pipe.

Another category of flow measurement devices actually determines velocity, and uses the cross sectional area of the pipe or duct to calculate flow rate. A pitot tube is a pressure tap with an opening facing into the fluid flow. By using a pitot-tube to sense total pressure, and subtracting the static pressure—sensed with a pressure tap perpendicular to the fluid flow—one can determine the velocity pressure, which is proportional to the square of the fluid velocity. Another velocity measuring device is a hot-wire anemometer, which measures the amount of energy needed to maintain a small probe at a constant temperature, and relates that energy to an air velocity. Since the velocity in a pipe or duct may vary across the cross-sectional area, particularly at the entrance to pipes or ducts or immediately downstream of any joints or devices, it is usually necessary to traverse the cross-sectional area, taking several measurements and averaging them.

Other measurements: Some of the other points that can be monitored are pressure (e.g., duct static pressure, building static pressure, refrigerant, differential pressure), dew point, relative humidity, equipment status or runtime (using current switches or possibly proxies such as temperature sensors for lighting status), light level, carbon dioxide levels, frequency, wind speed, wind direction, electrical current, water level, and barometric pressure.

Wiring

Wiring within a monitoring system or EMCS includes two types: wiring between the sensors and the data collection device, and wiring between data collection devices.

Wiring between sensors and device: Sensors are connected to the device by means of some form of wiring. This wiring is typically either a twisted pair of wires or coaxial cable.. When using twisted pairs, any environmental electrical noise that might affect the signal will most likely affect both wires, so the difference in voltage between the two wires should be not be affected. Coaxial cable is also protected from noise, since the outer shielding intercepts most noise. Whatever types of wiring are used, the wire must be run from the sensor to the logging device. This is sometimes done by running conduit. Issues that must be considered are the interference that is caused by installing the wiring, permanent changes that must be made to the building fabric, the appearance of the wiring or conduit in occupied spaces, electrical isolation, and lightning and fire protection requirements affecting electrical wiring. The material of the wiring is also important, as it is important to minimize the impedance of the sensor/wiring combination, since the wiring is essentially in series with the sensor. Some alternative methods of getting information from the sensors are infra-red signals, and power-line carriers.

Communication between devices: Several different methods are possible for linking units, and the relative advantages are discussed in Harrje et al. (1984). Some standardized methods of connecting devices include serial or RS-232 cables (most often used to communicate between computers and peripherals; see Auslander and Sagues 1981), IEEE-488 Bus (or GPIB, or HI-IB, standards for interfacing between programmable instruments and computers; see Omega 1990); twisted pairs, or a computer bus, ethernet, or other kinds of sophisticated network protocols. The rate at which data are transmitted is referred to as the "baud rate," and one baud equals one bit per second.

Signal and Data Processing

Once an analog (voltage or current) or digital (pulse or relay closure) signal reaches the device, often some additional processing must be done to translate the signal to a useful value. This processing can include signal conditioning; analog-to-digital conversion; pulse counting; calibration; sampling; calculating averages, totals, minimums and maximums; and more advanced processing routines—all of which are discussed below.

Signal conditioning: The last section referred to translation of sensor output to a useful and measurable voltage. There are several situations in which this would be done, and this is referred to in general as "signal conditioning." Signal conditioning can include amplifying small signals, (for example using a Wheatstone resistance bridge circuit), providing a reference temperature junction for thermocouples, demodulating signals from frequency- or amplitude-modulated carrier signals (for example 60 Hz sine waves, or pulse-width modulated signals), filtering noise from the signal, or linearizing output from non-linear sensors (Beckwith et al. 1982). This can be done within the transducer or transmitter, with an external circuit or device, within the data acquisition hardware, or within software of the datalogging or analysis computer.

Analog to digital converters and pulse counters: Analog signals must be converted to digital signals for a microprocessor to handle them. This is done using an analog-to-digital converter, or A/D converter (Auslander and Sagues 1981). Incoming pulses must be counted at this point. With both A/D conversion and pulse counting, the number of bits in the conversion is important, as it determines the resolution of the resulting measurement. For example, an 8 bit A/D conversion can have only one of 256 distinct values (2 raised to the 8th power). Thus, a temperature sensor that can read from 0 to 100 degrees would have a resolution of only 100/256 = 0.4 degrees. With a 12 bit A/D conversion, it could have a resolution of 100/4096 or 0.02 degrees. The pulse rate of the transducer determines the device resolution, but the number of bits on the pulse counter will be important, as the pulse counter is reset after it fills up (it overflows). For example, a 12 bit counter can only count up to 4096 before it overflows. If pulses are received at a rate of one per second, the counter will overflow after a little longer than an hour. If it is a 16 bit counter, which can count up to 65,563, overflowing after 18 hours. A device can usually be configured to increment a second counter when the first counter fills up, however, resolving this problem.

Another important attribute of an A/D converter or pulse counter is its input impedance: since a voltage measurement device is essentially wired in parallel with a sensor, its impedance should be as high as possible (in the megaohm range) to minimize error.

Calibration: Calibration refers to the translation of a signal such as voltage, current, or pulses into correct engineering units. Sometimes this is a simple matter of applying a scaling factor, (for example each pulse might correspond to 1 kWh, so 10 pulses represents 10 kWh). For other types of sensors, both offset (zero) and scale (span) factors must be applied (for example, if 0-10 volts corresponds to -32 to +212°F, then 3 volts represents 86°F). For nonlinear sensors, such as thermocouples, either a more complex equation must be applied, or a lookup-table can be used.

Sampling: Analog data can vary continuously with time. To be translated into a digital value, they are momentarily frozen in time, and discrete values are produced. The frequency with which these "snapshots" are taken is referred to as the scan rate. This is determined by the response time of the A/D converter and the number of sensors that must be scanned. Some sensors are referred to as "integrating," such as flow meters and watt-hour meters. With these, even though the values are sampled, no data are lost.

Calculating Average, Total, Minimum, or Maximum: To collect all the data on each scan would be cumbersome. For some data, a periodic snapshot is sufficient. For others, averages or totals must be calculated. Averages and totals can usually be provided over user-selectable intervals, ranging from minutes to days. In addition, it is sometimes useful to know minimum and maximum values for certain intervals. For all such data, it is important that the value have a time associated with it. A special purpose averaging algorithm that is sometimes used is a 15-minute sliding demand window. With this type of reporting, the average whole-building electrical demand for the previous 15-minutes is recorded. As time progresses, it always looks at the previous 15 minutes. This is done to optimize the operation of buildings that are on a utility demand charge, and it is designed to provide the same information the utility uses to determine the demand charge. Another special purpose averaging algorithm is conditional averaging, wherein values only go into an average when a particular device is operating.

Advanced processing: There are many other algorithms that can be applied to monitored data. These are standard on many different devices, or can be easily programmed. Examples include:

- *Missing data:* Special coding is provided for data that are missing, to differentiate them from valid "zero" data.
- *Limit checking:* An error flag is issued when the value of a point is larger or smaller than the expected range of values.
- *Sum checking:* The sum of all end-use energy consumption is compared to total building consumption to identify potential errors.
- *Repeated value checking:* If a value does not change at all when it should be changing, an error flag is issued.
- *Level-based binning:* Data are provided in a summary "binned" format that is used in many types of analysis.
- *Interchannel math:* Intermediate values are calculated based on values of measured points—for example cooling load can be calculated from a supply temperature, return temperature, and flow rate—and these resulting values are logged.
- *Computed status:* For multimode equipment (for example, a refrigerator with a defrost cycle), the operating mode can be inferred from the demand level, and the mode itself can be logged.

Data Storage

Once analog values have been converted to digital values and then to engineering units, they are stored, typically in random-access memory (RAM), or on a computer disk or tape. Usually, the data will be stored in a *circular buffer,* meaning that when the allocated storage space is filled up, the oldest data will begin to be overwritten. The data must be retrieved before this happens to ensure no loss of data.

The data can be stored on the device in either a binary format to be read by the device's native software, or in an ASCII format that can be read by other applications. Some store data in a binary format, and are capable of producing the data in any of a number of formats, including columnar ASCII data separated by spaces, comma-separated ASCII (which is easily read into spreadsheet programs), other sorts of easily read formats, or binary formats that can be read by specific spreadsheet programs.

Operator Interface

The operator interacts with the device to supply programming and configuration information, to determine the status of the equipment, and to retrieve data. Many devices use menu-driven setup procedures. Some also provide software for analyzing, reporting, and graphing the data. Either real-time or after-the-fact graphing of the data is an important way of reviewing for data quality. Some systems have more sophisticated abilities for data visualization. Other systems only display digital readings of point values. Some systems use a key pad on the body of the device, or allow connection of a lap-top computer, or both. The operator may also connect remotely, using communications hardware and software.

Communications

For permanent storage, the data are typically moved to some larger volume of storage, either a magnetic tape or computer disk. This can be done with a direct local connection, or remotely. This usually requires addition of a phone line, and either a modem (internal or external) or a direct RS-232 connection. The speed of this communication is also reported as "baudrate." The device will either answer the phone when a polling computer calls it, or can be programmed to place the call itself automatically when the data storage area is full or on a schedule. Some devices use public domain communication and transfer protocols, and others use proprietary software for achieving the communication and transfer. Most transfer mechanisms are capable of detecting errors in transmission. Some communication software provides logs of all transactions, errors, and other results of connections. Another role for remote communications is allowing remote programming of the device.

4. Comparison of EMCS and Monitoring Technologies

The technology used for dedicated monitoring and EMCSs are very similar—in some cases, identical. As an example of the similarity between the two, Table II-1 compares some of the previously mentioned technical characteristics for a specific EMCS model and a specific energy-monitoring datalogger: the Barrington Systems StarVIEW 4000 EMCS (Barrington 1989), and the Synergistic Control Systems Model C180 Survey Meter/Recorder (Synergistic Control Systems, Inc. 1989). These two pieces of equipment are the models used in the final case study of this research project, and more information on the architecture and technical details can be found in Chapter VI. The two are very similar in their technical characteristics. They are fairly representative of the types of systems that are commonly installed at the time of this writing. They illustrate that essentially the same types of equipment are included in both. The similarities and differences between EMCSs and dedicated dataloggers are discussed in more detail below, and specific information on these and other dataloggers and EMCS models are cited. This section uses the same organization as the previous section.

Sensors and Transducers

Much of the same information is of interest to monitoring projects and to building operations, so some of the same types of data are collected. The variables that one typically finds in an EMCS and in a typical monitoring project are shown in Table II-2. The principal differences are that EMCSs are much more likely to monitor building operational data, such as damper positions, setpoints, state variables of the working fluids, and equipment status. Monitoring projects, on the other hand, are much more likely to monitor end-use electrical demand.

Table II-1. Technical Characteristics of an EMCS and an Energy Monitoring Datalogger.

Attribute	Barrington Systems StarVIEW 4000 EMCS	Synergistics C180 Survey Meter/Recorder
I/O Device Name	MicroSTAR	C180 Survey Recorder
Max Number of Devices	32 MicroSTARs/LanSTAR	100 C180s
Analog Inputs per Device	4	15
Digital/Pulse Counter/Runtime Inputs per Device	4	16
Power Inputs per Device	4 Pulse Counters	16 CTs
Input Impedance	100 kOhm	10 MOhm
Analog A/D Accuracy	±0.25%	±0.2%
Pulse Counter Max Frequency	20 Pulses/sec	10 Pulses/sec
Wiring from Sensors to Device	Twisted pair	Twisted pair
Wiring between Devices	6-wire, or 4-wire trunk	RS232, or DC Loop Daisy Chain
Communication between Devices	52 kBaud	1200 Baud
Max. Distance between Devices	4000 Feet	5000 Feet
Minimum Integrating Interval	One Minute	One Minute
Processor	Zilog Z280	Motorola 6800
Number of Processor Bits	16	8
Processor Memory	1 MByte	32 kByte
Battery Backup	Lithium, 2 years	Lithium, 2.5 years
LAN Communications	Dedicated Zilog Z280 Communications Processor	Communications Interface Board
Operator Interface Types	Host, Touchpad	Host, Touchpad
PC Polling Software	StarView	Synernet
Communication to PC	Serial, Modem, Leased-Line Modem	Serial, Modem
Communication Speed	9600 Baud	1200 Baud
PC Type	IBM PC or Compatible	IBM PC or Compatible
PC Memory Needed	1.5MB	640 kB
PC Disk Space Needed	40 MB Hard Disk	Hard or Floppy Disk
Automatic Polling?	Yes	Yes
Remote Access Software	Norton pcANYWHERE	Synernet
Error Detection	Selectable	CRC
Offline Data Storage	PC Hard Disk	PC Hard Disk
PC Operating System	DOS/DESQview	DOS
Report Format	Spreadsheet Compatible	Spreadsheet Compatible, Spreadsheet, Binary

Table II-2. Data Potentially Measured in an EMCS.

Attribute	Temperature	Energy	Flow/ Pressure	Equipment Status	Valve/ Damper Position	Setpoint	Control Output
Each Zone:							
Zone	●				○	○	
Lighting		●		○			○
Each AHU:							
Cold Deck	●				○	○	
Hot Deck	●				○	○	
Precool	●		●			○	
Preheat	●		●			○	
Supply Air	●				○	○	
Return Air	●				○	○	
Mixed Air	●				○	○	
Supply Fan		●	●	○		○	○
Return Fan		●	●	○		○	○
HV Units	●	●		○		○	○
Whole Building:							
Electrical		●				○	
Chiller		●		○			○
CW Supply	●	●	●			○	
CW Return	●					○	
CW Delta T	●					○	
CW Pump		●		○			○
Cond Supply	●		●			○	
Cond Return	●					○	
Cond Delta T	●					○	
Cond Pump		●		○			○
Cond Fan		●	●	○		○	○
Boiler		●		○			○
HW Supply	●	●	●			○	
HW Return	●					○	
HW Delta T	●					○	
HW Pump		●		○			○
Reheat Supply	●		●			○	
Reheat Return	●		●			○	
Reheat Pump		●	●	○			○
DHW Supply	●					○	○
DHW Return	●					○	○
Condensate	●					○	○
Exhaust Fan		●	●	○		○	○
Outdoor Air	●		●				

● is a variable typically measured by both EMCSs and dedicated monitoring.
○ is a variable typically measured only by EMCSs.

In most cases, exactly the same sensors are available for use in EMCSs as in dedicated monitoring. For example, the Barrington Systems EMCS in the case study used a Kele watt-hour transducer. This has an accuracy of ±0.75% of the full-scale reading (Kele, no date). The C180 watt-hour measurements have an accuracy of ±0.5% of the full-scale reading. Ohio Semitronics makes a watt-hour transducer that is used both in EMCSs and in dedicated monitoring applications, and it has an accuracy of ±0.5% of full-scale reading (OSI 1991). Johnson Controls uses a solid state space temperature sensor that has an accuracy of ±1°F (Johnson Controls 1991), and Barrington uses a LM34 temperature sensor that has an accuracy of ±0.4°F. The C180 literature also specifies that a LM34 temperature sensor can be used, and the Lambert Engineering Data-Trap datalogger, specifies that AD590 temperature sensors can be used, which have an accuracy of ±0.25°F (Lambert 1989). Paddlewheel flow meters are used by both the LoanSTAR monitoring program (Robinson et al. 1992) and by the EMCS in the case study in Chapter VI. For both EMCS and monitoring applications, very accurate sensors are available, but something less accurate is usually chosen because of financial considerations.

Some attention is being paid to sensor accuracy in the EMCS industry. In their Standard 114-1986, ASHRAE wrote guidelines for specifying measurement requirements and recommended methods of verifying accuracy of EMCS instrumentation (ASHRAE 1987a). Standard 114-1986 provides typical values for accuracy required for different applications. The suggested accuracies for energy calculation applications are shown in Table II-3. For some applications, more accurate sensors may be required. For example, if the range of water flow is 1-30 feet per second, the error at full scale would translate to a significantly higher percentage error at low flow rates. A study was done to identify the implications of sensor inaccuracy (Kao and Pierce 1983). It was found that energy consumption could be up to 50% higher if inaccurate sensors are used.

Wiring

Sensors are wired to either a datalogger or the RCU of the EMCS. Wiring in both cases is identical. The two systems are somewhat similar in the number of input channels available, as well. Monitoring equipment in the EPRI survey ranged from 8 to 600 channels, although 8 to 16 is typical (EPRI 1992). EMCSs have similar numbers of channels. The Johnson Controls Metasys EMCS (Johnson Controls 1991) has ten points available on each Digital Control Module (their name for an RCU). The Barrington Systems EMCS has eight points on each MicroSTAR (their name for an RCU).

The number of input channels for each device may not be the truest measure of the ability to monitor data, however, as it is common to link together several devices at a site or complex, either for EMCSs or dedicated monitoring systems. In this linked configuration, all devices can be polled using only one communications link to the outside world. This is commonly referred to as "daisy-chaining." There is commonly a limit on the number of units that can be daisy-chained together. The incremental cost of adding another device is the significant parameter. For both the C180 and the Data-Trap dedicated loggers, up to 100 loggers can be linked together. The Barrington Systems EMCS can have 32 MicroSTARS for each LanSTAR (primary controller). The Landis & Gyr Powers System 600 can have an unlimited number of units connected (Landis & Gyr Powers 1992). With an EMCS, the connection between devices is often done via a sophisticated local area network (LAN). The Landis & Gyr Powers System 600 has a 19.2 kBaud network (Landis & Gyr Powers 1992). The Johnson Controls Metasys uses a 2.5 MBaud network that can be implemented using twisted pairs, coax cable, and fiber-optic cable (Johnson Controls 1991).

Table II-3. Data Accuracies Typically Required for Energy Calculation.

Space DBT	±0.5°F
Hot Air Supply - DBT	±1°F
Cold Air Supply - DBT	±1°F
Outside Air DBT	±1°F
Dewpoint	±3°F
Hot Water - S&R	±2°F
Chilled Water - S&R	±1°F
Condenser Water - S&R	±2°F
Temp. Difference - Water	±0.5°F
Temp. Difference - Air	±0.5°F
Flow - Water	±2.5 % of full scale
Flow - Air	±2.5 % of full scale
Pressure - Air Duct	±1.0 % of full scale
Pressure - Air Building	±1.0 % of full scale
Pressure - Refrig. Water	±2.0 % of full scale
Electric Meters	±0.25 % of reading

Source: ASHRAE Standard 114-1986.

Signal and Data Processing

Many of the data processing elements of monitoring and EMCSs are identical. For the most part, they use the same techniques for signal conditioning, A/D conversion, calibration, sampling, and averaging. The Data-Trap has an input accuracy of ±1%. The C180 has an input accuracy of ±0.25%. Both the Landis & Gyr Powers and Barrington Systems EMCSs have 12 bit data acquisition, which corresponds to a resolution of ±0.025%. While both have similar scan rates, it is possible that the data will be stored on the host rather than the RCU, so the data will have to be traveling greater distances, through more complex networks, and there will be accuracy and throughput considerations.

In terms of averaging, both typically have several different ways of summarizing the data: instantaneous values, averages over different intervals, totals, 15-minute demand windows, and peak values. One unique method of summarizing data available as an option in some EMCSs is "COV" monitoring. COV stands for change-of-value. In this method, data are only collected when the value has changed by at least a minimum threshold level, which can be set by the EMCS operator. Thus the precision of the measurement will depend on how the COV level is set. Figure II-3 shows a test of the errors introduced by this approach, (using synthetic data), for different relative COV levels. When the COV is set too high, the data are distorted. When it is set too low, data are collected too frequently. Figure II-4 shows this relationship. The setting of this value will determine how appropriate the data are.

In terms of other advanced processing procedures, the flexible programming capabilities of most EMCSs allow them to perform any kind of calculation that is needed. However, it is rare to find some of the algorithms mentioned earlier, especially sum checking, repeated value checking, level-based binning, and computed status.

Data Storage

Data are stored on an EMCS either on the RCU, the host, or a long term storage medium. This data collection facility is often referred to as "trending." Some EMCSs automatically collect hourly data on all points at all times, and store these data for 24 hours. In both EMCSs and dataloggers, data are first stored in memory, usually in non-volatile memory—meaning that the data will not be lost if power is interrupted—and the system has a battery backup in case power is lost. Usually, some of the memory is reserved for programming and configuration information. Sometimes the amount of memory reported for a logger includes this reserved area, but often the amount of memory available for data storage is reported explicitly. The EPRI survey found that system memory varied from 20 kbytes to 2 megabytes (EPRI 1992). The C180 has 32 kBytes of memory for data, and the Data-Trap has 512 kBytes. The Barrington and Landis & Gyr Powers EMCSs each have 1 MByte of memory.

Operator Interface

The most sophisticated operator interface in an EMCS is located on the host computer. It is often a graphical-user interface, using dynamic graphics to intuitively communicate the state of the system. The Johnson Controls Metasys EMCS operates under the Windows operating system (Microsoft 1991). Programming of an EMCS can be done using the host, with techniques that range from a graphical interface (Johnson Controls 1991), to C-language programming (Teletrol 1991). Interface can also take place at the RCU, through a keypad or a lap-top connection. Smaller hand-held interface devices are also commonly used (for example, in the Johnson Controls Metasys), and these can even connect directly into a zone thermostat and communicate with

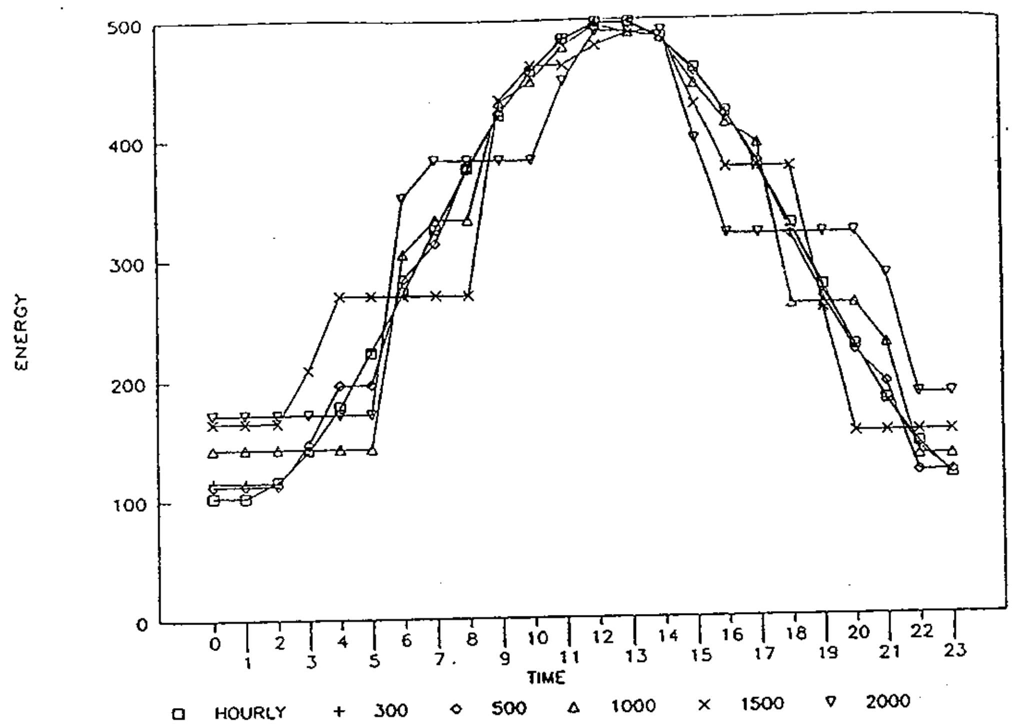

Figure II-3. The Effect of COV Level on Demand Profile. COV data were generated from synthetic sinusoidal data, at different COV levels. When the COV level is high relative to mean demand, the profile is distorted. For a low COV level, however, the data are very similar.

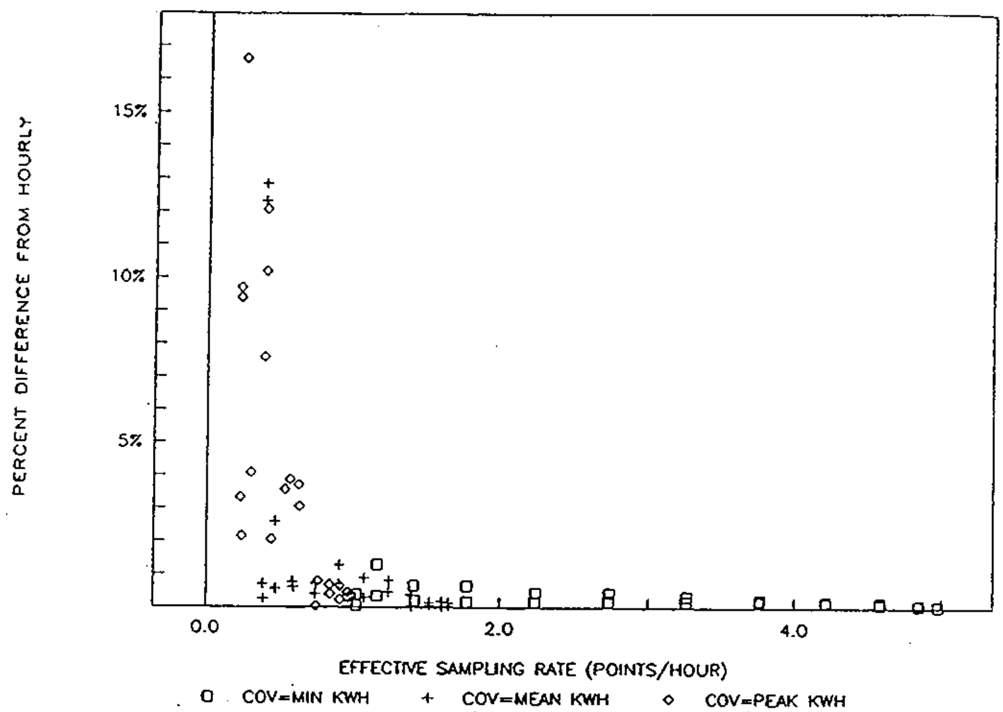

Figure II-4. The Effect of COV Level on Data Accuracy and Sampling Rate. COV data were generated from synthetic sinusoidal data, at different COV levels. When the COV level was high relative to mean demand (diamonds), the errors became unacceptably high. However, this occured during times of relatively low demand, which may be of lesser interest. When COV level was low (squares), effective sampling rate rises, possibly causing communications problems. A moderate COV level (crosses) resulted in a compromise between the two.

the entire EMCS network (as is done in the Landis & Gyr Powers System 600). The Barrington Systems EMCS has a telephone interface that uses voice simulation to allow the EMCS to "talk" to the operator, and the operator to respond using the telephone keypad.

Communications

Both EMCSs and dataloggers usually have a mechanism for connecting remotely. Both typically have capabilities for connecting to the system by a direct RS-232 connection or with a telephone. Dedicated monitoring systems often require a proprietary software on the remote end, as do many EMCSs.

Comparison of Capabilities

EMCSs and dedicated monitoring systems can contain almost identical equipment for monitoring. Very similar sensors are available, but what is installed in an EMCS will depend on the needs for control, and will vary from site to site. They also use very similar wiring and storage technology. Some of the data processing algorithms for dedicated monitoring systems are more geared to the application of energy monitoring, but most EMCSs could be programmed to process the data using similar algorithms. User interface in an EMCS is often quite sophisticated. Communications capabilities are similar between the two.

However, this kind of comparison is insufficient to evaluate whether or not EMCS monitoring is possible. It will be necessary to assess what is installed at a site. These technical characteristics also may not address the more logistical issues that can dominate in a monitoring application.

5. EMCSs for Monitoring

The previous section compared the technical characteristics of EMCSs and dedicated monitoring systems. They were found to be functionally very similar. Does this mean that EMCSs can be used in any situation where a dedicated monitoring system would be used? Although their technical characteristics are very similar, the process of collecting data will be very different. Before beginning to investigate this, it is important to outline what work has been done by others to investigate it, and to discuss the methods that might be used to carry out the monitoring.

Previous Work on EMCS Monitoring

Most EMCSs have a monitoring function as a standard feature, suggesting that it is a common application. However, there is little literature explicitly addressing the usefulness of EMCS monitoring, or for the applications of interest to building energy researchers. This section reviews the work that has been done, and identifies the few documented cases where it has been used. Most use of EMCSs for monitoring is informal in nature, and thus not well documented. This section also presents some of the critique of EMCS-based monitoring that has been presented in the literature.

- Using an EMCS for monitoring has been suggested for commercial (Akbari et al. 1987b), and for industrial buildings (Akbari et al. 1987a and 1988b). In these works, the authors outlined the basic characteristics of EMCSs, and discussed how they might be used for monitoring and load-management applications. As a follow on to this, Flora (1986) and LeConiac et al. (1986) carried out a proof of concept in one building, collecting data and assessing the potential for this application.
- Brambley and Lin (1987) demonstrated the use of EMCS monitoring and communications capabilities to test and monitor HVAC equipment under proportional-integral-derivative

(PID) control. To do this, the EMCS overrode its automatic control functions and manipulated actuators, and monitored the response of the system. Problems were encountered with EMCS data resolution, and occupants overriding the system during tests.

- Norford et al. (1987 and 1990) proposed methods of diagnosing building performance, using the kind of data that is collected by an EMCS. In the first study, they built a prototype as an example of how this type of diagnostic could be implemented, but did not use an actual EMCS in the study. In the second study, they defined the characteristics of a knowledge-based system for building operations that is designed to work with EMCS data, but they did not actually build such a system.
- Hartman (1990) suggested that EMCSs can be used for providing more timely energy-performance feedback to building operators, for use in evaluating control algorithms—for both short- and long-term strategies. A large hotel was used as a case study, and methods were presented to calculate degree-day data from EMCS temperature data, to present baseline energy-consumption data, to calculate expected performance, and to compare expected to actual performance.
- Pape et al. (1991) introduced methods for optimization and fault detection. They stated that this type of operation could be implemented using data that could come from an EMCSs.
- In the Advanced Customer Technology Test (ACT^2), carried out by Pacific Gas & Electric Company (PG&E), EMCS monitoring was considered (SBW Consulting, Inc. 1991). In an appendix to their project plan, they discussed the reasons for not selecting it. One of the reasons cited was the perception that EMCS data were only available for limited time periods. They also stated that EMCSs often measure only control, status, and operational variables, and only occasionally end-use energy consumption. Concerns were also stated about interruption of EMCS functions; liability; data reliability, resolution, and accuracy; and the requirement to modify hardware and software. The need for standardization especially between different sectors (e.g., residential and commercial), was also cited.
- Daryanian et al. (1992) discussed the optimal operation of a building under real-time prices, using active thermal storage. They suggested that EMCSs could carry out this type of optimization, but their prototype was carried out using a remote and dedicated control system.
- Solberg and Teeters (1992) identified the usefulness of EMCS-monitored data for HVAC commissioning and operation and maintenance. They suggested a list of points that should be monitored, for the example of air-handling unit monitoring, and suggested that trends of these variables should be included in specifications for EMCS systems. They included some output control data in their list of data to monitor, and acknowledged that these data are not as reliable as monitoring actual system response.
- Champaign (1993) also discussed the use of EMCSs in building commissioning, and identified trend logs as a useful tool. He discussed the usefulness of "command traces," or the tracking of not just how a piece of equipment is operating, but why. For example, when a fan is turned off, it may be because of an operator command, fire alarm overrides, optimum start/stop, demand limiting, or simple time-of-day scheduling. It is useful in diagnosis to know why it turned off.
- Gustafson (1993) used an EMCS in re-commissioning HVAC equipment at PG&E's Pacific Energy Center. Although the EMCS provided data that were quite useful in diagnosing building operation, the process of collecting the data was burdensome (Gustafson personal communication).
- The Newsletter of the Center for Electric End-Use Data discussed the potential use of EMCSs for monitoring (CEED 1994). They identified many advantages to using EMCSs

for monitoring, including the explanatory power of its operational data, and its cost-effectiveness for collecting end-use data. The article also acknowledged that there are several potential disadvantages, as well. First, because EMCSs have different design objectives, they will not necessarily be appropriate for collecting load-research data. The fact that EMCSs typically use their own proprietary communication protocol is cited as another problem with using EMCSs (although accessing the data by intercepting proprietary communications is only one method of collecting data—see discussion of other methods below). The advent of open communications protocols will solve this problem. Finally, utilities are cautioned that they should not necessarily assume that EMCSs will provide good-quality data, since some systems are not well maintained and do not use well calibrated and correctly placed sensors.

- EMCSs were used in a limited way the Energy Edge evaluation (Piette et al. 1994). At one site, the EMCS sensors were used as inputs to the Energy Edge monitoring. Additionally, a translator box was built to convert proprietary EMCS communications into data that the datalogger could understand. This was quite a difficult process. This method is discussed in the "Hybrid Logger" discussion later in this chapter.
- In their commissioning efforts, Portland Energy Conservation, Inc. uses in-place EMCSs when possible. In one study (PECI 1994), they used the EMCS to collect 96 channels of data. They had minor problems because the data collected were not coincident in time. They state that they had assumed that the values provided by the EMCS were accurate without formal testing. In some cases, they explicitly monitored control outputs instead of observing system response. This was because they were interested in diagnosing control algorithms and not necessarily quantifying building performance.
- Quadrel and Lash (1994) discussed different methods of carrying out building diagnosis. They defined four discrete aspects of the automated diagnosis process: observation of actual performance, knowledge of expected performance, comparison of actual and expected performance, and explanation of any differences. They discussed available systems that carry out these different levels of diagnosis, and identified many EMCS models that carry out partially automated diagnosis using data acquisition, graphical display, and multiple-level alarming.
- Tseng et al. (1994) used EMCSs in building commissioning. They included a list of the types of points to monitor, and made an argument that access to more data would usually aid commissioning efforts. They claimed that the cost of incremental sensors is small, relative to the total cost of the EMCS, and that the diagnostic power made available by installation of these sensors usually offsets this increased first cost. In particular, they suggested that VAV box air-flow data are often not included in an EMCS, but that they are quite valuable in diagnosis. They identified the advantage of monitoring actual hardware points, rather than relying on output control signals, or other software-derived points. They identified the need to review data carefully. In one building, they set up 90 points to be monitored for one year, and 70 additional points to be used for short-term diagnostics.

The work just discussed suggests that there is interest in using EMCS to collect data in building applications. EMCSs have been used in the context of a range of monitoring applications, from commissioning to energy savings analysis. None of the literature, however, addresses the use of the EMCS explicitly: it is simply the tool that was used to address other research questions. Many of these studies simply state that monitoring and analysis can be performed with an EMCS, but stop short of actually carrying out that monitoring and analysis with a real EMCS. In some cases, EMCS data collection is carried out, and problems with using the data are cited, although in no cases has explicit verification of the data been presented. These works stop short of performing a detailed comparison of EMCS monitoring with other methods, and do not analyze the detailed capabilities of EMCSs in general, or the needs for monitoring. It is apparent that research is needed to confirm its use.

Methods for Monitoring Using an EMCS

Earlier studies that touched on EMCS-based monitoring also did not present detailed documentation of methods that are used for obtaining data from the EMCSs. There are many different ways that one could transfer data from an EMCS to a remote polling computer, and each would have advantages and disadvantages. These methods are summarized here and in Figures II-5 through II-9. The relative advantages and disadvantages of each are discussed, and summarized in Table II-4. In general, it seems that upcoming methods of collecting information from an EMCS hold the most promise for application to building performance monitoring.

Generic terminal method: The procedure used in the case studies that appear later in this dissertation was to use a "remote" IBM PC-compatible computer (i.e., the computer is remote from the building being monitored) with a modem to dial up and connect to the EMCS's modem (see Figure II-5). This method can use any commercially available communications program. One then uses the remote computer to act as a terminal and log onto the EMCS system just as any other user, and run the trend utility, requesting that the data report be presented on the screen. The entire session is recorded in a log file on the remote computer, so that while the report is displayed on the screen, it is simultaneously recorded on the remote computer's disk. This procedure could be automated using a script file to watch for certain prompts coming from the EMCS, and to output the proper responses.

Proprietary method: Although the Generic Terminal method was used in the case studies, there are several alternate ways to retrieve data from the EMCS. In the Proprietary Method, the connection between the remote polling computer and the EMCS can be made via a LAN, an RS-232 connection, or a modem and phone line (see Figure II-6). In this scenario, proprietary software on the polling computer interacts directly with the EMCS software to request transfer of the data. Since direct-wired RS-232 communication can only be carried out over a limited distance (up to about fifty feet, Omega 1992), this requires the polling computer to be on-site—so that it is not truly remote. With a LAN connection, similarly, the computer may have to be on-site. For remote monitoring, a modem connection would be used. This method of collecting data could require installation of a different proprietary program for each building monitored.

Remote control method: The Remote Control method, (see Figure II-7), makes use of remote-control software. This software essentially allows remote control of a computer. The EMCS computer initiates a TSR (terminate/stay resident) program, and then invokes the EMCS program. The resident software runs in the background, constantly watching for a modem connection from the remote computer running its counterpart program. Once the EMCS software detects the presence of another computer running the remote software, it allows the person using the remote computer to issue commands to the EMCS computer. It is possible to password protect this connection. Any remote computer, then, can run the software on the EMCS computer. The result of this is that the remote polling computer can run a common and commercially available program to make a connection to the EMCS and run the proprietary EMCS software, while seeing the results on the remote screen. Several EMCSs use the same remote-control software for remote communication, so it could be used fairly generally. When using the Proprietary Method, the retrieved data are stored on the disk of the remote polling computer. In the Remote Control Method, the same procedure is used to retrieve the data, although they are stored to the EMCS

Table II-4. Evaluation of Methods of EMCS Monitoring.

	Proprietary	Generic Terminal	Remote Control	File Transfer	Hybrid Logger	(Future) Windows
Easily Automated	?	?	?	+	+	+
Short Time	+	—	?	+	?	+
Error Checking	+	—	—	+	?	+
No Interference	?	?	—	—	—	+
Easily Processed	+	—	—	+	+	+
Generic Access Software	—	+	+	+	+	+
Generic Access Methods	—	—	—	+	+	+
Easily Implemented	—	+	+	+	—	+

+ indicates that the characteristic is present.

— indicates that the characteristic is not present.

? indicates that the characteristic may or may not be present, depending on the project.

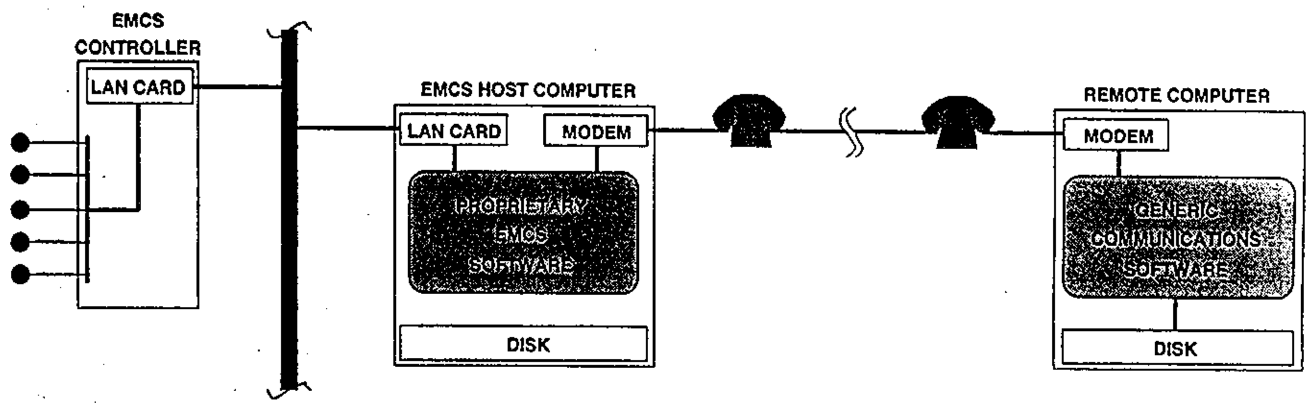

Figure II-5. Generic Terminal Method of Collecting Data from an EMCS. Generic communications software is used to connect to the EMCS software and request historical data. The data will be displayed on the screen, and can simultaneously be captured on the remote computer.

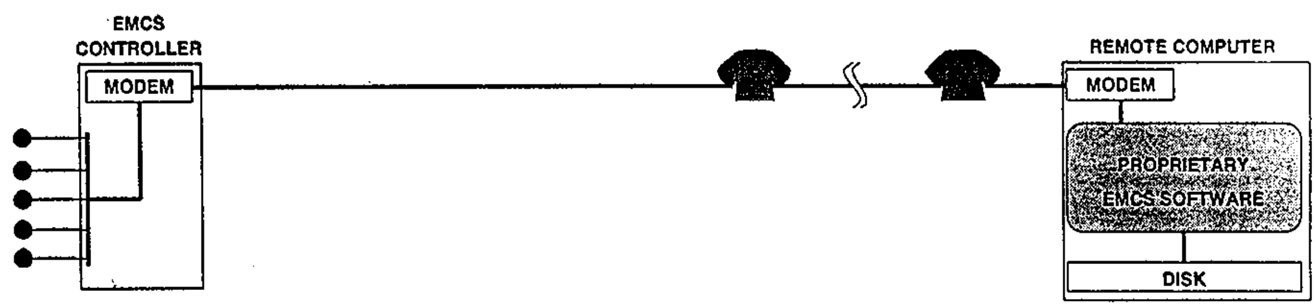

Figure II-6. Proprietary Method of Collecting Data from an EMCS. Proprietary EMCS software is used on the remote computer to communicate with the EMCS controller or host computer. The data file can be either transferred or displayed on the screen and captured into a remote file.

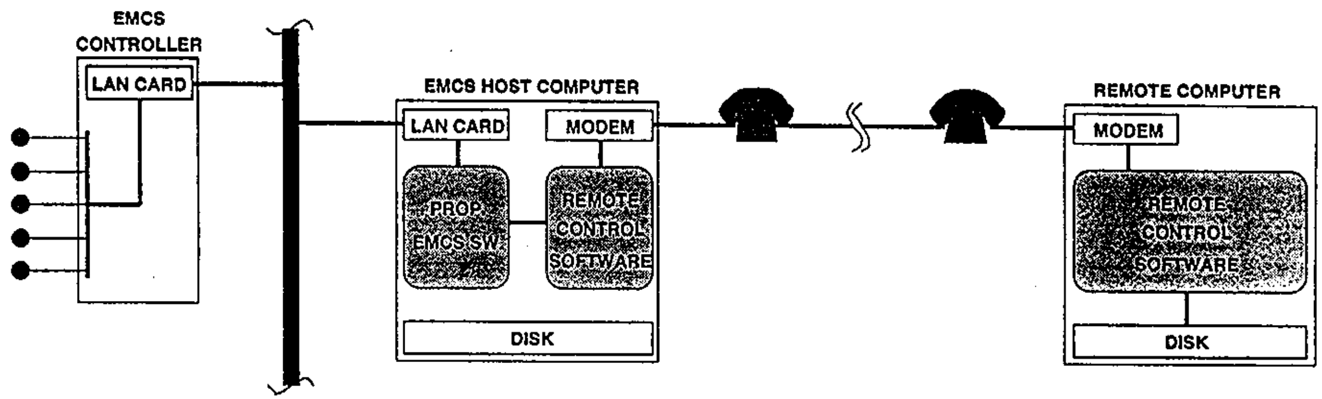

Figure II-7. Remote Control Method of Collecting Data from an EMCS. Generally available remote-control software is used to allow the remote computer to run the EMCS software that resides on the EMCS computer at the site. The data can be obtained from the controller, and displayed for capture on the screen.

disk. The data must then be displayed on the remote screen, and simultaneously captured into a log file on the remote computer disk.

File transfer method: A simpler variation on the Remote Control method is possible (see Figure II-8). It is possible to program the EMCS to retrieve data from the local controller automatically and store the data in an EMCS disk file. Once the data are on the disk, the EMCS software can be exited, and the file can be transferred to the remote computer. If a dedicated computer is added to the network, this would work well. However, if a connection is established with the existing EMCS computer, taking over and exiting EMCS software would not be a reasonable option.

Hybrid logger method: Another method is a hybrid EMCS/conventional datalogger approach (see Figure II-9). In this method, a conventional logger is used to tap into the EMCS at some point. An advantage to this method is that once the data are collected, they are in a format consistent with other data collected by the logger. Two such techniques were used by the monitoring contractors and sponsors in the Energy Edge monitoring project (see Piette et al. 1994), where the dedicated datalogger tapped directly into some of the EMCS sensors, and also tapped into the EMCS communication network to collect EMCS data.

The first approach is a possibility only if the input impedance of the monitoring device is high enough—at least in the megaohm range—which is likely in any monitoring device. One drawback of this approach is that wires have to be run out to the zone sensors, adding to the expense and the intrusiveness of the monitoring project. With the advent of wireless sensors, this problem would be eliminated.

In the second approach, a translator box can be used as an interface between the EMCS and a dedicated datalogger. This box taps directly into the communications bus and translates from the proprietary EMCS communications protocol to the protocol used by the datalogger. The box also functions to resolve timing issues by serving as a buffer to store the EMCS data until the logger requests them. This approach requires access to proprietary data protocols. Note that this is the *only* monitoring method that requires knowledge of low-level communications protocols.

Upcoming methods: With new generations of EMCSs, having complex network architecture and multi-tasking capabilities, there will be new methods for accessing the systems and transferring data. One of the methods with the most promise is based on multi-tasking software. Many EMCS manufacturers are starting to offer a version of the EMCS software that runs under *Microsoft Windows* or *OS2*, and takes advantage of data exchange capabilities. In this scenario, data are automatically written to an EMCS computer disk in a format designed to be read by other software. Remote access is made via a generic communications program running in one window, while the EMCS software is running in another window on the same EMCS computer. It would then be possible to transfer the data without the proprietary EMCS software being interrupted, and without an operator even noticing the connection. This method would allow use of generic communications software, error checking, a totally transparent connection, simple and quick data transfer, and an easily processed file format. This should enhance the usefulness of EMCSs for monitoring in future years. Since these Windows-based models were not commonly available at the time of this writing, they have not been investigated, however they are a very promising method of collecting EMCS data.

Another advancement in upcoming EMCS generations that will have implications for monitoring is the advent of open protocols for EMCS communication. Standardization mechanisms, such as

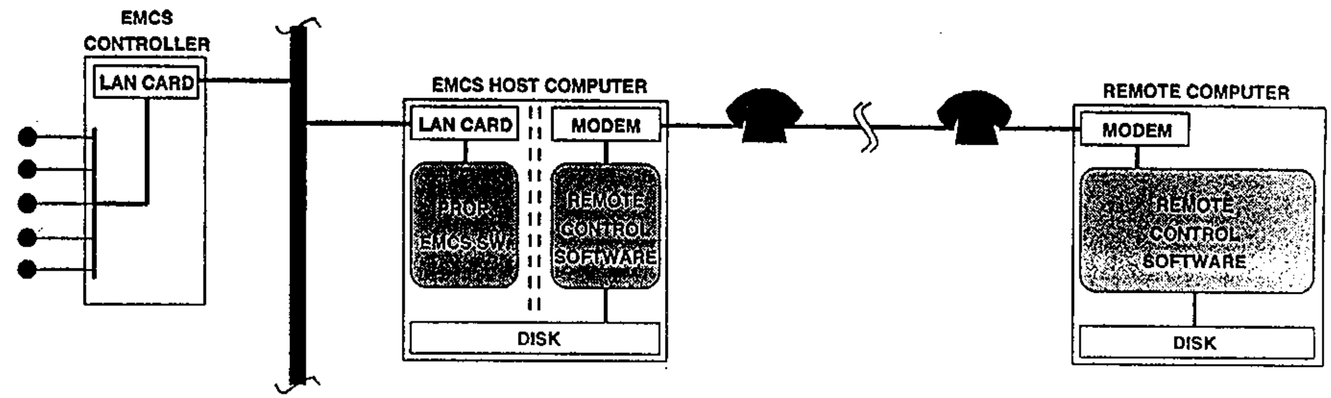

Figure II-8. File Transfer Method of Collecting Data from an EMCS. Generally available remote-control software is used to allow the remote computer to run the EMCS software that resides on the EMCS computer at the site. Data can be saved onto a host disk file and transferred directly.

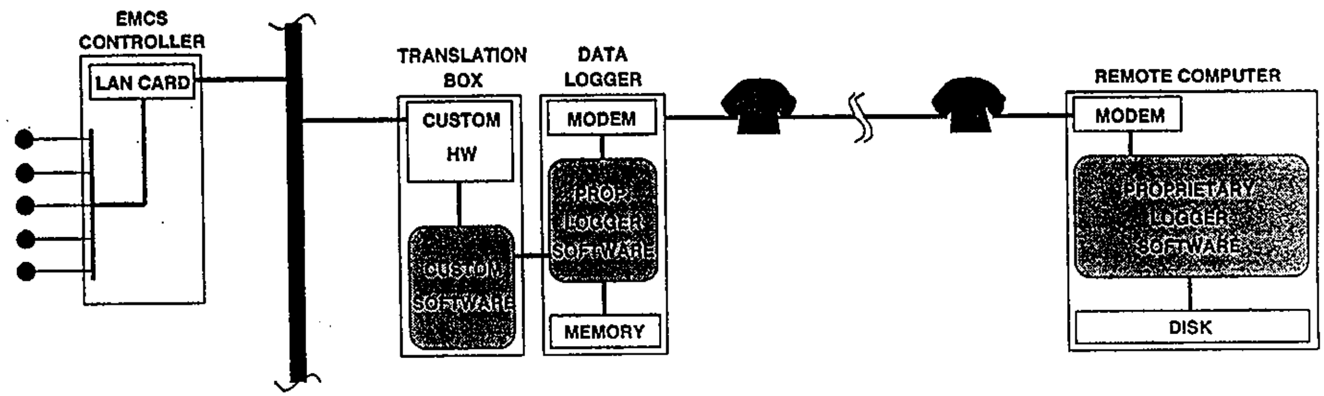

Figure II-9. Hybrid Logger Method of Collecting Data from an EMCS. A conventional datalogger can be used to collect data from the EMCS and transmit them to a remote computer. This requires either tying directly into the EMCS sensors, or intercepting the proprietary communication, and translating data into a format that the logger can understand.

the BACNet protocol (discussed earlier) would make both EMCS-based and hybrid approaches much more feasible. One method would be the possibility for a more standardized front-end. One could imagine the development of a "black box" that allowed a standardized window into an EMCS, and a secure storage area for very reliable storage of consumption data. This storage area could be made secure from both inadvertent reprogramming and intentional tampering, and thus could form the basis of utility revenue metering. Another way that standardized communications protocols would affect EMCS monitoring is by allowing loggers to connect into the EMCS at any location, and collect data without having to adjust for different manufacturers' proprietary communications protocols.

6. Conclusions

The intent of this chapter was to describe EMCSs and monitoring tools technically, in such a way that the two can be compared. This was done by outlining the development and architecture of both EMCSs and dedicated monitoring equipment. The fundamental characteristics that are common in both types of equipment were described generically, and then the differences between the two were identified. Previous work in EMCS monitoring and methods for monitoring with EMCSs were also presented.

It was found that both technologies are advancing very rapidly. EMCSs and dedicated monitoring systems are very similar in hardware: they use the same types of sensors, wiring, storage media, and processing. As a first assessment, this chapter suggests that EMCSs monitoring has a great deal of promise. It has generated a significant deal of interest in the building science community. However, there has been no work done to confirm that EMCSs are adequate alternatives to more conventional monitoring equipment, or to develop methods for assessing that adequacy in particular situations. The following chapters of this dissertation investigate this application further, to find out how effectively it will really achieve monitoring objectives.

III. REVIEW OF MONITORING PROJECTS

Selecting tools for monitoring is more complex than simply comparing technical specifications, as was done in the previous chapter. An important premise of this dissertation is that in any monitoring project, several planning steps must be taken: definition of the project's objectives, assessment of characteristics required of tools, identification of available resources and potential approaches, and evaluation of possible approaches. There is a spectrum of methods for evaluating building performance, ranging from pure monitoring to pure analysis. In many cases, a hybrid approach is optimum. Tools must be selected to be a good match with the objectives, resources, and limitations in the project. This is particularly true since there is pressure to spend limited monitoring dollars effectively, a strong need for reliability and authority in monitoring results, and a broad array of available monitoring tools and analytic techniques.

Although EMCS data collection hardware is similar to the hardware in a dedicated monitoring system, the methods used for monitoring, the different data available from the EMCS, and the constraints imposed by using someone else's equipment make it a very different process. Assessing whether or not EMCS monitoring makes sense in a given monitoring project requires going back to assessment of overall objectives of the application, and its constraints. The primary objective of this chapter is to create a general framework for this kind of monitoring project planning. Defining the basic attributes that a successful monitoring tool should have creates a basis for constructing guidelines for evaluating the potential for EMCS monitoring. These guidelines will be presented in Chapter V.

The scope of this chapter is purposely broad: since the tools suitable for different applications are likely to be different, it is appropriate to begin by discussing a broad range of applications. Later chapters of the dissertation, however, will focus on a single application: long-term, third-party, remote monitoring for evaluation of energy savings. By looking more closely at this application in later chapters, it will be possible to draw more specific conclusions and recommendations.

1. Existing Frameworks for Monitoring Project Planning

Despite advances in the industry, there remains a tendency in building monitoring to monitor first and ask questions after, and to focus more on monitoring considerations and issues than on the ultimate objectives of the monitoring. It is quite important to carry out thorough planning of a monitoring project to ensure that it meets its objectives in as effective and as efficient a manner as possible. Several different frameworks have been used to describe the process of planning a monitoring project.

In a workshop sponsored by the International Energy Agency (IEA), several monitoring professionals outlined the process for planning a monitoring project (see Fracastoro 1990, Gay 1990, Haberl et al. 1990, Stoops 1990, and Ternes 1990). These papers all discussed monitoring, presented the need for planning, and broke the planning process down into several steps:

- Fracastoro (1990) defined the following steps: understanding the task, definition of the aim of the investigation, evaluation of the problem, description of the system, design of the experiment and choice of model, planning of measurements, measurement campaign, and data analysis and presentation.
- Gay (1990) defined the following steps: clear definition of the objectives, inventory of the existing data, selection of the experimental strategy, measurements, and deduction of the

expected answers.

- Haberl et al. (1990) discussed the need to categorize the beneficiaries of the monitoring project, the type of project, the design of the experiment and the extent of the monitoring. They went on to discuss the types of trade-offs that will have to be made to balance these four categories.
- Stoops (1990) cited the following explicit steps for an evaluation monitoring project: evaluation design, analysis methodology, data needs assessment, monitoring design, data processing assessment/development, pilot test, full-scale implementation, quality assurance, operations, results production, and project termination.
- Ternes (1990) identified the following eight parts of the planning step: research questions and project constraints, analysis results, experimental design, analysis methods, field data, monitoring instrumentation, iterate on developed plan, and planning details.

In most monitoring efforts, the monitoring planning is formalized into a monitoring protocol. ASHRAE (1991), van Amerongen (1990), Mazzucchi (1987b), Misuriello (1987), Misuriello (1990), and Mixon (1989) discussed the needs for such protocols, or standardized project planning methodologies. In 1987, Misuriello defined protocols as "standardized experimental designs intended to answer specific building energy systems research questions through the collection and analysis of field performance data," and outlined a process by which uniform protocols could be developed. This process would include: definition of a classification system to group monitoring projects based on similarities in goals, approach and data requirements; identification of standard terminology and definitions; and provision of a guide specification that includes the following issues:

- statement of goals, objectives and research questions to be addressed,
- specification of data products that meet the objectives of the projects,
- specification of an experimental design approach,
- specification of data analysis procedures and algorithms,
- specification of field-monitoring data points,
- specification of verification and quality control procedures,
- hardware selection guidelines, and
- recording and data exchange formats.

In describing the issue of hardware selection guidelines, Misuriello goes on to say:

> "The selection of specific data acquisition hardware and associated sensors is recommended to be one of the final steps in the development of a monitoring protocol. This is because the hardware is driven by the analytical requirements developed through the structured procedure described above. As mentioned previously, there are certain trade-off constraints that need to be integrated into this process. However, the important point to note is that the design of a monitoring project should not begin with hardware selection."

In 1992, several papers were published in *ASHRAE Transactions* discussing the standardization of reporting of building characteristics data. Three of these papers were Haberl et al. 1992a, Landsberg 92, and Mazzucchi 1992. In its *1991 Applications Handbook*, ASHRAE published guidelines on planning of monitoring projects (ASHRAE 1991). The steps outlined in this handbook were identical to those above, recommended by Misuriello (1987), except that there is no guidance on hardware selection.

The common theme in all these papers was the need to identify objectives at the outset in a very thorough way, and use these objectives to guide decisions made over the life of the project. This will ensure that the monitoring will answer the research question, and do so in the most appropriate manner. The choice of monitoring tools is one of the decisions that must be informed by the clear assessment of objectives. Few of the types of papers discussed above go into any details on what the most appropriate tools are, or into the process that should be undertaken to select the tools. They assume that selecting the most appropriate tool for a monitoring application is a straightforward decision, and that the answer will become immediately apparent throughout the objectives assessment. However, they do not discuss in detail how this happens, and they do not provide guidance on determining appropriate tools. These frameworks are quite important contributions in ensuring that project objectives are achieved, although these frameworks were not designed to compare different monitoring methods, or to assess new methods of monitoring.

2. Proposed Framework for Monitoring Project Planning

Evaluating the usefulness of new tools for monitoring requires a planning process that defines objectives, assesses both needs and resources, considers alternative approaches to meeting the project objectives, and evaluates the approaches considered. Such a process is defined in this chapter, and used in the remainder of this dissertation as a tool in evaluating EMCSs for monitoring.

Figure III-1 describes the overall-sequence for the project planning process. First, the project objectives are defined. The constraints faced by the project, and the resources available within the project and on the site are next assessed. The monitoring and analysis approach one selects is the mechanism by which the project resources are applied to meet the project objectives and constraints. Alternative potential approaches are considered. Finally, the feasibility of the project is assessed: evaluating whether or not the project objectives and constraints will be met effectively using the available resources.

The monitoring project planning process thus is a combination of self-assessment and information-gathering processes. These planning steps will be carried out by the entity with overall responsibility for the monitoring, in consultation with project sponsors and any monitoring subcontractors. They must be carried out early in the project, and revisited frequently throughout the life of the project. Although Figure III-1 indicates the sequence in which the different issues are taken up, once all have been considered, the process is iterative: each step influences and is influenced by the other steps. Table III-1 summarizes the categories of monitoring efforts, and identifies the principal objectives, constraints, resources and approaches typically associated with that application. The following sections discuss the five steps in the monitoring project planning process in more detail.

Identify Objectives

It is quite important that a monitoring project be well thought out before monitoring ever begins. Because there is often more than one way to carry out a monitoring project, and many decisions must be made in the course of a project, it is important to be explicitly aware of the overall objectives of the project. Objectives can describe why one is doing the monitoring project, the general direction the monitoring will take, and the quantifiable targets that will be achieved. The objectives will depend on who pays for the monitoring, what their financial interest is in the results of the monitoring, and who is carrying out the monitoring. If the building owner is sponsoring the monitoring effort, then s/he will have very different objectives than if an outsider is sponsoring

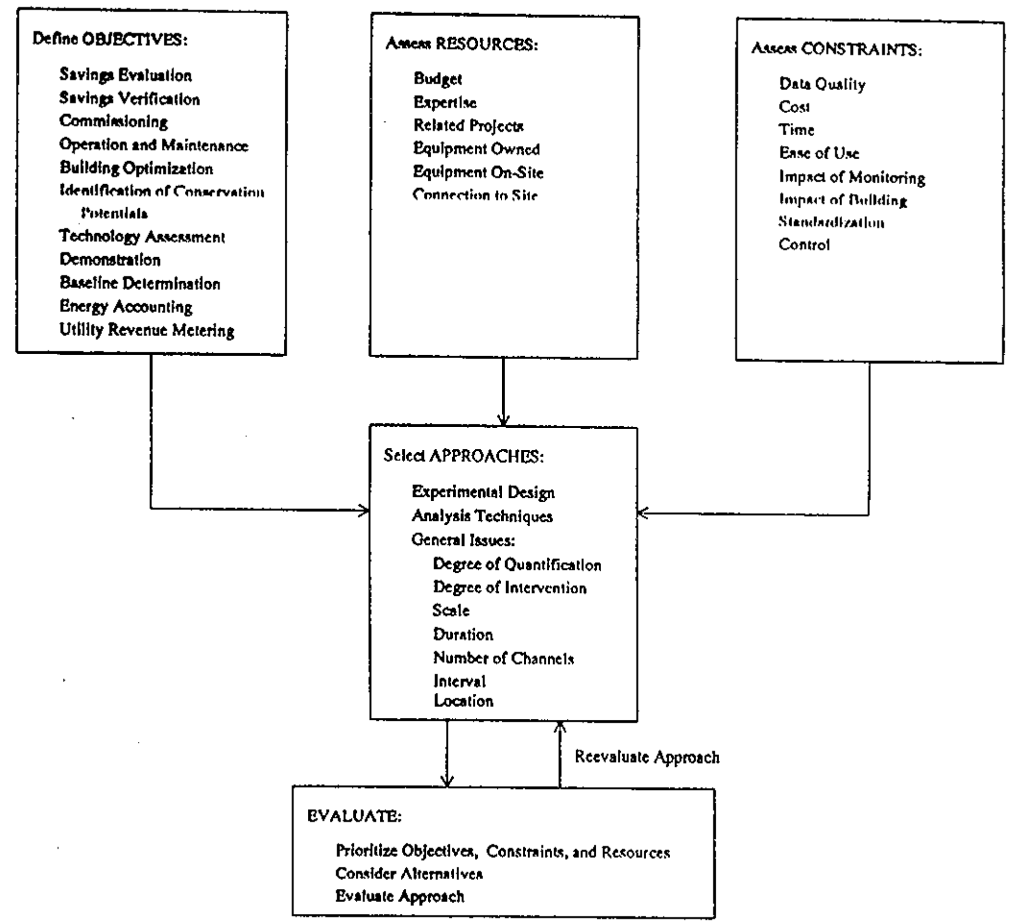

Figure III-1. Framework for Planning of Monitoring Projects. Thorough planning will help to ensure that monitoring will achieve its objectives. These steps should be taken early in the planning process. While they should be started in this order, they are iterative, and should be reevaluated frequently during the monitoring project.

Table III-1. Attributes of Different Categories of Monitoring Efforts.

Objectives	*Constraints*	*Resources*	*Approaches*
Savings Evaluation	Data Quality Little Time Impact of Building Impact on Building Standardization Control	Budget Expertise Related Projects Equipment Owned	Test-reference Quantification Observation Large Scale Varying Duration Few Channels Hourly Interval Remote Utility Bills Audits, Surveys Comparison Bldgs. End-use Disagg. Simulation Tuning Temperature Corr. Proxies
Savings Verification	Data Quality Cost Little Time Ease of Use Impact of Building Impact on Building Control	Budget Expertise Related Projects Equipment Owned Equipment on Site	Before-after Verification Observation Large Scale Long Duration Few Channels Short Interval Onsite/Remote Utility Bills Operational Data Audits, Surveys Enduse Disagg. Simulation Tuning Temperature Corr. Data Visualization Proxies
Commissioning	Data Quality Little Time Impact on Building Control	Expertise Connection to Site Equipment on Site	Simulated baseline Verification Intervention Small Scale Short Duration Many Channels Short Interval Onsite Operational Data Audits, Surveys Data Visualization Mo/Day Summaries Proxies
Operation and Maintenance	Data Quality Cost Ease of Use Impact of Building Impact on Building	Connection to Site Equipment on Site	Nonexp. Ref. Verification Intervention Small Scale Long Duration Many Channels Varied Intervals Onsite Utility Bills Operational Data Comparison Bldgs. Enduse Disagg. Data Visualization Mo/Day Summaries Proxies

Table III-1. Attributes of Different Categories of Monitoring Efforts (cont.)

Objectives	*Constraints*	*Resources*	*Approaches*
Building Optimization	Data Quality Ease of Use Control	Connection to Site Equipment on Site	Quantification Intervention Small Scale Long Duration Few Channels Short Interval Onsite Operational Data Enduse Disagg. Simulation Tuning Temperature Corr. Data Visualization Mo/Day Summaries Proxies
Identification of Conservation Potentials	Cost Ease of Use	Connection to Site Equipment on Site	Nonexp. Ref. Verification Intervention Small Scale Short Duration Many Channels Varying Interval Onsite Utility Bills Operational Data Audits, Surveys Comparison Buildings Enduse Disagg. Temperature Corr. Data Visualization Mo/Day Summaries Proxies
Technology Assessment	Data Quality Cost Ease of Use Impact on Building	Related Projects Equipment on Site	On-off Verification Quantification Observation Small Scale Short Duration Many Channels Short Interval Onsite Operational Data Audits, Surveys Data Visualization
Demonstration	Data Quality Ease of Use Impact on Building	Connection to Site Related Projects Equipment Owned Equipment on Site	On-off Verification Quantification Observation Small Scale Medium Duration Many Channels Hourly Interval Onsite Operational Data Data Visualization

Table III-1. Attributes of Different Categories of Monitoring Efforts (cont.)

Objectives	*Constraints*	*Resources*	*Approaches*
Baseline Determination	Data Quality Impact of Building Impact on Building Standardization Control	Expertise Related Projects Equipment Owned	Quantification Observation Large Scale Medium Duration Few Channels Hourly Interval Remote Audits, Surveys Comparison Bldgs. Enduse Disagg. Data Visualization Mo/Day Summaries Proxies
Energy Accounting	Cost Ease of Use	Connection to Site Equipment on Site	Quantification Observation Small Scale Long Duration Few Channels Long Interval Onsite Utility Bills Comparison Bldgs. Enduse Disagg. Temperature Corr. Data Visualization Mo/Day Summaries Proxies
Utility Revenue Metering	Data Quality Cost Impact of Building Impact on Building Standardization Control	Expertise Connection to Site Equipment Owned	Quantification Observation Large Scale Long Duration Few Channels Hourly Interval Remote Data Visualization Mo/Day Summaries

the effort. And if a third party carries out the monitoring, even if they are representing the building management they will have different constraints: for example, they will have limited access to the building. The objectives can be categorized, and these categories are listed in Table III-1 and discussed below:

- *Savings evaluation:* Since utilities in several areas are currently monetarily rewarded for their success at conserving energy, it is important to be able to measure how much energy is saved. Monitoring is an important part in this measurement process. The objective in these measurement studies is to determine the net annual energy and demand savings attributable to a program. Since it is important that this measurement be done in a standardized way, protocols for measurement for this particular application have been produced by utilities (see, for example, CPUC 1992, and SBW Consulting Inc. 1994), and by the energy service providers (NAESCO 1992). Both of these protocols stressed the importance of "ex post" measurements: some part of the payments for energy conservation are conditional on completion and verification of studies that demonstrate that savings have occurred. Monitoring is an important part of this "ex post" measurement. Three additional sources of information on measurement in evaluation of savings for DSM programs are EPRI (1991a, 1991b, and in press).

  Savings must also be evaluated in governmental programs. An example of a governmental program is the *Texas LoanSTAR* monitoring and analysis program (Claridge et al. 1991b). In this program, state-owned buildings receive loans to install energy retrofits, and monitoring is used to determine what the savings are. Another example of monitoring in evaluation programs is the *Energy Edge* evaluation (Gardner and Lambert 1987, and Piette et al. 1994).
- *Savings verification:* Closely related to evaluation of savings is verification of savings. In these cases, the objective is to satisfy contractual terms in verifying that projected savings are realized. This differs from true evaluation in a reduced need for statistical significance, contractual rather than academic standards, ability to change the assumptions by mutual consent, restricted timelines, need for simplicity or transparency, and the need for closure (Kushler et al. 1992). Verification is often required in third-party financing, shared savings, and demand-side resource bidding contracts.
- *Commissioning:* Commissioning has been defined as "The act of statically and dynamically testing the operation of equipment and building systems to ensure that they operate as designed and can satisfactorily meet the needs of the building throughout the entire range of operating conditions" (BPA 1992). The objective of monitoring in commissioning is to observe the behavior of the building and systems, in order to understand its performance. Commissioning usually takes place immediately after a building is built or after a retrofit is installed. Commissioning is sometimes funded by a utility that is providing incentive payments for incorporation of energy conservation measures. One example of a commissioning program is that carried out by Pacific Power and Light, in Oregon. A report to Clark Public Utilities documented one of the monitored sites: SEH America (PECI 1994). At this site, 92 parameters were measured at 15-minute intervals using an EMCS. The objective of the project was to find elements of the system that were not operating as intended and to identify opportunities to improve the efficiency of the building's systems. Other examples of the use of monitoring in commissioning can be found in Brohard and Krieg (1994), Champagne (1993), and Tseng et al. (1994)—the latter two of which use EMCSs in the commissioning efforts.
- *Operation and maintenance:* Operation and maintenance (O&M) feedback can be thought of as ongoing commissioning. The objective of monitoring is to identify problems affecting efficiency and remedy them. One example of this kind of monitoring was carried out at

PG&E's Pacific Energy Center, in San Francisco, CA. The results of this monitoring effort were shown in a document that described the objectives of "re-commissioning," and provided a performance verification testing plan (Gustafson 1993). Other examples the use of measured data in operation and maintenance are Athar et al. (1992), Haberl and Vajda (1988), Haberl et al. (1989), Herzog and LaVine (1992), Pape et al. (1991), Quadrel and Lash (1994), and Tanaka and Miyasaka (1994).

- *Building optimization:* Under dynamic conditions such as varying weather, occupancy, and rate structures, it is appropriate to optimize building operation. The objective of monitoring in this application is to provide feedback on building performance that is needed to minimize building energy use and cost while maximizing building utility. For example, a building with real-time rates would have to track past performance to be able to predict future performance and adjust operation to meet cost minimization objectives. Akbari and Heinemeier (1990), Akbari et al. (1989), and Blumstein et al. (1991) discuss the possibility of using real-time rates to send optimal economic signals to commercial buildings, and discuss the need for buildings to optimize their consumption. Braun (1990) and Daryanian et al. (1992) discussed the strategic use of thermal storage to respond to real time prices, and Cumali (1988) discussed the optimization of pumps, chiller, and fan power.
- *Identification of conservation potentials:* Monitoring can be an invaluable tool in identifying possible conservation measures. The objective of monitoring here is to identify how the building energy systems are currently using energy, and carefully observe patterns in consumption, thereby identifying areas of waste. Examples where monitoring was used for this application are Akbari et al. (1992), Haberl and Komor (1989), and Mazzucchi and Lo (1989).
- *Technology assessment:* An important application of monitoring is technology assessment. Often, it is impossible to understand or predict equipment consumption simply from design calculations or laboratory tests. The objective of monitoring in this application is to give a true picture of the building or system performance, and to uncover design problems or real-world operation effects that were not anticipated. Lorenzetti and Norford (1992), for example, used monitored data to assess the performance of variable-air volume distribution systems. Katipamula and Claridge (1992) studied air-handling units with monitored data. Hughes et al. (1987) used monitoring to carry out technical and market assessment of HVAC equipment. An extensive study of the Enerplex buildings in New Jersey allowed study of their conservation features: double glazed curtain walls, earth mass thermal storage, and natural ice mass cooling (see Harrje et al. 1984, DeCicco et al. 1986 and Norford et al. 1986.)
- *Demonstration:* Another objective of monitoring is to demonstrate the potential of energy conservation measures. This is often as important as developing the technologies themselves. One example of the use of monitoring for this application is the *Advanced Customer Technology Test (ACT^2) for Maximum Energy Efficiency*, carried out by PG&E (SBW Consulting, Inc. 1991). In this program, the utility attempted to determine the potential energy savings that can be obtained using cost-effective and available technologies. Retrofits were installed in case study sites, and they were carefully monitored before and after, both to determine energy savings and to ensure that customer acceptability is maintained.
- *Baseline determination:* Monitoring of individual buildings is also done for baseline studies. The objective in these studies is to understand present conditions thoroughly, to provide a solid basis for any kind of energy forecasting or program planning activities. For example, in 1988 Southern California Edison (SCE) carried out an end-use load study, in which they monitored HVAC, lighting, and other end uses in about 53 sites (ADM 1989). The objective of this study was to quantify the consumption of a representative sample of

buildings in SCE's service territory. Other examples of programs to study the performance of existing buildings are the *End-use Load and Consumer Assessment Program* (ELCAP—see Gillman et al. 1989, Taylor 1992, Taylor and Pratt 1989, Mazzucchi 1987a), PG&E's *Commercial End-Use Metering Project* (Baker and Guliasi 1988, and Kasmar 1989), and Sierra Pacific Power Company's *Energy Information Project* (Wright and Richards 1989).

- *Energy accounting:* Another objective of monitoring is to keep track of energy use and energy expenditures, as the first step in an overall energy-management strategy. The *ASHRAE Handbook of HVAC Systems and Applications* has a chapter on this kind of energy management (ASHRAE 1987b). Particularly when there are several buildings within a complex, or a chain of buildings, it is important to track building consumption over time to identify buildings that require attention and possibly retrofits, and to identify the savings from those retrofits. Many EMCSs carry out energy accounting, while it is most conventionally done by simply tracking utility bills. In carrying out energy management strategies, one should have more detail than can be obtained from utility bills, however. End use information would allow more relevant comparison of buildings, and clearer tracking over time.
- *Utility revenue metering:* One final objective for metering is to provide the basis for billing for energy supplies. Revenue metering is conventionally done with very robust and time-tested meters (EEI 1981). These are manually read about once a month, and bills are based on these readings. With the advent of more complex rate structures, such as time-of-use rates, peak demand charges, real-time pricing, and interruptible rates, however, it would be advantageous to have a more complex meter. It would also be advantageous to have meters that can be read remotely.

Identify Constraints

After defining principal objectives, other related considerations are defined. While objectives describe what is required from the results of the monitoring, these constraints describe what is required throughout the process of monitoring. These constraints may be relevant in different monitoring projects in different proportions, and are described below. The list is based, in part, on two surveys that were performed in recent years to assess the needs for monitoring in utility DSM evaluation and load research projects (EPRI 1989b, and Misuriello and Hopkins 1992).

- *Data quality:* One of the most important considerations made in choosing equipment is how closely the resulting data will represent the factor being measured. Many factors contribute to this: accuracy, precision, resolution, linearity, and reliability. It may also deal with the degree to which the data provide the answer to the research question. The ability to review data as they are collected is another important determinant of data quality. Several early field researchers commented on the need to review data as they are coming in (DeCicco et al. 1986 and Harrje 1982). However, the usefulness of reviewing data in real-time depends entirely on the ability to judge the quality of the data. This requires capabilities for data visualization or a way of determining expected values.
- *Cost:* Costs incurred by a monitoring project can include design, hardware, installation, commissioning, data retrieval, maintenance, and removal of equipment. Depending on the resources and the needs for accuracy, a project may sacrifice accuracy for cost. If use of low cost—but less accurate—equipment enables monitoring of more buildings, this might reduce the overall uncertainty of the result.
- *Time:* Time required for a project also includes several factors: design, installation, commissioning, data retrieval, maintenance, and removal of equipment. Often a monitoring project will require a quick startup. If installation of retrofits is held up in order to collect

pre-retrofit data, there will be significant pressure to install the equipment quickly, and equipment that has to be specially ordered will often not be used. Ease of installation and time required for startup are also important. Labor costs can be minimized by using easy-to-install sensors, thereby minimizing both the time required to install them, and the expertise required in the installation personnel.

- *Ease of use:* The ease of use of monitoring equipment is related to both time and money. Equipment that is simple to install, configure, and maintain will require less time to work with and also require personnel with fewer specialized qualifications. Equipment that is simple to use will also be less prone to errors. Some of the related needs for future monitoring equipment identified by Misuriello and Hopkins (1992) are: pre-defined "field-kits" to monitor common retrofits, proxy measurements that can substitute for harder-to-measure parameters, self-monitoring appliances, "smart" dataloggers that have on-site data processing capabilities, and expert system applications. Good documentation is also important in monitoring equipment. These would all contribute greatly to the ease of implementing monitoring.
- *Impact of building on monitoring:* Sensors and data collection equipment can be modified or damaged by building occupants and operations personnel. This can be either willful destruction or removal of the equipment, or accidental damage to the equipment or data (O'Neal et al. 1992).
- *Impact of monitoring on building:* It may be unacceptable to have any disruption of building occupants, or require any time from the building operations staff. This will depend to a great extent on who is carrying out the monitoring, what interest the building management has in the results in the monitoring, and the relationship between building management and building occupants. The installation of monitoring equipment in a facility may also raise liability concerns. Whenever connecting electrical equipment to building equipment, issues of electrical isolation and interference must be considered. However, if the building equipment experiences problems after monitoring is installed, a monitoring project could face liability claims, even if the monitoring did not cause the problem.
- *Standardization:* In some cases standardization of equipment and procedures is of primary concern. This is particularly true in large projects with many different buildings. Another situation in which this is a primary need is utility and shared-savings programs, where one party must justify to another that savings have occurred. In this case, using standardized equipment and procedures aids in the justification. A related concern is compatibility between equipment and data from other projects.
- *Control:* In all monitoring studies, the person doing the monitoring needs to have control over the data. However, if the equipment resides in another's building, that sense of control could be strained. Tools and methods that maintain the monitoring team's degree of control over the data will be preferable.

Identify Resources

After assessing the constraints of a monitoring project, a careful assessment of resources available for the monitoring project should be carried out. In a project where money is no object, this step could be overlooked, but most projects have a limited budget, and an attempt must be made to make the best use of these resources. Resources will be needed at the start of the project for planning and installation, and throughout the course of the monitoring for the collection and processing of data, and the maintenance of monitoring equipment.

- *Budget:* Financial resources available to a monitoring project can vary greatly. The monitoring budget can sometimes be expressed as dollars per building monitored, dollars per point, or a percentage of retrofit or conservation measure cost. Often, there are limitations on how the monitoring budget can be spent, in terms of capital versus labor costs. The budget for a project should include up-front costs, as well as ongoing costs for data retrieval, analysis, and maintenance.

- *Expertise:* Individuals at or near the site or within the monitoring project who have particular expertise, incentive, and willingness to participate in the monitoring can be a resource in monitoring. An example of this is the monitoring and control system installed at the steam plant at Texas A&M. Because of the availability of highly educated and inexpensive engineering students, much of the system could be custom designed (Heinemeier and Akbari 1993).
- *Connection to site:* An advantageous geographical or organizational connection to site can be beneficial in a monitoring project. An example of this is monitoring of a large engineering building on the Texas A&M campus (Katipamula and Claridge 1992). Access to the building was greatly facilitated by the fact that the monitoring team had their headquarters next door to the studied building.
- *Related projects:* If similar or complementary projects are taking place at the same time, it may be possible to achieve an economy of scale by carrying them out jointly or sequentially. For example, the monitoring carried out for this dissertation was used not only to assess the use of EMCSs for monitoring, but also to provide savings estimates for a shared-savings contract.
- *Equipment owned:* Monitoring equipment already owned by the monitoring team (or available to the team) may be a useful resource in a project. Even if the equipment is not what would have been otherwise chosen, if it is already available, it may be the best choice.
- *Equipment on site:* Equipment already existing at the site, such as an EMCS, computers, sensors, or wiring, might be used in a monitoring project. One example of this is the baseline monitoring that was performed at Lawrence Berkeley Laboratory's Building 62 (LBL 1989). This equipment was left in place after the study. Several years later, it was decided to monitor the building after the retrofit, to estimate savings, and the original CTs were used with a new logger. Another example of this is the Emerald Public Utilities District building, where existing EMCS sensors were used in a monitoring project (Piette et al. 1994).

Identify Approaches

The monitoring approach is a proposed action plan for achieving the monitoring project's objectives. Inputs, outputs and methods should be defined early, although it is common to have to adjust some of these aspects as the project progresses. It is at this point in the process that the channels to be monitored are defined, accuracy requirements are set, and resources are matched to requirements to determine what methods will be used. In some cases, the monitoring approach will be dictated by external forces, for example by protocols for Demand Side Management (DSM) measurement and evaluation (CPUC 1994). In other cases, there is more latitude in the selection of an approach.

- *Experimental Design.* The experimental design is the conceptual plan by which the research question embodied in the project objectives will be answered. Several different experimental designs might be used to answer the research question. Some of the general strategies or experimental designs that could be used are described in detail in ASHRAE (1991), and summarized below:
  - *Before-after:* Data on building or system operation are collected before a conservation measure is installed or energy management strategy is enacted to establish a baseline, and then after to detect the effects of the measure. Other kinds of changes that affect

consumption must also be accounted for, such as weather or changes in occupancy. An example of this approach is the LoanSTAR program, described earlier, and again in Chapter IV. In that program, whenever possible, buildings were monitored both before and after installation of a retrofit (Claridge et al. 1991b).

— *Simulated baseline:* In the case of a new building, there is no period of time before a measure is installed. In cases such as this, the actual performance, or a simulation of a building with the measure can be compared to a simulation of the building without the measures. This can provide detailed estimates for different scenarios, but its accuracy is limited by the accuracy of the simulations. An example of this approach is the Energy Edge program, where each building was simulated, and monitored data were used to calibrate the model. The simulation was then altered to "remove" the retrofits, and the difference represented the estimated savings from the program. Kaplan et al. (1990) and Koran et al. (1992) discuss this use.

— *On-off:* In some cases, it is possible to install a measure, and then collect data both with the measure in operation, and with the measure not in operation. In this way, its effects can be measured directly. The measure must be reversible, and must revert to previous operation when it is turned off. For example, the NAESCO Standard requires this approach for monitoring EMCS savings (NAESCO 1992).

— *Test-reference:* Performance of a test building is compared to that of a similar building that was not affected by the program, used as a control case. This is often used in conjunction with the before-after approach, so that changes in the affected building can be compared with changes in unaffected buildings. The draft monitoring protocols recommended for California utilities fall into this category (CPUC 1994).

— *Nonexperimental reference:* Rather than comparing a building with a particular similar building, here the building is compared with a commonly accepted standard or reference building. This can be a comparison with a compilation of building performance, such as the BECA databases (see, for example, Piette 1986) or the CBECS database (EIA 1993). Alternatively, it can be compared with simulation results for a standardized or prototypical building, subjected to the same weather as the actual building.

- *Analysis Techniques.* Another consideration that must be made in selecting an approach is the degree to which measured data will be relied upon to provide the answer to the research question. To some extent, analysis can sometimes substitute for monitored data, or supplement lower quality data, in approaches such as the following:

— *Non-metered data:* Utility bills, surveys, audits, and reviews of comparison buildings such as the Commercial Building Energy Consumption Survey (CBECS—see EIA 1993) or the Building Energy use Compilation and Analysis (BECA—see, for example, Piette 1986) may supply some of the information that is needed.

— *End-use disaggregation:* Whole building data can be disaggregated using statistical or engineering models. One method for doing this is Conditional Demand Analysis (CDA). In CDA, a multiple-regression is performed on the whole-building energy consumption, using building characteristics and equipment as possible explanatory variables (Parti et al. 1991). This statistical method allows consumption of different end uses to be estimated. Another statistical method is Non-Intrusive Load Monitoring (NILM). NILM takes high-frequency readings of whole-building consumption, and watches for on/off transitions. The magnitude of the transitions, in terms of both real and reactive power, are matched to a list of equipment known to be in the building. Another similar method is the Enduse-Disaggregation Algorithm (EDA), which uses whole-building data and building and equipment characteristics, along with outdoor temperature and humidity data. Regression of whole-building load with temperature suggests the contribution of the thermal conditioning equipment, and the other information about building characteristics leads to estimates of the other end uses (Akbari et al. 1988a). This is a combined statistical/engineering method.

— *Simulation tuning:* While simulations are an important tool for conservation analysis, they are only as good as the input data, which are often difficult to specify completely. By using monitored whole-building or end-use data, or operational data, to check the results of the simulation, the inputs can be adjusted until the output matches the measured data, and then the calibrated model can be used to carry out other types of "what-if" analysis. A prime example of this is the Energy Edge evaluation (Piette et al. 1994).

— *Temperature correlation:* Simple correlations of whole-building or end-use energy consumption with outdoor climate indicators can be useful in estimating savings. This method is used in PRISM (Fels 1986) and in the LoanSTAR program (Kissock et al. 1992). These can be simple linear or change point models.

— *Data visualization:* Much information can be obtained about building operation and energy performance by simply looking at the data in innovative graphic ways. For example, three-dimensional load signatures, demand histograms, correlations with other data, and animation of time-series graphs have all been used to review building consumption data (for example, Belur et al. 1992)

— *Monthly or daily summaries:* Although hourly or 15-minute data are often the norm, many research objectives can be met with analysis of monthly or daily data. For example, PRISM normalization (discussed earlier) requires monthly data, and most analysis in the LoanSTAR program uses daily data.

— *Proxies:* It is sometimes possible to estimate the value of a parameter that is difficult to monitor by measuring a parameter that is easier to monitor. For example one can estimate lighting runtime with a temperature sensor mounted in the fixture rather than monitoring lighting energy consumption; one can estimate fan consumption by monitoring the outgoing speed signal to a VFD; or power can be estimated by measuring current.

- *General Issues.* General issues that must be addressed in selecting an approach are:

— *Degree of quantification:* A project that is designed to quantify energy savings will be very different from one that is simply designed to verify energy savings. The objective of performing quantification imposes constraints on the data quality, while verification may impose constraints on the methods that can be chosen to perform the verification (see Kushler et al. 1992).

— *Degree of intervention:* Some monitoring projects are designed to identify how a building is performing, and others are designed to improve building performance. These are two very different objectives, and may require different methods and different tools.

— *Scale:* When only one or a handful of buildings (usually fewer than about a dozen) are monitored in order to learn something that is applicable to a larger population, the project can be considered a case study. It can be either an indepth investigation of a particular technology or type of building, or a pilot study of a monitoring program that will be more extensive. The budget for these programs, per site, is usually higher than would be possible in a larger project. An example of the use of monitoring in a case study program is the evaluation of the *Energy Edge* design assistance program in the

Pacific Northwest (Piette et al. 1994). In this program, 28 buildings were being monitored to determine how much less they used than they would have used if they had been built without design assistance. This program was a preliminary study that contributed to the design of a larger-scale program.

Large-scale monitoring programs often include a manageable number of buildings: fewer than about fifty. But, in order to obtain enough information to generalize to a large population of buildings, detailed monitoring must be done in each building. In these programs, the budget per building is typically somewhat limited, and the methods for monitoring must be standardized and streamlined. The Energy Edge evaluation project discussed above can be considered a "pilot" project for a much larger program, *Energy Smart Design*. In the Energy Smart Design program, much less detailed monitoring will be carried out, but for a larger number of participants. Baker (1990) discussed the need to carry out large scale programs, and suggested that the appropriate role for more detailed end-use monitoring is as a supplement to class-load data, and Giffin (1994) discussed the way that different levels of monitoring might be applied, and how tradeoffs can be made. EPRI is investigating the use of wireless network of dataloggers for use in monitoring electrical equipment in very large numbers of commercial buildings (EPRI 1993). Very low-level monitoring—for example equipment runtimes—might be used as a statistical link between small-scale, detailed monitoring and more extensive surveys or utility bills.

— *Duration:* Monitoring can include spot measurements (e.g., covering a few seconds or minutes), short-term measurements (e.g., less than a few weeks), medium-term measurements (e.g., up to a year), or long-term measurements (over the lifetime of the building or conservation measure). Monitoring over the long term is difficult, due to the ongoing expense of collecting data and maintaining equipment. However, the persistence of the savings from a measure is an important and often a poorly understood factor. The measurement protocols drafted for California utilities (discussed earlier) require a persistence study, although the type and time of such studies was a source of disagreement (CPUC 1992). The equipment one uses for short-term measurements may be very different from the equipment used for long-term measurements. For example, equipment for short-term measurements will not need to be designed to prevent tampering or fit unobtrusively into a mechanical closet.

— *Number of channels:* Some monitoring projects monitor whole-building energy consumption (electric), and others monitor individual energy end uses in the building. ELCAP, for example, monitored whole-building consumption, along with interior lighting, exterior lighting, hot water, heating, cooling, ventilation, food preparation and refrigeration, and other miscellaneous loads, in 78 buildings in the Pacific Northwest (Taylor and Pratt 1989, and Taylor 1992). The LoanSTAR monitoring program monitored buildings at several different levels, from whole-building data and limited end-use data, to at least 20 channels of data from a building (Claridge et al. 1991b). It is also possible to monitor other channels, such as outdoor air temperature, other climatic data, and physical parameters that characterize the operation of the equipment. Advanced and specialized sensors can also be used, such as vibration sensors to detect the wear on motor bearings, or complex power analyzers to determine not only the amount of power consumed, but also the power factor.

— *Interval:* Data can be collected at extremely short intervals: for example one-second averages of power to identify equipment transients (Norford and Mabey 1992, and Norford et al. 1992). For comparison with utility demand charges, electrical demand is often measured with a 15-minute sliding window. Both 15-minute and hourly-interval data are very common (ELCAP, for example, collected hourly data), and for some studies, daily or monthly data will be most appropriate (for example, PRISM analysis requires monthly data, see Fels 1986). Haberl and Komor (1989) discussed how different intervals of data—from monthly to two-minute—can be used to identify conservation opportunities.

— *Location:* Finally, the location from which the site is monitored can vary. Often the data will be collected at a central monitoring location, over telephone lines, as is done in the LoanSTAR monitoring program. In other cases, the data are collected manually from the site.

Evaluate

After objectives, constraints, and resources have been assessed, and different approaches investigated, the next step is to evaluate the project plan. This will involve several different steps.

- *Prioritize Objectives, Constraints, and Resources:* Often, it is not possible to meet all project objectives, within the constraints and resources of a project. In such cases, one must prioritize. Some will be essential, while others may be simply desirable qualities. For example, a minimum level of accuracy is often an absolute requirement, while any accuracy beyond that will be desirable but not necessary. Or one will want to carry out the project at a minimum cost, but will have no firm requirement for the cost. Tradeoffs must often be made among the constraints: giving up in one category to gain in another. For example, if cost is a constraint, one may be able to substitute labor for hardware, especially if the personnel are available. Or there may be a desire for standardization, but if sufficient personnel is available, routines can be developed to provide a consistent front end. Or having a system that is very easy to use may be more important than having high accuracy, and simple proxy measurements may be chosen.
- *Consider alternatives:* Often evaluation will determine that an approach will not satisfy the project objectives and constraints, or that sufficient resources are not available. In some cases it is possible that by adapting the approach, the constraints can be met with the available resources. For example, the scale of the project might be changed to provide a larger sample, if the accuracy of the measurements at each site will not be sufficient.
- *Evaluate approaches:* The potential approaches should be evaluated. The most important determination to make is the likelihood of being able to answer the research question with the data that will be collected using each approach. If the question remains unanswered, the project resources were wasted. Among approaches that will answer the research question, approaches that will successfully and effectively apply the available resources to meeting the objectives within the constraints should be identified. Any of these approaches can be selected. If none of the approaches will be appropriate, then new approaches should be identified.

3. Conclusions

In order to investigate the application of EMCSs to building monitoring, a method must exist to evaluate the effectiveness of proposed monitoring tools. This chapter outlined existing frameworks that have been used to describe the process of planning a monitoring project. It was found that these frameworks do not provide sufficient detail on equipment selection to be used as a basis for evaluating EMCSs. The existing frameworks did strongly argue for the need to assess objectives before initiating monitoring. This chapter contributes to the field of monitoring by providing an alternative framework for planning monitoring projects. This framework is unique in that it allows comparison of alternative approaches to achieve project objectives, given a set of constraints and resources.

The framework can be applied in a range of monitoring applications, to evaluate very different proposed tools. Later in this dissertation, this framework will be used for the particular case of assessing the EMCS as a potential resource in monitoring for savings evaluation. Assessing its value as a resource, however, is not always straightforward, particularly since it will be used somewhat differently than other conventional monitoring tools. For example, data quality was identified as a constraint for monitoring. But data quality is fairly abstract, and there is a need for greater specificity in defining constraints. There is also a need for methods of assessing the EMCS as a potential resource. Is EMCS monitoring likely to provide high quality data? This is difficult to evaluate simply from the technical discussion in the previous chapter. The evaluation process would be facilitated by construction of guidelines that outline how to identify what is needed of an EMCS for monitoring, and provide methods for assessing what is available in the EMCS. These guidelines will be presented in Chapter V. As a precursor to that, however, several exploratory case studies of EMCS-based monitoring will be carried out.

IV. EXPLORATORY CASE STUDIES OF EMCS MONITORING

Previous chapters reviewed the capabilities of conventional monitoring tools and EMCSs, and provided a framework for assessing the general needs for tools in monitoring projects. This chapter now proposes the EMCS as one of the possible alternatives to dedicated monitoring.

Like any tool, EMCS monitoring has advantages and disadvantages, limitations and strengths, and it can be used most effectively in only a subset of applications. Understanding these characteristics ensures that this tool will be used most effectively. For example, EMCSs are designed primarily for providing information to the on-site building operator, so in some cases remote access may be awkward or impossible, or may require different methods than access to other sorts of dataloggers. In an application where remote access is not essential, this will not cause any problems. In applications where remote access *is* essential, however, the methods would have to be assessed to determine whether they are appropriate for the application.

Thus tool assessment is important, although it can also be somewhat difficult. It may be difficult to tell from reading typical EMCS documentation, for example, how long it would take to download data, or how accurate and reliable the data will be. It is not simply a matter of scanning a technical specification sheet. Methods used to assess EMCSs for monitoring will be different than methods used to assess dataloggers. Chapter II only presented simple technical details, and Chapter III presented needs for tools without sufficient technical specificity. There is still a need for standardized and specific methods of assessing the EMCS as a monitoring tool, and one of the most important contributions of this dissertation is a set of such methods, presented in the next chapter.

Understandably, monitoring professionals have been reluctant to use "untried" or "unproven" methods. Therefore, to show in a systematic way that EMCS monitoring can effectively replace conventional monitoring in some cases would make this method more available to the building monitoring community. The next step in evaluating the use of EMCSs for performance monitoring is to demonstrate that they can, in fact, be used. To guide development of the necessary methods, EMCS-based monitoring was carried out in several case studies to identify crucial issues that could not be anticipated from simply theorizing about EMCS monitoring, and to present them with greater specificity.

In this chapter, eight case studies are presented—in three series—to confirm that EMCS monitoring is possible, to identify the issues that arise in EMCS monitoring, and to determine how EMCS monitoring fits into the framework developed in Chapter III. This chapter identifies and outlines the advantages and disadvantages of EMCS monitoring at each site. It then identifies, categorizes, and refines the issues that were brought up by each site. Only summaries of each study are presented, and the reader is directed to several publications that discuss the studies in much more detail. At the end of this chapter the case studies are evaluated, to determine what they imply about EMCS monitoring. The results of the case studies lead into the next chapter, where they form the basis for guidelines for EMCS monitoring.

1. Remote Third-Party Long-Term Monitoring for Evaluation of Savings

Each monitoring project has its own needs. These needs are specific to the individual project, and it would not be possible to assess EMCSs in detail for all possible projects in this dissertation. It is impossible to provide even general guidelines for monitoring for the entire range of monitoring applications. There is a need for a more bounded focus. The balance of this dissertation will address the specific application of remote monitoring by a third party to determine savings from an HVAC retrofit program or measure. Although the detailed results from the dissertation will focus on this application, the overall results will be more broadly applicable, and the overall evaluation will be discussed again in the final chapter of the dissertation.

The particular application of third-party monitoring for evaluation of energy savings deserves specific attention because it is:

- *Important:* There are strong market forces that could be brought to bear to encourage conservation if it were possible to compare investments in energy efficiency with investments in energy supply. To have enough confidence in those investments, however, it is essential that the benefits be measurable. The ability to measure efficiency benefits is currently a bottleneck in efficiency efforts.
- *Common:* Building performance monitoring is an expanding field, as more utilities are required to carry out rigorous evaluations of program benefits, and larger financial institutions are becoming involved in conservation investments.
- *In a state of flux:* Because of new requirements, and moves towards deregulation in the utility industry, the mechanisms for delivering and evaluating efficiency programs are currently being formed and reformed. This is a time when monitoring tools are being assessed, and new tools are being considered.

The objectives, constraints, resources, and approaches for this monitoring application were touched on briefly in earlier sections, but they are discussed in more detail here.

Objectives:

The primary objective of this application is to collect data that will support analysis in observing and quantifying long-term energy savings from HVAC retrofits in commercial buildings. The fact that it is carried out by a remote third party will have implications for project constraints, resources, and approaches.

Constraints:

- *Data quality:* Because money is riding on what is discovered in the monitoring project, very reliable data will be needed. The typically large scale and the long term of such a monitoring project also imply a need for reliable data.
- *Cost:* Since money is riding on the results of the monitoring, more money may be available for monitoring than in other applications. Often a percentage of retrofit costs, or of realized savings is earmarked for evaluation.
- *Time:* The fact that there is a financial interest implies a need for quick startup, using readily available hardware. Since the objective is usually to observe rather than intervene, the need for immediate feedback of information from the monitoring is not crucial.
- *Ease of use:* Large scale and long term would require either very easy-to-use equipment or staff with considerable monitoring experience.
- *Impact of building:* Since money is riding on the monitoring results, a third party is affecting someone else's equipment, and the building owners will not benefit from the results of the project, there will be a greater concern about the potential to lose data if building operations interfere with monitoring.

- *Impact on building:* Since a third party is affecting someone else's equipment, and the building owners will not benefit from the results of the project, there will be a greater need to minimize intrusiveness, and a greater concern about reliability, and liability. Tools used for this application will have to be more robust than in some other applications.
- *Standardization:* The large scale and long term of such a monitoring project imply a need for standardization. Shared-savings contracts often clearly specify the way in which savings must be demonstrated. This again is a reason to use standardized and well-accepted monitoring tools.
- *Control:* Since money is riding on the results of the monitoring, it will be crucial that the monitoring team maintains control over data collection processes.

Resources:

Some part of the energy savings is often allocated to monitoring effort. In addition to monetary resources, the large scale of the projects may also imply that equipment salvaged from an earlier monitoring effort will be available for this building. On the other hand, since a third party is paying for the project, carrying it out, and benefiting from it, their access to the site will be affected, and it will be more difficult to make use of any equipment already existing at the site, or to intervene in building operation when problems do occur.

Approaches:

The scale of an energy savings evaluation is likely to be large, since the entity carrying out or sponsoring the evaluation is likely to be in the business of providing energy services. The project will probably be long term to address concerns about persistence of savings. Depending on how the monitoring project is structured, it may be impossible to intervene if operational problems are uncovered. For example, if the building is a part of a statistical sample intended to represent other buildings, it would not be appropriate to affect the building performance. However, if the building does not represent other buildings, the third party will have an interest in fixing any problems that become evident throughout the monitoring. There may be constraints on available data analysis methods and monitoring approaches. With the advent of new monitoring techniques and analysis methodologies, however, it should still be possible to consider other methods such as statistical end-use disaggregation, simulation tuning, or proxy measurements, as well as new tools.

2. Methods and Subjects of the Case Studies

With a more focussed application in mind, the next step is to test EMCS monitoring, and to identify issues that arise. The case study approach was chosen because it is impossible to test every possible scenario for EMCS monitoring adequately. It is also exploratory in nature, since it was unknown at the outset what issues are relevant and important for EMCS monitoring for this application. While constraints have been discussed, defining constraints is only the first step in determining the specific characteristics of the hardware and procedures that will be needed for monitoring. The monitoring of a building is a complex process, and it would be impossible to control every variable involved, and to do so in a statistically valid sample of cases. The case study is a well established method of addressing this challenge while investigating complex issues:

> "The need to use case studies arises whenever an empirical inquiry must examine a contemporary phenomenon in its real-life context, especially when the boundaries between phenomenon and context are not clearly evident." (Yin 1981).

The eight case study sites included offices, university buildings, and a department store. Most were campuses, building complexes, or chains. The studies were carried out as three Series, in 1987, 1991, and 1992, respectively. The three series included a range of EMCS models: early systems with centralized processing (Series 1, 1987), more recent systems with a distributed architecture (Series 2, 1991), and state-of-the-art systems (Series 3, 1992). The characteristics of each site are shown in Table IV-1. Some of the sites were chosen because of their participation in energy conservation programs. These studies were not conducted specifically for this dissertation, although each series had objectives very similar to the dissertation's objectives. The research projects and case-study sites are discussed in the following sections.

Series 1

In the first series of case studies, the original objective was to collect and analyze data from buildings to begin to develop methods for disaggregating whole-building load data into end uses, as well as to perform an initial assessment of EMCS monitoring in commercial buildings. In the two California buildings—Levi Plaza Office Complex and Bullocks Department Store— the EMCSs were installed in about 1980 and had a centralized architecture. The existing EMCSs were used to collect whole-building electricity consumption, along with supplementary information such as outdoor temperature, and operational data such as equipment status. The supplementary information was used to perform the disaggregation. For both buildings, data were periodically retrieved from the EMCSs using a remote personal computer that accessed the EMCS over telephone lines and emulated the EMCS terminal. The available data included hourly or 15-minute interval whole-building electrical demand, outdoor air temperature and periodic equipment status or run-time information. In addition, on-site surveys of both buildings were performed. The operational information and on-site surveys were used to create inputs for a simulation model. The buildings were simulated, and the EMCS-monitored consumption and temperature data were used to adjust the simulation results. This was one of the developmental applications of the End-use Disaggregation Algorithm (see Akbari et al. 1988a).

In terms of assessing the use of EMCSs for monitoring, the studies in Series 1 were used to make a preliminary identification of issues. They identified needs for reliability, monitoring of the right points, communications, and storage. This study was sponsored by the Universitywide Energy Research Group, and by the Department of Energy. The sites are described in more detail in Heinemeier et al. (1989), and Heinemeier and Akbari (1987).

Series 2

The second series of case studies involved several buildings in the Texas LoanSTAR Monitoring and Analysis Program. The overall objective of this EMCS study was to evaluate whether or not the EMCSs could be used for monitoring in the LoanSTAR program. The LoanSTAR (Loan to Save Taxes And Resources) Program was a $98.6 million revolving loan fund established by the Texas Governor's Energy Office, with money from Texas' oil overcharge funds (see Claridge et al. 1991b). In this program, loans were made available to fund energy-conservation retrofits in state, public school and local government buildings. In the program, the energy consumption of each loan recipient was measured before and after installation of the retrofit, and savings were estimated after accounting for the effects of weather and changes in operation. Monitoring ranged from whole-building utility billing data to detailed sub-metered data. Many of the sites in the program had EMCSs, and expansion of the EMCS was often one of the retrofit measures included in the loan.

Table IV-1. Characteristics of Case Study Sites.

Site	LEVI	BULL	PVAM	TT	UTSMC	CAP	A&M	COMP
Location	San Francisco, CA	Torrance, CA	Prairie View, TX	Lubbock, TX	Dallas, TX	Austin, TX	College Station, TX	Houston, TX
Site Type	Office Building Complex	Department Store Chain	College Campus	Medical College Campus	Medical College Campus	State Office Building Complex	College Campus	Corporate Headquarters
# of Bldgs. at Site	5	32	46	1	23	42	200	20
Buildings Studied	One Office Building	One Store	One Library Building	One Medical Building	Four Medical Buildings	One Office Building	One Engineering Building	Entire Site
Building Size	332,000 sq. ft.	226,000 sq. ft.	149,000 sq. ft.	811,000 sq. ft.	94,000 - 181,000 sq. ft.	183,000 sq. ft.	324,000 sq.ft.	N/A
EMCS	Staefa, EMS-1	Custom, on IBM	Johnson Controls, JC/85/40	Honeywell, Delta 1000	Landis & Gyr Powers, System 600	Teletrol Integrator 286	Landis & Gyr Powers, Insight AT	Johnson Controls, Metasys
Installation	1980	1980	~1986	~1986	~1986	~1992	~1992	~1992
Number of Points	500 in Complex	N/A	200 on Campus	2000 in Building	6000 on Campus	N/A	>10,000 in Building	N/A
Data Collected	Wh.Bldg. Submet. OAT Runtime	Wh.Bldg. OAT Status Other	Wh.Bldg. CHW HW OAT	Wh.Bldg. CHW HW OAT Other	Wh.Bldg. CHW HW OAT	N/A	N/A	N/A
Monitoring	9/87-10/87	1983-1986	6/91-10/91	N/A	9/90-1/91	N/A	N/A	
Download Frequency	Hourly-Daily Daily	Monthly	Bi-weekly	N/A	Bi-weekly	N/A	N/A	N/A
Data Frequency	Hourly - Monthly	15-minute - Monthly	Hourly	N/A	COV	N/A	N/A	N/A
Analysis Methods	Graphical, Exploratory, Temp. Corr., Simulation, Disaggregation,	Graphical, Exploratory, Temp. Corr., Simulation, Disaggregation,	Graphical Analysis	Graphical Analysis	Graphical Analysis	N/A	N/A	N/A

In this series of field trials, EMCSs at three sites were evaluated to determine if they might be used to collect information for the LoanSTAR savings analysis. These sites were one college campus (Prairie View A&M) and two medical research buildings (Texas Tech--Lubbock and the University of Texas Southwest Medical Center). The EMCSs at these sites were all installed in the mid 1980's, and had a more modern, distributed architecture. The relevant EMCS-monitoring characteristics identified in the previous series of case studies—data measurement, storage, access, and processing—were explored in more detail at each of these sites, and evaluation criteria were developed to provide more detail on what is needed for each characteristic. The study was sponsored by the Texas Governor's Energy Management Center through Texas A&M University, and also by the Department of Energy. More information on these sites can be found in Heinemeier (1993), Heinemeier and Akbari (1992), Heinemeier et al. (1992), and Claridge et al. (1991a).

Series 3

The third series of case studies included three sites. Again, the original objective of this EMCS study was to evaluate whether or not the EMCSs could be used for monitoring in the LoanSTAR program. Two of the sites were related to the LoanSTAR Monitoring Program: the State of Texas Capitol Complex and Texas A&M University. The third site was the Compaq Computer Corporation Headquarters. Although it was not a LoanSTAR retrofit site, it was an interesting contrast to the two other agencies. The EMCSs at these sites were all advanced models, installed in the early 1990's. In this study, the evaluation criteria and issue list developed in the earlier two series of case studies were used to evaluate three additional case-study sites, and to refine and expand the considerations with an eye towards creating the guidelines presented in the next chapter. An additional objective of the series was to investigate the non-technical issues that are often important in EMCS monitoring. To carry out this investigation, the Energy Managers and Maintenance Supervisors at all three sites were interviewed, and the EMCS manufacturers were contacted to obtain as much information as possible about the systems. Discussion of this analysis can be found in Heinemeier and Akbari (1993). Again, this study was sponsored by the Texas Governor's Energy Management Center through Texas A&M University, and also by the Department of Energy. More information on these sites can be found in Heinemeier and Akbari (1993), and in Heinemeier (1993).

Case Study Methods

Similar methods were used at each site in order to obtain information about the building and EMCS, and to assess the capabilities of the EMCS for monitoring. At each site, the person in charge of operating the EMCS was called to make a preliminary assessment of the system. The following questions were asked:

- What is the EMCS model and manufacturer?
- Does the system have a trend or history facility?
- Is there some way to log onto the system remotely, as a VT100 terminal? Is there a modem and telephone line?
- Will the trend facility display collected samples to the screen of the terminal?
- Data should be collected at *(sampling interval)* for *(number of points)* and will be polled *(downloading frequency)*. Will this be possible with the system? Will this interfere with system operation?

If the system looked at all hopeful, a meeting was set up and the following information was requested:

- building or EMCS plans showing the location of sensors of interest;
- sensor, transducer, and analog-to-digital converter documentation;
- documentation on the trend facility, including manual sections on trend point definition, trend report generation, and file transmission;
- the phone number of the EMCS modem, the communications parameters to use in accessing the system (these include baud rate, parity, data bits, and stop bits), a login, and a password.

At a site visit, data collection procedures were discussed and demonstrated, and the facility was toured, including looking at the sensors.

For those buildings where data were collected, the following steps were performed from a remote site:

- Started recording a log file;
- dialed into the modem and logged onto the EMCS, using the login and password provided;
- displayed point definitions for the points of interest, making sure the definitions include engineering units;
- displayed a list of the points that are already setup for trending;
- went through the procedure for defining hourly trend points, trend groups, and trend report (as applicable);
- requested an hourly trend report display or transmission, using a shorthand notation, if available; and
- logged off and stopped recording the log file.

The log file was kept for evaluating transmission time, determining data processing procedures, defining a script for automating access, and as general documentation. Once the procedure for retrieving data was worked out, data were collected, and in some cases analyzed. Often the retrieval procedure was automated. Finally, the process of retrieving the data was evaluated, and the important issues were identified.

3. Case Study Findings

Following are summaries of each of the case studies, indicating what problems and opportunities arose, and what the principal contribution of each study was. After presenting these summaries, the issues brought up in each case study are discussed and evaluated issue by issue.

Levi Plaza Office Building (LEVI)

- A five-building complex with over a million square-feet of offices, restaurants, banks, and computer facilities, located in San Francisco, CA. The EMCS had about 400 points. Energy data available in this EMCS included both whole-building demand, and demand submetered into central-plant and distributed end-uses.
- The computer had access to three disk drives, two of which were used for control, and one to store data. Data storage capacity was not a limiting factor in this EMCS.
- Data were averaged over several different intervals: one could obtain the last 10 minutes of 1-minute averages, hour of 5-minute averages, day of hourly averages, month of daily averages, or year of monthly averages. Because only the most recent day of hourly data were

available, hourly data were downloaded once a day. The data access procedure was automated.

- Although reasonable data were successfully collected, the EMCS-monitored data differed from utility-bill data by a factor of two. The calibration factor on the pulse initiator was incorrect by a factor of two, and all data were corrected after the fact.
- The primary contribution of this work was to suggest that EMCSs may have the capability to automatically store data at several useful intervals, and that sensor calibration is a very important issue.

Bullocks Department Store (BULL)

- A department store chain on the West Coast. Focus was on one 226,000 ft^2 store near Los Angeles, CA. A host computer communicated over phone lines with local computers in each store. Each building was controlled separately but schedules and set points could be changed by the host computer. The monitored data included whole-building demand data and outdoor air temperature.
- The local EMCS averaged data at 15-minute intervals. The 15-minute data were logged for 24 hours, then the host computer downloaded the data from each store to a disk once a day and stored them for a year. The host computer also stored the monthly electrical consumption and peak demand data for all stores for about three years. Data had to be retrieved one day at a time, which was slow. A script file was used to automate the data access procedure.
- To look at the most recent data, the host computer was called, and the host computer called the store to interrogate the local control unit. This process used both of the host computer's phone lines, and the host was then unable to communicate with any other stores for control functions.
- The primary contributions of this work were to suggest that chains may be a particularly hopeful area for EMCS monitoring, although communications are more crucial in this case, and to illustrate that in many cases a great deal of data may have already been collected and archived.

Prairie View A&M University (PVAM)

- A university campus in Texas, with 46 buildings. The EMCS was connected to over 2000 points. All of the buildings were on a central utility electricity meter, and steam and chilled water were circulated to each building from a central plant. The EMCS had a whole-building electric meter and temperature and flow sensors to calculate heating Btu/hour and cooling tons, for each building.
- Host trending had an absolute limit of 200 points, and 3000 samples per point. In RCU trending, the absolute limit was 400 points, and 64 samples per point. Data could be uploaded to the host automatically. Communications paths in this system were fairly loaded, so the real limitation on data storage was due to communications constraints.
- It was only possible to obtain samples of power data, not averages of energy data, and the precision of the data was very low. One could specify the time for trending to begin, and if the host lost power and restarted, it resumed trending normally.
- Remote access was difficult. Trend data could be stored in a disk file, or printed to a printer. However, the disk file could not be automatically transferred to the remote computer, and the trend data could not be displayed on the screen. The access problem was solved by configuring remote computers to act like printers.

- The trend log file was fairly straightforward to process. Ten datapoints per line had to be time- and date-stamped.
- The primary issues identified in this work were communications traffic as a potential data availability concern, and the problem of inability to collect averaged data. It also was a good example of "jury-rigging" a system to be more appropriate for monitoring.

Texas Tech University Health Science Center--Lubbock (TT)

- A large medical research building in Texas, about 811,000 ft^2. The EMCS had 1800-2000 points. The building was split into four mechanical "pods", with one central plant. Each pod had an electric meter and temperature and flow sensors to calculate heating Btu/hour and cooling tons. Weather sensors and condensate meter points were added.
- Data-logging software was installed to allow trending of 999 points. Most data were instantaneous samples, not hourly averages. Data collection began as soon as the trend points were initialized, which may or may not have fallen at the top of the hour. If the host lost power and restarted, data collection restarted immediately, not necessarily at the top of the hour.
- Remote access was difficult. Trend data could be stored in a disk file, or printed to a printer. However, the disk file could not be automatically transferred to the remote computer, and the trend data could not be displayed on the screen. The only solution was to store the data to disk files, and have the EMCS operators move the data files to another computer, and send them electronically via a mainframe network. This transfer had a very high transmission rate, and a very high reliability (error checking and correction). However, the human step was unavoidable.
- The files were stored in a machine-readable "DIF" format. A spreadsheet program was used to translate to a text format. Once in text format, headers and unnecessary information were removed. Some points were reported as accumulating values, so processing included subtracting one value from the next to calculate the hourly change.
- The primary contribution of this work was to identify collecting data at the top of the hour as an important concern. It was also an example of a system not well suited to remote operation, so it suggested the need to consider alternative ways of transferring data.

University of Texas Southwest Medical Center (UTSMC)

- A large medical research center in Dallas, TX. The EMCS had nearly 6000 connected points. All of the buildings were on a central utility electricity meter, and steam and chilled water were circulated to each building from a central plant. In each building, the EMCS had one or two electric meters, and temperature sensors on steam and chilled water lines. However, there were no flow sensors to calculate heating Btu/hour and cooling tons.
- Host trending was capable of recording data for 50 variables. Data were originally acquired by the RCU, but were then immediately transmitted over the local network to be stored by the host computer. Few of the available trend points were being used at the site, so trend capacity was not a problem. Remote trending was similar to Host trending, except that the data were stored in the local memory of the RCU, and transferred to the host computer upon request. The limitation on the amount of collected data derived from the amount of memory available on the RCU. Archiving resembled Host trending, except data were moved to a more permanent disk file once a day. Only this permanent file could be accessed.

- The data reports were defined for a 132-column printer, but the EMCS could display only 80 columns on the screen. Therefore, several columns were truncated and their data were not accessible. Error checking was not possible. Complex user interaction was required, suggesting that automation would be difficult.
- The EMCS used COV (change of value) trending, where the system collected a piece of data only when its value has changed—for example, the time and cumulative energy consumption were recorded when 300 kWh had been consumed. The data had to be translated to an hourly format. Depending on the COV level, this could introduce error. In the buildings where the building consumption during peak hours was less often than the COV level, the time resolution of the data was insufficient to characterize the building demand profile accurately, because data were collected much less than once an hour.
- The EMCS did not send carriage returns at the end of each line. The log file, then, often consisted of several very long lines. The EMCS display included a status line, which was written to the log file whenever the status line was refreshed. Data were not reported in a straightforward columnar format. One could determine the identity of a value only by where it occurred on the line.
- The primary lessons learned at this site had to do with the format of the data report. The combination of several formatting complications made the data very difficult to access. This leads to the desire to create a standardized and simple format. This site also introduced the issue of COV monitoring, which may be an interesting alternative to hourly data collection.

State of Texas Capitol Complex (CAP)

- 42 state buildings in Austin comprised a complex of 5 million square feet. Steam and chilled water were distributed to most of the buildings, and all buildings were maintained by one entity.
- There were several different types of EMCSs in these buildings. A prior system never worked correctly, and was altered to serve as a fire safety system, with a custom-programmed front end. The control room for the EMCSs housed 6 different host computers.
- The newest systems in the buildings, and the system of choice for the operators, was based on standardized PC-AT technology, so it could be easily upgraded as computing technology evolves. The system was programmed in C, allowing the staff greater flexibility in programming.
- Any point could be trended, and stored in a disk file. These trends could be samples, averages, minimums, maximums, or setpoints. Up to 999 samples per point could be stored, with a total of 20,000 samples.
- Some of the capabilities for monitoring were not programmed into the system, but since the system was very flexible, it could be programmed to perform most needed functions, such as ensuring that data are stored at the top of the hour.
- There were several ways to connect to the system, but all required proprietary software.
- The system had a modem, but it was in constant use and was not available for monitoring.
- The energy manager at the complex had drafted EMCS specifications, to ensured that any new systems purchased would have certain capabilities. These specifications ensured most—but not all—monitoring capabilities would be present. In particular, it required that sensors be calibrated and inspected, no more than 10% of inspected sensors could fail inspection, and the system should have remote access capabilities and be able to store up to

5000 samples of data.

- The primary contributions at this site were identification of problems when many different systems were installed at a given facility, and identification of the advantages of flexible programming. There were several ways of connecting, but all required proprietary software.

Texas A&M University (A&M)

- This campus in College Station, TX, had about 200 buildings. It was the home-base of the Energy Systems Laboratory—the group carrying out most of the monitoring and analysis tasks for the LoanSTAR program.
- The campus had several EMCS systems. The principal system was connected to about 25 buildings, and the university had a National Purchase Agreement with that systems vendor, allowing them to purchase that equipment more easily. The system had 230 remote control units, and 11 hosts.
- One of the buildings—an Engineering building—was a LoanSTAR retrofit site, had LoanSTAR monitoring, and also had an EMCS. The EMCS was upgraded as a LoanSTAR retrofit, and the building was converted from dual-duct constant volume to Variable Air Volume.
- The dedicated LoanSTAR equipment monitored many of the same points that were connected to the EMCS. The EMCS had tens of thousands of points in that building alone.
- When LoanSTAR- and EMCS-monitored data were compared, there were several discrepancies. The flow meters for the hot water monitoring were installed in different sections of pipes: one on a recirculating leg, the other on the building input. Thus, they were measuring different things.
- The chilled water flow meter was apparently reporting data as "gallons per minute", although they were actually gallons per hour. When this was changed, there was still a discrepancy, and it was discovered that the LoanSTAR monitoring was using an incorrect calibration constant.
- The whole building power meter on the EMCS was not functioning correctly. When it was replaced, it was always within 10% of the LoanSTAR monitoring.
- The EMCS was capable of trending 50 points, and there was ample capacity.
- Data had to be manually averaged, since it could only average 10 samples together. Data were sampled at 6 second intervals, and 10 samples were averaged to obtain one-minute data. Ten one-minute data averages were averaged to obtain ten-minute averages, and 6 ten-minute averages were averaged to obtain hourly averages.
- Access was difficult, since only one phone line was available, and it would have conflicted with other connections to the system. Since the LoanSTAR monitoring team was located onsite, they installed a hardwired connection between their office and the EMCS.
- The main contributions of this study were the comparison of EMCS and more conventionally monitored data. It is clear that both EMCS data and conventionally monitored data can have problems, and both must be closely scrutinized. Averaging was difficult to implement, but it worked once it was programmed. Conflicts in access were a problem.

Compaq Computer Corporation (COMP)

- This was the headquarters of a large computer manufacturer, located in Houston, TX. The facility consisted of 3.7 million square feet, in 13 administrative buildings, and seven manufacturing buildings. The site had 6500 employees.

- The site had several EMCSs, and was a beta-test site for an advanced model EMCS.
- The advanced model EMCS was being used to collect hourly whole-building energy consumption data in one building, and store them for one year, in a DBase format.
- The new EMCS essentially networked earlier existing EMCS field panels by the same manufacturer, utilizing two different levels of network. The system operated under Microsoft Windows (Microsoft 1991), so it was capable of using Dynamic Data Exchange to allow applications to access data collected by the EMCS in real time.
- 30-minute samples of data were stored for 24 hours for every point in the system. Totals could be saved on an hourly, daily, weekly, or monthly basis, and automatically uploaded.
- The field panels could store any number of points and number of samples. When the memory was full, it automatically uploaded the data to the host computer.
- There had been a problem with a relay in the system. The EMCS showed a heater turning on and off, using a night setback strategy. However, in reality, the relay was stuck closed, and the heater never turned off.
- The major contribution of this work was as an example of a new generation of EMCSs with new operating systems, networking capabilities, and new methods of access. It was also an example of a system where all points were monitored and stored for 24 hours. The problem with the stuck relay pointed out the need to verify outgoing signals before using them for analysis.

4. Analysis and Evaluation

The eight case studies just presented provided insight into the use of EMCSs for remote third-party monitoring for evaluation of energy savings. They brought up many issues that might not otherwise have been considered when attempting to use EMCSs for this application. The following discussion introduces the major categories of issues that were encountered, and evaluates the case studies according to these issues. The major categories and the evaluations are summarized in Table IV-2. These issues are further developed into the form of guidelines in the next chapter.

Data Points

It is important that the EMCS collect the points that are needed for analysis, or points that can provide the same information. All the case study buildings were able to monitor whole building electrical consumption, and all of the multi-building sites were able to monitor whole-building cooling and heating water consumption. Most could monitor outdoor air temperature, and a weather station was added to TT in order to collect more detailed weather information. In addition to these data, all of the sites had access to more information on building and system operation.

Data Accuracy

The data must be of sufficient accuracy, precision, and reliability to support the analysis. Sensor accuracy was not assessed directly in any of these sites. Data precision was a problem for the PVAM power meter. Location of sensors is another important issue related to accuracy, as discovered at A&M. However, once EMCS data problems at the A&M site were resolved, the meters provided data very close to the conventionally metered data. Sensor accuracy and calibration were sometimes problematic issues for conventional monitoring as well as for EMCS monitoring. The stuck relay at COMP indicates the type of reliability problems that can occur.

Table IV-2. Evaluation of EMCS Monitoring Capabilities in Case Studies.

	LEVI	BULL	PVAM	TT	UTSMC	CAP	A&M	COMP
Data Points	+	+	—	—	+	?	+	+
Data Accuracy	?	?	—	?	?	?	+	+
Sensor Calibration	—	?	?	?	?	?	—	?
Data Recording	+	+	+	—	+	+	+	+
Data Averaging	+	+	—	—	+	+	+	+
Data Storage	—	+	—	+	—	+	+	+
Data Format	+	+	+	+	—	+	+	+
Data Time Stamping	+	+	+	—	—	+	+	+
Remote Connection	+	+	+	+	+	+	—	+
Data Transfer	+	+	+	—	+	+	+	+
Simple Process	+	+	+	—	—	+	+	+
Rapid Process	+	—	+	—	—	+	+	+
Error Detection	—	—	—	+	—	+	—	?

+ indicates that the Case Study was successful in this characteristic.

— indicates that the Case Study was not successful in this characteristic.

? indicates that the characteristic is not known for this site.

Sensor Calibration

Even accurate sensors can give incorrect readings if they were not calibrated correctly to begin with, or are not periodically recalibrated. The miscalibration of the demand meter at LEVI and the various sensors at A&M points out the importance of calibrating sensors, or, at least, comparing EMCS values with some reference to determine their accuracy. The specifications for future EMCSs at CAP indicated that sensors must be calibrated, although periodic recalibration was not performed at any of the sites.

Data Recording

The EMCS must have a way of recording historical data. All of the case-study EMCSs had this capability, except TT. With this EMCS, a separate software module had to be purchased to allow monitoring of historical energy consumption data. Once this software was installed, the EMCS was able to record historical data.

Data Averaging

Beyond measuring the appropriate variables, an important consideration in EMCS monitoring is how the values are stored. For example, at LEVI and BULL, the power was averaged over some interval of time. At UTSMC, electricity consumption pulses were constantly totalized to provide a cumulative value. Either of these methods would be sufficient to provide the necessary hourly consumption data. At PVAM and TT, however, only "instantaneous" values of power were recorded, which would be quite inaccurate for reporting hourly energy use. A&M was not originally programmed to calculate averages, but with difficulty, it was reprogrammed and performed well. In addition, the pulse rate on the energy meter at PVAM was too slow to provide very short-interval data accurately. The EMCS at PVAM did have a facility for totalizing values, but it could not easily be integrated with hourly trending. The system at CAP could store averages, minimums, maximums, or samples, and could be programmed to collect basically any kind of data needed. The EMCS at LEVI provided information on the performance of the building from yearly to one-minute intervals. The system at COMP collected 30-minute data on all points in the system.

Data Storage

All of the sites had sufficient trending capacity, at least in theory. In practice, however, both PVAM and UTSMC were limited by communication considerations. Both of these sites had several different ways of collecting data, due to the distributed architecture of the EMCSs. These sites indicated that networking concerns may be more important considerations than raw data storage space or absolute point limits in evaluating the usefulness of an EMCS for monitoring. Also, at some sites, the available trending capacity was more fully utilized than at others, leaving little capacity free for energy data. Availability of the trend capacity is therefore difficult to predict for a particular site by simply knowing the EMCS model. The system at COMP automatically uploaded data whenever the memory filled up, which was an interesting solution to storage problems. The EMCS at LEVI only reported hourly data for the previous day, making it necessary to download data daily. The storage of a year of short-interval (15-minute) demand and temperature data in the EMCS at BULL made daily or even weekly downloading unnecessary, allowing more flexibility in deciding when to download data. The potential to download demand and temperatures for a number of stores in one access would have made this EMCS a convenient monitoring tool, because all the data were in the same format, and time would have been saved in accessing the systems and analyzing the data.

Data Format

Data should be transferred in an easily processed format. The data from TT, LEVI, and BULL were reported in an acceptable format, and only minor processing had to be done, such as parsing the date into day, month, and year; and subtracting cumulative values to obtain hourly values. With the system at PVAM, the log file included a command line, a header, and lines of data samples for each point. The headers had to be removed, a time stamp for each sample had to be calculated, and the data had to be put in columnar form. Data from UTSMC required quite a bit of sophisticated processing, due to several factors: only 80 out of 132 columns of data were displayed, carriage returns were not transmitted, a status line appeared in the middle of the data at any time, the data were not in conventional columnar format, and the data were in COV rather than hourly format. All of these could be dealt with, but when taken together, made data collection quite cumbersome.

Data Time Stamping

In order to be compatible with data from other monitoring projects, other buildings within a project, and weather data, the data available from an EMCS are often required to be reported at regular intervals—often hourly. The EMCSs at PVAM and LEVI were capable of doing this reliably. The EMCS at BULL produced 15-minute data, which could easily be aggregated to provide hourly data. The EMCS at TT could theoretically record data at the top of each hour, although if the system were rebooted, it would not begin collecting at the correct times, so it should be considered unreliable in this sense. The system at CAP could be programmed to provide data at the top of the hour reliably. The EMCS at UTSMC provided data by COV rather than on an hourly schedule. The data could be processed to provide hourly data values at the top of the hour. In buildings where the COV level was set to a fairly low value, little error was introduced (as determined for the reasonableness of the building's load shape). For other buildings, the COV level was set too high to provide a reasonable load shape.

Remote Connection

In many monitoring projects, data must be collected remotely. This requires hardware and software mechanisms in the EMCS to allow connection to the outside world. All case-study EMCSs had such a mechanism. They were not all available for monitoring activities, however. With current systems, there is a potential for energy monitoring to interfere with EMCS control operations, and for control operations to interfere with energy monitoring. The EMCSs at A&M and BULL had outside phone lines, but monitoring use of those phone lines precluded their use by the EMCS manufacturer and remote sites. At BULL and A&M, there were conflicts when EMCS phone lines were used to interrogate remote buildings. An additional phone line and modem in the host computer would have allowed access to the system more often and for longer periods. It is best to have one phone line that is not needed for control, because it is essential that outside monitoring not interfere with control. There was also a potential for problems at PVAM. Once the system was reconfigured to recognize dial-ins as printers, *all* dial-ins were recognized as printers, including operators calling in from home to check on the system, or the regional office calling in to troubleshoot problems. Apparently, this was not a severe problem as there was very little that could not be done with the computer configured as a printer, although the interface was less user-friendly.

Remote Data Transfer

Once a remote connection is made, EMCS software and hardware must allow transfer of the data. All sites except PVAM and TT were immediately capable of remote data transfer, using one of the methods discussed earlier. PVAM required a minor configuration change to allow transfer of the data. The system had to be site-reconfigured. The site personnel did not have the expertise to do this. TT did not allow remote access to the data. The data were stored to the local disk, and another computer had to be used to transfer the data.

Simple Process

When performing case studies, logging onto an EMCS manually to download data was not a problem. However, in a larger-scale evaluation project, a more automated method of data retrieval must be used, and this requires that the process of requesting data be relatively simple. Most communications software packages allow the user to create a script file, which can automatically dial the phone, watch for prompts coming from the EMCS, issue the appropriate responses, and log the session. The EMCS at PVAM was very well suited to this form of automation. After dialing the phone, the script file had only to provide the correct login name, and then issue one-line commands to request the data. Interactions with the EMCS at UTSMC, on the other hand, were more complex. A whole series of questions were asked, and responses had to be provided to request the data. This could potentially be automated, although it would be significantly more complex than at PVAM. At TT, the EMCS operator manually copied the data from one computer to another and then transmitted it over a mainframe network. Since this required a human action on-site, it cannot be considered automated. From the monitoring end, however, the network file transfer procedure could be easily automated. Data collection from both LEVI and BULL was automated with a script file. Although, in each case, the transaction with the EMCS was slightly more complicated than PVAM. No problems occurred with the process. The system at CAP would require the use of proprietary software.

Rapid Process

The amount of time required for transmission of the data is also an important consideration. All of the EMCSs allowed a dial-in connection at 1200 or 2400 baud. However, the speed of the transfer will depend to an even greater extent on the conciseness of the report format, and on whether or not the report is generated as it is being displayed. The data from PVAM were in a very compact form. The data from UTSMC were in a much bulkier report format, which was generated as it was displayed; thus it took quite a bit longer to transmit. The data from TT were in Data Interchange Format (DIF), which is very bulky. However, the transmission from TT took place over a mainframe network at a very high transmission rate. Since the data from BULL were at 15-minute, rather than hourly intervals, there were more data to transfer. Combined with the low transmission rate, it was a very slow process.

Transmission Error Detection

Errors can occur, not only due to faulty or inaccurate sensors, but also when transmitting data from the site. In all sites except TT, data were displayed on the remote computer screen, and simultaneously stored in a log file. No form of error checking took place. At TT, the data were transmitted over a computer network, using a standardized file transfer protocol—FTP. This protocol includes both error checking and correction, so transfer was quite reliable.

5. Conclusions

To create guidelines for EMCS monitoring, more specific information was needed on how the EMCS resource can be applied, and several exploratory case studies were carried out on a well bounded monitoring application. The application was remote, long-term, monitoring by a third party to evaluate the savings of an HVAC retrofit project or program. The needs, resources, and approaches that are typical for this application were outlined.

Eight case studies were carried out, over the course of several years. The case studies established that EMCS-based monitoring is possible. Aside from a few supplemental sensors at one site, no hardware was added at any of the sites. It was, however, inconvenient to use the EMCSs for monitoring in almost every case. Most of the difficulties encountered in these studies were related to easily remedied software problems, and few problems with existing EMCS hardware were encountered. The case studies showed that non-technical or logistical issues often dominate the monitoring process, suggesting that a simple comparison of technical characteristics, such as the comparison made in Chapter II, is an insufficient evaluation.

When the experiences using EMCSs for monitoring at these eight sites were compared, several categories of issues became apparent. While defining these categories of issues is a very important step towards evaluating EMCS monitoring, they are too qualitative to be provide guidance to individuals interested in assessing an EMCS at a particular site for a particular monitoring project.

In a few of the case studies, it took considerable time to discover whether the system would work or not. Sometimes, if a question to an EMCS operator about his or her system's capabilities wasn't asked in exactly the right terms, the correct answer wasn't given. The fact that an EMCS is present at a site does not mean that it can be used for monitoring. Even if one knows that the EMCS model used at a site is the same as one that was used for monitoring at a previous facility, differences in installed options, or in the degree of utilization of the existing capabilities may prevent the system from being used.

Since EMCSs are designed to be highly adaptable, capabilities and monitoring costs often must be evaluated on a site-by-site basis. However, knowing what questions to ask and what the answers mean makes determining a system's capabilities much more straightforward. Having the requirements for monitoring written down and as clearly specified as possible, in the form of guidelines, should help. The issues identified in this chapter will form the basis for the more specific guidelines for EMCS monitoring that are presented in the next chapter.

V. DEFINITION OF GUIDELINES FOR EMCS MONITORING

In Chapter III, a general framework was created to describe the process of planning monitoring projects. This consisted of assessment of the objectives, constraints, resources, and approaches for the project; and evaluation. Chapter IV identified issues that become relevant for the special case of remote EMCS monitoring in support of energy savings evaluation. This chapter integrates the results of the two earlier chapters by adapting the planning framework to the specific application of remote EMCS monitoring for energy savings evaluation. In this adaptation, the steps concerning assessment of constraints and resources are reinterpreted to relate specifically to EMCS monitoring issues. In the previous chapter, the requirements were stated qualitatively. In this chapter, they are expressed again qualitatively, but this time with much greater technical specificity. As the necessary next step in determining specific technical requirements, this chapter identifies the metrics that are used to express the specific technical requirements, and presents methods for assessing whether or not these requirements are met. Even for a very specific monitoring application, however, one cannot specify generically what the constraints will be in all instances, and so one cannot determine what the specific technical requirements will be for all instances. However, it is possible to discuss how the constraints can be translated to very specific technical requirements, and how these requirements can be assessed. These are the goals of the guidelines presented in this chapter.

The guidelines developed in this chapter will allow the monitoring personnel on particular evaluation projects to assess the usefulness of EMCSs in their projects. While specific technical requirements cannot be provided for all possible projects, the guidelines provide guidance on how to determine specific technical requirements, and to assess the resources available in the EMCS. These guidelines will also aid practitioners attempting to use EMCSs—as they are currently configured—for monitoring, to EMCS specifiers who want to make sure that the EMCSs they install will have monitoring capabilities, and to EMCS manufacturers who want to make sure that their next models will be more appropriate for monitoring.

The guidelines are represented as thirteen sets of issues, corresponding to the issues presented in the previous chapter. Guidelines are presented in three categories: data issues, storage issues, and access issues. The issues range from what data are measured to the resulting data format. The guidelines consist of a qualitative description of the technical or logistical requirements for the application of remote monitoring for savings evaluation; ways to improve or supplement capabilities; alternatives or tradeoffs that could be made if requirements are not met; and metrics and methods for assessing whether or not a tool meets the requirements. These guidelines are also presented in Heinemeier and Akbari (1992b).

This is a rapidly evolving technology. Since the contribution here was methods, not results, the contribution should continue to be valid regardless of technological advances, and for a wide range of EMCS sophistication. Note that these guidelines do not necessarily represent the current technology: none of the systems encountered in the case studies in the previous chapter included all of these functions. The guidelines can be thought of rather as a standard for comparison. The fact that a system does not fit these guidelines does not imply that it cannot be used. On the contrary, in most cases, some alternative means of achieving the objective can be worked out. For example, it may be possible to install additional hardware or software to supplement the existing system less expensively than installing an entire monitoring system. Just as the applicability of an EMCS for monitoring must be evaluated on a case-by-case basis, individualized evaluation of the feasibility and costs of supplementing the existing system may be required.

1. Overall Process

Chapter III discussed how objectives, constraints, and resources for monitoring projects are assessed. Equipment already residing at the site was identified as one potential resource, and this is the category under which EMCS monitoring would fall. With conventional dataloggers that are designed specifically for monitoring buildings, the resource assessment step is fairly straightforward: it consists of simply noting the technical specifications of different loggers, and matching them to the capabilities required for the project. With EMCS evaluation, however, reviewing technical specifications is really only the first step in collecting the information needed to assess the resource. This section describes the overall process for collecting information on the EMCS and assessing its use in monitoring.

Collect and Review EMCS Documentation

The first step is to gather all relevant information. Chapter II provided information on a few systems. An earlier review of EMCSs also described the technical characteristics of a more comprehensive list of EMCSs (Akbari et al. 1989). The EMCS manual should be acquired if possible, along with any other technical EMCS documentation that discusses monitoring capabilities as well as methods for collecting data. One must consider that some capabilities may be available, but not installed at the site.

Meet with EMCS Operator and Building Management

Next, talk with the EMCS operator or building management. This would ideally be a face-to-face meeting, at which the objectives of the monitoring are discussed. If the EMCS operator understands the need for the data, and the overall objectives of the project, it will be much easier to obtain assistance later. At this meeting, constraints on access to the building and other limitations such as access to key personnel should be discussed.

The EMCS operator will have to be quite involved in the monitoring, as he or she will be relied upon to:

- provide information on system capabilities and documentation of equipment,
- demonstrate how to carry out monitoring,
- in some cases configure the system to enable monitoring or reconfigure items that are not working, and
- sometimes reset the system if it becomes hung up during a remote access.

To be of assistance, the operator must have three things: the information needed to help, the incentive to help, and the resources to help. Often an EMCS operator does not have detailed information on the system. Most systems are designed to be user friendly, and if the system is working correctly, keeping it running will not require a detailed knowledge of the technical capabilities of the system. However, systems do not always work correctly, and training is an important part of turning an EMCS over to the building staff. The EMCS operator is the most likely source of information. Often it is the building management that has the incentive to perform the monitoring, and the EMCS operator will not benefit significantly from the information. In this case, it will be important that the building management communicate to the EMCS operator why the monitoring is being done, and that it is to the facility's benefit to have more detailed information on operation and energy savings. Often the operator will not have the resources to spend a great deal of time in implementing monitoring. In this case, it will be important that the monitoring team be as unobtrusive as possible.

Meet with EMCS Vendor or Contractor

The EMCS vendor or contractor may also be a good source of information. There will be many functions that are not used at the site, and the EMCS operator may not be aware of them. The vendor should know the details of the site. Also, the vendor should have a better technical understanding of the operation of the system. The vendor, however, may have little incentive and few resources to provide much assistance. If the vendor's assistance is crucial, it may be necessary to purchase some of his or her time. If the site has a service contract with the vendor or contractor, they may be able to ask for the services of the vendor at no cost, particularly if assistance is needed because the EMCS is not working properly.

Tour Site and Obtain Demonstration of EMCS Monitoring

The next step is to visit the site. The meeting with the building management and with the EMCS operator can be held at this time. While visiting the site, it is important to obtain as-built documentation of the EMCS, including plans and documentation on sensors. A list of points used in the system should also be obtained at this time. The site should be toured, and the different sensors should be identified. Also during this visit, the EMCS operator should enable data collection if possible, set it up to monitor the points that are needed, and demonstrate the data-collection facility. Step-by-step instructions should be given on how to access the system and transfer the data, including instructions on how to reset the system if it becomes hung up. The operator should provide a telephone number that can be used for monitoring, login names and passwords needed to access the system, and any necessary instructions on how to avoid interfering with system operation.

Confirm EMCS Monitoring Capabilities

In the course of collecting this information on the system, its capabilities for monitoring must be assessed. The guidelines that follow in the next section provide broad categories of the issues that must be addressed in ensuring that the system will be a suitable monitoring tool. The three categories of issues are Data Issues, Storage Issues, and Access Issues. For each of the issues, several sources of information will be relied upon to determine if the system can meet the requirements. During this assessment, the anticipated cost of carrying out EMCS monitoring will have to be compared with the cost of installing a dedicated monitoring system. EMCS monitoring is likely to require no purchase or installation of additional hardware or software, but it may require more time to assess its capabilities, verify its data, and process its output.

2. Guidelines for EMCS Monitoring: Data Issues

Table V-1 summarizes the guidelines that discuss data issues. The guidelines are presented in more detail below.

Points: Are the physical attributes necessary for analysis measured?

Technical Issues:

For most monitoring projects, the analysis methods clearly define the set of data to be collected. The physical parameters that will provide these data constitute the points that must be measured. In most cases, the sensors used in an EMCS are very similar to those used in dedicated monitoring projects. They can include power transducers or pulse-counting energy meters, as well as temperature, pressure, and humidity sensors. Sensors are installed to meet the building's, and not the monitoring project's objectives. Hence, while certain variables such as whole-building energy consumption are often measured, submetered end-use consumption often is not measured.

Table V-1. Guidelines for EMCS Monitoring: Data Issues.

Specific Issue	Metric	Assessment Methods
Data Points: Are the physical attributes necessary for analysis measured?	List of points that are needed: do they exist?	Obtain a list of points, sensor documentation, EMCS/building plans, tour of building.
Data Accuracy: Is the equipment sufficiently accurate to provide data needed to perform analysis?	End-of-line uncertainty of each needed point, in percent of the minimum value expected, or ± an engineering unit.	Obtain documentation of sensors, transducers, A/D; historically "faulty" points; reality check with current values, data trends, or expected values; inspect sensors; carry out short-term parallel monitoring.
Sensor Calibration: Are sensors in proper calibration?	Difference between sensor and "true" value, in percent of the minimum value expected, or ± an engineering unit, over expected range of values.	Obtain documentation of factory calibration, recalibration efforts; carry out field recalibration.

If the necessary points are not available, it may be possible to monitor a "proxy" for the parameter of interest, rather than monitoring it directly, since EMCSs have access to a great deal of other information on building operation. For example, monitoring on-time rather than submetering load will provide the necessary information to evaluate the performance of a controls retrofit program if loads are constant. As another alternative, if the necessary points are not measured, one might be able to install additional sensors, while making use of existing EMCS networking and data storage capabilities.

For monitoring to calculate energy savings, the most common and important variables to monitor are whole-building and end-use electricity consumption. When analysis includes normalization, parameters such as indicators of operating hours, and outdoor air temperature and other weather variables must be measured. Temperatures and flows are used in calculating cooling or heating loads, necessary to estimate equipment efficiency. Equipment runtimes may confirm operation assumptions that are input to a simulation model.

Relationship to Constraints:

Data quality. A proxy measurement is usually of lesser accuracy than a direct measurement of the parameter of interest. Care should be taken, for example, to ensure that output control signals reliably reflect actual operation. Care must also be taken to ensure that proxy measurements will effectively contribute to answering the research question.

Cost. If no sensors must be installed, the cost of monitoring will be greatly reduced. Adding new sensors to an EMCS may be less expensive than installing sensors in a dedicated monitoring system, since much of the wiring and communications are already present. However, integrating with EMCS hardware and coordinating with EMCS contractors make the process more complex.

Time. If no sensors must be installed, the time required for initiating monitoring will also be greatly reduced. It is possible that data can be collected immediately. Adding new sensors to an EMCS may take less time than installing sensors in a dedicated monitoring system, since much of the wiring and communications are already present. If proxies are measured, one-time measurements will have to be taken to establish the correspondence between the proxy and the value of interest.

Ease of use. If no new sensors are installed, initiation of monitoring will be very simple. If proxies are used, an additional analysis step will be required.

Impact of building on monitoring. Since the EMCS sensors do not belong to the monitoring team, there is a possibility that the building personnel will move or change the sensors without notification. However, if a sensor is damaged, the building personnel will be more likely to know about it if it is used for control than if it is a dedicated monitoring point belonging to the monitoring team. Thus, they would be more likely to bring it to the attention of the monitoring team.

Impact of monitoring on building. If no sensors are installed, the monitoring will intrude less into the operation of the building than if monitoring is dedicated. The ability to install additional sensors will depend on how fully loaded the system already is, and on the willingness of the building management to cooperate.

Standardization. If standardization of monitoring points across buildings is important, then it may not be advisable to use proxy measures, unless they are used in other buildings as well.

Control. If sensors belong to the facility, the monitoring team has less control over changes to them.

Assessment Methods:

The measure of whether or not a system can provide the necessary data is simply whether or not the appropriate points are monitored. In assessing needs, one first prepares a list of necessary and desirable measurements, and potential proxy measurements. Then, the EMCS operator can usually generate a list of all the points (input and output) connected to the system, including their engineering units, and sometimes calibration constants, and sampling frequencies. The lists of needed and available points can then be compared. Documentation of the sensors should be acquired. One should identify the points on EMCS or building plans, and tour the building to determine that the correct sensors are installed in the correct place. If most, but not all, of the points needed for analysis are present, one can investigate installing the necessary points and integrating them with the EMCS. The cost of the sensors and the installation of the points would then be compared with estimates of the cost of installing an entire dedicated monitoring system.

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

Technical Issues:

Data accuracy is a crucial issue in many monitoring projects. While in some projects it may be sufficient to verify equipment operation qualitatively to obtain savings estimates, in many cases much more accuracy is required. Accuracy can be differentiated from issues such as reliability and precision, although the term is used here to refer generically to all the following issues:

- *Accuracy* refers to the expected absolute error between the reported value and the actual value. The accuracy may vary across the operating range of the sensor, and it will often be reported as a percentage of the full scale value (e.g., a temperature sensor with a range of 0-100°F that has a reported accuracy of "±2% FS" may have an error of up to 2°F across its range). This stated accuracy may be a design limit, tested maximum limit, guaranteed maximum, or typical value.
- *Precision* is often used interchangeably with accuracy, although it refers to the scatter of data: a sensor can be very precise—having little scatter—but if it is miscalibrated it will be inaccurate. The reported accuracy figure, then, applies only if the sensor is correctly calibrated and no systematic errors exist.
- *Resolution* is the smallest difference between two readings that can be distinguished. For example, if a watt-hour transducer has a pulse rate such that one pulse equals 1 watt-hour, its resolution is 1 watt-hour, and it will be impossible to measure anything smaller than that. It is particularly an important factor for measurements with digital output.
- *Linearity* refers to the degree to which a sensor's output has a linear relationship to the value being measured. Note that, again, if the sensor is miscalibrated, it may be quite linear, and yet inaccurate.
- *Reliability* is a more subjective factor, reflecting the likelihood of the sensor to provide the expected output. Factors that could affect reliability are mechanical parts that may have a potential to break down, manufacturing quality control, the need for battery backup, and the types of materials and fittings used.

It is important to note that quality assurance is a difficult issue even with dedicated monitoring, particularly in large programs with several monitoring contractors (see, for example, O'Neal et al. 1992, and Halverson et al. 1988). The same kinds of sensors, transducers, and input hardware are available for use in an EMCS as in a dedicated monitoring installation. The same accuracy is therefore possible. The accuracy of the installed sensors is specified by the EMCS contractor, in order to be adequate for control of the building. For those sensors used primarily for control, reasonable accuracy is usually required, and the building personnel should have incentive to monitor whether or not the sensors are providing believable values, since bad data may result in bad building operation and possibly comfort impacts. However, "believability" does not necessarily correspond to "accuracy."

Table II-3 suggested accuracy goals for EMCSs to be used for energy calculations. For monitoring to evaluate savings from energy conservation programs, however, the required accuracy will depend on the method that will be used to evaluate savings. For example, a direct measurement of savings might involve measurement of energy consumption both before and after a retrofit. Or data may be measured to supply inputs to a simulation model. These different approaches will have very different requirements for accuracy. Often, different statistical treatments of the data will impose different requirements for accuracy of individual readings. In general, smaller samples of buildings will require higher accuracy data in individual buildings.

Relationship to Constraints:

Data quality. The accuracy of a measurement influences the accuracy of the results of the analysis. If data quality is a primary concern for the project, special care should be taken to ensure the accuracy of any EMCS measurements.

Cost. There is usually a clear tradeoff made between sensor accuracy and sensor cost: more accurate sensors are usually more expensive. However, since the cost of the sensor is borne by the building management, it is not relevant to the monitoring project. If sensors are installed specifically for the monitoring, however, their cost will be borne by the monitoring project. Since the same sensors would be installed with dedicated monitoring as with the EMCS, this represents no difference.

Time. For EMCS monitoring, most of the time will be required to assess the quality of the data. It could require more time in the case of an existing EMCS than for specification and installation of dedicated sensors.

Ease of use. It is much easier to assess the accuracy of data when the monitoring team installs the sensors themselves, because there is more information about what was actually installed, and how it was installed.

Impact of building on monitoring. Impact of the building operation on monitoring is an important consideration whenever data accuracy is important. If the sensors can be easily tampered with, then data may be lost or compromised. This is a concern for both dedicated and EMCS monitoring.

Impact of monitoring on building. If accuracy concerns necessitate installation of improved sensors, then the intrusiveness of the sensors will become an issue, just as in dedicated monitoring.

Standardization. When savings estimates rely upon statistics involving several buildings, the accuracy of the data in each building will have to be known. If standardization of data accuracy across buildings is important, then it will be more important to assess data accuracy carefully.

Control. Control is a primary concern if data quality is important. The monitoring team will have less control over data quality with an EMCS. Even if sensors are accurate, the team may feel less comfortable about using them than if they had been installed specifically for monitoring.

Assessment Methods:

The measure of accuracy is the accuracy of the reading reported by the EMCS. It should be reported in either ± an engineering unit, or as a percentage of the minimum value expected. The accuracy of sensors, transducers, and analog-to-digital converters all affect the accuracy of the measurement so they must all be considered. The required accuracy will depend on the analysis that will be performed.

This is illustrated in an example of determining required sensor accuracy when the required accuracy of the result is specified. For example, when calculating the savings from nighttime shutoff of a constant speed pump, one might take a one-time measurement (or short-term monitoring) to determine the power drawn when the pump is operating, and monitor pump runtime over a longer period. Power and off hours are shown with their respective uncertainties:

$$\mathrm{kW} \pm \delta\mathrm{kW} \qquad \text{(V-1)}$$

$$\mathrm{offhrs} \pm \delta\mathrm{offhrs} \qquad \text{(V-2)}$$

where δkW is the uncertainty in the kW reading, and δoffhrs is the uncertainty in the hours of operation. The savings is equal to the product of the power and the off-hours. The uncertainty for any such product (or quotient) is found from the following equation:

$$\delta\mathrm{savings}/\mathrm{savings} = \sqrt{(\delta\mathrm{kW}/\mathrm{kW})^2 + (\delta\mathrm{offhrs}/\mathrm{offhrs})^2}. \qquad \text{(V-3)}$$

If the controller has turns the pump off for 16 hours/day during the week, and 24 hours/day during the weekend, it should be off for 5120 hours/month. If pump start-time and stop-time are detected to within five minutes, there will be an uncertainty of ten minutes/day, or five hours/month (0.1%). With a power reading of 10±0.1 kW (1%), the resulting savings is 51,200±500 kWh/month, or about one percent uncertainty.

In another example, the savings from a retrofit might be measured from simple pre- and post-retrofit consumption:

$$\mathrm{kWh}_1 \pm \delta\mathrm{kWh}_1 \qquad \text{(V-4)}$$

$$\mathrm{kWh}_2 \pm \delta\mathrm{kWh}_2 \qquad \text{(V-5)}$$

The savings is the difference between the two, and the uncertainty of any such difference (or sum) is found from the following equation:

$$\delta\mathrm{savings} = \sqrt{(\delta\mathrm{kWh}_1)^2 + (\delta\mathrm{kwh}_2)^2} \qquad \text{(V-6)}$$

For example, if the pre-retrofit consumption is 5000 kWh, with a five percent uncertainty of 250 kWh; and the post-retrofit consumption is 4000 kWh with a two percent uncertainty of 80 kWh; the savings will be 1000±262 kWh, for a resulting uncertainty of 26%. The "Measurement and Instrumentation" chapter in the *ASHRAE Handbook of Fundamentals* also provides information on sensor accuracy considerations (ASHRAE 1989).

Documentation of as-built accuracy should be available from the EMCS operator. The operator can also be asked which points are known to be faulty. Next, a reality check should be performed: look at current values, or any data trends and judge whether they make sense. Are they changing when they should be? Is the magnitude roughly what can be expected given the type and size of equipment in the building? Given the values of other variables, does the value make sense? For many variables—for example, zone temperatures, or whole-building annual energy intensity—it will not be difficult to determine if the readings are in the right range. For other variables, however, it would take much more specialized knowledge about the building to make this kind of assessment. Perhaps other EMCS data can be used to confirm the value. For example, if a flow sensor is showing a negligible flow, it may be a sensor error, but if the VFD speed control shows a very low speed, or if the fan on/off status point is showing that the fan is off, it may be correct.

If possible, the sensors themselves should be inspected: are they the same sensors (type and size) specified in the plans? Are they installed in the proper location? Are the wires connected? Are they obviously damaged? Not all sensor problems would be detected by such an inspection, and it may be impossible to inspect some sensors that are embedded in equipment, but some problems might be identified in this way.

For any points that may be suspect, or any crucial points, it may be advisable to perform short term monitoring in parallel to the EMCS monitoring. This might consist of taking one-time or very short-term readings of the value. Or it might consist of installing a sensor and portable data logger for a short period of time.

Sensor Calibration: Are sensors in proper calibration?

Technical Issues:

It is often not enough to have accurate sensors: sensors must be in good calibration when they are first installed, and the calibration must be maintained. Since this is not always done with EMCSs, and calibration documentation is often not available, it is sometimes necessary perform field calibration, or at least to compare EMCS values with some reference to determine their accuracy. For example, utility bills or readings from hand-held instrumentation can be used in this comparison.

Sensor calibration is especially important when data accuracy is not crucial to the operation of the building. In these cases, the building managers may not have incentive to double-check values or replace a sensor that is known to provide false values. In one of the case studies in Chapter IV, an electrical meter was miscalibrated by a factor of two. Since building personnel were only interested in changes from day to day, and not in the absolute value, they had never discovered the problem.

Calibration is particularly important for energy savings calculations, since they often involve comparisons between two different sensors at one time (for example, a differential temperature calculation), or one sensor over time (for example, the change in energy consumption before and after a retrofit). Since differences are often directly translated to savings estimates, calibration is often one of the primary issues in monitoring for energy savings calculations.

Relationship to Constraints:

Data quality. Calibration is as important to data quality as is sensor accuracy. The calibration of all essential sensors should be checked. When carrying out field calibration, it is important that data are collected over the expected range of values.

Cost. The cost of sensor validation must be figured into the total program cost whether dedicated or EMCS-based monitoring is being performed. Recalibration of sensors may be more expensive than initial calibration, since access to the sensors can be difficult.

Time. Recalibration of sensors is may also require more time than initial calibration, since access to the sensors can be difficult.

Ease of use. If documentation of sensor calibration is available and sufficient, recalibration may not be needed, and verifying data will be much simpler.

Impact of building on monitoring. Calibration factors can, intentionally or unintentionally, be changed by EMCS operators.

Impact of monitoring on building. Since calibration is important for controlling the building, the EMCS operator might be willing to participate in calibration efforts.

Standardization. Often, a monitoring program will have standard calibration procedures. These should be used, if at all possible, on the EMCS sensors.

Control. Since calibration factors can be changed by the building personnel, and access to sensors can be difficult, the monitoring team is likely to have little control over calibration.

Assessment Methods:

The measure of calibration is the same as the measure of accuracy: the error in a reading, expressed either ± an engineering unit, or as a percentage of the minimum value expected. While calibration should be checked over the entire range of expected values, the greatest percentage error will occur when the value is the lowest. Some sensors are calibrated at the factory, and their calibration factors are supplied in the product literature. Generic thermocouple calibration tables are also available for different types of thermocouples. Some other sensors must be recalibrated in the field. This can be done by comparing the sensor output with a known reference sensor, and adjusting calibration factors until they agree well, over a wide range of values. As an example of recalibration efforts, the LoanSTAR monitoring program operates their own calibration laboratory to ensure that the sensors are reading correct values (see, for example, Bryant and O'Neal 1992, O'Neal et al. 1990, Robinson et al. 1992, and Turner et al. 1992). If many similar sensors are used, a sample of the sensors can be calibrated. One might not need to calibrate all sensors if an acceptable percentage are still in calibration.

Many types of sensors should be periodically recalibrated. The frequency with which sensors should be recalibrated depends on the type of sensor. Sensors that are open to the environment, and sensors that include mechanical parts are particularly in need of periodic recalibration: especially flowmeters, dewpoint sensors, and static pressure sensors. For example, it has been recommended that relative humidity sensors be recalibrated at least every six months (Bryant and O'Neal 1992). The EMCS operator should have access either to information on factory calibration of sensors, or to documentation of subsequent recalibration.

3. Guidelines for EMCS Monitoring: Storage Issues

Table V-2 summarizes the guidelines that relate to storage issues. These guidelines are discussed in more detail below.

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

Technical Issues:

To be useful for monitoring in any application, an EMCS must be capable of recording data. Most EMCS models have this capability. The current value of all EMCS points is usually available for immediate use in control applications, (for example in a calculation to determine if more cooling is required), and these data can often be stored for further analysis. Because of the usefulness of historical data for building operation, most EMCSs have a facility for storing large amounts of data, often called "trending."

In a monitoring tool for calculating energy savings, as in any other monitoring project, the ability to store data is an absolute requirement. If a particular EMCS does not have storage capability, it is possible that the necessary software is available from the manufacturer, but has not been installed at the site. In that case, the software could be added. Since operators are working with

Table V-2. Guidelines for EMCS Monitoring: Storage Issues.

Specific Issue	Metric	Assessment Methods
Data Recording: Do software and hardware permit recording of historical data?	Existence of a function for recording data to memory or disk. Requirement to share data space with building operations.	Description in manual of history facility; discussion with EMCS operator; demonstration.
Data Averaging: Are historical data recorded at intervals appropriate for analysis?	Existence of averaging, instantaneous, and totalized data; interval at which data can be provided.	Description in manual of data processing; discussion with EMCS operator; demonstration; engineering units in reports; documentation of sensor types.
Data Storage: Does the system have an available data storage capacity sufficient for monitoring applications?	Amount of memory or disk space needed for storing data for the number of days, points, and intervals that will be used.	Documentation of maximum number of points, or samples per point, memory capacity, disk space; discussion with EMCS operator about amount of capacity that is available; short-term assessment.
Data Format: Are data available in an easily processed format?	ASCII or binary data; data are in rows or columns; column separation; all data in one file; existence of headers; text in quotes; coding of missing values.	Description in manual of history facility; demonstration with a sample collected report.
Time Stamping: Does the system record the time 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?	Data are recorded at specific times; format is unambiguous.	Description in manual of history facility; demonstration with sample data; trend point definition; specification of time to begin collection.

the same data space, it is possible for them intentionally or unintentionally to delete or reset trend data. It is important that the EMCS operators are kept up-to-date on data-collection activities. The amount of attention that they can spend on monitoring will depend on what the relationship is between the building and the monitoring. If the building has some interest in what the data show, they will be more apt to provide assistance. In the case of third-party monitoring, where the outside party is billing the building for energy savings, the building has an interest in making sure that the savings estimates are correct. However, it is the management and not the operator that usually has this interest, so it is important to keep in direct communication with the operator. One way of accomplishing this is to provide feedback to the operators (for example, by circulating plots of the data) to allow them to see what has been collected and its usefulness.

Relationship to Constraints:

Data quality. If the EMCS cannot collect data, data will not be available for analysis. If the data space is shared, the quality of the data may be affected.

Cost. Monitoring with an EMCS may be much less expensive than installing dedicated monitoring. If any software must be added, however, the cost will likely have to be borne by the monitoring project.

Time. If monitoring capabilities exist, then monitoring can be initiated fairly quickly. If data monitoring capabilities must be supplemented, it may take time to obtain the necessary software and/or hardware, to install it, and to learn to use it.

Ease of use. If monitoring capabilities exist, it will be much simpler to begin collecting data. The collection procedures, however, may be more or less easy to use than a dedicated monitoring system, depending on how user-friendly the software was designed to be.

Impact of building on monitoring. If software or hardware are added, they may be less likely to be tampered with than EMCS software or hardware installed for the building's needs. If the data storage area is shared, there is a potential for loss of data.

Impact of monitoring on building. If software or hardware are added, care will have to be taken to ensure that the EMCS continues to operate correctly.

Standardization. Standardization in data collection will be a factor only as it relates to issues such as data format and access procedures, which are discussed later.

Control. If the data collection hardware and software are not owned by the monitoring team, there will be less control over the data collection process.

Assessment Methods:

The metrics here are the existence or absence of a method for recording data to system memory or the disk, and whether or not the data storage area is shared by building operation activities. For most applications, it is essential that data can be collected by the EMCS. The need for security of the data should be carefully assessed. The EMCS operator should know if the EMCS has a facility for trending, archiving, or collecting historical data. Copies of manual pages summarizing the trend facility may be required to determine if it is really applicable. For example, some trending programs only allow graphs of trended data to be displayed, but one has no access to the data proper. The procedure for displaying or transmitting trend data should be demonstrated.

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

Technical Issues:

The analysis tool used will determine the time step needed for data collection. In addition to allowing the user (e.g., the EMCS operator or monitoring team) to select the data interval, it is important to know whether the data are instantaneous "snapshots," averages, totals, or maximums.

Many monitoring projects use 15-minute or hourly interval data. Many others, however, use much longer or shorter intervals. For example, savings estimation using the Princeton Scorekeeping Method (PRISM) require monthly data (Fels 1986). Load signature analysis carried out for diagnostics would require intervals as short as fractions of a second (Norford and Mabey 1992 and Norford et al. 1992). Using daily data can enable the detection of overall trends that are difficult to detect in all the fluctuations of hourly data, but if the fluctuations are of interest, they would be masked in the daily data.

For variables that are slowly and smoothly varying, such as outdoor air temperature, it might be acceptable to take a sample of the value once an hour. Short-interval samples might suffice to characterize some variables that are varying more. For example, five-minute samples of a variable such as fan power may be sufficient to define rough demand profiles.

However, for quickly changing variables or those requiring more precise characterization—for example, equipment that has a duty cycle and turns on and off several times throughout a day, or equipment with large power spikes on startup—it may be necessary to collect averaged data. If a snapshot were taken at the time of a power spike, for example, interpretation of the data would incorrectly imply that that was the demand throughout a larger interval. Alternatively, if one wants to understand the peak values of a variable, one would want to monitor the maximum value over the interval.

Other variables require totals. Any variable in which a flow is measured, but an accumulated value is the desired quantity to characterize, will require some form of integration. Energy, water consumption, and runtime are examples of these types of variables.

Some systems allow data to be collected in any of the above-mentioned methods, but one method must be chosen for all data points. It is not possible in these systems, for example, to collect hourly temperature averages as well as hourly samples of cumulative electrical energy consumption. Averages, totals, and maximums can often be calculated in the EMCS software, if the system does not allow for this type of automatic data processing. This will require sampling and storing high frequency data.

Averaging is a particularly important issue for electrical energy monitoring in savings evaluations. There are several ways to measure electrical power and energy consumption. One method uses a pulse counter installed on a utility kWh meter or watt-hour transducer. Each pulse corresponds to a certain amount of energy. The EMCS accumulates pulses--or kWh--and reports cumulative energy: in a time series, one reading is subtracted from the next to determine the total energy consumed over that period. These data should be sampled, and not averaged or totaled, because the cumulative value at the end of an hour corresponds to the amount of energy consumed during that hour. There are two ways to report this: measuring the time for a given number of pulses, or measuring the number of pulses in a given amount of time. The former is referred to as COV monitoring. COV monitoring has the characteristic that when the value is changing quickly, very short interval data are collected; and when the value is changing very little, very long interval data are collected. COV monitoring was discussed in greater detail in Chapter II. In another method for measuring energy, power is measured directly using a watt-transducer, and an analog signal, proportional to the instantaneous power, is read by the EMCS. This instantaneous power must be averaged to be used for energy analysis.

Again, the format of the data must match the savings analysis technique used, or an alternative analysis technique must be selected.

Relationship to Constraints:

Data quality. If only instantaneous snapshots of data values are available, accurate estimates of averages over a period will be difficult or impossible to obtain. Any calculated averages should be accompanied by an indicator of whether or not of the data during the averaging interval were missing.

Cost. Averaging should have no effect on monitoring cost.

Time. If average values must be calculated in the EMCS software, it will take some time to program the EMCS and ensure that it is calculating the averages correctly.

Ease of use. Averaging may be available at the most common intervals, but if average values must be calculated in the EMCS software, it will take effort to program and test the averaging routines. This will require learning a fair amount about how the EMCS is programmed, or significant assistance from building personnel.

Impact of building on monitoring. Averaging should not change the impact that building operations have on monitoring.

Impact of monitoring on building. If the EMCS must be programmed to calculate averages, one must ensure that the increased computation does not adversely affect EMCS operations. If the EMCS can only implement one averaging or totalization technique at a time, then any change for monitoring may also affect data collection for the building's use.

Standardization. The need for averaged data will be driven to a great extent by the need for standardization among buildings. COV data collection may not be appropriate if there is a strong need for standardization among buildings.

Control. The monitoring team will want to be able to select averaging techniques to suit their needs, and an inability to do so will result in loss of control over the process.

Assessment Methods:

The measures of data averaging capabilities are the existence or absence of averaging or totalizing functions, and the interval at which data can be provided. The EMCS manual's discussion of trending should indicate whether or not there are averaging or totalizing functions. Information obtained during the demonstration will also contribute to this determination: what are the engineering units in which the data are expressed? Is there mention of averaging during the transaction to request historical data? The EMCS operator may also help in making this determination. The type of sensors used may indicate whether or not averaging is needed. Data measured with a watt transducer will have to be averaged, while those from a watt-hour transducer with a pulse counting output will not. It is important to find out whether different points can be averaged in different ways, or whether one averaging method must be used for all trended points.

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

Technical Issues:

Before data are downloaded to the remote computer, they will be stored for some period of time on-site, and there must be sufficient storage capacity to hold all the data. If there is not enough storage capacity, one alternative is to purchase more memory. Or, it may be that there is enough space on a temporary basis for short term monitoring. It may also be possible to download the data more frequently, or collect data at a larger recording interval, so that fewer data are stored. Alternatively, it may be possible to install an additional computer in the EMCS network to collect the data.

The required storage capacity will depend on how much data will be collected. This, in turn, will depend on the number of points to be monitored, the precision of the points, the frequency of sampling, the frequency of downloading, the amount of uncertainty in the downloading frequency, and the need to permanently archive data. For a monitoring project to calculate savings, one might monitor several energy channels (including whole-building electric), several weather variables, and state variables for several different systems (e.g., supply and return temperatures and flowrates for a chiller). For example, if averages on twenty variables are collected, hourly data are downloaded once a week (but sometimes it may be up to 8 days between downloads), and the data require six bytes of memory for each value, about 23 kilobytes of storage will be required (20×24×8×6), depending on the structure of the file. Many savings evaluation projects collect large amounts of hourly data, and storage is a primary consideration.

Relationship to Constraints:

Data quality. Data can be lost due to memory overflow. There can be a tradeoff between the precision of the data (i.e., the number of significant digits recorded) and storage space. With COV monitoring, a relatively high COV level will result in a smaller amount of data collected—except at times of rapid change—although it will result in reduced accuracy.

Cost. The cost of an additional computer may, in some cases, make EMCS monitoring more expensive than dedicated monitoring. Usually, however, a fairly unsophisticated computer can be used for this purpose. This might be "last year's model," which can often be purchased quite inexpensively.

Time. If data must be downloaded more frequently due to storage considerations, then time required for monitoring will be affected.

Ease of use. Ease of monitoring will also be affected if data must be downloaded more frequently due to storage considerations.

Impact of building on monitoring. Data collected for building or EMCS purposes can encroach upon data collected for monitoring purposes. This can either be done explicitly by the EMCS personnel, or it can be done automatically if data storage space fills up.

Impact of monitoring on building. Similarly, data collected for monitoring purposes may encroach upon data collected for building or EMCS purposes. With a distributed architecture, information being trended for energy monitoring is traveling along the network paths as other EMCS information. One must consider both the impact of energy monitoring traffic on other operations, and the impact of the other operations on energy monitoring.

Standardization. The need for standardization may result in less latitude in selecting downloading frequencies and data precision, which may be affected by storage capacity considerations.

Control. Sharing data storage space with other EMCS uses could result in a loss of control over data.

Assessment Methods:

The measure of amount of storage is the amount of memory or disk space needed for storing data for the number of days, points, and intervals that will be used in the monitoring.

Most systems have sufficient storage capacity for this, at least in theory. Capacity can be broken down into three related issues: memory, disk space, and communications. Many systems have an absolute number of points that can be trended, the maximum number of samples that can be stored per point, or the total memory capacity that is available to trend data. In addition to knowing these limits, one must ascertain how much of the total capacity is available. Some of the slots will be used for the building control operations. Disk space is seldom a limitation on EMCSs with a host computer, but again available capacity must be ascertained.

In practice, many systems are limited more by communication considerations than storage space. Many EMCSs have a distributed architecture with networked remote control units (RCUs) and the ability for a host computer to be connected in the network. Data can either be stored on the RCU, on the host computer, or on the host's peripheral data storage medium (hard or floppy disk or magnetic tape for longer term storage). In these systems, networking concerns may be more important considerations than raw data storage space or absolute point limits in evaluating the usefulness of an EMCS for monitoring.

Some systems have absolute limits on the number of points that can be trended, or the number of samples that can be saved. This can be found from manual descriptions of the trending facility. The number of points already being trended for building operation activities should be determined from the EMCS operator. In terms of overall storage space, the amount of space that will be occupied by the expected data should be estimated. Then, one should find out where the data will be stored: are they stored on the host disk, on a controller's memory, or on an archive medium such as magnetic tape? Then, the amount of space generally available for stored data, and the currently available capacity should both be determined. Availability of the trend capacity is difficult to predict for a particular site by simply knowing the EMCS model. Even when investigating the system more closely, it is sometimes difficult to ascertain capacity. The EMCS operator or vendor will have a sense of how fully loaded the system is. If they are close to their limits in terms of memory, disk space, or communications throughput, they will probably be aware of it, as it has probably been causing problems. And the only sure way to know that there is enough capacity for monitoring is to start monitoring, and for at least the first few weeks, keep very close contact with the EMCS operators to find out if problems are occurring.

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

Technical Issues:

After retrieving a data file, a preprocessing step is required to put the data into a format that can be used for analysis. The original file formats will vary widely, and can be important determinants of the suitability of an EMCS for monitoring.

For many energy conservation programs, specialized computer tools and programmers are not available, and often spreadsheet programs are used for data analysis. It is then highly desirable to have a format that is designed to be read by a computer, and not by a person. Many EMCSs have formats designed to be imported to spreadsheets, and can also be read by other programs such as AWK (a common UNIX facility for data processing based on pattern recognition—see Aho et al. 1988). Another consideration is how often data must be processed, and how much data will be collected.

The ideal format would be an ASCII file with one column for each point, and no header information. A separate file should be available to indicate engineering units and which channels correspond to which variables. Each line in the data file should be time- and date-stamped. Columns should be separated by spaces, commas, or tabs. If possible, lines should not be longer than 80 characters. Any non-numeric characters should be in quotes. Missing data should be identified as missing, not blank or zero. Finally, each line should be concluded with a carriage-return. While none of these are hard and fast requirements, they greatly facilitate processing.

Some additional types of processing that may have to be done are: parsing the date into day, month, and year; parsing the time into hour, minute, and second; subtracting cumulative values to obtain differences (and marking the intervals during which the counter was reset as unreliable); removing the login, command line, and header lines from the log file; calculating the time for each sample, if only the beginning time and sampling interval are known; and transposing the data from rows to columns.

Some of the problems encountered in the case studies were that only the first 80 characters of a 132 character line displayed, carriage returns were not transmitted, a status line appeared periodically in the middle of the data, the data were not in conventional columnar format, the data were in COV rather than hourly format, missing data were blank, and numeric and alphanumeric data were mixed. All of these could be dealt with, but when taken together, made data collection quite cumbersome.

Relationship to Constraints:

Data quality. If data files must be processed to extract data, then any idiosyncracies in the data file format may potentially result in incorrect translation of data.

Cost. If data file processing is complex, a programmer may be required to create a robust translation procedure.

Time. Time will be required either to "massage" data into the appropriate format as they are collected, or to set up and run a robust processing procedure.

Ease of use. For small data files, it may not be difficult for someone reasonably proficient in editing to reformat the data manually. For larger files, or if data are coming in frequently over a long period of time, manual processing is not feasible, and a robust automated method should be devised. The size of the file may also make methods such as spreadsheet macros cumbersome.

Impact of building on monitoring. Data file format should not change the impact that building operations have on monitoring.

Impact of monitoring on building. Data file format should not change the impact that monitoring has on building operations, either.

Standardization. Particularly for large programs, it is advantageous to have only one data-processing routine. If several different file formats are used, from several different EMCSs, the processing task may become unmanageable.

Control. Many monitoring teams may want to define a file format useful for their needs, and this format may not be available from the EMCS.

Assessment Methods:

There are several metrics for appropriate file formats: whether or not data are in an ASCII or binary format; whether different points constitute different rows or columns; whether all the data are collected in one file; whether values are separated by spaces, commas, tabs, or at all; whether headers are used; whether text values are in quotes; and how missing values are coded. The data format should be shown in the EMCS manual, or a printout or diskette file from the demonstration can be kept. If the format is not appropriate, alternative formats are sometimes available. Sometimes trend data are available in a "spreadsheet compatible" format, which is easily imported into a spreadsheet program, and can easily be processed. Another important issues is how predictable the file format is. Even a complex file format can be processed, so long as it is quite predictable. It will be much more complex, however, to process data files that change in format over time and have random, spurious information included at different times.

Time Stamping: Does the system record the time 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?

Technical Issues:

The data time interval must be selected in order to be appropriate for the intended analysis. In addition to having the correct interval, often the data must be collected at certain times. Many EMCSs are reportedly capable of recording hourly data. However, in some cases, if the system is rebooted, the data collection time may shift to the time when the system was rebooted. If the system collects data at specified intervals rather than at specified times, the data must be checked, and if the trend has shifted, it must be reset.

In energy savings analysis, hourly data are often quite important. For example, often hourly consumption data will be matched with hourly weather data from a weather service, or hourly status data from the EMCS. This is difficult to do when the hourly data are recorded at thirteen minutes past the hour. Or a logger may collect data at odd intervals such as 16 minutes, which cannot easily be integrated into an hourly value. Another example of the need for coincident data is the matching of monthly energy bills with monthly degree-day data in PRISM to normalize consumption estimates. Energy bills typically cover roughly a month of consumption, although there is no guarantee that the month will start at the beginning of the calendar month, as the weather data will. If the requirement is to characterize load shapes, however, data such as COV may be sufficient.

There are several different formats for timestamping data, and most of them can be used in monitoring. The primary consideration, however, is that it must be unambiguous: it must be clear what period of time a piece of data corresponds to. For example, if an hourly average was collected at "Hour 1," this could either correspond to the hour between midnight and 1:00 am, or that between 1:00 am and 2:00 am. It could also be confused with 1:00 pm.

Relationship to Constraints:

Data quality. If the time for data collection slips, it will become difficult to relate the data to other supposedly coincident data. If the timestamp is ambiguous, misinterpretation of data is possible.

Cost. Checking data constantly to ensure that the time for data collection has not slipped will require additional processing time, and therefore additional costs.

Time. Checking data constantly to ensure that the time for data collection has not slipped will require additional processing time. Resetting the EMCS data collection will require either detailed knowledge of EMCS programming, or assistance from the EMCS operator.

Ease of use. The additional processing step of checking data constantly to ensure that the time for data collection has not slipped will make the system less easy to use.

Impact of building on monitoring. The collection of data at incorrect times is an example of ways in which building and EMCS operations affect monitoring.

Impact of monitoring on building. Time stamping should not change the impact that monitoring has on building operations.

Standardization. The format for the timestamp must be unambiguous, and it should be consistent from site to site.

Control. Since the monitoring team does not have control over when the EMCS is functioning correctly or malfunctioning, there will be a loss of control over the data.

Assessment Methods:

The metrics for time format are whether or not data are recorded at specific times; whether data format is unambiguous; and a clear definition of whether the hour number refers to the hour before or after the top of the hour. Much of this can be determined from the manual, and from a demonstration of the data collection capabilities and a sample demonstration session. One can tell if the system will reliably collect data at the correct times by looking at how the trend point was defined. If it does not ask for the time to begin collection, or if it does not imply that data will be available at the top of the hour, it might collect data as soon as it is enabled. Another method is to look at some collected hourly data. If the data are recorded at strange times, (for example, at 13 minutes after each hour) it has probably shifted. If the EMCS has battery backup, it will be less likely to become reset.

4. Guidelines for EMCS Monitoring: Access Issues

Table V-3 summarizes the guidelines that address access issues. These guidelines are also described in more detail below.

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

Technical Issues:

For remote monitoring, there must be some way to retrieve data from the site. In some cases, it is possible to retrieve collected data manually. For example, if the monitored site is physically close to the intended destination of the data, it may be possible to periodically visit and collect data from the EMCS. In many cases, however, manual collection of the data is not feasible. In order to access the data remotely, one can make use of the fact that most EMCSs allow for a remote computer to be tied into the system's network. If it is not possible to connect to the host computer, it may be possible to connect through an RCU. If there is no way to connect to the EMCS remotely, it may suffice to visit the site periodically and collect the data on a diskette, or to have the operator do this and mail the diskette. Another alternative is to take advantage of the existing EMCS sensors, while installing additional wiring and dataloggers. One might also be able to take advantage of the EMCS networking capabilities, and collect data throughout the building using a datalogger taking its input from the analog outputs of one centralized EMCS.

Table V-3. Guidelines for EMCS Monitoring: Access Issues.

Specific Issue	Metric	Assessment Methods
Remote Connection: Can users connect to the EMCS remotely, using generic communications software?	Ability to connect with system remotely; requirement for proprietary communications software.	Description in manual of remote connection; discussion with EMCS operator; demonstration over phone lines (remote or nearby); number of phone lines.
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?	Ability to have history data file transmitted or displayed to remote screen; requirement for proprietary data transfer software.	Description in manual of remote history file access; demonstration with sample log file; discussion with EMCS operator.
Simple Process: Can users request historical data with a simple command?	Automation ability; number of keystrokes for logging on and off and requesting data for a specified number of points, interval and downloading frequency; command line or menu orientation.	Description in manual of remote history file access; demonstration with sample log file; discussion with EMCS operator.
Rapid Process: Is the time required to transmit the data short?	Amount of time for logging on, requesting data, and receiving it—for the number of days, points, and intervals that will be used, and downloading frequency.	Timed demonstration with sample log file; modem communications rate; real-time report generation; data format.
Transmission Error Detection: Are data transmission errors automatically detected and corrected?	Transmission uses an error-checking protocol that detects and corrects any erroneous data transmissions.	Description in manual of the file transfer process.

The need for remote connection will depend on the scale of the project (it will be difficult to visit many sites in this way), the frequency of retrieval, how accessible the building and EMCS are (will it require help from on-site personnel? is a key needed to get into the building or EMCS command center? is permission needed to enter the facility?), and the availability of personnel to collect the data.

This remote computer can either be a "dumb" terminal or a microcomputer, equipped with a modem and communications software, and emulating a terminal with standardized protocols. Communication takes place over commercial telephone lines. Most EMCSs include the required hardware and software for communications, and have a telephone line dedicated to the EMCS use. These can usually be used by monitoring projects. It may or may not be important that the software residing on the remote computer be non-proprietary, or at least non-unique to the EMCS being monitored. If only a few sites are being monitored, it may be acceptable to purchase one computer program for each. If many sites are monitored, and they require many different programs to access, a generic program will be preferable.

There can be a conflict if the EMCS phone line is used both for remote monitoring and EMCS operation. Usually, if the connection is made at night, interference is minimized. There is sometimes the potential to for the communication to freeze, and it is desirable to be able to call someone—usually the EMCS operator—and have the terminal reset. If tying up the system's telephone is a problem, one could consider purchasing an additional phone line and modem. If the system has a distributed architecture, and tying up the host computer is a problem, it might be possible to call into an RCU instead. Another alternative is sometimes to install another computer into the EMCS network, dedicated to data collection and communications.

Relationship to Constraints:

Data quality. In applications where remote access to data is necessary, the ability to connect to the EMCS host or some alternate site in the EMCS is crucial in determining whether or not data will be available.

Cost. Proprietary EMCS or communications software is likely to be more expensive than generic software. Even if it is not, acquiring different programs for different EMCS models would be quite expensive.

Time. Time will be required to learn how to use different proprietary programs, and to automate access and data processing procedures.

Ease of use. If a new proprietary program must be used, the process of using the EMCS for monitoring will be less straightforward, regardless of how simple the program is to use.

Impact of building on monitoring. Changes that are made to the EMCS could result in the need to acquire different proprietary software to make a connection. This would not be the case if generic communications software could be used.

Impact of monitoring on building. If the EMCS only allows one outside user to connect to the system at a time, or the number of access points into the system is limited, then connections to carry out monitoring could interfere with connections to carry out building or EMCS functions. Also, if the system must be reconfigured to allow outside users, the EMCS use would be affected.

Standardization. Proprietary software unique to the EMCS model would result in different methods for different buildings, which conflicts with the need for standardization.

Control. If generic software is used, changes in EMCS software will have less affect.

Assessment Methods:

The metrics here are the ability to connect to a system remotely, and the requirement for proprietary software. The need for collecting data remotely should be assessed first. Reviewing the EMCS manual, talking with the EMCS operator and vendor, and a demonstration of the system will show if it is possible to connect remotely. The need for using non-proprietary or non-unique software should also be assessed. Must the software be provided by the EMCS vendor, or is it "off-the-shelf" software? If data can be collected using public-domain or generic communication software, then separate software will not have to be purchased for each EMCS.

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?

Technical Issues:

If a remote connection is needed, it will also be necessary to ensure that the data can be transferred through this connection. Simply being able to connect to an EMCS remotely is not enough. One must also be able to access the EMCS's stored data. For third-party monitoring projects, many buildings are monitored, and the ability to transfer data remotely is a primary consideration.

There are two classes of methods for downloading data: displaying a report on the remote computer's screen, or transferring a data file. In the first method—the Generic Terminal method, described in Chapter II—one uses the remote computer to log onto the EMCS system, and run the trend utility, requesting that the data report be presented on the screen. The entire session is recorded in a log file on the remote computer, so that while the report is displayed on the remote screen, it is simultaneously recorded into a screen-capture file on the remote disk.

In the second class of methods—either the Proprietary, Remote Control, or File Transfer Methods, described in Chapter II—the data are stored to an EMCS disk file, and transferred to the remote computer using a file transfer algorithm. The file transfer algorithm can either be embedded in the EMCS computer software, or can be implemented in a communications program, running in parallel with the EMCS software.

Relationship to Constraints:

Data quality. If the screen transfer method is used, transmission errors, (discussed later), are a concern.

Cost. If separate file transfer software is needed, its cost must be considered.

Time. The file transfer method will be quicker (discussed later) than the screen display method.

Ease of use. The file transfer method will be simpler (discussed later) than the screen display method.

Impact of building on monitoring. EMCS operations that display data on the screen will affect concurrent data collection using the screen display method.

Impact of monitoring on building. If communications software is running in parallel, the EMCS must be on a computer with an operating system that allows multiple processes, and the asynchronous communications must not conflict with the more essential EMCS tasks.

Standardization. If proprietary file transfer software is used, there will be less standardization among buildings.

Control. The method for transferring data is quite important, and will be determined by EMCS characteristics. This results in a loss of control over the process for the monitoring team.

Assessment Methods:

The metrics are the ability to have a history data file transmitted or displayed to a remote screen, and the requirement for proprietary file-transfer software. The EMCS operator should know if it is possible to use screen capture or file transfer to transfer data. If the EMCS operator suggests that the first method is possible, make sure the data can be displayed on the screen, rather than just to a printer or disk. The manual will also provide information about this. Again, one must ensure that the data themselves can be displayed, not simply graphs of the data. If the file transfer method is used, the need to use proprietary file transfer software to carry out the transfer should be investigated.

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

Technical Issues:

Many energy savings projects have a large scale and experienced staff are not available to collect data from the sites. In such cases, a simple or an automated method of data retrieval is needed. Often, the EMCS will have a "verbose" mode, in which a prompt is issued for each part of the command, and a "concise" mode, in which an entire command is entered on a command line. One needs to identify if there is a shorter concise command that can be used.

A simple procedure is not an absolute requirement, but it makes automation much easier. Most communications software packages allow the user to create a script file, which can automatically dial the phone, watch for cues coming from the EMCS, issue the appropriate responses, and then move on to the next building. Ideally, after dialing the phone, the script file should only have to provide the correct login name, and then issue one-line commands to request the data. Often, however, one has to specify information such as what points are of interest, what period of time the report is to cover, what recording interval should be used, and where to send the report (to a screen, printer, or data file). If the transaction is complex or cannot be automated in a trustworthy way, it will be necessary to have a technician on hand to periodically ensure that the access is proceeding smoothly, and reinitiate the connection if it is stuck.

Relationship to Constraints:

Data quality. If the data collection process is automated, ensuring that data are not lost requires that the automation routine be very robust. This is particularly true if the program will be running unattended, if the polling staff are not capable of resetting the program, or where the EMCS can behave in unpredictable ways.

Cost. The simplicity of the data collection will not affect the cost of monitoring, beyond the time required for defining automation methods and transferring data.

Time. It takes time to create an automation routine, to carry out monitoring if transfer is not automated, or to attend to an automated data transfer.

Ease of use. A simple data transfer procedure would be easier to use. A more complex transfer will not affect ease of use, however, if it can be successfully automated.

Impact of building on monitoring. If building or EMCS activities cause the EMCS to react in unpredictable ways, an automation routine may fail, unless it is quite robust, or unless it is attended.

Impact of monitoring on building. If an automated access becomes stuck, it is possible that it would affect the operation of the EMCS.

Standardization. Having many different access procedures for many different buildings would be unmanageable, unless they are very simple or could be successfully automated.

Control. If the access is not robust, and is prone to getting stuck, the monitoring team will not have control over the data transfer procedures.

Assessment Methods:

The metrics for this are whether or not the transfer can be reliably automated, and the number of keystrokes required for logging on and off and requesting data for a specified number of points, given the data interval and expected downloading frequency. If the data are requested by issuing a succinct command, it should be easy to automate. A demonstration will indicate what commands are used to request data. This will give an indication of how complex the interaction is and how unpredictable the transaction may be, and will also be used in creating a script. The transaction should be carried out manually several times before attempting to automate it. Any alternative methods of requesting data should be identified. Particularly if the transaction will be automated, it is crucial that the EMCS operations staff that will be working during the times that data are transferred are informed of monitoring activities, are knowledgeable on how to reset the system, and know how to contact the monitoring team if problems arise.

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

Technical Issues:

The amount of time required for transmission of the data is also an important consideration in larger scale energy savings evaluation projects. Alternatives, if the data transfer is too time consuming, are to download less frequently (so that there is proportionally less header information), to use a longer data interval (obtaining fewer samples), to use a higher speed modem (9600 baud modems are now common), or to find out if there is an archive facility that does not generate the report as it is being displayed, and may have less header information.

Most EMCSs allow a dial-in connection at 1200, 2400, or 9600 baud. However, the speed of the transfer will depend to an even greater extent on other factors: whether the data are in an ASCII raw data file (rather than binary), if the data are embedded in a report; if the report format is verbose; if the report is generated as it is being displayed; and if the EMCS is busy in accomplishing other tasks while data are downloaded, the transfer may be slow. Using this time along with the number of useful samples obtained (i.e., only the data of interest) and the number of ASCII characters per sample, one can calculate the average number of samples transmitted per second. As a rule of thumb, dividing the baudrate by 100 will give an estimate of the number of samples that could be transmitted per second. This assumes 6 characters per sample, 8 bits per byte, and that the speed of transfer in bits per second is in reality only about half the specified baudrate. For example, at 2400 baud about 24 samples should be transmitted per second. Ideally, the value obtained from the demonstration should not be less than about a tenth of the reference value. In the case studies, some systems met this criterion, although some systems were significantly slower than this.

Relationship to Constraints:

Data quality. The time for transfer will impact data quality if the amount of data transferred has to be reduced, either by reducing the precision of the data or the data-collection interval.

Cost. The cost of the telephone call might be significant, especially for projects with a large number of sites across a wide area.

Time. If many buildings will be polled in a short period of time, each connection will have to be as brief as possible. If the access must be attended, the time for transfer will limit the number of buildings that can be monitored.

Ease of use. The time required for transfer should have no impact on the ease of use.

Impact of building on monitoring. Any changes in EMCS loading can affect the time it takes to transfer the data.

Impact of monitoring on building. If it takes a long time to transfer data, the EMCS will be tied up for a longer time, being more potentially disruptive.

Standardization. The time required for transfer should have no impact on standardization.

Control. Since the time required for the transfer may be determined by EMCS functions, there will be a loss of control.

Assessment Methods:

The metric is the amount of time for logging on, requesting data, and receiving it—for the number of days and points, and the data intervals and collection frequency that will be used. The time required for transfer can be determined from a demonstration. At this demonstration, note the time before the data were requested, and again after the transmission completes. The number of useful measurements contained in the transmission should be used to characterize the "rate" of information transfer, as described above. Other relevant information are the hardware communications rates, whether or not the report is generated as it is being transmitted, and how much unnecessary information—such as headers—the data report contains.

Transmission Error Detection: Are data transmission errors automatically detected and corrected?

Technical Issues:

Errors can occur, not only due to faulty or inaccurate sensors, but also when transmitting data from the remote site. Since data are traveling over commercial telephone lines, noise in the phone lines can obliterate data, or change values. Many file transfer programs include a protocol for detecting and correcting transmission errors. Some programs allow users to select whether or not the protocols are used, since there is often a transmission-rate penalty for such cautious transmission. If data checking is not possible, one alternative would be to send the data twice and compare them. If discrepancies are detected, the data should be sent again. This redundancy obviously requires tradeoffs with quick transfer and easy processing.

How crucial it is to have error-free data transmission should be evaluated for a project. The importance of individual data points, as well as the ability to recover data if they are lost will determine this.

Relationship to Constraints:

Data quality. Any data transmission errors that go undetected will affect data quality.

Cost. Error detection capabilities should not affect the cost of monitoring.

Time. Many error detection protocols slow down data transmission significantly. If data are sent twice, the transfer will take more time.

Ease of use. If data must be sent twice, the procedures for transferring the data, comparing them, and determining the correct values if there is a discrepancy will greatly increase the complexity of the process.

Impact of building on monitoring. Error detection should not change the impact that building operations have on monitoring.

Impact of monitoring on building. Error detection should not change the impact that monitoring has on building operations.

Standardization. The same error detection protocol should be used in all buildings if standardization among buildings is important.

Control. Transfer techniques that allow the user to select whether quick or reliable transfer is more important would give the monitoring team more control over the reliability of the transfer process.

Assessment Methods:

The metric here is the existence of an error detection and correction protocol. In systems that have the capability to transmit data files rather than display them on the screen, it may be possible to use a public-domain file transfer protocol, such as Kermit, which can both recognize and correct bad data. One needs to determine if the transmission uses a standard protocol, and if the protocol includes error detection and correction. Systems that only allow screen display do not perform error checking, and are thus susceptible to communications errors. The amount of time that typically goes by before data are checked may also be relevant: if data are routinely checked immediately, then if any errors are found, it will be possible to transfer the data again before data are erased.

5. Conclusions

The intent of this chapter was to provide specific guidelines for remote EMCS monitoring, carried out by a third party, to evaluate savings from an HVAC retrofit. These guidelines comprise the greatest part of the contribution of this dissertation. The guidelines were based on the categorical issues identified in the case studies of Chapter IV, but are much more detailed.

Each guideline corresponds to one of the issues presented in the previous chapter. Each guideline consists of a discussion of the technical issue that is addressed, how that issue relates to the constraints that are identified as needs for monitoring in Chapter III, and what methods can be used to assess an EMCS at a site. The guidelines comprise a concrete set of methods that can be used by a project planner who is assessing the use of EMCSs. While it was not possible to define in this dissertation what the needs will be for every particular monitoring project, the guidelines do provide metrics with greater specificity, and provide methods for evaluating the capabilities at a particular site. As an example, the next chapter describes how these guidelines and their associated methods were applied in a particular field trial, to illustrate their use and demonstrate their benefit.

While the guidelines were specifically designed for the application of monitoring by a remote third party to evaluate energy savings, this chapter also discussed how the requirements in an application relate to the constraints. The guidelines are therefore applicable to a wider range of applications. These guidelines may also have application to other efforts, such as guiding the specification and installation of EMCSs or the design of new systems.

VI. CONTROLLED CASE STUDY OF EMCS MONITORING

In Chapter III a general framework was created for the process of monitoring-project planning, and in Chapter IV, several exploratory case studies were carried out 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. In Chapter V, guidelines were created to apply the monitoring project planning process to the particular application of assessment of EMCSs for remote monitoring for savings evaluation. The issues identified in Chapter IV were formalized into the guidelines, to provide a procedure for evaluating EMCS monitoring.

In this chapter, a more methodical field trial is conducted to test the guidelines. Again, the focus narrows, this time to a particular example of the type of monitoring application discussed in Chapters IV and V (remote third-party monitoring to evaluate energy savings). In addition to testing the guidelines, this field trial serves as a more thorough demonstration of EMCS monitoring capabilities, and identification of problems and advantages. The guidelines developed in the previous chapter are used to assess EMCS monitoring at a controlled site. This case study also serves as a detailed and quantitative comparison of EMCS and conventional monitoring techniques, according to the guideline criteria. The objectives of this study, in order of importance, are: 1) to demonstrate and evaluate the use of the guidelines for assessing EMCS for monitoring; 2) to evaluate the process and effectiveness of collecting data with an EMCS; and 3) to demonstrate other potential benefits of EMCS monitoring which could be further developed.

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, and to provide a clear example of how the guidelines can be applied.

The first section below documents the case study site, and discusses the methods that were used to investigate the capabilities and collect data. The next sections document what was found in the study. The findings are organized in parallel with the guidelines developed in Chapter V—first assessing constraints, according to the guidelines, and then assessing the EMCS as a resource. After presenting these findings, the next section discusses the significance of the findings, and evaluates the usefulness of the EMCS for monitoring in this application.

1. Description of Controlled Study Site

Lawrence Berkeley Laboratory

The site chosen was Lawrence Berkeley Laboratory (LBL). LBL is a National Laboratory, operated by the University of California (UC) for the Department of Energy (DOE). There are over 100 buildings at LBL, primarily laboratories and office buildings, and including auditoriums, cafeterias, and several large experimental facilities such as particle accelerators. LBL lies on a hill adjacent to the UC campus in Berkeley, and has a very mild climate.

The buildings at LBL are maintained by the Facilities Department. Within this department are the Chief Inspector, Facilities Planner, the Maintenance & Operations Division, and the

Architecture & Engineering Division. Within the Architecture & Engineering Division, are several groups, including Architecture, Mechanical Engineering, Electrical Engineering, and In-House Energy Management (IHEM). Several individuals within the Facilities Department—including the EMCS operator, the shared savings project manager, IHEM engineers, and electricians—were very helpful in carrying out, investigating, and documenting both the EMCS and the dedicated monitoring.

Case Study: Building 62—Inorganic Materials Laboratory

The case-study building was built in 1965 with approximately 56,000 gross square feet, 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 LBL's Materials and Chemical Sciences Division and houses several chemistry, chemical engineering, nuclear engineering, ceramics, solid-state physics, and metallurgy research groups.

The building consumes about 3 million kWh per year in electricity, (50 kWh/square-foot per year), and about 100,000 therms per year (2 therms/square-foot per year), for a total of about 700 kBtu/square foot per year (all in resource units, which reflect the relative inefficiency of electricity as a fuel). Annual energy costs are 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. 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 boilers with pumps, supply fan, return fan, exhaust fans, a pump for low-conductivity water (LCW—for laboratory experiments), lighting, 120-volt circuits (including task lighting), and an emergency 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).

Shared-Savings Conservation Project

Building 62 is the subject of a pilot study of shared savings sponsored by DOE. With shared savings, a contractor finances and installs energy-conservation measures, and the resulting savings in energy bills are shared between the contractor and the building owner. The 1992 Energy Policy Act recommends the use of this kind of performance contract. DOE's Federal Energy Management Program, which has responsibility for coordinating conservation programs in federal buildings, sought to encourage this performance approach as well. Although straightforward in concept, the actual details of the contracting and the process of verifying savings can be complex, and a pilot study, carried out by a technically very competent agency, was thought to be helpful in determining ways to simplify the process (Rhea 1993). This pilot study focussed primarily on the procurement process, and did not evaluate monitoring or savings estimation methods.

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.

Retrofits: The energy-conservation measures (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. The total installation cost was estimated at about $274,500 and the projected annual savings are 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 are 430,000 kWh, and 41,000 therms. The contractor paid for the construction costs, and will be repaid by LBL from the savings.

Savings calculations: Since a fraction of the savings realized from the retrofits must be paid to the contractor, it is quite important to clearly specify the method for determining savings. The formulas for estimating savings were agreed upon and stipulated in the contract. These formulas are summarized in Table VI-1. 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.

- *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 is estimated from pre- and post-retrofit one-time kW readings. 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.
- *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.
- *Chiller:* 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 NOAA for San Francisco Airport. By assuming a value for the constant loads (averages based upon the monitored data), monitoring the independent loads, and using the

Table VI-1. Methodology for Monthly Energy Savings Calculations for Shared Savings in Controlled Case Study.

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

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

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

* indicates that the source of the data is the EMCS.

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 are carried out by the EMCS.

Energy Management and Control System

After lighting modifications, the measure with the greatest anticipated savings is installation of an EMCS. Estimated savings are $9,500 in electricity and $3,500 in gas, for a total savings of about $13,000. The installation cost is $72,000, for a simple payback time of five and a half years. Savings are to be 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 is a Barrington Systems StarVIEW 4000 (Barrington 1989). This system is currently used in many of LBL's buildings, and a site-wide building automation expansion project is underway. The EMCS was installed in Building 62 in 1993. The overall architecture of the EMCS is illustrated in Figure VI-1, and discussed in more detail in Table VI-2. Each of the buildings connected to the EMCS has at least one "LanSTAR" (primary controller) and several "MicroSTARs" (Local Input/Output Boxes). The LanSTARs are connected together within one of several local area networks (LANs). Building 62 has two LanSTARs and six MicroSTARs. The primary host computer is located in Building 76 (where the Refrigeration Division is located), and an additional host computer is located in Building 90 (where IHEM is located). The input and output points used in the system are shown in Figure VI-2, which is direct EMCS output. Once the input points are measured, they are stored momentarily at the MicroSTAR. The LanSTAR collects data from the MicroSTARs whenever requested by the host computer. The primary host computer constantly scans the LanSTARs and obtains the most recent data possible.

The EMCS "host" runs on a PC-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 is called "StarVIEW," and it runs under the DESQview multi-tasking operating system (Quarterdeck). Remote connections are accomplished using the pcANYWHERE remote control program (Symantec 1991). 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. These hourly data for the previous day and the current day (so far) can then be viewed graphically, or manually exported to a spreadsheet-ready disk file (ASCII, comma delimited, with headers). These data are available as monthly and daily summaries as well.

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

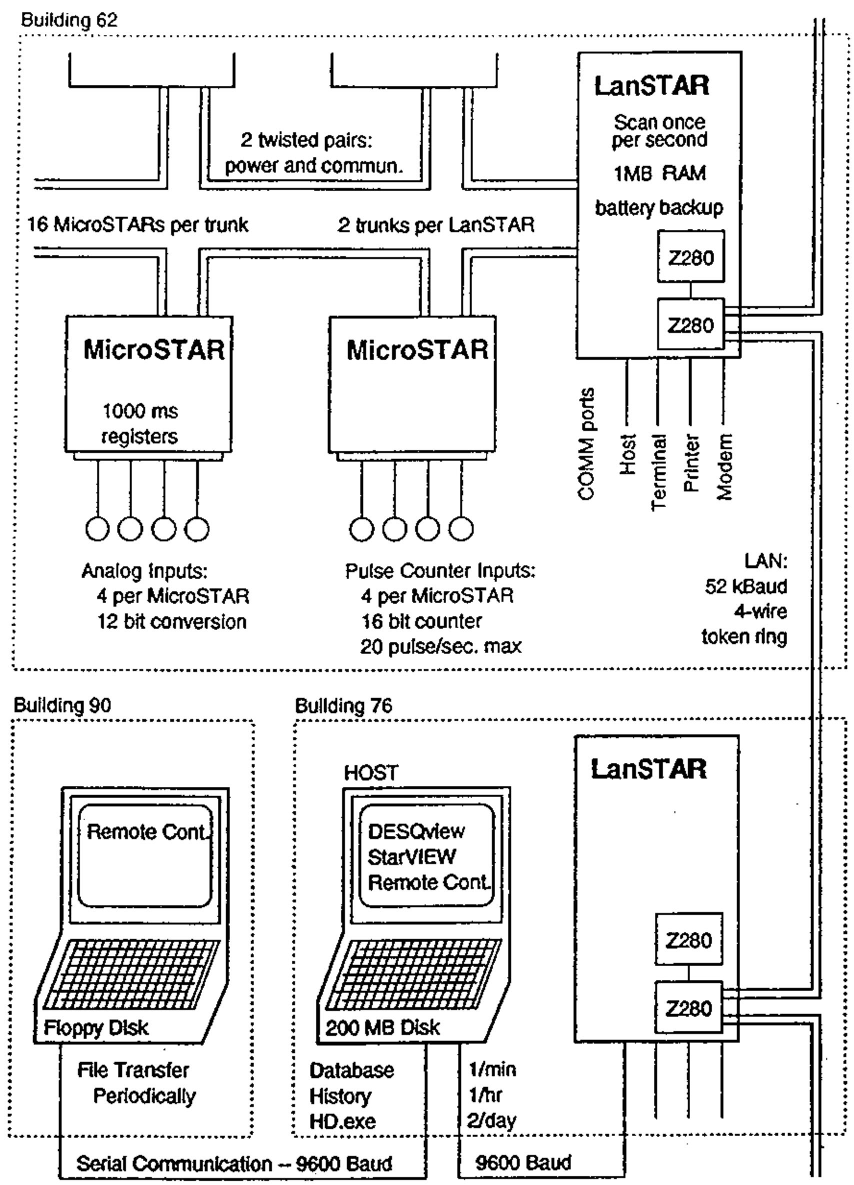

Figure VI-1. Architecture of Barrington 4000 EMCS in Case Study. The Barrington 4000 is a distributed control system, spread across several buildings at LBL. The building being studied—Building 62—has several MicroSTARs and two LanSTARs. The LanSTARS are networked to a LanSTAR in Building 76, which is in turn connected to a terminal in Building 90, where data were ultimately retrieved.

Table VI-2. Description of Barrington Systems Starview 4000 EMCS in Controlled Case Study.

MicroSTAR:

- Analog inputs: 4 analog inputs per MicroSTAR; 12 bit A/D. Input impedance is: 250 kilo-ohms for 0-10VDC voltage input; 100 k-ohm for 0-4VDC voltage input; and 180 ohms for current input.
- Digital inputs: 4 digital or pulse counting inputs per MicroSTAR; 16 bit pulse counter; up to 20 pulses/second; one pulse equals 2 counts.
- MicroSTAR scans each input about once a second.

LAN:

Communications to MicroSTAR:

- Up to 2 trunks: 16 MicroSTARs/trunk, for a total of 32 MicroSTARs/LanSTAR.
- Trunk is two twisted pairs: one for power and one for communications, up to 4000 feet.
- LanSTAR polls the MicroSTARS when data are needed: for control; when data requested by Host—sends data only if value has changed; about once a minute for LanSTAR trend points (up to 64 points/LanSTAR; 15-minute averages; stored for up to 7 days in main processor RAM.)

Main Processor:

- Zilog Z280 Microprocessor unit, 16 bit, 10MHz.
- Up to 1 M-byte RAM, with 2 year lithium battery backup.
- High speed serial interface to Communication Processor

Communication Processor:

- Zilog Z280 Microprocessor unit, 16 bit, 10MHz, dedicated to LAN operations.

Communications Ports:

- Four serial ports used for: connection to host computer; local terminal; printer; modem for outside access. Also a leased-line modem port.

LAN Connections:

- Each LanSTAR has 2 LAN connection blocks; LanSTARs are daisy-chained together to form network.
- LAN communication is 52kBaud; 4-wire telephone cable; up to 2000 feet.

Host:

- Personal Computer-386, with 200 MB hard disk; connected to a LanSTAR by RS232 cable to the first COM port, operating at 9600 baud.
- StarVIEW operates under DESQview (a quasi-multitasking operating system). The program allows the operator to view data from any of the LanSTARs on the LAN.
- "Scanner" software always runs, and constantly polls all LanSTARS on the LAN. Often takes up to 8 minutes to make a complete cycle.
- Database samples current values of all points once a minute (data may be up to 8 minutes old, however).
- History facility calculates averages, totals, minimum, maximum, etc. for all points from data in database. At any time history can be queried to determine up to the last 2 days of hourly data.
- HD.EXE program can store the hourly averages for the previous day to a spreadsheet-readable disk file on the host computer.
- The supervisory control program is scheduled to run the HD.EXE twice a day.
- A host can retrieve disk files from another host, elsewhere on the same LAN, by using a remote control program to transfer the disk file.

All Points on Site : LBL - IHEM 01-11-1994 16:30:55

Name	Description	Currently	Units	Status
62 66A1 KWH	62 FEEDER 66A1 KWH	0.0	Counts	Old Data
62 66A3 KWH	62 FEEDER 66A3 KWH	0.0	Counts	Old Data
62 ARU2 KWH	62 CHILLER-2 KILOWATT HOURS	0.0	KWH	Old Data
62 ARU2 LOAD	62 CHILLER-2 LOAD SIGNAL	0.0	LOAD	Old Data
62 ARU2 S/S	62 CHILLER-2 START/STOP	STOP	Command	Old Data
62 BLDG OCC	62 BUILDING OCCUPANCY FLAG	VACANT	Command	Old Data
62 BR1 HWR TMP	62 BR1 HOT WATER RETURN TEMP	0.0	Deg F	Old Data
62 BR1 HWS TMP	62 BR1 HOT WATER SUPPLY TEMP	0.0	Deg F	Old Data
62 BR1 S/S	62 BOILER BR-1 START/STOP	STOP	Command	Old Data
62 BR1 TIMER	62 BOILER-1 LOW TEMP TIMER	0.0	MINUTES	Old Data
62 BR1,2 REQ	62 BOILER-1,2 REQUEST FLAG	NO REQ	Command	Old Data
62 BR2 HWR TMP	62 BR2 HOT WATER RETURN TEMP	0.0	Deg F	Old Data
62 BR2 HWS TMP	62 BR2 HOT WATER SUPPLY TEMP	0.0	Deg F	Old Data
62 BR2 S/S	62 BOILER BR-2 START/STOP	STOP	Command	Old Data
62 CHW OPT S/S	62 CHW OPTIMAL START/STOP	STOP	Command	Old Data
62 CHW OPT TMR	62 CHILL WATER OPTIMAL TIMER	0.0	MINUTES	Old Data

Detail | Events | History | Broken | Repaired | Switch | Vary | NextPage

PTSUM... Rel 11.14.89

All Points on Site : LBL - IHEM 01-11-1994 16:31:01

Name	Description	Currently	Units	Status
62 CHW OPTMIN	62 CHILLER OPTIMAL MIN FROM ZAT	0.0	Deg F	Old Data
62 CHW REQ	62 CHILLER REQUEST	NO REQ	Command	Old Data
62 CHWR TEMP	62 CHILL WATER RETURN TEMP	0.0	Deg F	Old Data
62 CHWS TEMP	62 CHILL WATER SUPPLY TEMP	0.0	Deg F	Old Data
62 CT1 CWR	62 CONDENSER WATER RETURN TEMP	0.0	Deg F	Old Data
62 CT1 CWS	62 CONDENSER WATER SUPPLY TEMP	0.0	Deg F	Old Data
62 CT1 CWS SP	62 CT1 CONDENSER WATER SETPOINT	0.0	Deg F	Old Data
62 CT1 S/S	62 COOLING TOWER 1 START/STOP	STOP	Command	Old Data
62 DOM HW SP	62 DOMESTIC HOT WATER SETPOINT	0.0	Deg F	Old Data
62 DOM HW TEMP	62 DOMESTIC HOT WATER TEMP	0.0	Deg F	Old Data
62 DOM HWV	62 DOMESTIC HOT WATER VALVE	0.0	% OPEN	Old Data
62 GP1 FAIL	62 GP-1 FAIL FLAG	CLEAR	Command	Old Data
62 GP1 MINUTES	62 GP-1 MINUTES OF RUNTIME	0.0	MINUTES	Old Data
62 GP1 RUNTIME	62 GP-2 HOURS OF RUNTIME	0.0	HOURS	Old Data
62 GP1 S/S	62 GP-1 START/STOP (CHWP)	STOP	Command	Old Data
62 GP1 STS	62 GP-1 STATUS (CHWP)	OFF	Status	Old Data

Detail | Events | History | Broken | Repaired | Switch | Vary | NextPage

PTSUM... Rel 11.14.89

Figure VI-2. Point List from EMCS used in Case Study. Many operational points are standard equipment in an EMCS. This type of list identifies which points are connected in this EMCS. The list is created by hitting "Printscreen" when a listing of current point values is displayed.

All Points on Site : LBL - IHEM 01-11-1994 16:32:2[illegible]

Name	Description	Currently	Units	Status
62 GP1 TIMER	62 GP1 FAIL TIMER	0.0	MINUTES	Old Data
62 GP1,2 L/L	62 GP1,2 LEAD/LAG FLAG	GP1	Command	Old Data
62 GP2 FAIL	62 GP-2 FAIL FLAG	CLEAR	Command	Old Data
62 GP2 MINUTES	62 GP-2 MINUTES OF RUNTIME	0.0	MINUTES	Old Data
62 GP2 RUNTIME	62 GP-2 HOURS OF RUNTIME	0.0	HOURS	Old Data
62 GP2 S/S	62 GP-2 START/STOP (CHWP)	STOP	Command	Old Data
62 GP2 STS	62 GP-2 STATUS (CHWP)	OFF	Status	Old Data
62 GP2 TIMER	62 GP2 FAIL TIMER	0.0	MINUTES	Old Data
62 HIBAY OVR	62 HIGHBAY AFTER HOURS OVERRIDE	NORMAL	Status	Old Data
62 HV2 S/S	62 HV-2 START/STOP	STOP	Command	Old Data
62 HV2 STS	62 HV-2 STATUS	OFF	Status	Old Data
62 HV2,3 OCC	62 HV-2,3 OCCUPANCY FLAG	VACANT	Command	Old Data
62 HV3 S/S	62 HV-3 START/STOP	STOP	Command	Old Data
62 HV3 STS	62 HV-3 STATUS	OFF	Status	Old Data
62 HW OPT S/S	62 HW OPTIMAL START/STOP	STOP	Command	Old Data
62 HW OPT TMR	62 HOT WATER OPTIMAL TIMER	0.0	MINUTES	Old Data

Detail | Events | History | Broken | Repaired | Switch | Vary | NextPage

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All Points on Site : LBL - IHEM 01-11-1994 16:32:32

Name	Description	Currently	Units	Status
62 HW OPTMIN	62 BOILER OPTIMAL MIN FORM ZAT	0.0	Deg F	Old Data
62 IND HW SP	62 INDUSTRIAL HOT WATER SETPOINT	0.0	Deg F	Old Data
62 IND HW TEMP	62 INDUSRTIAL HOT WATER TEMP	0.0	Deg F	Old Data
62 IND HWV	62 INDUSTRIAL HOT WATER VALVE	0.0	% OPEN	Old Data
62 MASTER OVR	62 MASTER OVERRIDE	NORMAL	Status	Old Data
62 MAXRANGE	62 AHU S-1 MAX RANGE FOR SASP	0.0	Deg F	Old Data
62 MAXZAT	62 MAX TEMP OF COOLED ZONES	0.0	Deg F	Old Data
62 MINZAT	62 MIN TEMP OF NON-COOLED ZONES	0.0	Deg F	Old Data
62 OSA	62 OUTSIDE AIR TEMPERATURE	0.0	Deg F	Old Data
62 S1 ECN DMPR	62 AHU S-1 ECONOMIZER DAMPER	100.0	% RETURN	Old Data
62 S1 ECN OFF	62 AHU S-1 ECONOMIZER CLOSE DOWN	OUTSIDE	Command	Old Data
62 S1 HWV	62 AHU S-1 HOT WATER VALVE	0.0	% OPEN	Old Data
62 S1 HWV SAFE	62 AHU S-1 HWV FAIL SAFE	OFF	Command	Old Data
62 S1 KWH	62 AHU S-1 KILOWATT HOURS	0.0	KWH	Old Data
62 S1 MAT	62 AHU S-1 MIXED AIR TEMP	15.0	Deg F	Old Data
62 S1 MAT SP	62 AHU S-1 MIXED AIR SETPOINT	15.0	Deg F	Old Data

Detail | Events | History | Broken | Repaired | Switch | Vary | NextPage

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Figure VI-2 (cont.). Point List from EMCS used in Case Study. Many operational points are standard equipment in an EMCS. This type of list identifies which points are connected in this EMCS. The list is created by hitting "Printscreen" when a listing of current point values is displayed.

All Points on Site : LBL - IHEM 01-11-1994 16:34:07

Name	Description	Currently	Units	Status
62 S1 RAT	62 AHU S-1 RETURN AIR TEMP	0.0	Deg F	Old Data
62 S1 RF S/S	62 AHU S-1 RETURN FAN START/STOP	STOP	Command	Old Data
62 S1 RF STS	62 AHU S-1 RETURN FAN STATUS	OFF	Status	Old Data
62 S1 SAT	62 AHU S-1 SUPPLY AIR TEMP	15.0	Deg F	Old Data
62 S1 SAT SP	62 AHU S-1 SUPPLY AIR SETPOINT	15.0	Deg F	Old Data
62 S1 SAT SP*	62 AHU S1 SAT SP (REAL #S)	0.0	Deg F	Old Data
62 S1 SF STS	62 AHU S-1 SUPPLY FAN STATUS	OFF	Status	Old Data
62 S1 STP	62 AHU S-1 SUPPLY STATIC PRESS	-1.3	" W.C	Old Data
62 S1 STP SP	62 AHU S-1 STATIC PRESS SETPOINT	-1.3	" W.C.	Old Data
62 S1 VFD FLT	62 AHU S-1 VFD FAULT	CLEAR	Status	Old Data
62 S1 VFD S/S	62 AHU S-1 SUPPLY FAN VFD S/S	STOP	Command	Old Data
62 S1 VFD SPD	62 AHU S-1 VFD SPEED SIGNAL	0.0	% F.S.	Old Data
62 ZONE 1 ZAT	62 ZONE 1 RM 139 ZONE TEMP	0.0	Deg F	Old Data
62 ZONE 2 ZAT	62 ZONE 2 HIGH BAY ZONE TEMP *NC	0.0	Deg F	Old Data
62 ZONE 2 ZSP	62 ZONE 2 HIGH BAY SETPOINT	0.0	Deg F	Old Data
62 ZONE 3 ZAT	62 ZONE 3 RM 139 ZONE TEMP *NC	0.0	Deg F	Old Data

Detail | Events | History | Broken | Repaired | Switch | Vary | NextPage

All Points on Site : LBL - IHEM 01-11-1994 16:34:09

Name	Description	Currently	Units	Status
62 ZONE 4 ZAT	62 ZONE 4 RM 221 ZONE TEMP	0.0	Deg F	Old Data
62 ZONE 5 ZAT	62 ZONE 5 RM 235 ZONE TEMP *NC	0.0	Deg F	Old Data
62 ZONE 6 ZAT	62 ZONE 6 RM 313 ZONE TEMP *NC	0.0	Deg F	Old Data
62 ZONE 7 ZAT	62 ZONE 7 RM 355 ZONE TEMP *NC	0.0	Deg F	Old Data
62 ZONE 8 ZAT	62 ZONE 8 RM 118 ZONE TEMP	0.0	Deg F	Old Data
62 ZONE 9 ZAT	62 ZONE 9 RM 246 ZONE TEMP *NC	0.0	Deg F	Old Data
TEST 1		0.0	Deg F	Old Data
TEST 2		15.0	Deg F	Old Data

Detail | Events | History | Broken | Repaired | Switch | Vary | NextPage

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Figure VI-2 (cont.). Point List from EMCS used in Case Study. Many operational points are standard equipment in an EMCS. This type of list identifies which points are connected in this EMCS. The list is created by hitting "Printscreen" when a listing of current point values is displayed.

format *MM-DD-YY.hd*. This program can be run at any time, or it can be initiated by the EMCS's Supervisory Controls program to be run automatically at a certain time every day.

There are a few additional methods of collecting data with this system, which were not pursued in this study, but which may have promise for other applications. One alternative location for storing data is on the controller. Up to 64 points can be monitored there, with 15-minute resolution, for up to 1 week before data are overwritten. The data can be retrieved by connecting directly into the controller, through one of the serial ports. Proprietary software must be used for this connection: the Viewport facility in the StarVIEW program. Another facility is called "trend," which allows the operator to view the one-minute database values. This can be done only for predefined points, although it is not possible to retrieve and store the data remotely. In another method, the operator can define custom report formats. Averages can be calculated from database data to be inserted into the report format, and then these are stored in non-ASCII files, to be printed. These are generated as needed by the EMCS. This facility has the advantage that one could define a suitable streamlined format with no extraneous information. However, since they are not stored in an ASCII file format, they can only be used with a generic terminal screen-dump method, which is not ideal.

IHEM Parallel 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, IHEM is also monitoring the building to verify the savings estimates received from the contractor. IHEM was able to make use of equipment left behind by the previous monitoring project, particularly the current transducers (CTs).

The equipment used for this monitoring is three Synergistic Control Systems, Inc. C180 Survey Meter/Recorders (Synergistic Control Systems, Inc. 1989). 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 Synernet software can be run on a PC 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 C180 datalogger is included in the review of specific dataloggers in Chapter II. The loggers are daisy-chained together so that one access can retrieve data from all three loggers, and the architecture of the system is shown in Figure VI-3. The points being monitored by the dedicated datalogger are shown in Figure VI-4. Hourly data for these points are available since August 1993.

Sources of Information

After this site was identified as a potential case-study site, several meetings, site visits, and other activities were carried out to assess EMCS capabilities. The collection of information followed the methods described in Chapter V.

- *Collect and review EMCS documents:*
  - Reviewed the building documentation, including the building audit, EMCS documentation, monitoring documentation, a report on the shared-savings contract, and the contractor information packages.
- *Meet with EMCS operator and building management:*

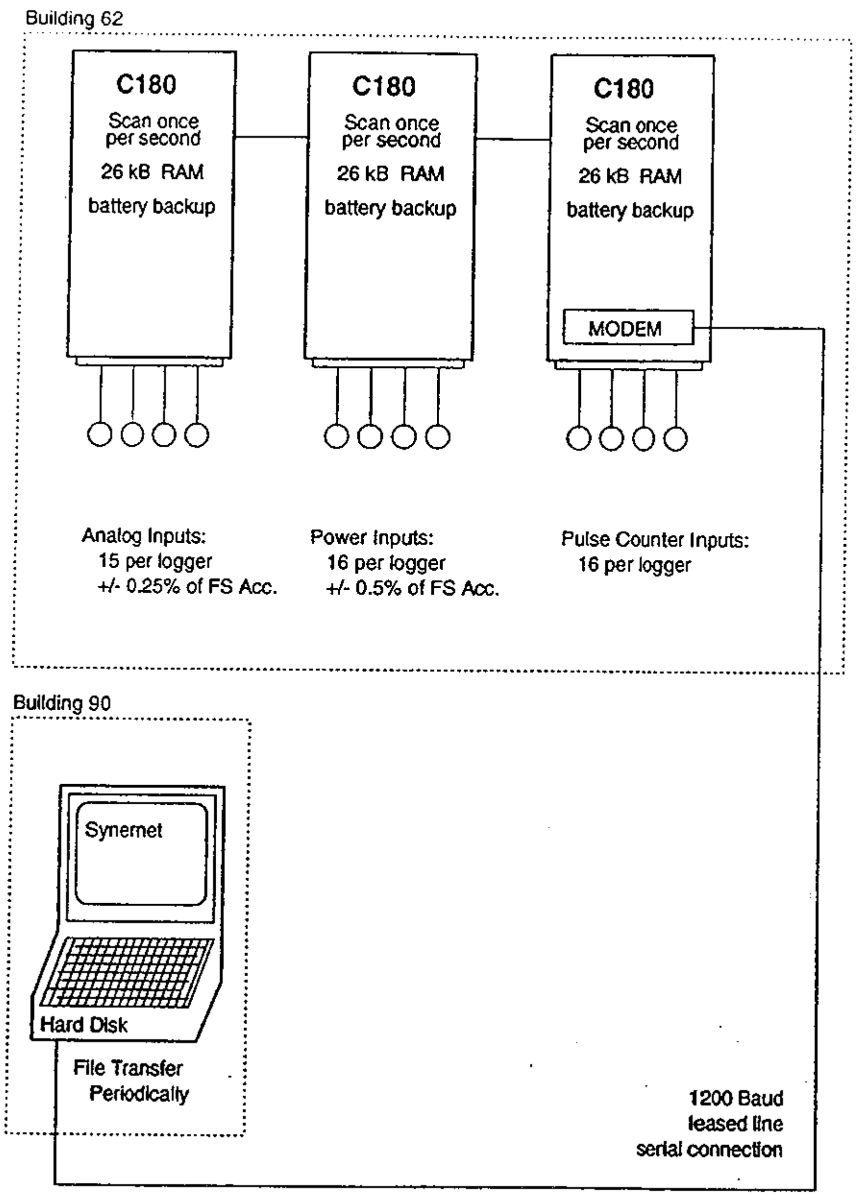

Figure VI-3. Architecture of Synergistics C180 Dedicated Monitoring System in Case Study. The C180 is a specialized building demand monitoring tool. It has several analog and digital inputs, in addition to 16 CT inputs and 8 voltage inputs. The case study building had three loggers installed, connected by leased line to a PC.

		1864				
	Meas.	Phase	Amps		Channels	
0	Mains	A	400		1	Mains
1	Mains	B	400		2	HiBay Lt
2	Mains	C	400		3	HV2
3	HiBay	A	100		4	HV3
4	HiBay	B	100			
5	HiBay	C	100			
6	HV2	A	100			
7	HV2	B	100			
8	HV2	C	100			
9	HV3	A	100			
10	HV3	B	100			
11	HV3	C	100			
12						
13						
14						
15						
	1865					
	Meas.	Phase	Amps			
0	Lighting	A	400			
1	Lighting	B	400			
2	Lighting	C	400			
3	Export	A	400			
4	Export	B	400			
5	Export	C	400			
6	Chiller	A	400			
7	Chiller	B	400			
8	Chiller	C	400			
9	66A1	A	200			
10	66A1	B	200			
11	66A1	C	200			
12						
13						
14						
15						
	1866					
	Meas.	Phase	Amps			
0	Supply Fan	A	400			
1	Supply Fan	B	400			
2	Supply Fan	C	400			
3	Rt Fan	A	100			
4	Ex Fan	A	100			
5	CNDR Pmp	A	100			
6	ChWtr Pmp	A	100			
7	Ht Wtr Pmp	A	100			
8	Emer Lt	A	100			
9	Emer Lt	B	100			
10	Emer Lt	C	100			
11	Mains	A	2000			
12	Mains	B	2000			
13	Mains	C	2000			
14						
15						

Figure VI-4. Point List from Dedicated Monitoring used in Case Study. The dedicated monitoring in the case study monitored the energy consumption of 16 end uses within the building. For most end uses, three phases were monitored. For the return and exhaust fans, and the pumps, however, only one phase was measured to conserve CTs.

- — Worked with the EMCS operator and refrigeration engineers to identify methods of downloading data remotely.
- — Requested that the EMCS operator obtain a point list, and more detailed information on EMCS monitoring.
- — Selected points to be monitored for case study, and gave the list to the EMCS operator.
- — Talked with the EMCS operator to discuss specific technical characteristics of the EMCS.
- — Met with the EMCS operators at another installation with the same EMCS model to discuss how monitoring could be accomplished at that site.
- — Reviewed diagrams of EMCS and dedicated datalogger architecture with the EMCS operator and IHEM.
- — Met with the EMCS operator to determine how the kWh data were calculated, and to troubleshoot problems with the data.

- *Meet with EMCS vendor or contractor:*
  - — Met with the controls company president and engineers, along with the EMCS operator to discuss potential methods of downloading.
  - — Talked with the controls company engineers to discuss problems with current transducers.
- *Tour site and obtain demonstration of EMCS monitoring:*
  - — Visited the building along with engineers from IHEM to review the dedicated monitoring and EMCS points.
  - — Participated in a demonstration of monitoring using the EMCS.
- *Confirm EMCS monitoring capabilities:*
  - — Accompanied shared-savings project manager and the EMCS operator when the EMCS was commissioned.
  - — Requested that IHEM install short-term monitoring—funded by the shared-savings management contract—to confirm the values of certain points; and oversaw installation of the monitoring.
  - — During installation of verification monitoring, inspected the CTs from both the EMCS and the dedicated monitoring.
  - — Installed temperature sensors in three of the zones that were monitored by the EMCS to collect short-term data to verify the EMCS temperature data.

Since this was a research project, there were more meetings than would typically be expected in a monitoring project, and more documentation was collected.

For this case study, data were collected from both the EMCS and dedicated monitoring. Once a month, the IHEM computer in Building 90 was used to retrieve data from the dedicated monitoring. These data were in a spreadsheet format, and it was necessary to translate this into an ASCII format for analysis for this study. Also once a month, the EMCS computer in Building 90 was used to retrieve data from the EMCS. Data from both the dedicated monitoring and the EMCS were uploaded to a UNIX platform, and analyzed using tools such as AWK pattern-matching programs, UNIX shell scripts for data processing, and Xvgr for graphing (Turner 1993). This analysis and the methods of retrieving the data are presented, discussed in more detail, and evaluated in the following sections.

2. Findings: Applying Guidelines to Assess Constraints

The guidelines developed in Chapter V provide a structure for evaluating the capabilities of the EMCS for monitoring and for comparing it with the dedicated monitoring. Below, for each of the guidelines, there is a section discussing constraints for this monitoring project.

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

According to the shared-savings 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 runtimes of the pumps and two heating-ventilating units. These are fed into the agreed-upon formulas, shown in Table VI-1, to calculate monthly energy savings. For more detailed savings assessment, however, whole-building electricity consumption is also needed. In order to learn more about the operation of the building or the performance of the retrofits, one would want also 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 flowrates), and setpoints.

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

The data accuracy needs for calculating savings in the shared savings 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 two to three percent (LBL 1989). If the post-retrofit energy consumption were measured to an accuracy of three percent, then the resulting savings calculation would have an accuracy of approximately five percent.

Sensor Calibration: Are sensors in proper calibration?

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

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 where 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. 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.

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 runtime variables—must all be reported as monthly or hourly averaged or totalized values.

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

The data storage requirements for the shared savings 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 thirty bytes. If storage space allows, hourly data and less-essential operational data should 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.

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.

Data Time Stamping: Does the system system record the time 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.

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

The contractor is an outside entity in a contractual agreement with LBL 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 LBL, interference is not acceptable. It will be unacceptable for them to interfere with building operation, or to require much assistance from the LBL staff.

Since the contractor is located in Houston, it is very 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 shared-savings contracts, so it would be preferable to use more generic software.

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 without any 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.

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

Since the contractor has a large number of shared savings contracts, they will 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 since they will be monitoring several other buildings.

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

Since monthly data are so small, the speed of the transmission is not essential. For the hourly data, however, the contractor will 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.

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 quite 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.

3. Findings: Applying Guidelines to Assess Resources

Now that constraints are clearly defined, the EMCS is investigated in detail as a potential resource to use in the monitoring effort. The capabilities of the conventional monitoring are presented as one alternative to the EMCS. Any other alternative methods—either alternative methods implemented in the EMCS or ways to achieve project objectives with the resources available—are also discussed. In some cases, the data retrieved from the dedicated monitoring are used to evaluate the data from the EMCS.

Figures VI-5 through VI-9 show the data collected by the EMCS, and Figures VI-10 and VI-11 show the data collected by the dedicated datalogger. This format is useful for reviewing the overall trend of the data, although for more detailed review or analysis of the data, more readable graphic formats must be used. In each graph, the point names describe what point is being monitored, and the points correspond to the lists shown in Figures VI-2 and VI-4.

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

Obtaining a list of all points on the system required the assistance of the EMCS operator. It was a simple matter for the operator to bring up a list of points on the EMCS host screen, and then print the screen to the printer. The resulting point list is shown in Figure VI-2. 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. Note that the 88 EMCS points in this building include all types of points: inputs, outputs, setpoints, and virtual (calculated) points. One important point that it does not include is a whole-building electric meter. 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 Occupied or

Unoccupied mode. After obtaining the list of point names, it required the assistance of the EMCS operator to decipher what each point means. Table VI-3 indicates what each points represents, along with its engineering units.

Table VI-4 indicates the 40 points monitored in this study. This is a sampling of the different types of points available, focussing on the information that was needed to monitor the operation of the air-handling unit and the chiller. It also includes all the watt-hour transducers, and zone temperatures for a representative cooled, uncooled, and high-bay zone. No information on heating or hot water use was monitored. Use of the guidelines leads to the conclusion that EMCS will be able to provide the needed information.

In addition to the data needed for savings calculations, the EMCS provided a great deal of other operational data. Some of this other information could be used as a substitute for—or supplement to—energy consumption data, in a number of different ways. Figures IV-12 through IV-29 illustrate how occupancy data, operational data, and proxies might substitute for monitored energy data. This analysis represents an extension of EMCS monitoring capabilities, and illustrates the fact that EMCS data may provide a rich source of information on building operation that will support new methods of analysis.

Figure VI-30 shows the kWh points monitored by the dedicated monitoring and by the EMCS. Clearly, the dedicated equipment monitors more end uses than the EMCS. Table VI-5, however, is a comparison of the same dedicated-monitoring points with some of the other data monitored by the EMCS. 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 temperature measurements are made by a Barrington series of temperature transmitters, based on the LM34C Integrated Circuit temperature sensor. According to the EMCS literature, these have a range of 0-230°F, and a typical accuracy of 0.4°F. According to the technical specifications for the integrated circuit, it has a typical accuracy of 0.4°F at 77°F, 0.6°F at 0°F, and 0.8°F at 230°F (National Semiconductor 1990). Its design limit, however, is 2.0°F at 0°F, and its tested limit is 1.0°F at 77°F. The static pressure sensor is a Modus T30 series, with an accuracy of ±1% of full range (0 - 2.5") including non linearity. Both temperature and static pressure sensor accuracies meet the ASHRAE Standard 114 suggestions for accuracy for energy calculation (see, again, Table II-3). Status is indicated by a Neilson-Kuljian D150 Current Switch.

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 4096, 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 Kele WHP-234 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. This should meet the needs identified in the previous section.

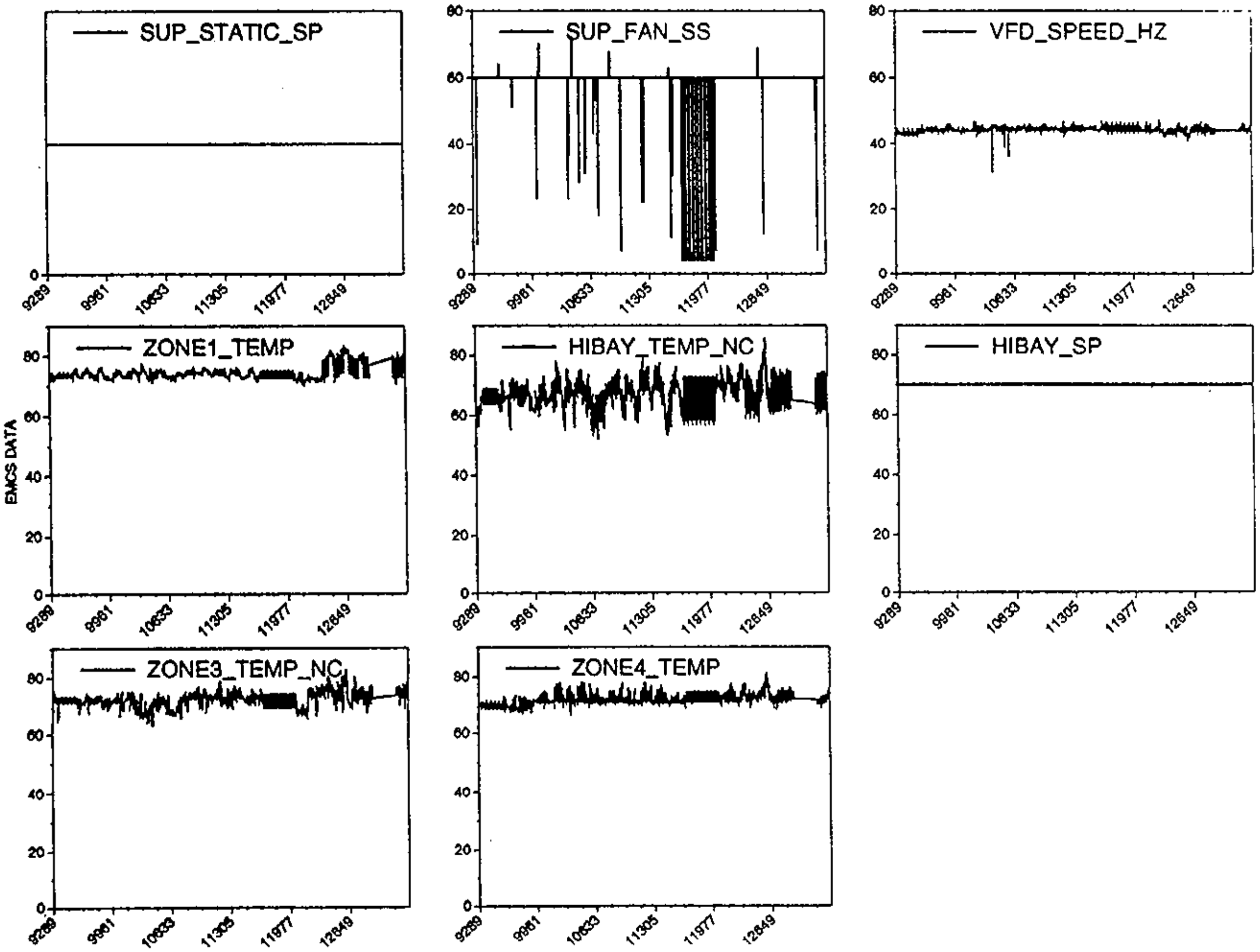

Figure VI-5. Data collected from EMCS in Case Study Building. The EMCS collected many different types of data, including both energy consumption and operational data.

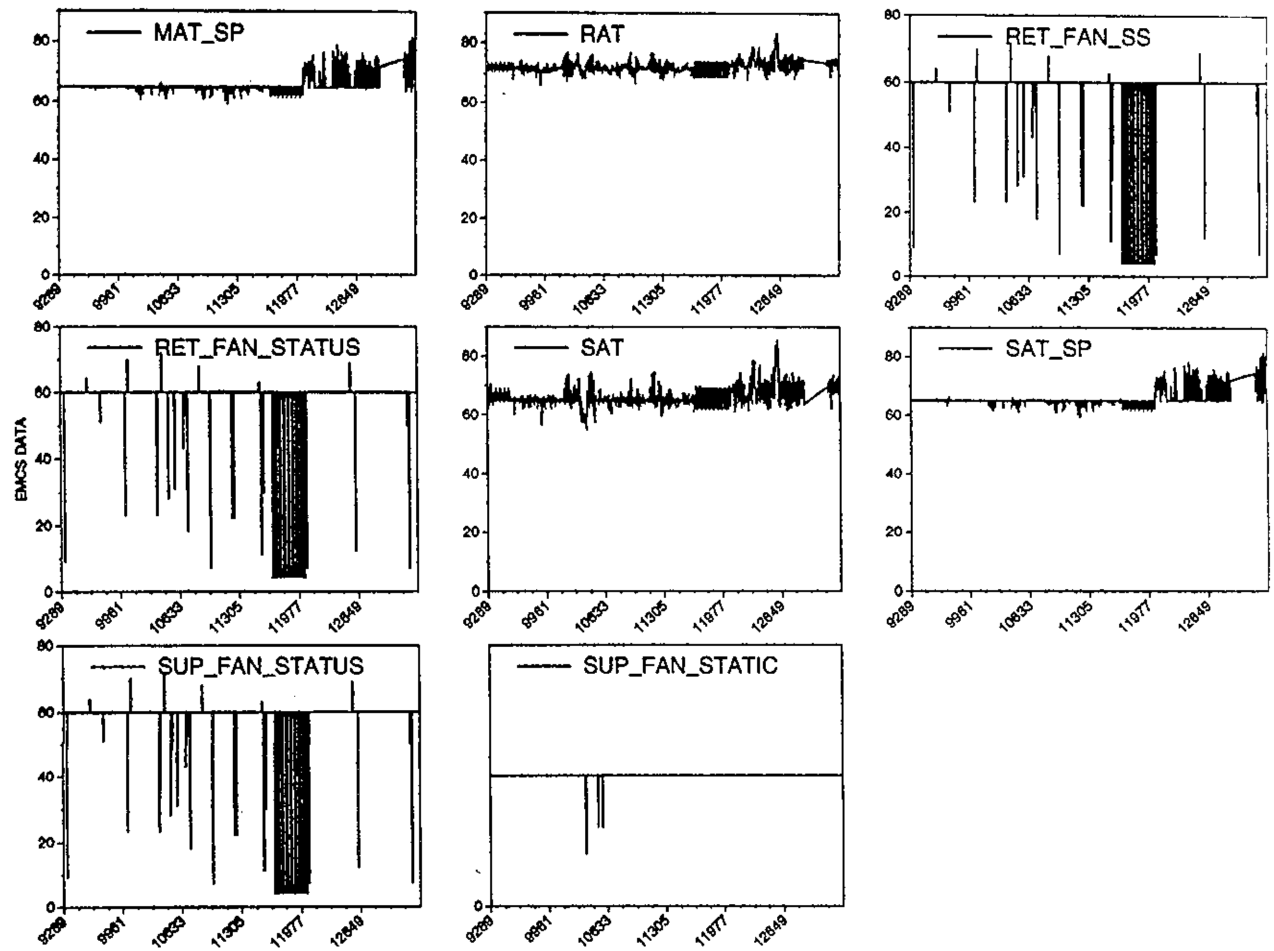

Figure VI-6. Data collected from EMCS in Case Study Building (cont.). The EMCS collected many different types of data, including both energy consumption and operational data.

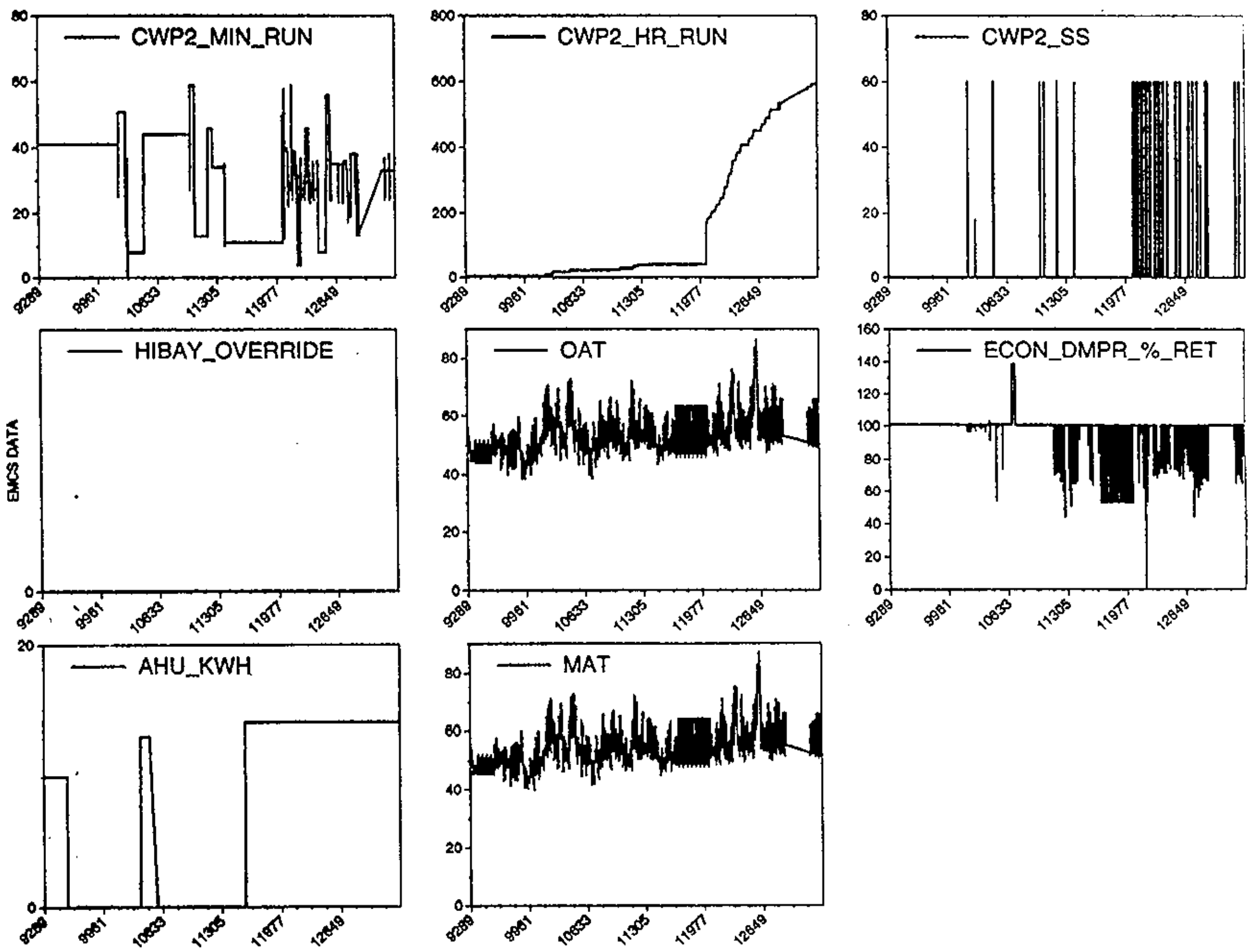

Figure VI-7. Data collected from EMCS in Case Study Building (cont.). The EMCS collected many different types of data, including both energy consumption and operational data.

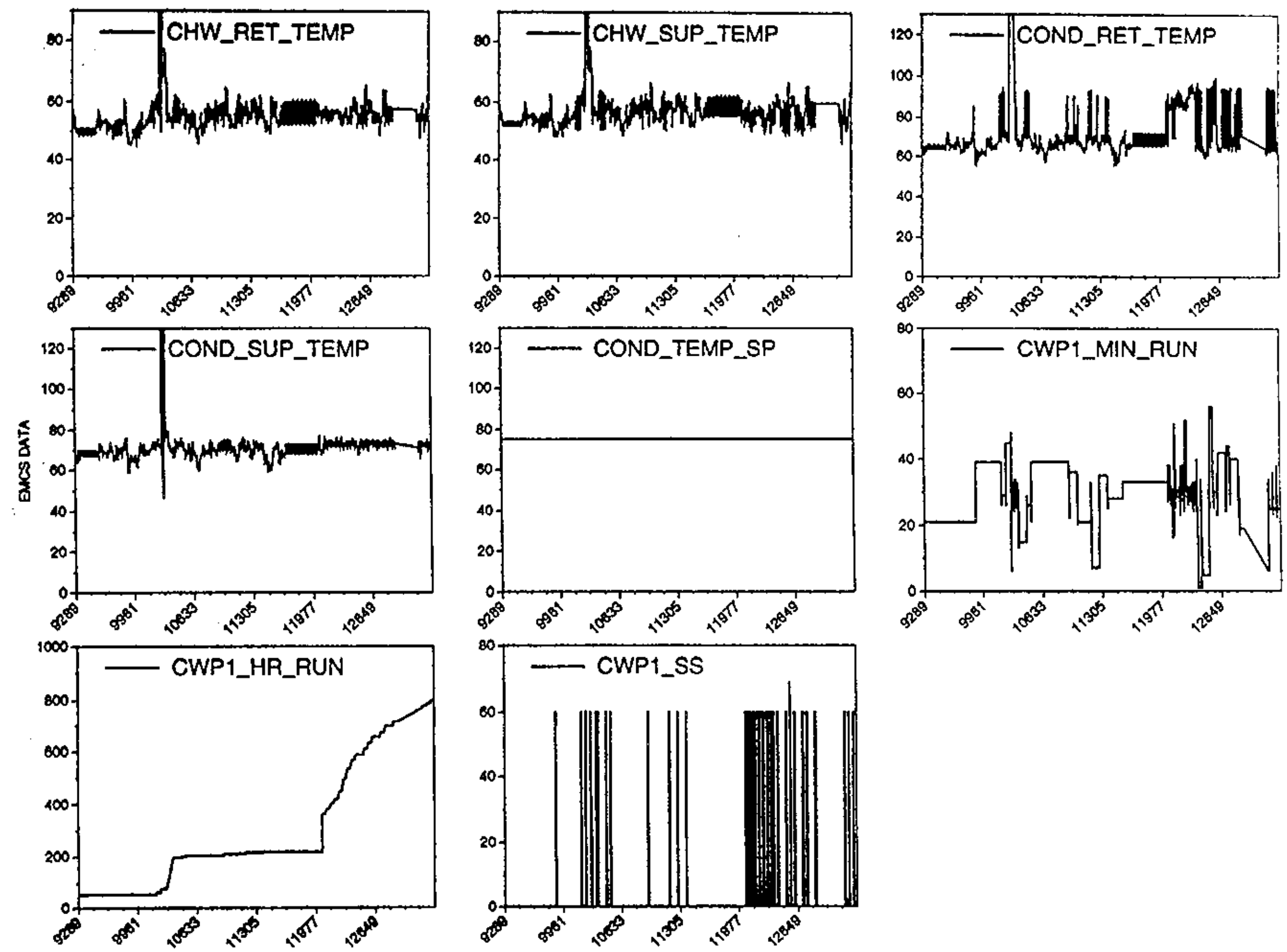

Figure VI-8. Data collected from EMCS in Case Study Building (cont.). The EMCS collected many different types of data, including both energy consumption and operational data.

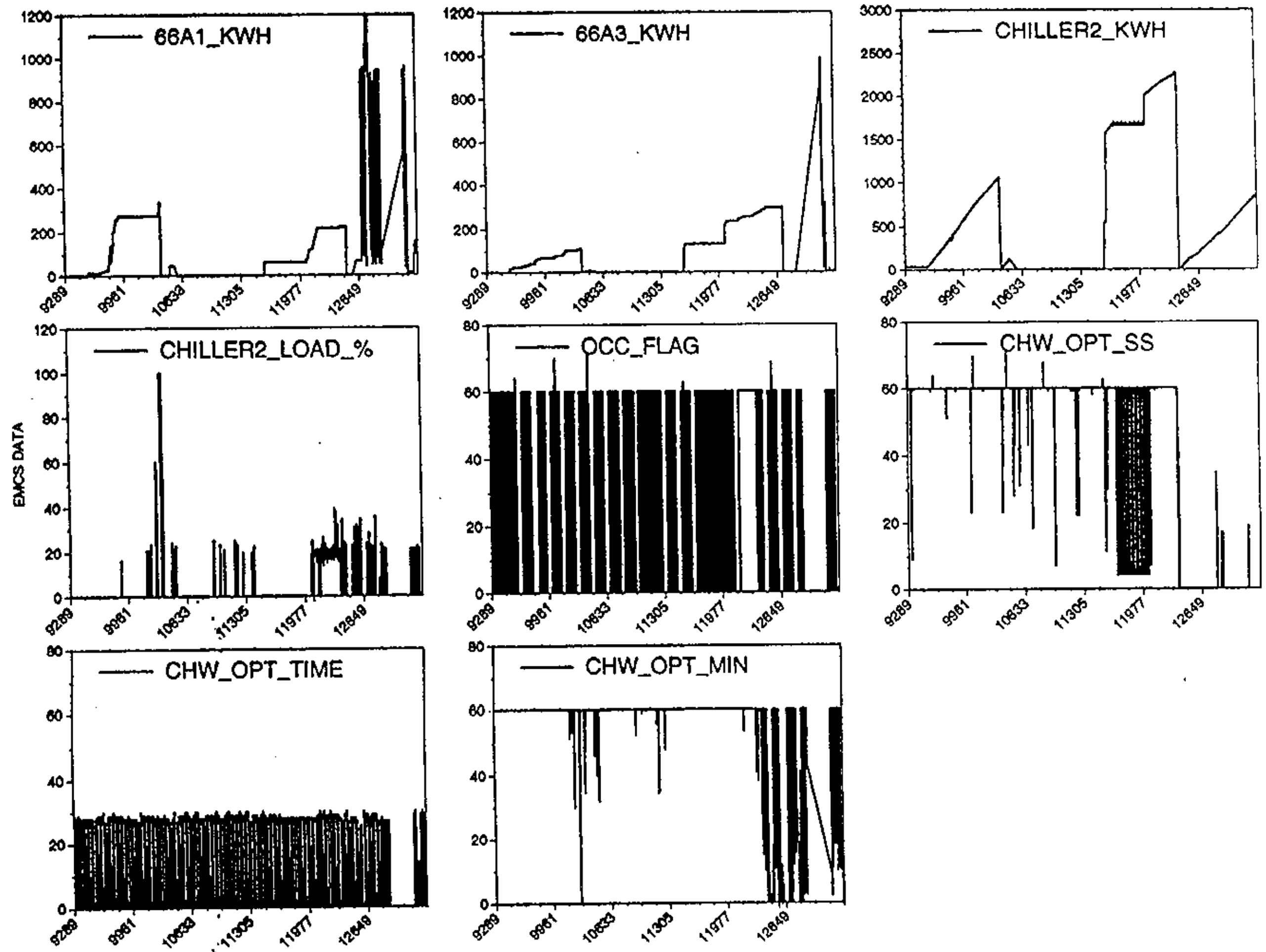

Figure VI-9. Data collected from EMCS in Case Study Building (cont.). The EMCS collected many different types of data, including both energy consumption and operational data.

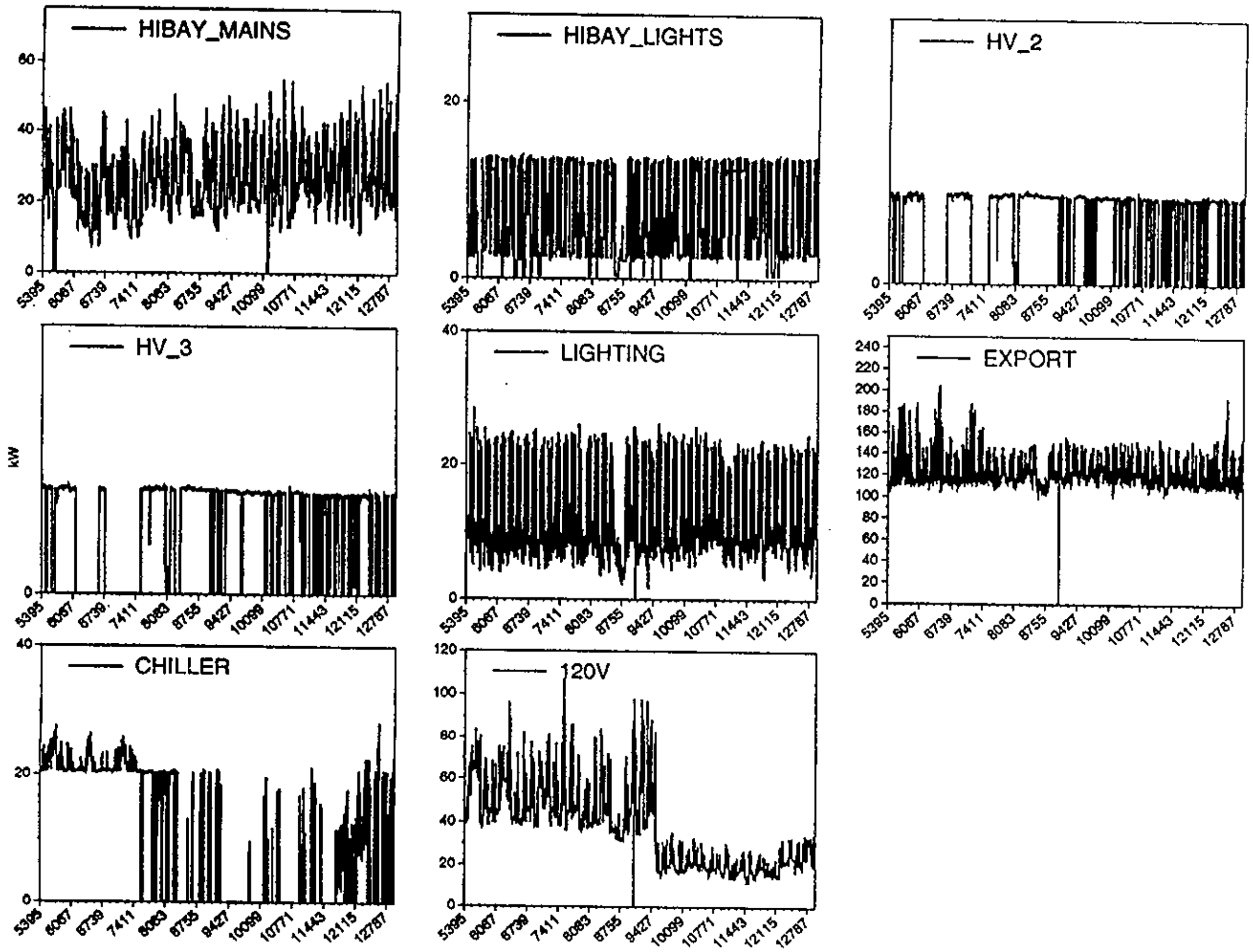

Figure VI-10. Data collected from Dedicated Monitoring in Case Study Building. The conventional monitoring was installed in parallel to the EMCS, to confirm EMCS data. 16 end-use energy channels were monitored.

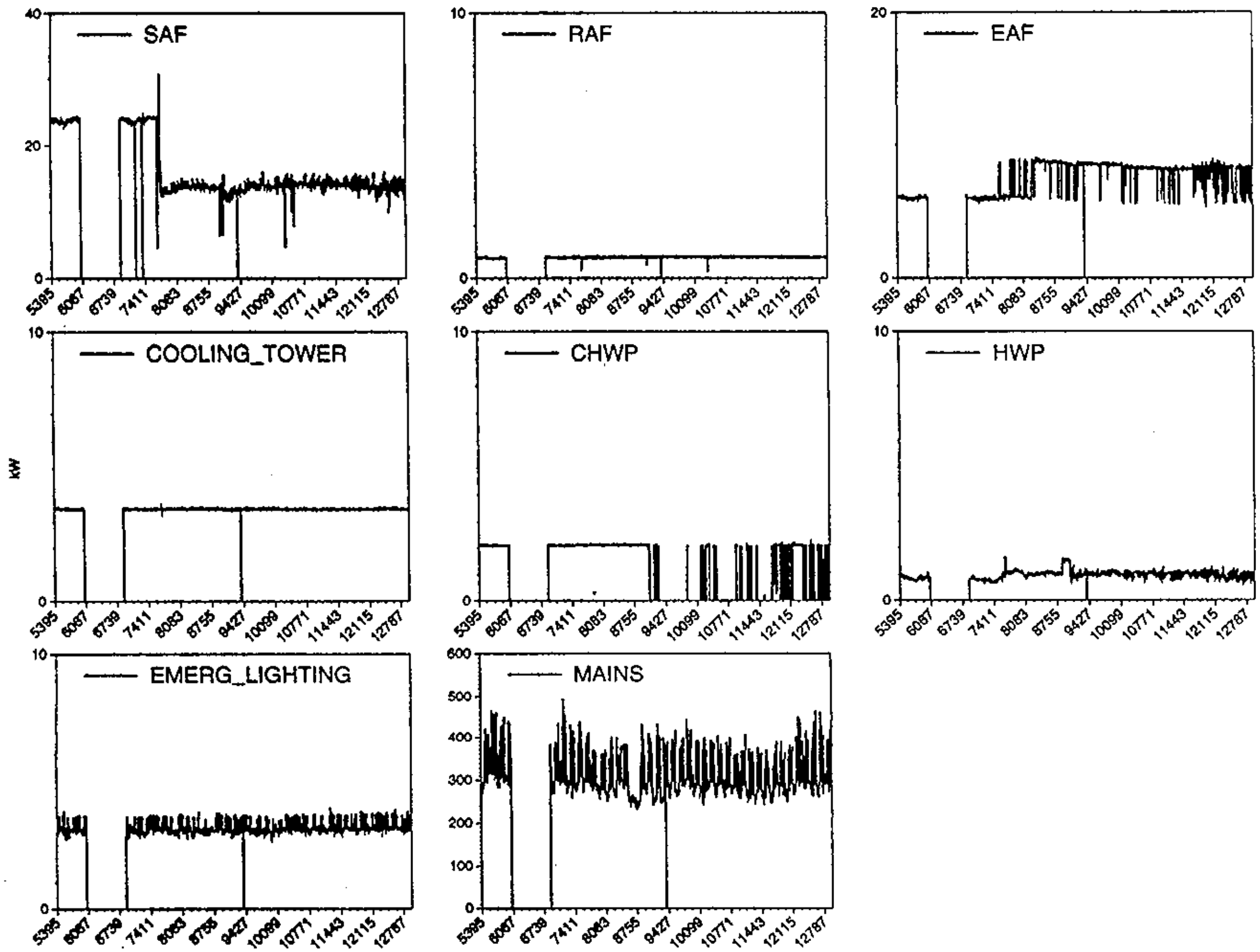

Figure VI-11. Data collected from Dedicated Monitoring in Case Study Building (cont.). The conventional monitoring was installed in parallel to the EMCS, to confirm EMCS data. 16 end-use energy channels were monitored.

Table VI-3. Description of EMCS Points in Controlled Case Study.

Description	Units	Meaning
kWh	Counts	Pulse counts--to be translated to kWh
kWh	KWH	Cumulative kilowatt hours
CHILLER LOAD SIGNAL	LOAD	Calculated from SP-CHWR; PID output
START/STOP	Command	START or STOP; outgoing control signal
OCCUPANCY FLAG	Command	VACANT or OCCUPIED
TEMP	Deg F	Air or water temperature
TIMER	MINUTES	Reset once an hour--increments an hour counter
TIMER	HOURS	The MINUTES timer sets this when it passes 60
REQUEST FLAG	Command	REQ or NO REQ
SETPOINT	Deg F	Intermediate value, control signal calculated from this.
VALVE	%OPEN	Outgoing signal calculated from this
FAIL FLAG	Command	CLEAR or FAIL
STATUS	Status	ON or OFF; incoming signal
LEAD/LAG FLAG	Command	GP1 or GP2; indicates lead pump
OVERRIDE	Status	NORMAL or OVERRIDE; incoming signal
MAX TEMP OF COOLED ZONES	Deg F	Used to reset supply temperature
MIN TEMP OF UNCOOLED ZONES	Deg F	Used to reset supply temperature
ECONOMIZER DAMPER	% RETURN	Damper position; outgoing signal calculated from this
ECONOMIZER CLOSE DOWN	Command	OUTSIDE or RETURN
FAIL SAFE	Command	ON or OFF
SAT SP(REAL #S)	Deg F	Same as SAT SP except can be used in calculations
STATIC PRESS	" W.C.	Duct static pressure
VFD SPEED SIGNAL	%F.S.	0-60 Hz; outgoing signal

Table VI-4. EMCS Points Monitored in Controlled Case Study.

Point Name	Description
66A1 KWH	FEEDER 66A1 KILOWATT HOURS
66A3 KWH	FEEDER 66A3 KILOWATT HOURS
ARU2 KWH	CHILLER-2 KILOWATT HOURS
ARU2 LOAD	CHILLER-2 LOAD SIGNAL
BLDG OCC	BUILDING OCCUPANCY FLAG
CHW OPT S/S	CHW OPTIMAL START/STOP
CHW OPT TMR	CHILL WATER OPTIMAL TIMER
CHW OPTMIN	CHILLER OPTIMAL MIN FROM ZAT
CHWR TEMP	CHILL WATER RETURN TEMP
CHWS TEMP	CHILL WATER SUPPLY TEMP
CT1 CWR	CONDENSER WATER RETURN TEMP
CT1 CWS	CONDENSER WATER SUPPLY TEMP
CT1 CWS SP	CT1 CONDENSER WATER SETPOINT
GP1 MINUTES	GP-1 MINUTES OF RUNTIME
GP1 RUNTIME	GP-2 HOURS OF RUNTIME
GP1 S/S	GP-1 START/STOP (CHWP)
GP2 MINUTES	GP-2 MINUTES OF RUNTIME
GP2 RUNTIME	GP-2 HOURS OF RUNTIME
GP2 S/S	GP-2 START/STOP (CHWP)
HIBAY OVR	HIGHBAY AFTER HOURS OVERRIDE
OAT	OUTSIDE AIR TEMPERATURE
BL1 ECON	AHU S-1 ECONOMIZER DAMPER
BL1 KWH	AHU S-1 KILOWATT HOURS
BL1 MAT	AHU S-1 MIXED AIR TEMP
BL1 MAT SP	AHU S-1 MIXED AIR SETPOINT
BL1 RAT	AHU S-1 RETURN AIR TEMP
BL2 S/S	AHU S-1 RETURN FAN START/STOP
BL2 STATUS	AHU S-1 RETURN FAN STATUS
BL1 SAT	AHU S-1 SUPPLY AIR TEMP
BL1 SAT SP	AHU S-1 SAT CALC SETPOINT
BL1 STATUS	AHU S-1 SUPPLY FAN STATUS
BL1 STP	AHU S-1 SUPPLY STATIC PRESS
BL1 STP SP	AHU S-1 STATIC PRESS SETPOINT
BL1 S/S	AHU S-1 SUPPLY FAN VFD S/S
BL1 SPEED	AHU S-1 VFD SPEED SIGNAL
ZONE 1 ZAT	ZONE 1 RM 139 ZONE TEMP
ZONE 2 ZAT	ZONE 2 HIGH BAY ZONE TEMP *NC
ZONE 2 ZSP	ZONE 2 HIBAY ZONE SETPOINT
ZONE 3 ZAT	ZONE 3 RM 139 ZONE TEMP *NC
ZONE 4 ZAT	ZONE 4 RM 221 ZONE TEMP

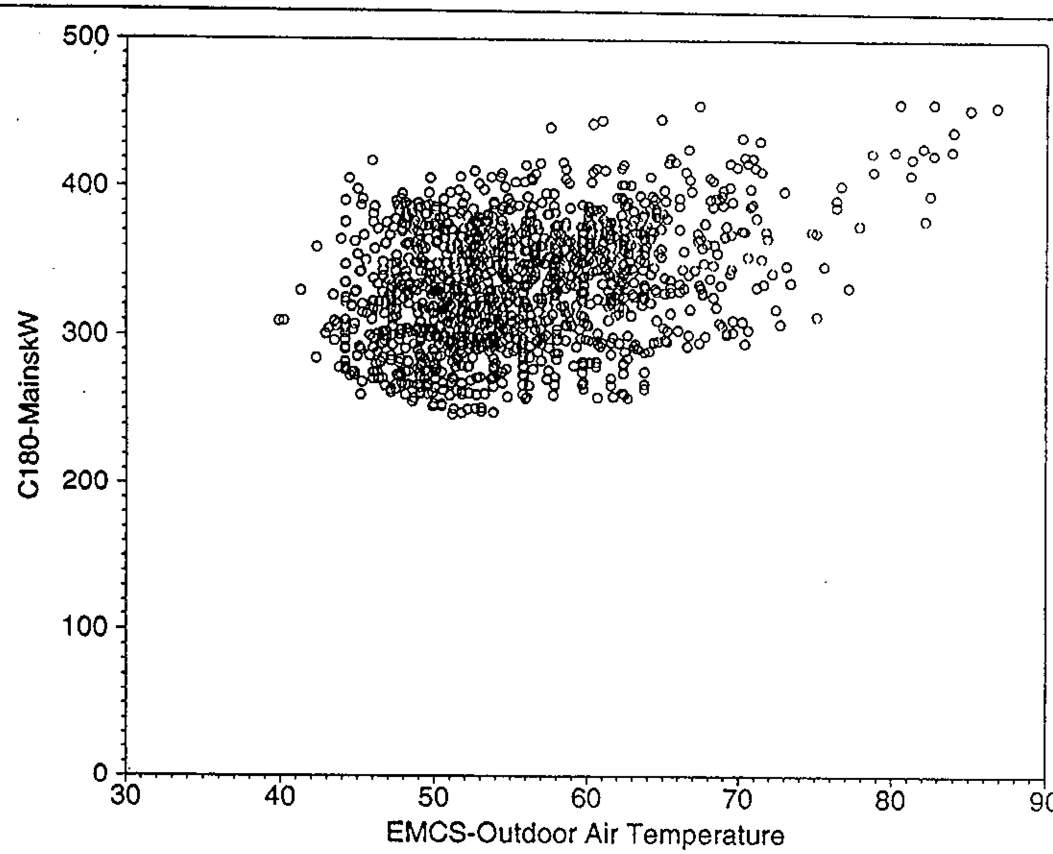

Figure VI-12. EMCS Occupancy Data. The EMCS has a point to indicate the occupancy mode of the building. During operating hours (7am to 8pm), this flag is set to one, and at other hours it is set to zero. It is set to zero during the weekend, but does not seem to be set to zero on holidays. The equipment takes this flag as a signal to turn on and off. During one period, this flag was set to one for an entire week, and the cooling equipment ran continuously for that week. Thus, it is not truly an indicator of occupancy, but will serve as a convenient indicator of when the equipment is operating and when it is not. This figure shows the whole-building consumption (measured by the dedicated monitoring) as a function of outdoor temperature (measured by the EMCS), for "Occupied" hours. One example of the use of this Occupied variable would be monitoring the average consumption of an end use only during operating hours.

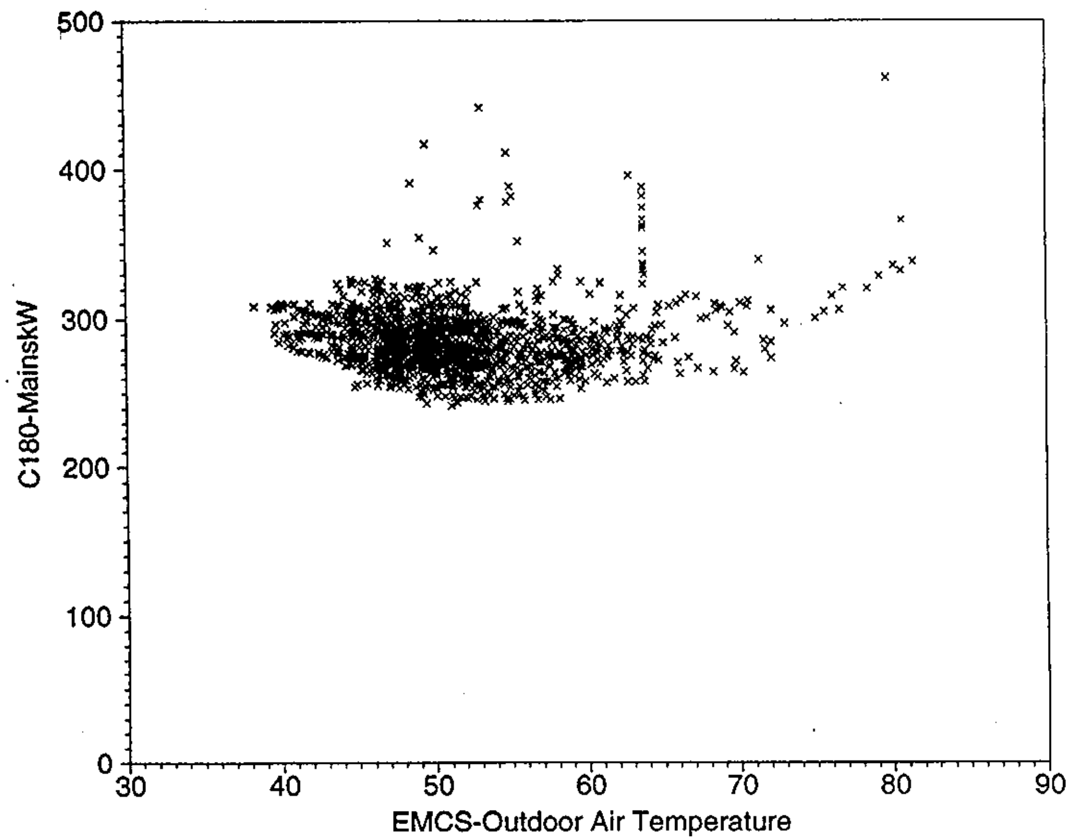

Figure VI-13. EMCS Occupancy Data (cont.). This figure shows the whole-building consumption (measured by the dedicated monitoring) as a function of outdoor temperature (measured by the EMCS), for "Unoccupied" hours. Clearly there is a very different pattern of consumption during the unoccupied hours—for example, there is much less scatter—although the consumption is still quite high.

AHU S-1.

This unit is to operate continuously. The variable frequency drive will modulate the fan speed to maintain a constant duct supply static pressure of .80" W.C.

The Heating control valve shall be modulated to maintain a supply air temperature set-point that will be reset based on the coldest space temperature of a non-cooled area. The coldest space temperature minimum shall be 70 deg. F. Nitesetback shall be brought on if the lowest zone (interior) temp is less than 68 deg.

The return dampers shall be controlled to provide an economizer cycle. The return dampers shall be fully open and the exhaust dampers fully closed whenever the heating valve is open. When no heating is required, the dampers shall modulate to maintain a mixed air temperature setpoint. The mixed air setpoint shall track the supply air setpoint. The economizer cycle shall be in effect until the outside air temperature is greater than return air temperature. When this occurs, the return dampers shall be fully open and the exhaust dampers fully closed.

HV-2,3

HV-2 and HV-3 serve the high bay area. These units shall be started and stopped based on an optimal Start/Stop routine that will bring zone temperature to 70 deg F on week-days and 60F during unoccupied hours. The zone thermostat will have an occuppied override switch to control HV units during unoccupied hours. Run times for HV-2 and HV-3 will be kept. The occupancy schedule for HV-2,3 will be Monday thru Friday, 8am - 5pm.

CHILLED WATER SYSTEM

The chilled water system shall be operational during the hours of 7am to 8pm. Chiller shall have Auto/Manual switch to allow local operator to Start/Stop. When in manual, control will fall back to original chiller controls.

Chiller start will be based on an optimal start routine that monitors the temperature of cooled spaces and energizes the cooling equipment such that the warmest cooled zone-1,4,8,9 is below 76 deg F by 7am. The chilled water system shall be deenergized when the economizer section can provide enough cooling to maintain warmest cooled space

Figure VI-14. Sequence of Operations for EMCS in Case Study Building. The expectations from the Sequence of Operations, the text that describes how the EMCS was to be programmed. The intended operation of the EMCS was well specified, and the operational data collected by the EMCS can confirm this sequence.

below 76 deg F.

One chilled water pump shall be energized whenever cooling is required. The lead chilled water pump shall alternate daily. Proof of new lead chilled water pump must be established before shutting off lag chilled water pump. If lead chilled water pump fails, the second pump will be energized and the alternating routine disabled until the failure is corrected. Chiller will be energized once operation of chilled water pump is confirmed.

Chilled water setpoint from Energy Management System. Setpoint will be reset to maintain the warmest cooled zone below 76 deg F. When on manual control, setpoint will be fixed at chiller. Low limit chilled water setpoint shall be 45 deg. F.

Chiller KWH will be collected. Also runtimes for chilled water and condenser water pumps will be kept.

CONDENSER SYSTEM

The tower fan shall be started and stopped to maintain a condenser water supply setpoint of 75 deg.

HOT WATER SYSTEM

The hot water system shall be operational during occupied hours, and whenever Fan S-1 and hot water valve is open. During unoccupied hours, the system shall be operational only when the coldest heated zone falls below 68 deg F.

The system shall be started based on an optimal start routine. Boiler 1 shall be energized and via its internal controls will maintain hot water supply setpoint (set at boiler). If boiler 1 is unable to maintain setpoint of 175 deg F., as sensed by hot water supply temperature, boiler 2 will be energized.

The domestic hot water (DHW) and industrial hot water (IHW) are heated from the primary hot water loop. The hot water setpoint shall be reset to maintain the coldest uncooled zone above 70 deg F. If the temperature of the DHW drops below the DHW setpoint of 120 deg F. or the IHW drops below the IHW setpoint of 150 deg F., the setpoint reset program shall be overridden and the boilers controlled to maintain 10 degree increase in hot water supply temperature until both the DHW and IHW setpoints have been met. The control valves to the DHW and IHW heating loops shall be closed during unoccupied hours. Valves will modulate to maintain DHW and IHW during occupied hours.

Figure VI-14 (cont.) Sequence of Operations for EMCS in Case Study Building. The expectations from the Sequence of Operations, the text that describes how the EMCS was to be programmed. The intended operation of the EMCS was well specified, and the operational data collected by the EMCS can confirm this sequence.

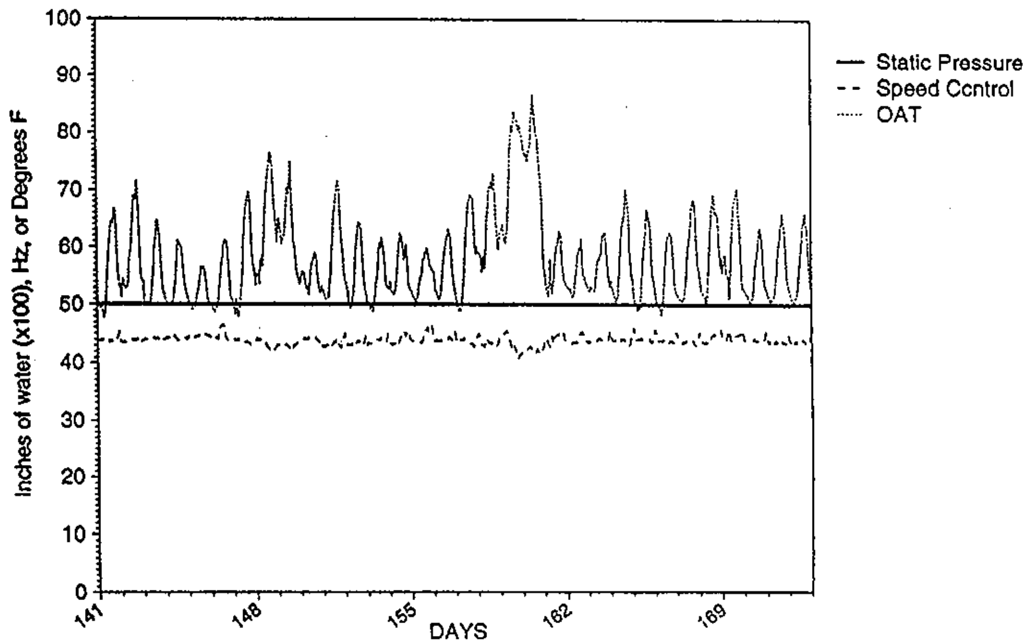

Figure VI-15. EMCS Operational Data: Fan Control. It may be easier to diagnose operational problems from EMCS-collected operational data than from consumption data. For example, many of the monitored points can be compared with the expectations from the Sequence of Operations (shown in Figure VI-14). This figure shows control of the supply fan. Although a variable frequency drive was installed, the system is constant volume, and the drive is used simply to reduce the flow of an oversized fan. According to the Sequence of Operations, the fan should run continuously, and maintain a static pressure of 0.8 inches of water. As the graph shows, the static pressure is a constant 0.5 inches, rather than 0.8 inches. This is because the pressure reduction from removing the fan inlet vanes was greater than expected, resulting in the ability to operate at with a lower static pressure setpoint, and more savings from the retrofit than anticipated. The monitored value of the static pressure was always 0.5 inches, although it varied somewhat around that value. The system did not report sufficient significant digits to determine static pressure more accurately. After this was pointed out to the EMCS operator, the format was changed for the point to show more significant digits. This does not affect the operation at all, just the output format. The speed control to the VFD on the supply fan was fairly constant.

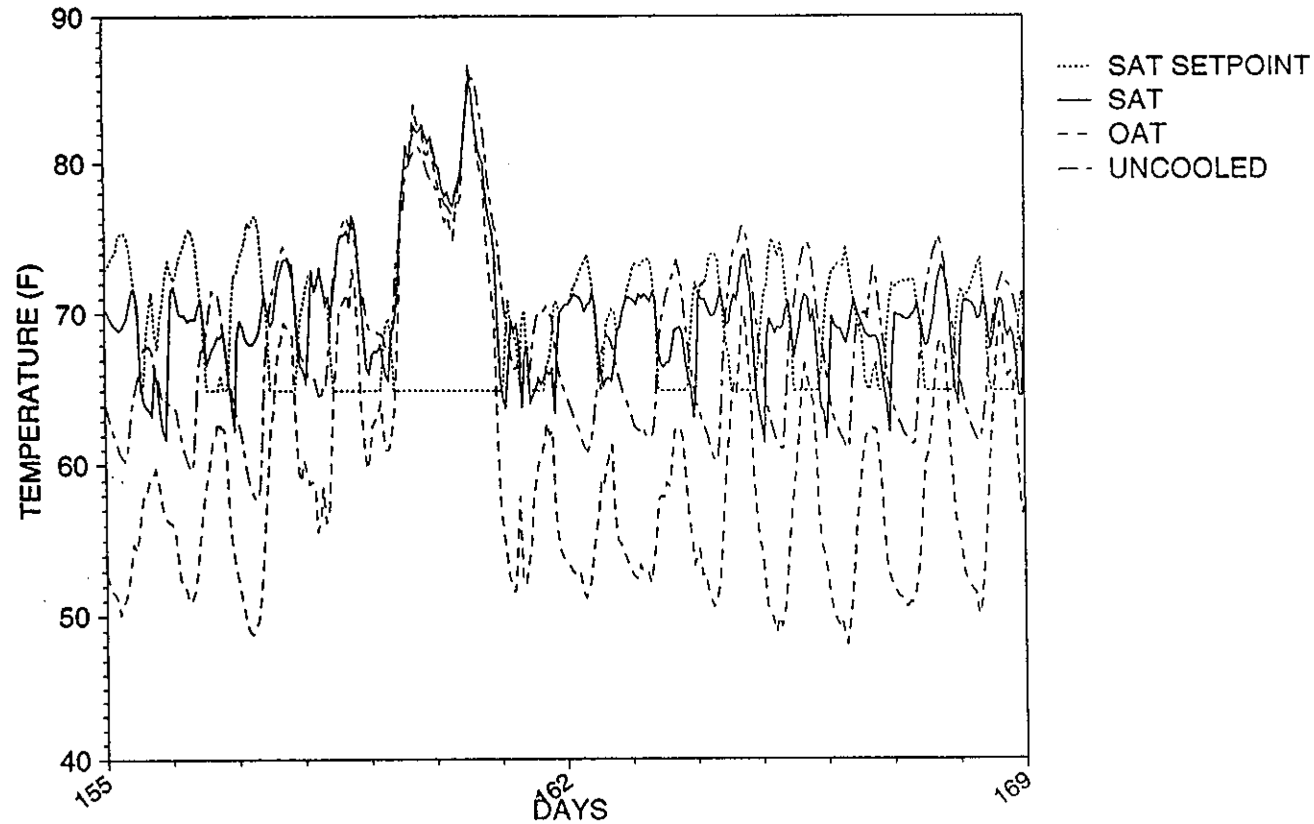

Figure VI-16. EMCS Operational Data: Supply Temperature Control. According to the Sequence of Operations, the supply air should be heated to maintain the coldest space temperature in an uncooled zone at or above 70°F during the day, and 68°F at night. The supply air is never cooled. The supply air temperature setpoint was a constant 65°F during the day, except for the very coldest days, when it rose during the day. At nights, the temperature setpoint rose to about 75°F. The actual supply air temperature was always between about 60°F and 70°F, except on the two very warm days, when it is expected to rise (since it is not cooled). The zone temperature (this is only one of the uncooled zones—not necessarily the coldest) was below 70°F on weekends, and sometimes went well below 68°F during weekdays as well.

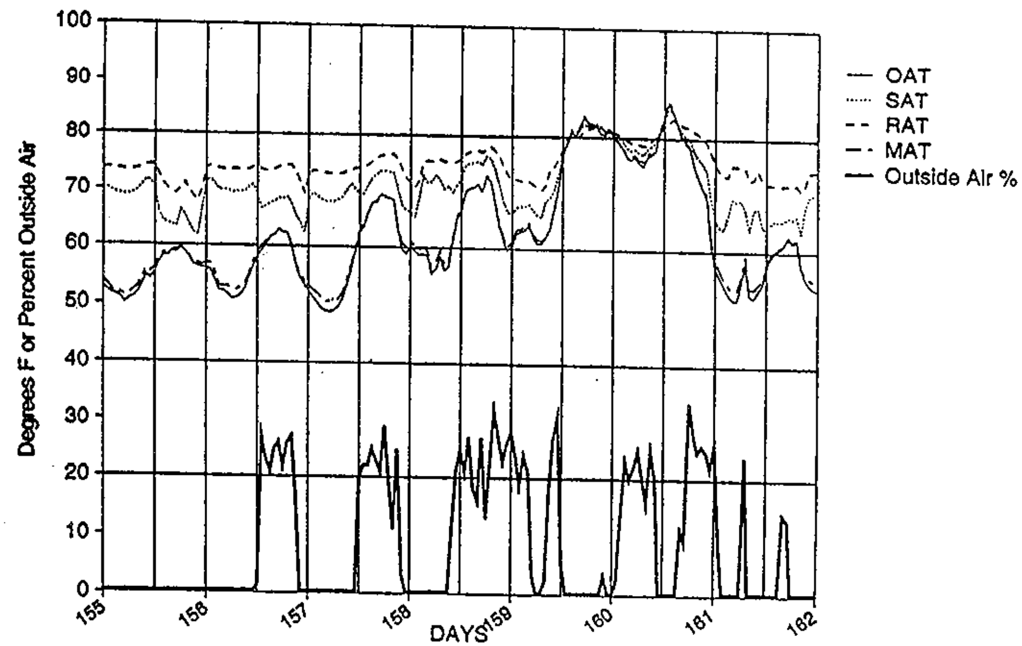

Figure VI-17. EMCS Operational Data: Economizer Control. Since there is no cooling, when there is no heating the mixed-air temperature (MAT) setpoint should track the supply-air temperature (SAT) setpoint. The economizer should be at the minimum outside air setting when the building is being heated, and when the outside air is warm enough, it should modulate open to maintain the mixed air temperature at the supply air temperature setpoint. When the outdoor-air temperature (OAT) is greater than the return air temperature (RAT), the outside air dampers should close, and again bring in minimum outside air. Since the supply air is not cooled, the outdoor air temperature will essentially never be above the supply temperature, and this is clearly seen for the two warm days, when the outdoor, mixed, supply and return air streams are all at about the same temperature. As expected, whenever the outdoor air is warm—above about 60°F—the fraction of outside air climbs. When the outdoor air is too hot—above about 80°F—the fraction again drops to the minimum, as expected. However, it is surprising that the mixed air and outdoor air temperatures are always so similar. This is not what one would expect for economizer operation, and may suggest operational problems.

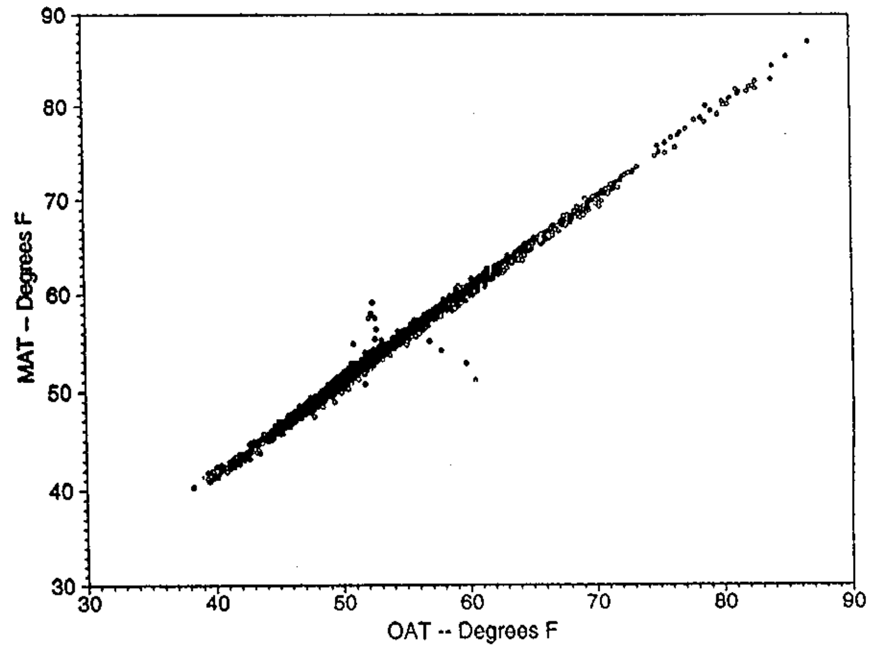

Figure VI-18. EMCS Operational Data: Economizer Control (cont.). This graph shows the striking correlation between mixed air and outside air temperatures throughout the monitoring period, over a wide range of temperatures. This indicates some sort of problem: the mixed air temperature should equal the outside air temperature when the economizer is on full outside air operation. However, when the economizer is off—when the it is cold outside and outside air is at a minimum—the mixed air temperature should be somewhere between the outside air temperature and the return air temperature (since it should be a mixture of the two). Two possible problems that could cause data such as these are incorrect sensor placement—perhaps the mixed air sensor is placed in the wrong run of duct—or faulty operation of the economizer dampers. Recall that the outside air fraction is a control signal sent to the dampers, not a verification of actual outside air fraction, so that it is not known for sure that the dampers are responding to the signal. Unfortunately, no data on the heating side had been collected, and with the existing data it was impossible to determine whether the fault was in the sensor or the economizer. However, since this EMCS always has access to hourly data for all points, for the previous 24 hours, it was possible to go back and review the previous day's operation.

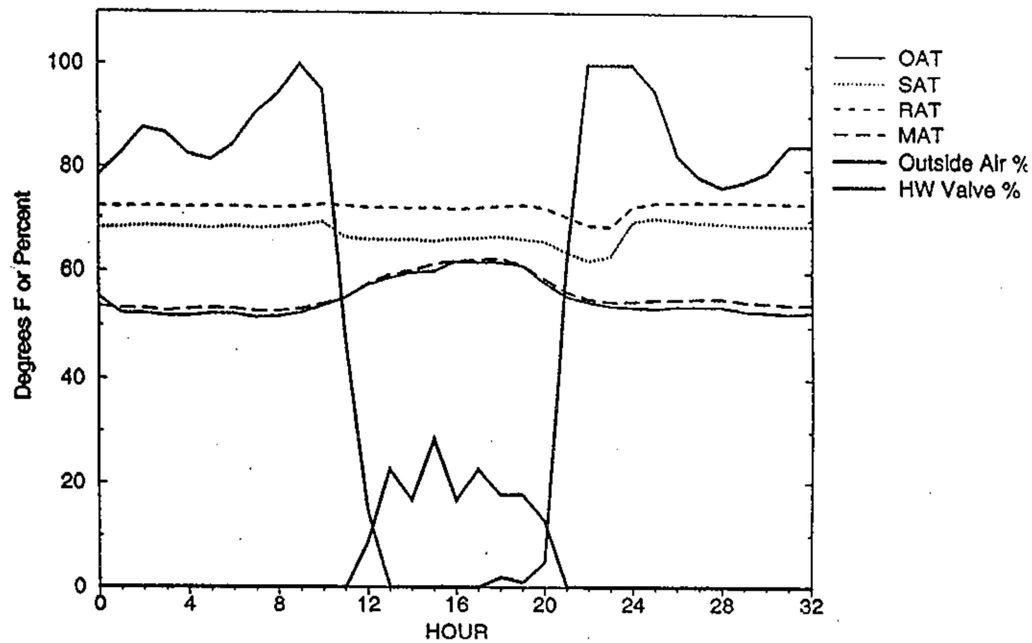

Figure VI-19. EMCS Operational Data: Economizer Control (cont.). One day of data, including the position of the heating control valve. At times when the economizer called for minimum outdoor air, the heating was almost fully on. This suggests that the building received significant outside air even when the economizer control called for minimum outside air. After reviewing this with the shared savings project manager, and reviewing the building's mechanical plans, it was discovered that the building is actually designed to operate with a large amount of outside air, because a large fraction of the floorspace is laboratories with their own exhaust system. The outdoor air intake and supply fan are sized for 100,000 cfm, while the return fan and recirculating dampers are sized for only 20,000 cfm. When the EMCS indicates "100% return," this actually means that the building is operating with 80% outside air. This illustrates the usefulness of having one day of hourly data collected automatically for all points, but also illustrates the difficulty in evaluating measured data, and the need to truly understand the particular building.

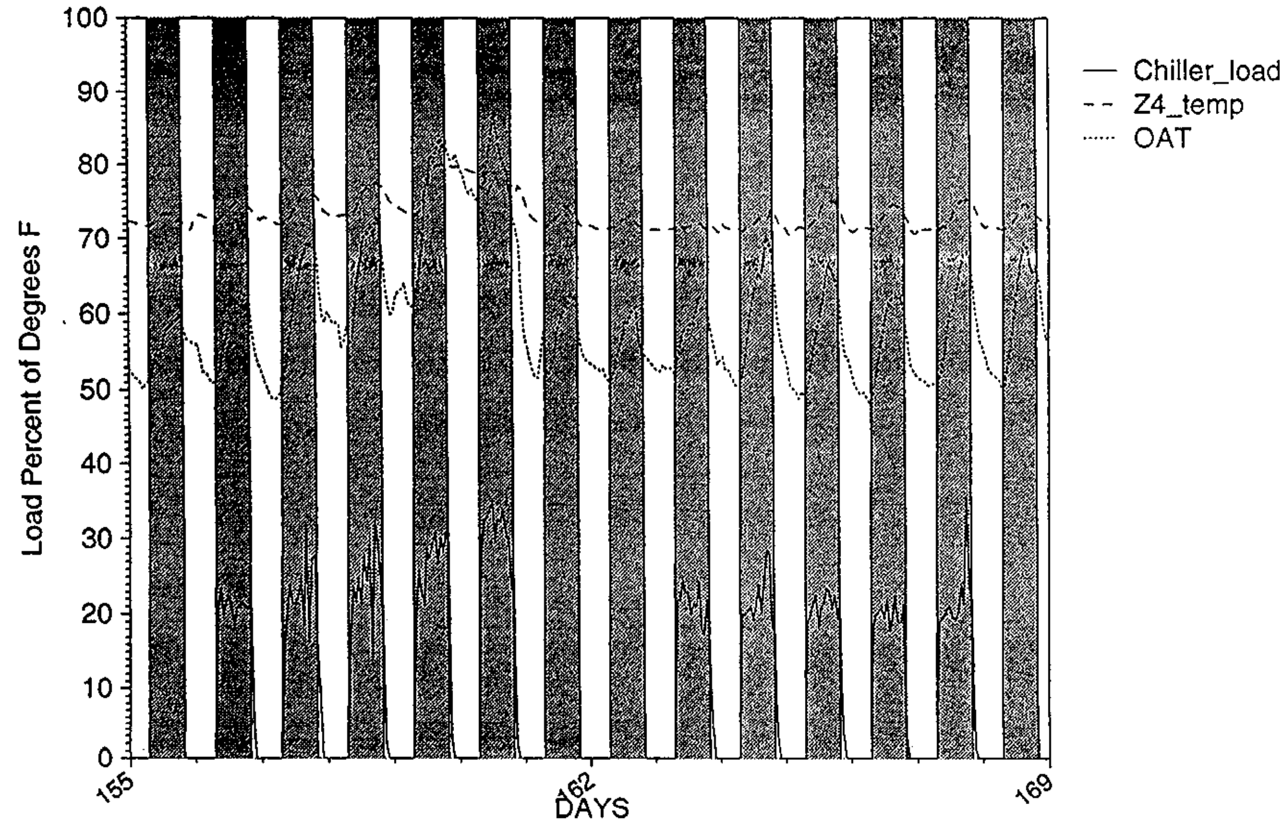

Figure VI-20. EMCS Operational Data: Optimal Stop and Start Control. According to the Sequence of Operations, the chilled water system should operate between 7am and 8pm. Optimal start should ensure that the temperature in the warmest zone (1, 4, 8 or 9) is below 76°F by 7am. The shaded periods in the figure correspond to the occupied period, as indicated by the "Occupied" variable. The chiller loading, (a calculated output), and one of the zone temperatures are shown, as is the outdoor air temperature. The temperature in the occupied zone is above 76°F in the morning only on one day, when the nighttime temperature was unusually high. The temperature that morning was about 79°F. The chiller did not turn on any earlier that morning, indicating that optimal start was not invoked, or that it was not dynamically invoked to start earlier when an unusually warm night occurred. The call for cooling was always zero during unoccupied hours.

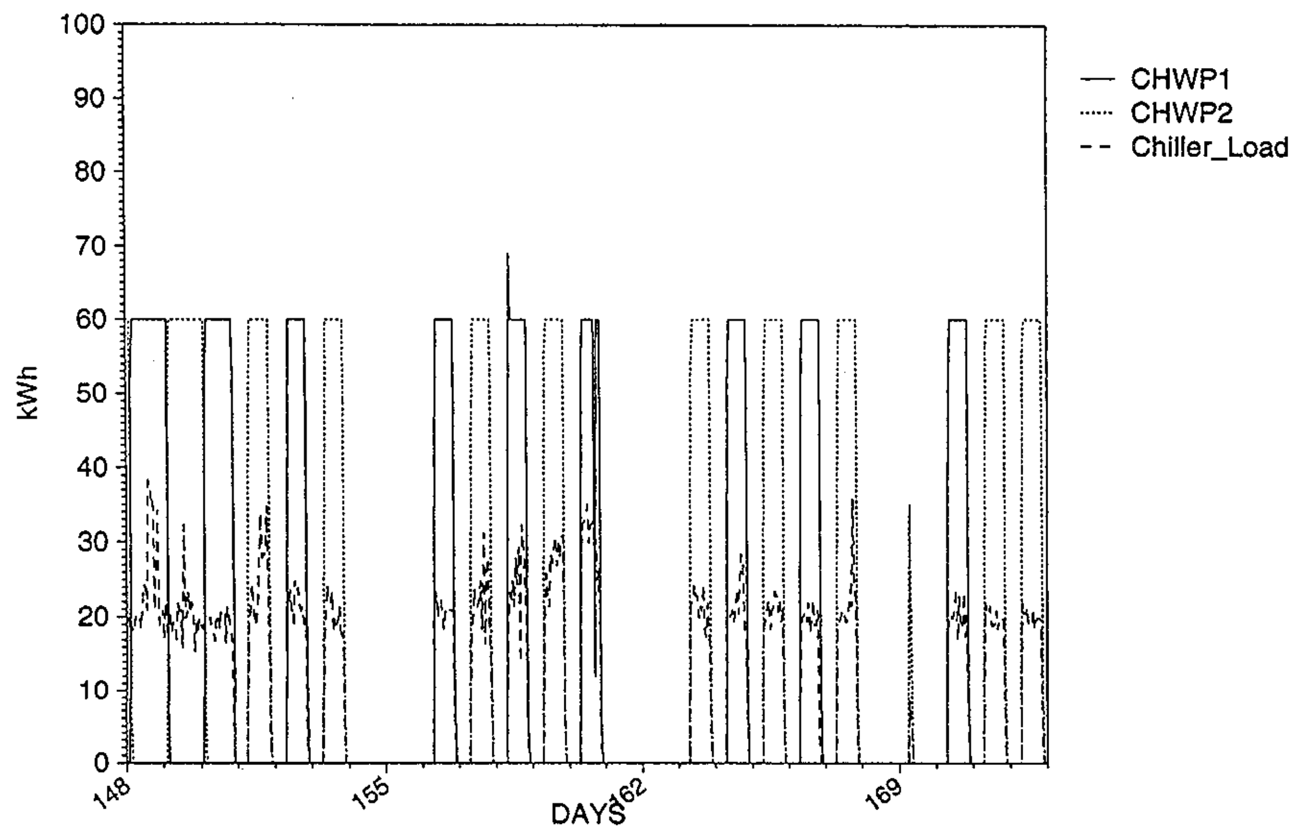

Figure VI-21. EMCS Operational Data: Chilled Water Pump Control. According to the Sequence of Operations, the pumps should operate only when cooling is required, and the two pumps should alternate daily. The figure confirms both characteristics of operation, as the pumps never operate when there is no call for cooling, (indicated by the chiller load point), and they alternate daily.

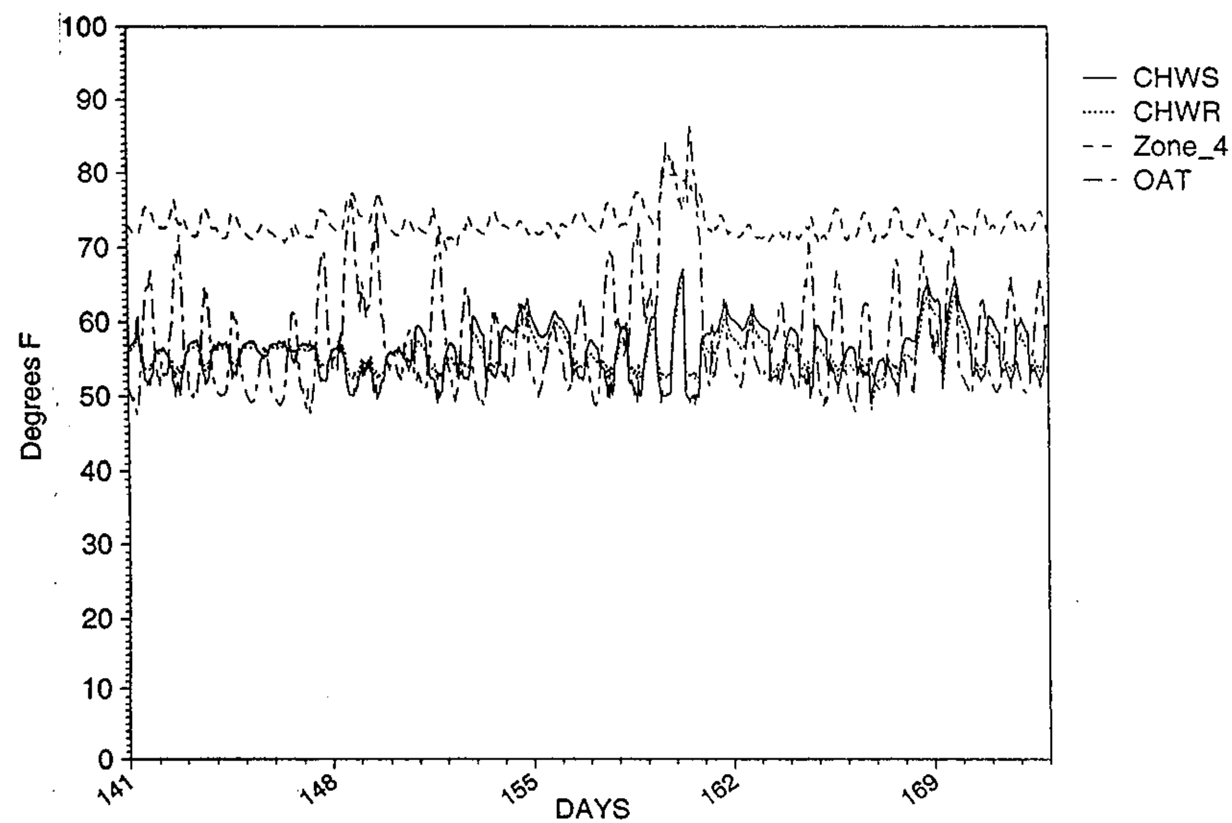

Figure VI-22. EMCS Operational Data: Chilled Water Supply Temperature Control. According to the Sequence of Operations, the setpoint should maintain the lowest cooled zone temperature below 76°F, and the chilled water temperature should not go below 45°F. The figure confirms this, as the chilled water supply temperature was never below 45°F, and the zone temperature was almost always below 76°F. It rose to almost 80°F during the warmest day.

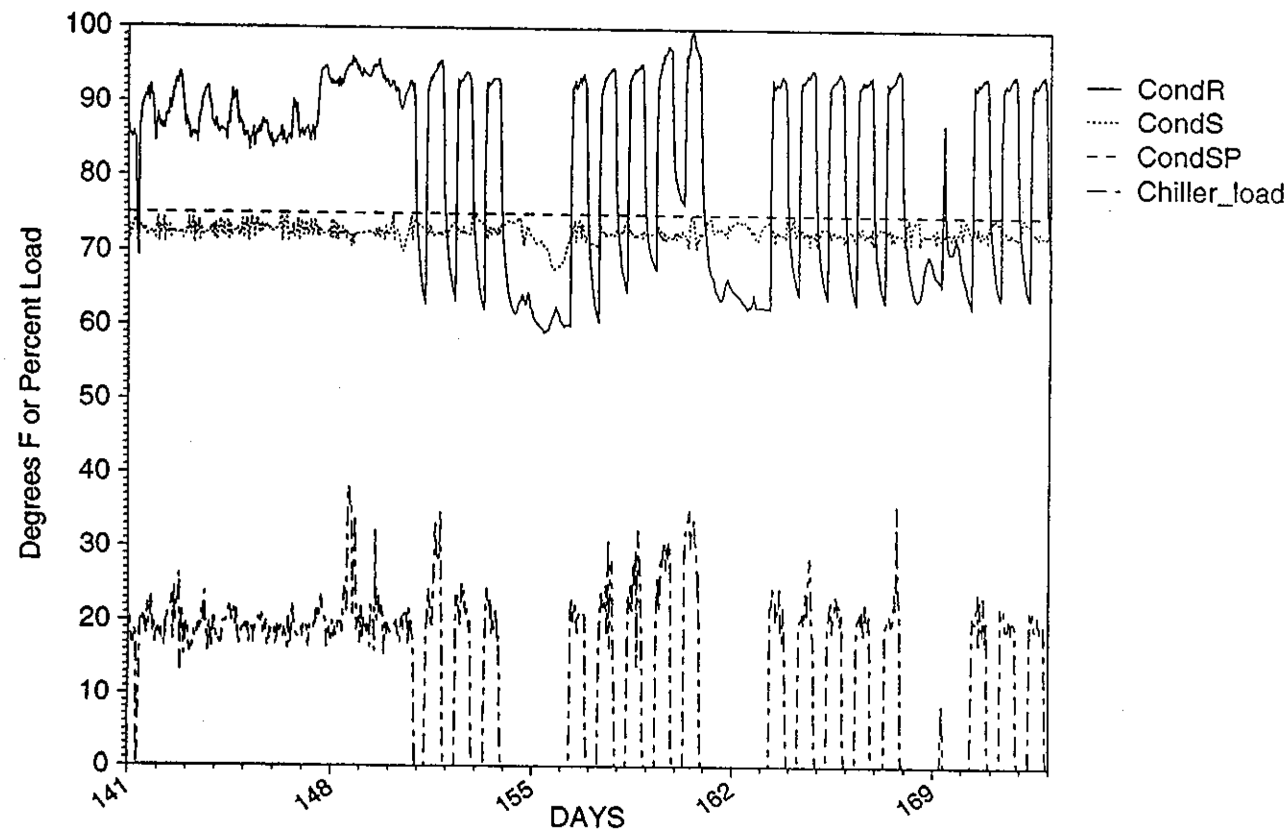

Figure VI-23. EMCS Operational Data: Cooling Tower Control. According to the Sequence of Operations, the cooling tower fan should maintain the condenser water supply temperature at 75°F. The condenser supply temperature appeared to be very well controlled, but it was always offset several degrees below the setpoint. **In this figure, one week can be seen where the cooling system was overridden and left on for an entire week.**

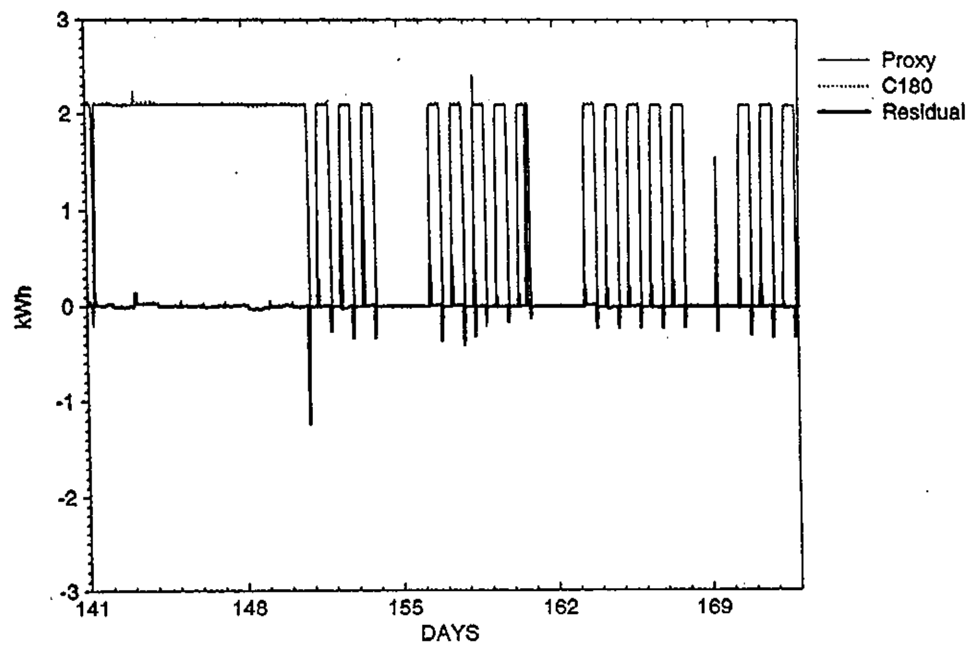

Figure VI-24. EMCS Proxy Measurement: Chilled Water Pump. If power consumption data are not available, it is sometimes sufficient to monitor a proxy for the consumption. Here, chilled water pump status is being used as a proxy for pump energy consumption. (Note that the pump status is an output signal, not an input signal). It is possible to use status as a proxy because the pumps are assumed to be a constant load. The first day of the dedicated monitoring was used to provide a scaling factor. Data collected while the pumps were running were used to calculate this scaling factor, which was 2.09 kWh for each hour of operation. After calculating this scaling factor from the dedicated monitored data for a short period of time, it was applied to the rest of the status data. Here, the consumption measured by the dedicated monitoring is marked "C180" and is indicated by a dotted line. The calculated proxy for the consumption is a thin, solid line. The error (or residual) resulting from using this proxy is indicated with the thicker line. This proxy was a very good indicator of energy consumption, except during the "shoulder" hours, during which the equipment turned on or off.

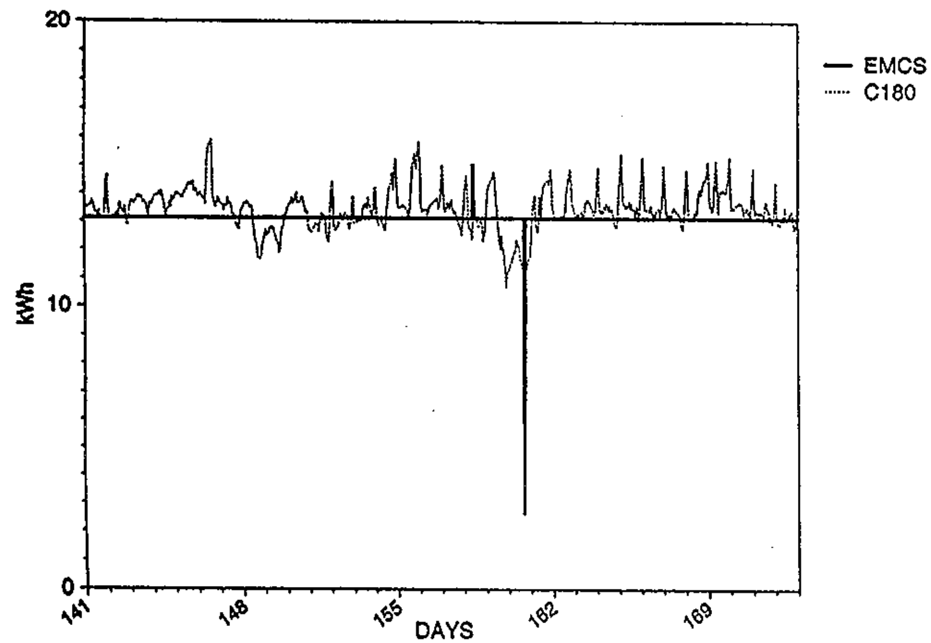

Figure VI-25. EMCS Proxy Measurement: Supply Air Handling Unit. A proxy calculation, similar to that shown in Figure VI-24, is here shown for the supply air fan. A scaling factor of 113.1 kWh was used. Although the fan has a variable-speed drive, it is used in a constant-volume distribution system, so the flow does not vary much. The proxy does represent the overall level of the consumption, but it misses the smaller variations in the consumption. Since the status variables are control outputs, they may be less reliable indicators of operation than actual measurements of operation. It is possible, for example, for the system to "think" it is turning the fan on and off, while in reality the relay is broken or the point is overridden. Can this type of point serve as a proxy for operation? This EMCS is equipped with "proof switches" for all major pieces of equipment, which should be more reliable indicators of whether or not a piece of equipment is on. Proof switches are often used with EMCSs to make absolutely sure that one piece of equipment is operating before another is turned on, for example making sure that a fan is running before opening a cooling valve, to prevent freezing of coils. In this example, the proof can either be current switches that make sure the fan is drawing current, or a flow sensor to ensure that there is actually flow. This EMCS used current switches as proof of fan operation. When status and proof points were compared for the return fan, the correlation was perfect. For the supply fan, however, there were two hours during which the system considered the supply fan to be operating, while the proof switch indicated that it was not operating. Where they exist, proof switches are more reliable for use in a proxy measurement.

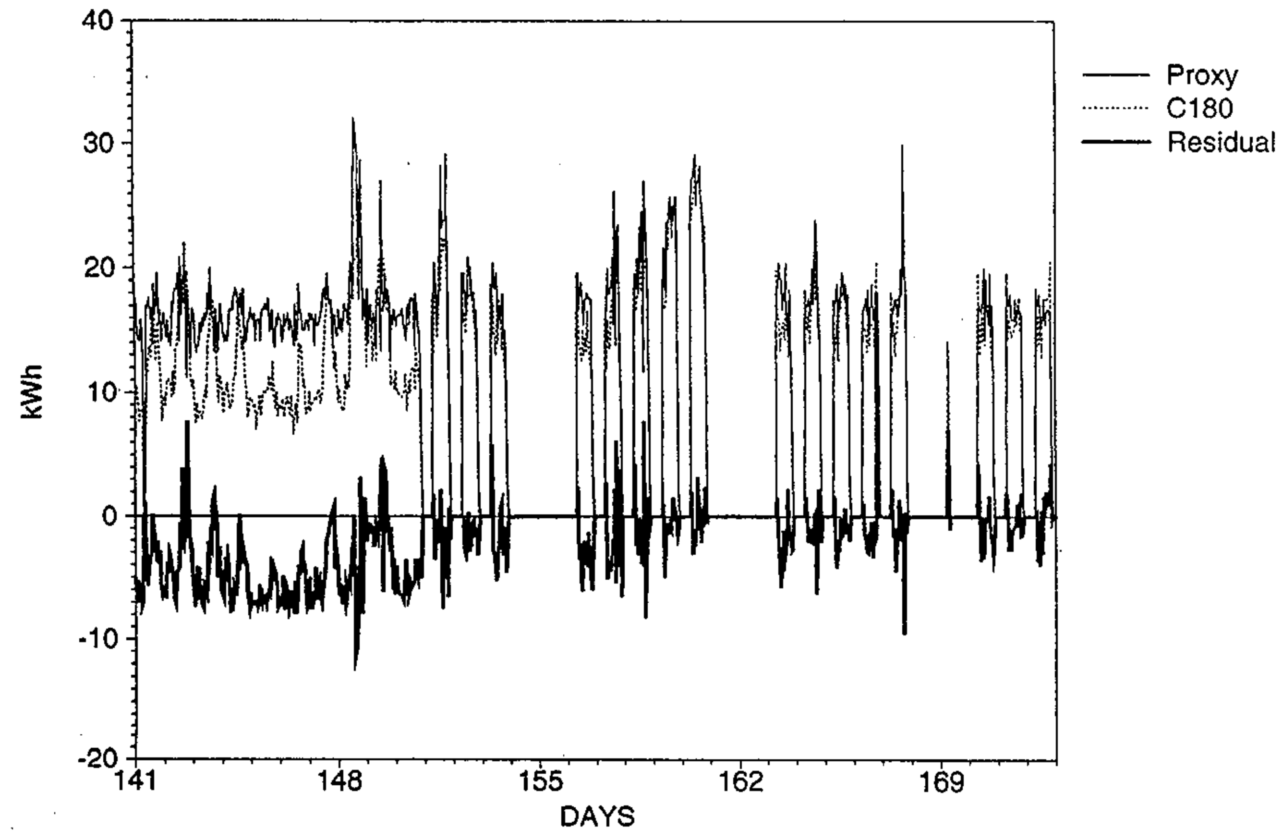

Figure VI-26. EMCS Proxy Measurement: Chiller. This figure shows a proxy for chiller energy consumption. The chiller is operated with a PID (Proportional-Integral-Differential) control loop, where the output control signal is based on the difference between the chilled water return temperature, and its setpoint. The output of this PID loop is the "chiller loading" signal, which goes out to the chiller (the chiller has a Honeywell controller of its own, and only required this chiller loading signal). This load signal might serve as a proxy for chiller consumption. This proxy should be multiplied by the chiller status variable, since it is possible for the PID loop to calculate a load while the system is actually turned off. The proxy was calculated by using one day of data collected by the dedicated monitoring to calculate a scaling factor. The averages used were 16.7 kWh, and 19.9% chiller loading, for a factor of 0.84kWh/%. As the residual indicates, the error in using this proxy is quite large during some hours.

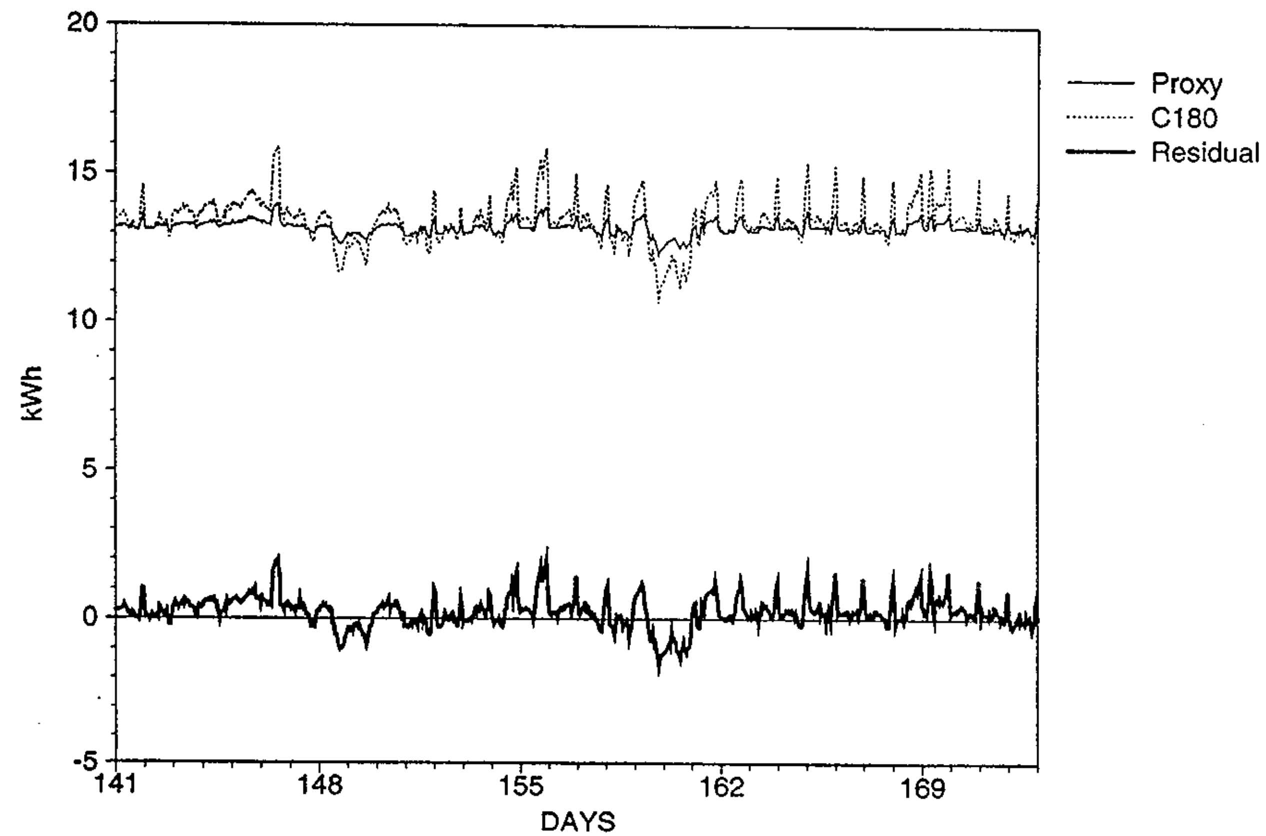

Figure VI-27. EMCS Proxy Measurement: Fan Speed Scaling. Another proxy that could be used to substitute for monitoring the supply fan consumption is speed control. This figure shows the result when the output speed control to the variable frequency drive (in Hertz) is scaled according to one day of monitored data, collected by the dedicated monitoring. Averages for the day were 13.0 kWh and 43.2 Hz, for a factor of 0.30 kWh/Hz. This does a much better job of capturing fluctuations than simply using the fan status. On average, the error was low, but when the consumption is much different from the mean, the error was largest. This suggests that a linear or polynomial regression may provide a better fit.

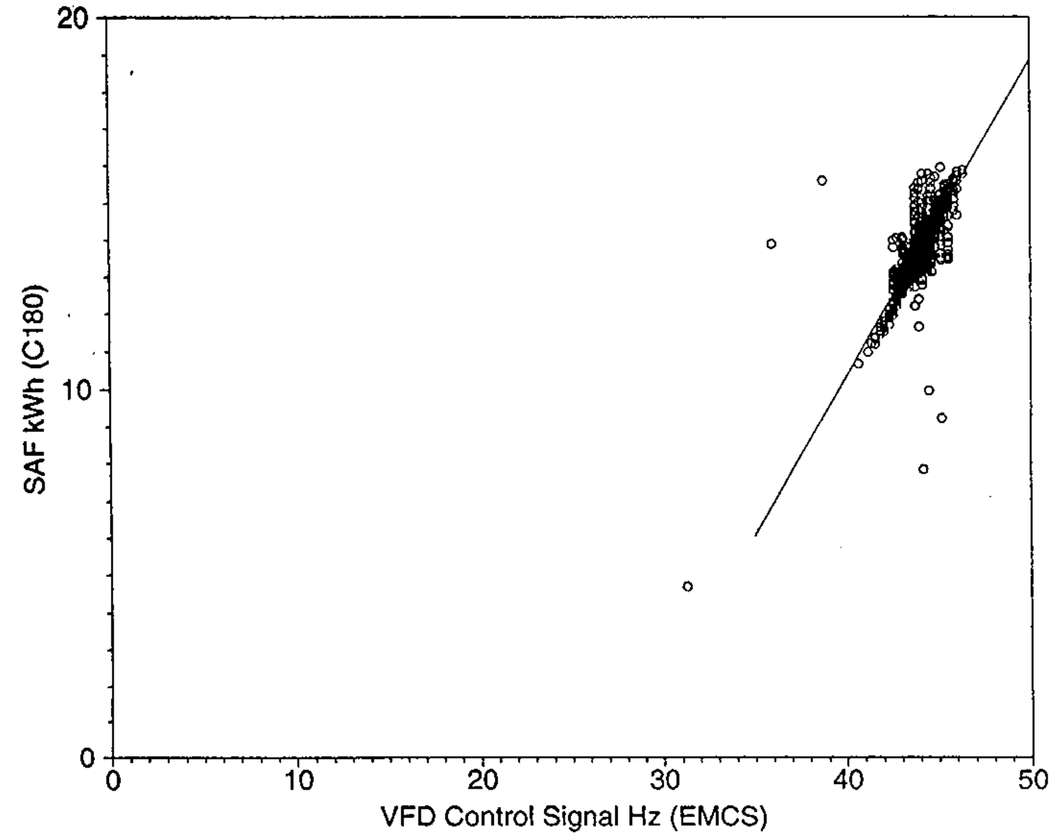

Figure VI-28. EMCS Proxy Measurement: Fan Speed Regression. As suggested in the previous graph, a simple scaling factor may not produce as good a proxy measure as a regression of fan kWh versus Hz, which is shown here. The best-fit line had a constant of -23.8 kWh, and a coefficient of 0.852 kWh/Hz. The R-squared of the fit was 0.76. A period of over 3000 hours of data collected by the dedicated monitoring were used to perform this regression. When only the first week of data were used, however, the best fit line was considerably different. When fewer data are used, therefore, one must make sure that a wide enough range of operation is included in the calculation.

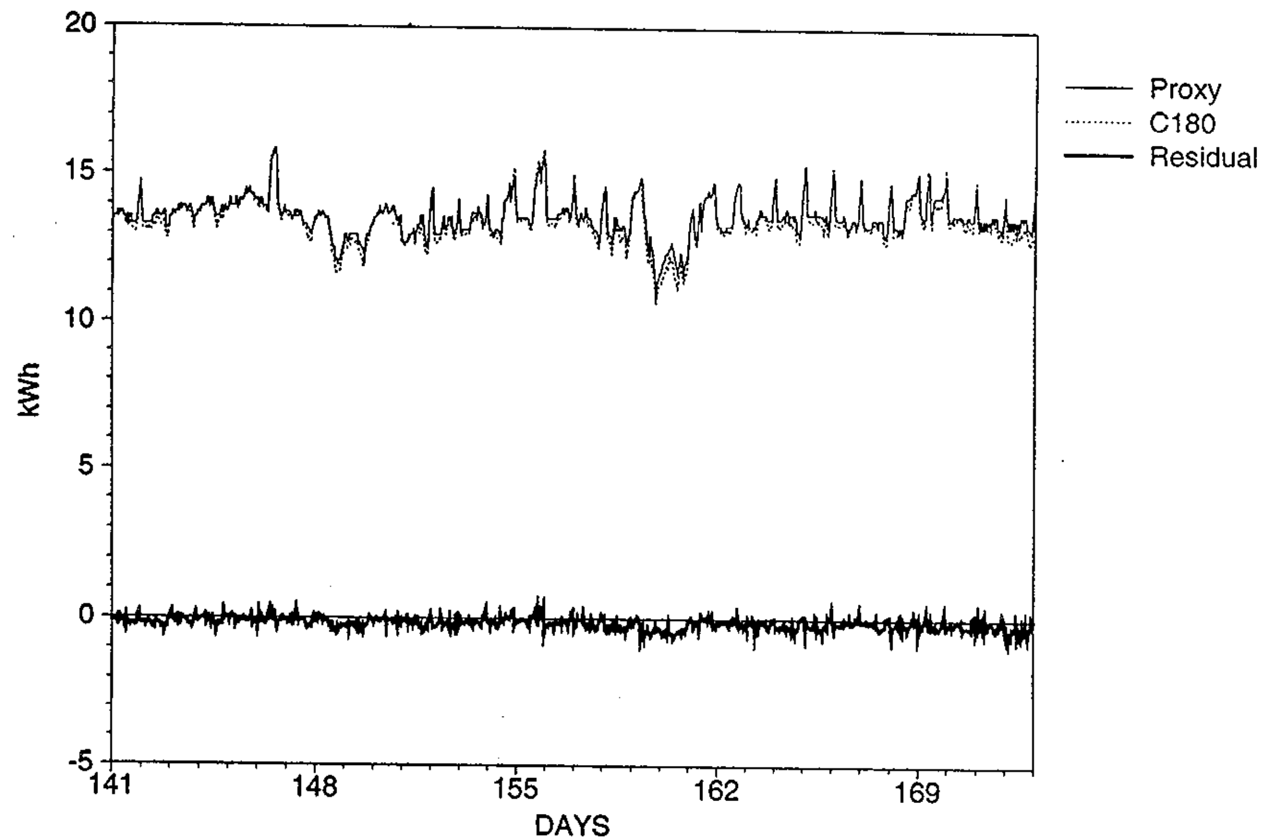

Figure VI-29. EMCS Proxy Measurement: Fan Speed Regression (cont.). The result of the proxy calculation with the regression based on the full data set, as shown in the previous figure. If the fan were operated over a wider range of speeds, one would probably want to perform a polynomial fit to the data, since fan power should vary with the cube of the flow (nominally). There is very good correspondence between the proxy and the measured quantities, although this must be traded off with the need for a large amount of data to perform the regression.

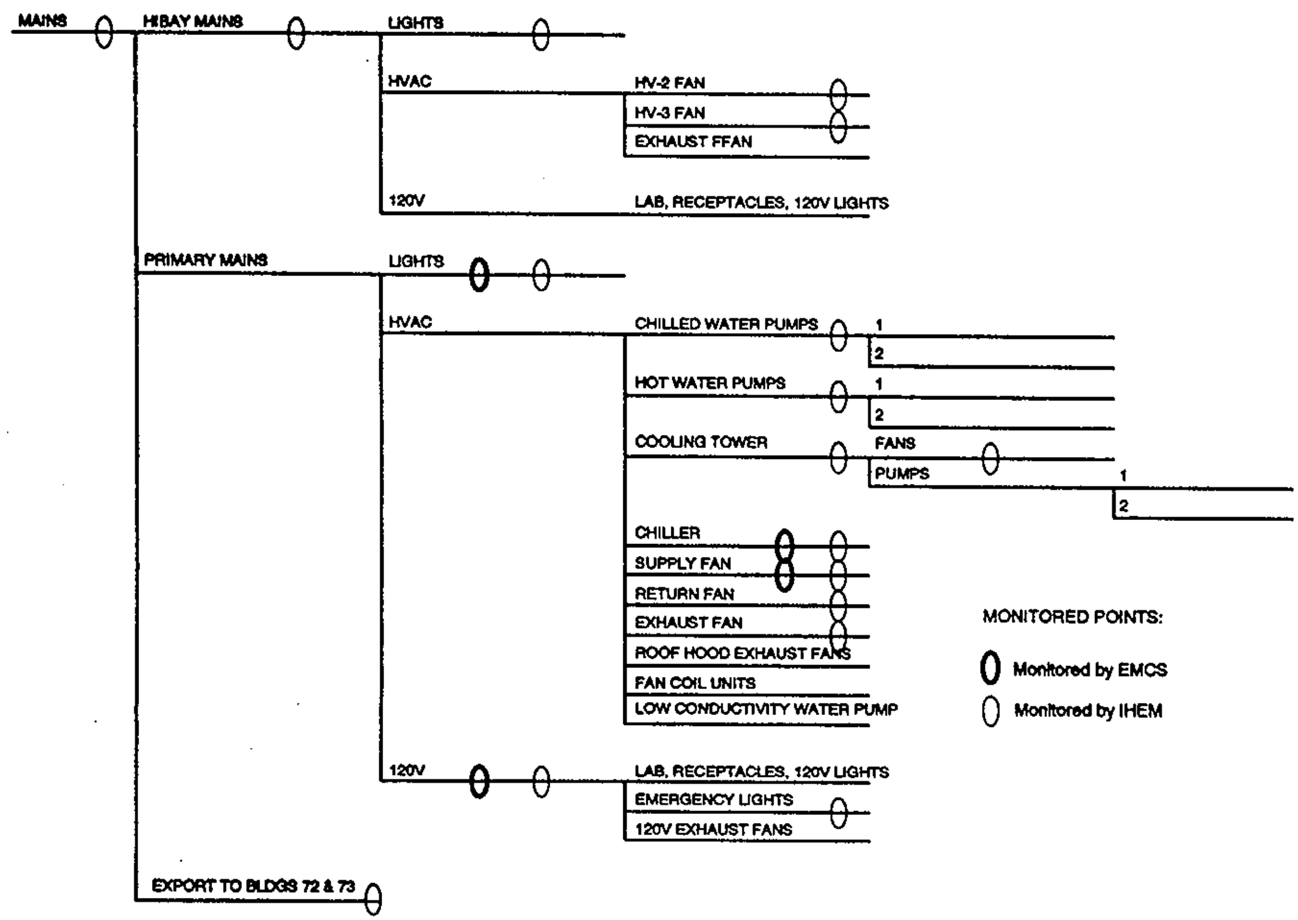

Figure VI-30. Measurement Points for EMCS and Dedicated Monitoring. The EMCS measured many of the same points as the dedicated monitoring, so a good comparison of the two methods was possible.

Table VI-5. Points Available on EMCS and Dedicated Monitoring in Case Study.

Equipment	Dedicated	EMCS
Mains & Misc	Whole Building kWh	-
	High-Bay kWh	-
	Feeder 66A1 (misc) kWh	DI: Feeder 66A1 (misc) kWh
	Export kWh	
Lighting	Main Building Lighting kWh	DI: Feeder 66A3 kWh
	High-Bay Lighting kWh	-
	Emergency Lighting kWh	-
Chiller	Compressor kWh	DI: Compressor kWh
	-	DO: Chiller Start/Stop
	-	AO: Chiller Load Signal
	-	AI: Chilled Water Supply Temperature
	-	AI: Chilled Water Return Temperature
	Chilled Water Pumps kWh	-
	-	DO: Chilled Water Pump 1 Start/Stop
	-	DI: Chilled Water Pump 1 Status
	-	DO: Chilled Water Pump 2 Start/Stop
	-	DI: Chilled Water Pump 2 Status
	Cooling Tower Fan & Pumps kWh	-
	-	DO: Cooling Tower Fan Start/Stop
	-	AI: Cooling Tower Water Supply Temperature
	-	AI: Cooling Tower Water Return Temperature
Fans	Supply Fan kWh	DI: Supply Fan kWh
	-	DO: Supply Fan Start/Stop
	-	DI: Supply Fan Status
	-	AO: Supply Fan VFD Speed Signal
	-	DI: Supply Fan VFD Fault
	-	AI: Supply Air Temperature
	Return Fan kWh	-
	-	DO: Return Fan Start/Stop
	-	DI: Return Fan Status
	-	AI: Return Air Temperature
	-	AI: Outside Air Temperature
	-	AI: Mixed Air Temperature
	-	AO: OA/RA Damper Control Signal
	-	AI: Static Pressure
	Exhaust Fan kWh	-
Heating/Ventilating Units	HV Unit 2 (Fans) kWh	-
	-	DO: HV Unit 2 Start/Stop
	-	DI: HV Unit 2 Status
	HV Unit 3 (Fans) kWh	-
	-	DO: HV Unit 3 Start/Stop
	-	DI: HV Unit 3 Status
Boilers	Boiler Pump kWh	-
	-	DO: Boiler 1 Start/Stop
	-	DO: Boiler 2 Start/Stop
	-	AI: Hot Water Supply Temperature
	-	AI: Hot Water Return Temperature
	-	AO: Hot Water Valve Control Signal
	-	DO: Hot Water Valve Failsafe
Domestic Hot Water	-	AO: DHW Valve Control Signal
	-	AI: DHW Supply Temperature
Industrial Hot Water	-	AO: IHW Valve Control Signal
	-	AI: IHW Supply Temperature
Zone Temperatures	-	AI: Zones 1-9 Tempertures
	-	DI: Main-Building Afterhours Override
	-	DI: High-Bay Afterhours Override

Since sensor specifications are not always the best way of reassuring oneself about sensor accuracy, the operations staff can point out which points they count on for accurate control, and which points they check. According to the EMCS operator, the points that are checked frequently are chilled water supply temperature, duct static pressures, pump status, and boiler water supply and return temperatures. These points may be more reliable than others. They do not regularly check any of the runtime or kWh data, so if there were problems with these points, they might not know about them.

One means of assessing 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 EMCS CTs. For the miscellaneous end-use channel, the CTs that were initially installed had too low a capacity for the power actually drawn. This caused the watt 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 eventually changed and the transducer replaced in mid-June, 1994.

In another example of giving the data a reality check, 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. Since the data looked too low to them, they investigated further and discovered 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 60Hz sine wave. Since the output of VFDs is not at 60Hz and not a smooth sine wave, they should not be measured on the output side, but 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, the correct size equipment 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. After inspecting the CTs on the chiller, it became apparent 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: a Dranetz 808 Electric Power/Demand Analyzer and an Esterline Angus A.C. Motor/Load Surveyor. The Dranetz meter collected data at a 15-minute interval and has an accuracy of ±0.8% of reading, or ±0.2% of full scale (Dranetz 1992). There were problems with the paper tape used to collect data on the Dranetz Analyzer, so the data were somewhat sporadic. However, they were sufficient to determine whether or not the meters were reading accurate data.

Figures VI-31 and VI-32 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

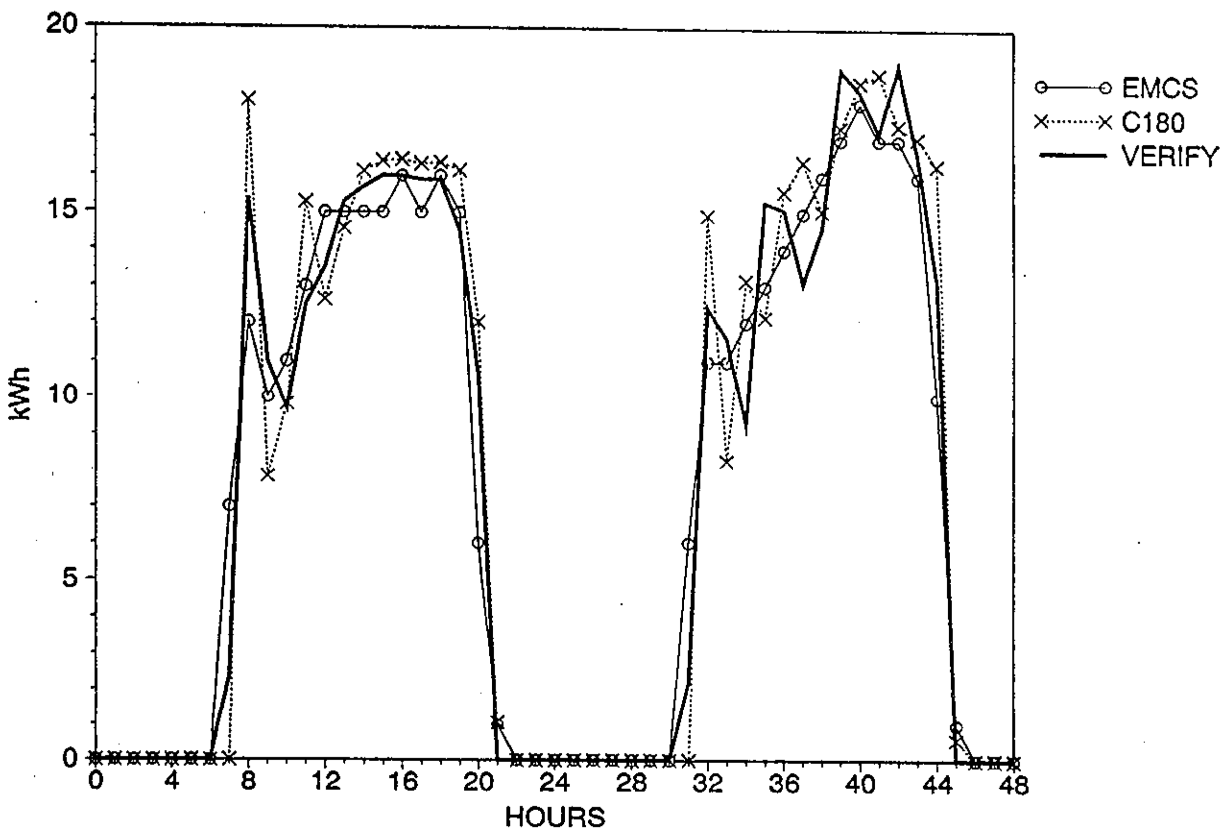

Figure VI-31. Verification of EMCS and Dedicated Monitoring for Chiller. A short-term datalogger was used to verify the data from the EMCS and the C180 dedicated monitoring. On the first day, the verification logger was a Dranetz Analyzer collecting 15-minute data. Thereafter, it was an Esterline Angus Load Surveyor collecting one hour data. The EMCS was not collecting reliable data.

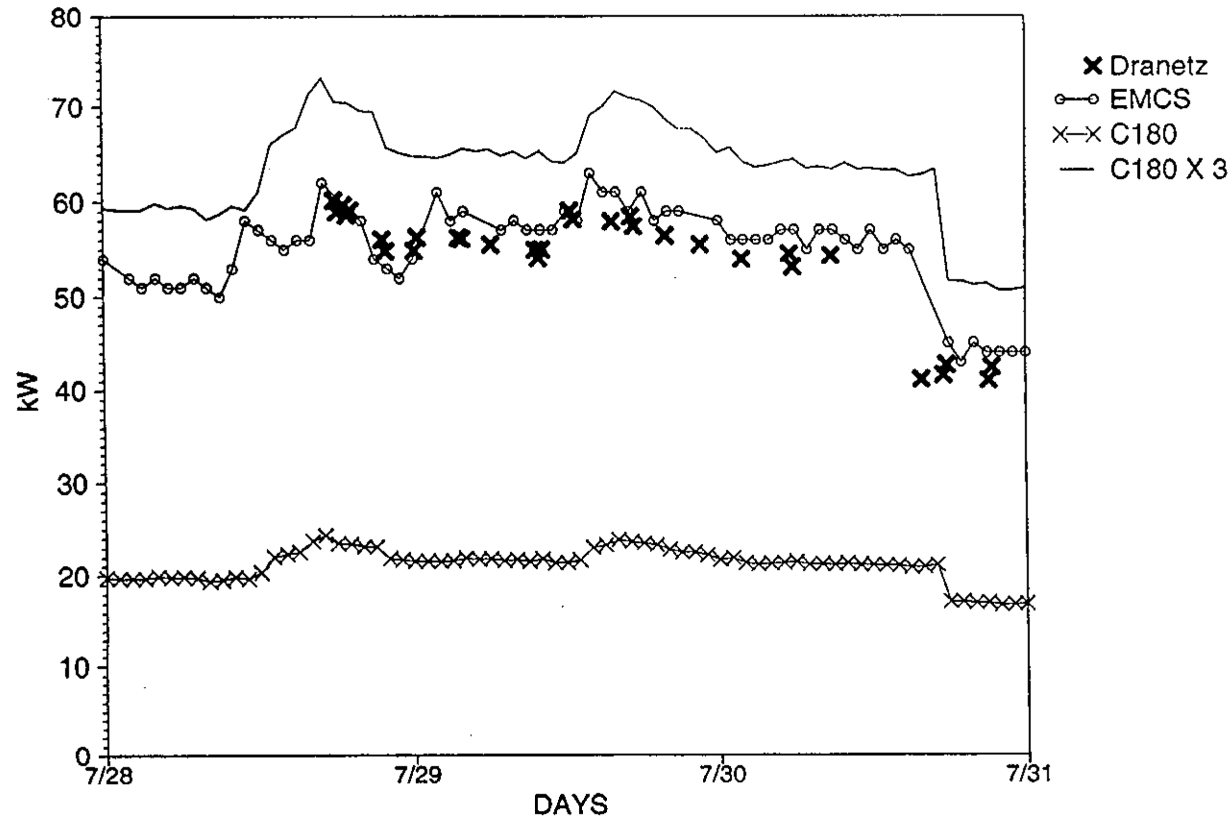

Figure VI-32. Verification of EMCS and Dedicated Monitoring for Miscellaneous. A Dranetz short-term datalogger was used to verify the data from the EMCS and the dedicated monitoring. The EMCS provided more reliable data than the C180 dedicated monitoring, because two CTs had been removed from the dedicated equipment. When scaled up by a factor of three, the C180 still was not correct.

verification monitoring. For the chiller, the data from the EMCS, the dedicated monitoring, and the verification monitoring were all fairly close. On an hourly basis, there was a ten percent difference between any two of the three. On a daily basis, however, the difference between the EMCS and the verification, and that between the dedicated monitoring were both about two percent.

For the miscellaneous end use, clearly the trends in the data were the same as those found in the dedicated monitoring data (see Figure VI-32). However, the magnitude of the data was about three times higher than the dedicated monitoring. When the verification monitoring was installed on the panel[2] 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 shows that the miscellaneous channel in the dedicated monitoring data dropped to a 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 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 ten percent difference on an hourly basis. If loads were balanced, it would be possible to multiply the data from one phase by a factor of three to estimate the full three-phase load. Figure VI-32 also shows the single-phase data multiplied by a factor of three, and the resulting power reading is quite a bit higher than the verification monitoring. Therefore, the phases are not balanced, and it would not be sufficient to monitor only one phase.

Verification monitoring was also performed for some of the zone temperatures. HOBO XT temperature microloggers (Onset, no date) with external thermistors were placed close to the EMCS temperature sensors in the four zones that are being monitored for this study. Each of these microloggers is capable of monitoring temperature in one location for 1800 readings: every 12 minutes for 15 days. The accuracy of the sensors is reported as ±0.2°C, or ±0.36°F, (about the same accuracy as the EMCS). Thus, they are not accurate enough to truly evaluate the accuracy of the EMCS sensors, but they are considered reliable, and can confirm that the EMCS value is near the expected value. In each of the three offices, permission of the occupants had to be obtained to place the sensors. Figures VI-33 and VI-34 show the data for one uncooled space, and one cooled space. The temperatures matched quite well for the uncooled space—within a few percent—but the temperatures for the cooled space show significant deviations both in magnitude (the micrologger measured approximately two degrees less than the EMCS) and in responsiveness. Some of the difference may be because 12-minute data are being compared with hourly data, or there may be problems with the location of the sensor. Since the microdatalogger has about the same stated accuracy as the EMCS, one can not necessarily conclude that the EMCS sensors are faulty or miscalibrated.

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 that was encountered with the dedicated monitoring was that it was discovered after several months of monitoring that while some points were monitored with one CT on each of the three phases,

[2] Author's note: This installation involved placement of the CTs onto the busbars, deep inside a 480V panel, for which I am deeply indebted to the professional electricians.

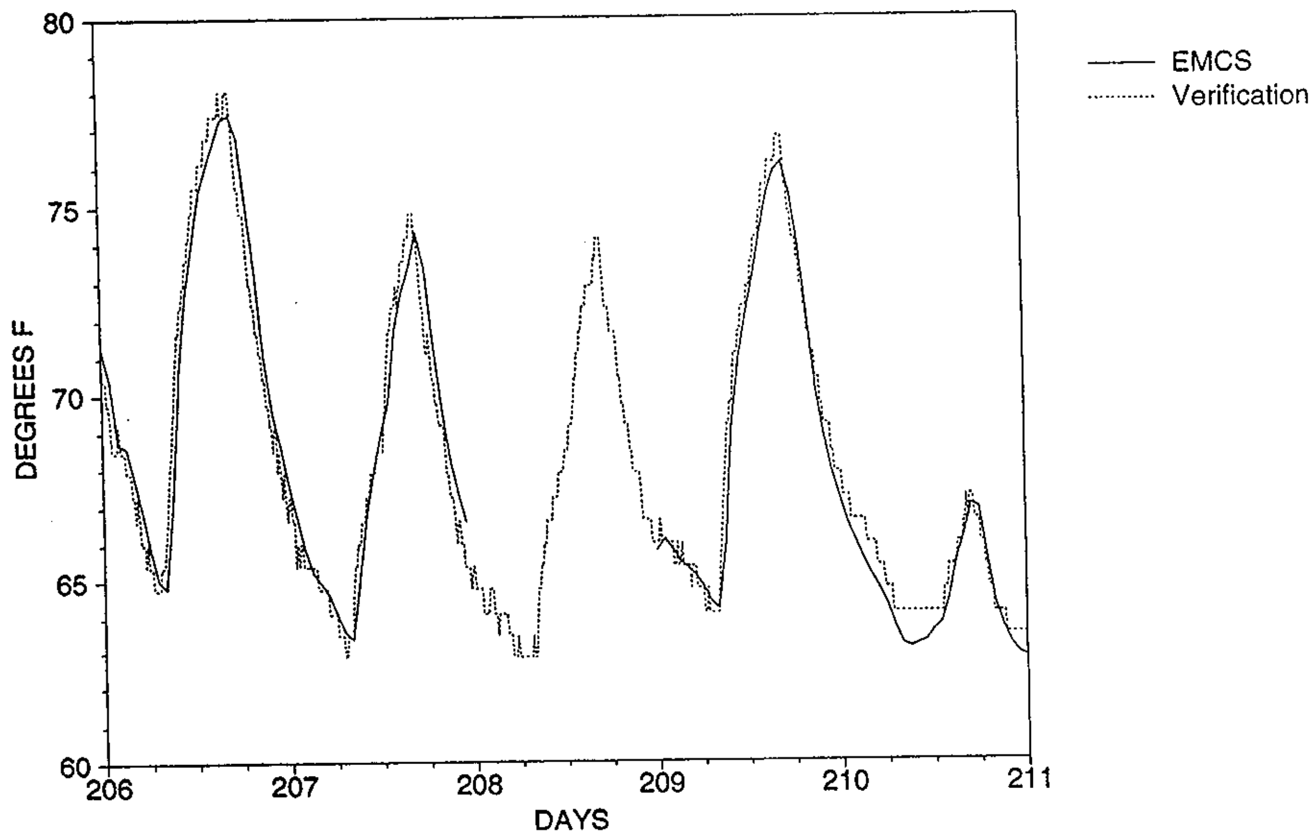

Figure VI-33. Verification of EMCS Temperature Data in an Uncooled Zone. The temperature as measured by the EMCS was quite close to that measured by a HOBO-XT microdatalogger.

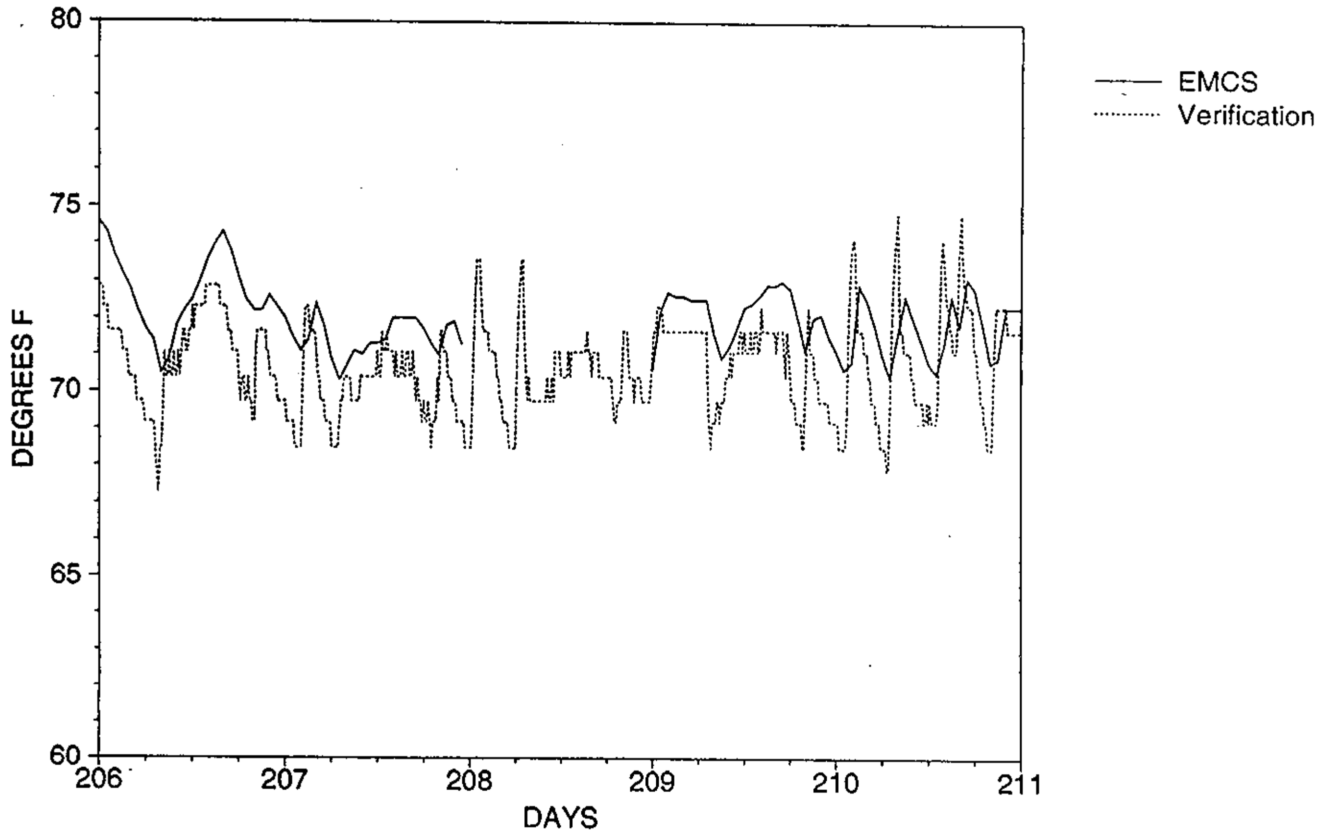

Figure VI-34. Verification of EMCS Temperature Data in a Cooled Zone. The temperature as measured by the EMCS was quite different from that measured by a HOBO-XT microdatalogger.

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 onto other IHEM engineers. The chilled water, cooling tower, and hot water pumps, shown in Figure VI-11, must be scaled upwards by a factor of three to obtain the appropriate value.

Another minor problem with the dedicated monitoring was that the chiller channel registered a very small negative power reading when the chiller was turned off. This may be a calibration problem. Since the logger is capable of accurately reporting negative power readings (i.e., current moving the wrong direction through the CT), these were reported as negative numbers, and when monthly totals were calculated, they resulted in totals that were too low. While this is not usually a significant problem, it was significant during months when little cooling was being done. Some loggers report negative power readings as positive, others report them as zero.

In conclusion, 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 shared savings evaluation, as specified in the constraints assessment. Dedicated monitoring and a third set of monitoring confirm that the data are accurate enough. There were problems with both EMCS and dedicated monitoring.

Sensor Calibration: Are sensors in proper calibration?

According to the shared savings 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.

Although temperature sensors were not calibrated, in other buildings where the facilities department is responsible for EMCS operation, there is more verification of sensor calibration. In one such study, in LBL's Building 2, space temperature sensors were checked against hand-held thermometers. This study was undertaken because a new EMCS was being installed, and sensors from the old EMCS were used. This study found that 50 out of the 300 temperature sensors that were tested were more than 5°F off. These were recalibrated to match the data from the hand-held sensors by adjusting only the offset, and not the span. The sensors used in the new EMCS are integrated circuit type, based on the National Semiconductor LM34 chip, and should typically require no calibration.

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

The EMCS has four methods of recording historical data: host history files, trending, controller monitoring, and custom report formats. The first method was used in this study. The EMCS operator was asked to set up hourly monitoring. The operator was originally under the impression that only 16 points could be monitored, but determined from the manufacturer that it was possible to monitor up to 40 points. The operator was given a list of the 40 points to be monitored, and used a PC editor to create the point definition file. The operator set up a supervisory routine to initiate this hourly data collection program four times a day, at 6am, noon, 6pm, 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. According to the Guidelines, the EMCS is capable of recording data.

For the most part, data collection proceeded very smoothly. One problem occurred when the system was rebooted, and for some reason hourly data collection was not reenabled. This was discovered after one day, and one day of data was lost. Data space was shared with the building operators, but no problems were encountered.

As a comparison with the EMCS, the architecture of the dedicated monitoring equipment is shown in Figure VI-3. This 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 able to be collected. If the connection between the dedicated datalogger and the polling computer breaks down, of course, data cannot be collected. However, this collection only takes place once a month, while it takes place roughly once a minute for the EMCS.

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

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, runtimes, and totals can also be collected. The EMCS operator was consulted to determine how averaging took place. 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. Assessment according to the guidelines indicates that data would be available at intervals appropriate for analysis.

Figures VI-35 and VI-36 show cumulative data for the miscellaneous and chiller end uses. For the kWh and runtime 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 1000 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 from 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. Every time 30 pulses were accumulated, the software kWh variable was incremented by ten kWh. Thus the energy consumption could not be known more with more resolution than ±10 kWh. If the pulses themselves were monitored, rather than this software point, then the precision would be three times as great. It was not possible to monitor pulse counter input points directly, however, and the EMCS operator had to create virtual points, which take their values from the pulse counters, and can be monitored. Both the direct kWh data and the data calculated from the pulse counter data are shown in Figure VI-37. Although the data are reading the same trend, they look quite different. Both methods would provide the same monthly summaries, but hourly data would differ. Since the hourly data are known to only ±1 kWh, the overall hourly data resolution is only 10%, at an expected minimum value of about 10 kW (10 ± 1 kWh/hour).

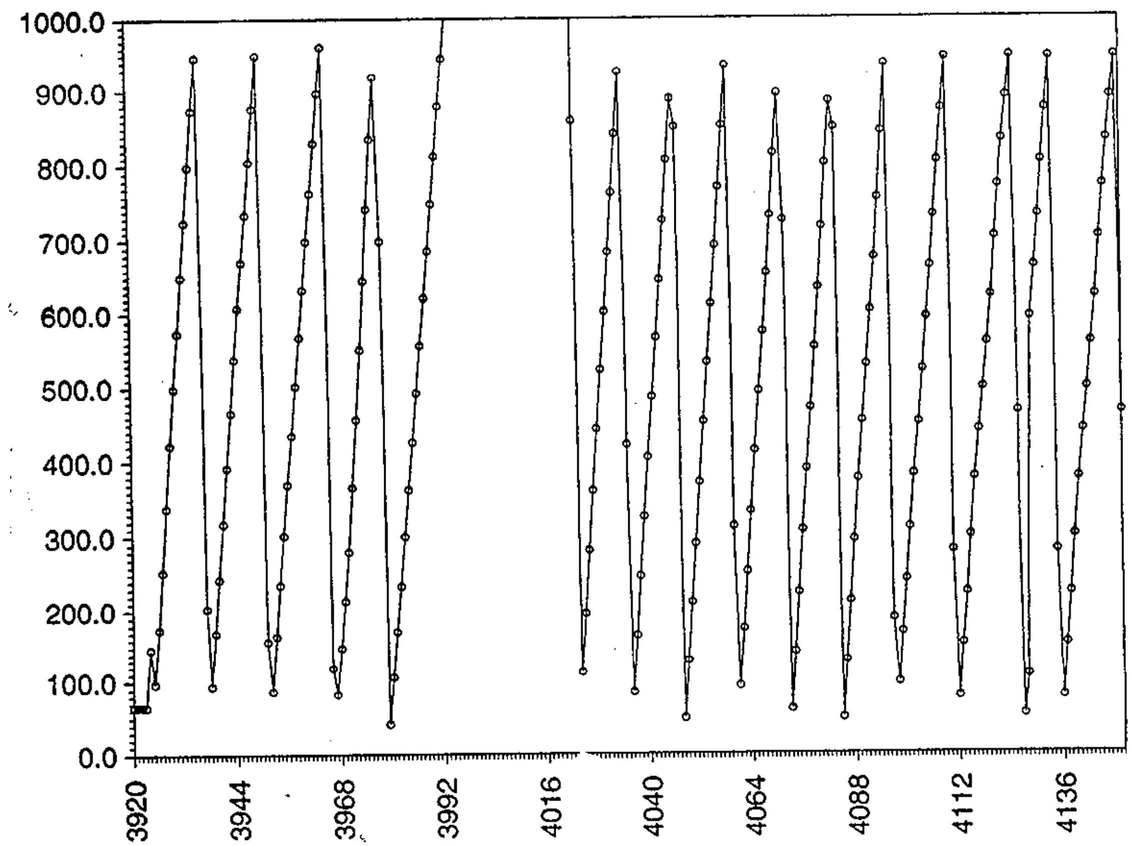

Figure VI-35. EMCS Cumulative Data for the Miscellaneous KWH Point. The kWh points were averages of a cumulative value over an hour. The cumulative value was incremented whenever one kWh has been consumed. Whenever the kWh point reached 1000, it was reset. This occured one to two times a day. It was difficult to interpret the data during the hour that the counter is reset.

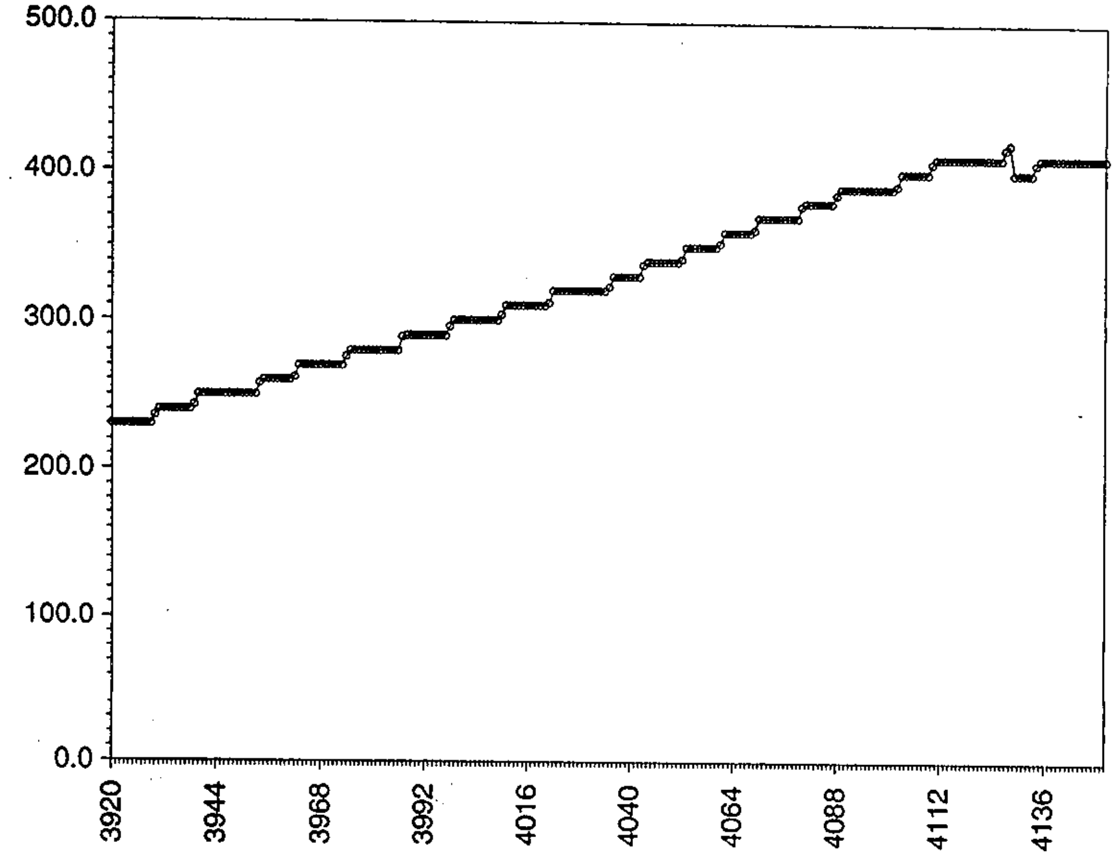

Figure VI-36. EMCS Cumulative Data for the Chiller KWH Point. The kWh points were averages of a cumulative value over an hour. The cumulative value was incremented by ten whenever ten kWh had been consumed. Whenever the kWh point reached 1000, it was reset, but this seldom occurred because the transducer was not operating correctly.

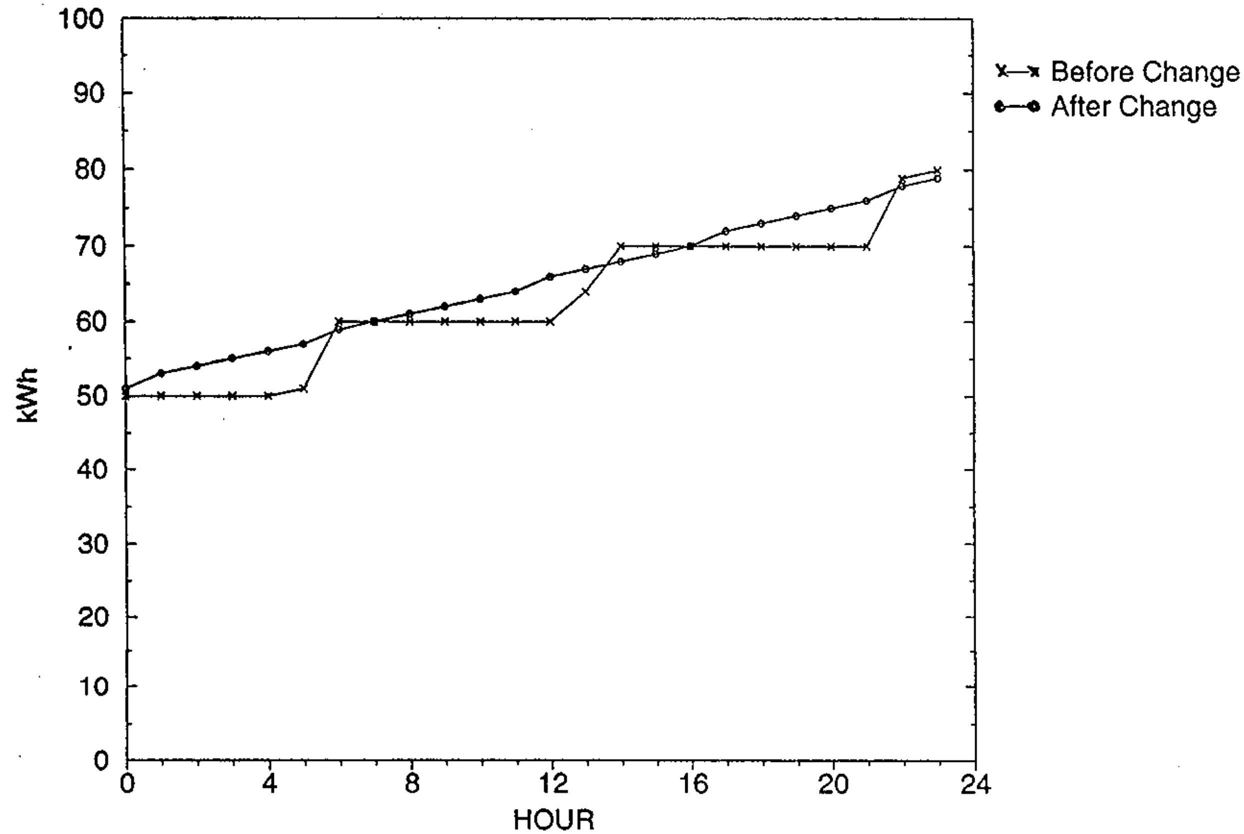

Figure VI-37. EMCS Cumulative Data for the Chiller KWH Point. Since the kWh point was incremented by whenever ten kWh were consumed, it had little precision. Another point was created to allow incrementing whenever one kWh was consumed.

Figure VI-38 shows the runtime data from one of the chilled water pumps. Runtime data are cumulative as well. A "minute" point is incremented for every minute that the equipment operates, and when the point passes sixty minutes, it is reset to zero and an "hour" point is incremented by one. Thus, the runtime should be known to ± 1 minute. This is one part in 60 for hourly data, for an overall resolution of about 2%. When this minute point is averaged over an hour, and then one subtracts each hour from the next, however, 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?

There is 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 very 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 occupy 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. If data were retrieved from the controller rather than the host computer, data can be stored for 64 points for one week. With Trend monitoring, data can be viewed for 4 points for two days, although they cannot be stored.

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

The EMCS data format is reasonably concise (see Figure VI-39). Since the data are intended to be read with a spreadsheet, their format is very 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. According to the guidelines and the identified constraints, the EMCS data format should be acceptable.

The data format for the data collected by the dedicated monitoring is shown in Figure VI-40. There are several different formats that can be used, including ASCII data, binary spreadsheet files, or binary files designed to be read by the datalogger software. The data can be stored either with or without header information. Data were obtained directly from IHEM after they were already downloaded from the logger. IHEM had stored the data in a spreadsheet format, and processing in the UNIX environment required the data to be in an ASCII format, so the spreadsheet program was used to manually export the data to an ASCII file. The data were then transferred from the PC to the UNIX environment. Downloading the data directly from the logger (i.e., not relying upon IHEM to collect the data) would allow storing them directly as an ASCII file. At different times, different methods were used for this transfer, and this resulted in some files having extra carriage-returns at the end of each line, requiring an additional processing step for some files. Also, the dedicated monitoring data format did not always have a consistent number of fields at the beginning of the records. Since the processing program looks for data in the sixth field, for example, having a different number of fields in some cases greatly complicates processing. These kinds of difficulties can be dealt with, but they make processing more complex, time-consuming, and costly.

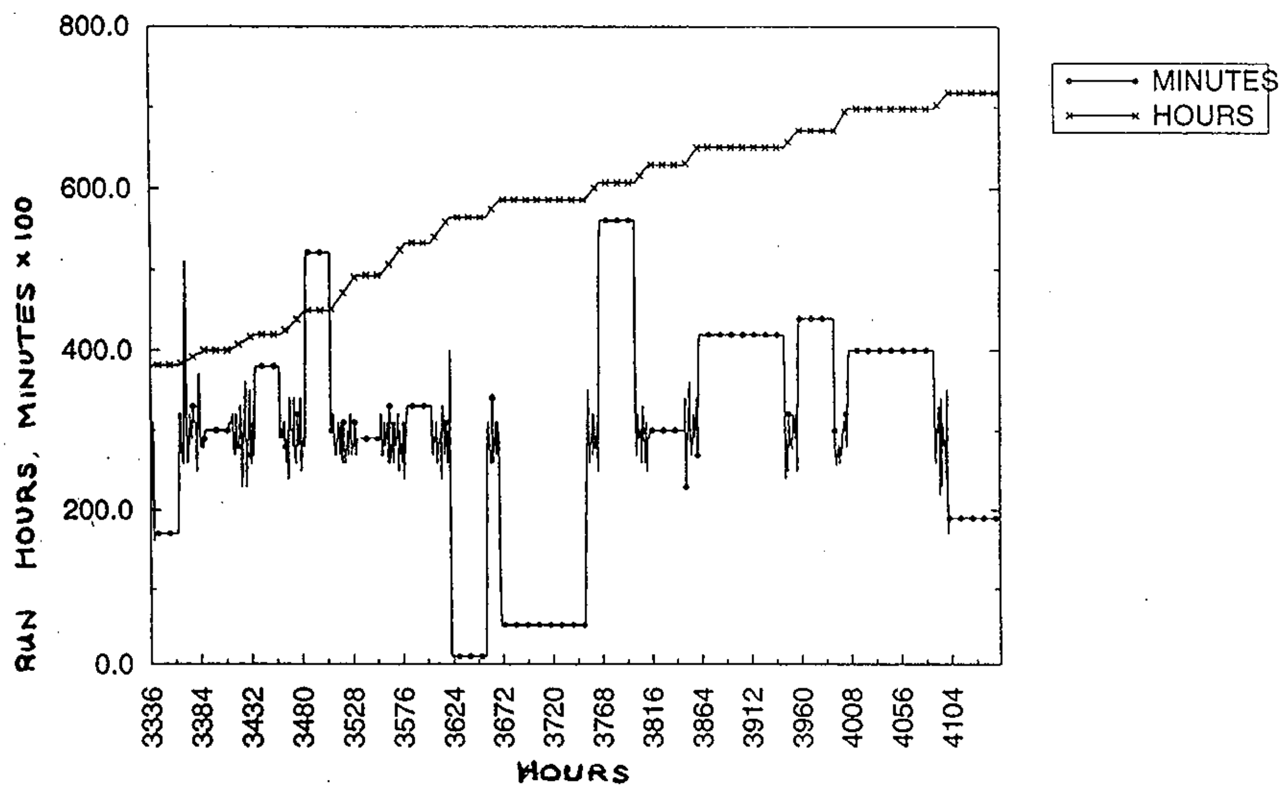

Figure VI-38. EMCS Cumulative Data for Chilled Water Pump Runtime. Runtime is also a cumulative point. The *minute* point was incremented by one whenever the pump had operated for a minute. The *hour* point was incremented by one whenever the minute point hit 60. Since both values are averaged over an hour for reporting, the minute data are very difficult to interpret.

```
"StarVIEW/4000 SpreadSheet -Summary Data for Yesterday"

"Created on 07-06-1994 at: BLUE SYSTEM     LanSTARs       -- LBL - C & M   "

"COL B contains data for 62 66A1 KWH     - 62 FEEDER 66A1 KILOWATT HOURS   "
"COL C contains data for 62 66A3 KWH     - 62 FEEDER 66A3 KILOWATT HOURS   "
"COL D contains data for 62 ARU2 KWH     - 62 CHILLER-2 KILOWATT HOURS     "
"COL E contains data for 62 ARU2 LOAD    - 62 CHILLER-2 LOAD SIGNAL        "
"COL F contains data for 62 BLDG OCC     - 62 BUILDING OCCUPANCY FLAG      "
"COL G contains data for 62 CHW OPT S/S  - 62 CHW OPTIMAL START/STOP       "
"COL H contains data for 62 CHW OPT TMR  - 62 CHILL WATER OPTIMAL TIMER    "
"COL I contains data for 62 CHW OPTMIN   - 62 CHILLER OPTIMAL MIN FROM ZAT "
"COL J contains data for 62 CHWR TEMP    - 62 CHILL WATER RETURN TEMP      "
"COL K contains data for 62 CHWS TEMP    - 62 CHILL WATER SUPPLY TEMP      "
"COL L contains data for 62 CT1 CWR      - 62 CONDENSER WATER RETURN TEMP  "
"COL M contains data for 62 CT1 CWS      - 62 CONDENSER WATER SUPPLY TEMP  "
"COL N contains data for 62 CT1 CWS SP   - 62 CT1 CONDENSER WATER SETPOINT "
"COL O contains data for 62 GP1 MINUTES  - 62 GP-1 MINUTES OF RUNTIME      "
"COL P contains data for 62 GP1 RUNTIME  - 62 GP-2 HOURS OF RUNTIME        "
"COL Q contains data for 62 GP1 S/S      - 62 GP-1 START/STOP (CHWP)       "
"COL R contains data for 62 GP2 MINUTES  - 62 GP-2 MINUTES OF RUNTIME      "
"COL S contains data for 62 GP2 RUNTIME  - 62 GP-2 HOURS OF RUNTIME        "
"COL T contains data for 62 GP2 S/S      - 62 GP-2 START/STOP (CHWP)       "
"COL U contains data for 62 HIBAY OVR    - 62 HIGHBAY AFTER HOURS OVERRIDE "
"COL V contains data for 62 OAT          - 62 OUTSIDE AIR TEMPERATURE      "
"COL W contains data for 62 BL1 ECON     - 62 AHU S-1 ECONOMIZER DAMPER    "
"COL X contains data for 62 BL1 KWH      - 62 AHU S-1 KILOWATT HOURS       "
"COL Y contains data for 62 BL1 MAT      - 62 AHU S-1 MIXED AIR TEMP       "
"COL Z contains data for 62 BL1 MAT SP   - 62 AHU S-1 MIXED AIR SETPOINT   "
"COL [ contains data for 62 BL1 RAT      - 62 AHU S-1 RETURN AIR TEMP      "
"COL \ contains data for 62 BL2 S/S      - 62 AHU S-1 RETURN FAN START/STOP"
"COL ] contains data for 62 BL2 STATUS   - 62 AHU S-1 RETURN FAN STATUS    "
"COL ^ contains data for 62 BL1 SAT      - 62 AHU S-1 SUPPLY AIR TEMP      "
"COL _ contains data for 62 BL1 SAT SP   - 62 AHU S-1 SAT CALC SETPOINT    "
"COL ' contains data for 62 BL1 STATUS   - 62 AHU S-1 SUPPLY FAN STATUS    "
"COL a contains data for 62 BL1 STP      - 62 AHU S-1 SUPPLY STATIC PRESS  "
"COL b contains data for 62 BL1 STP SP   - 62 AHU S-1 STATIC PRESS SETPOINT"
"COL c contains data for 62 BL1 S/S      - 62 AHU S-1 SUPPLY FAN VFD S/S   "
"COL d contains data for 62 BL1 SPEED    - 62 AHU S-1 VFD SPEED SIGNAL     "
"COL e contains data for 62 ZONE 1 ZAT   - 62 ZONE 1 RM 139 ZONE TEMP      "
"COL f contains data for 62 ZONE 2 ZAT   - 62 ZONE 2 HIGH BAY ZONE TEMP *NC"
"COL g contains data for 62 ZONE 2 ZSP   - 62 ZONE 2 HIBAY ZONE SETPOINT   "
"COL h contains data for 62 ZONE 3 ZAT   - 62 ZONE 3 RM 139 ZONE TEMP   *NC"
"COL i contains data for 62 ZONE 4 ZAT   - 62 ZONE 4 RM 221 ZONE TEMP      "

"00-01 am",687.0,187.0,730.0,0.0,0.0,0.0,0.0,25.4,55.3,57.5,67.3,70.4,75.0,25.0,777.0,0.0,
33.0,575.0,0.0,0.0,51.8,100.5,14.0,52.6,74.5,73.8,60.0,60.0,70.2,74.5,60.0,0.5,0.5,60.0,43
.8,78.2,62.8,70.0,75.6,  72.2
"01-02 am",734.0,198.0,734.0,0.0,0.0,0.0,0.0,20.1,55.3,57.5,65.8,69.9,75.0,25.0,777.0,0.0,
33.0,575.0,0.0,0.0,51.2,100.5,14.0,52.5,74.7,73.7,60.0,60.0,70.0,74.8,60.0,0.5,0.5,60.0,43
.8,78.6,62.4,70.0,75.5,  72.1
"02-03 am",781.0,209.0,740.0,0.0,0.0,0.0,0.0,16.5,55.2,57.3,64.5,69.1,75.0,25.0,777.0,0.0,
33.0,575.0,0.0,0.0,51.0,100.5,14.0,52.4,75.2,73.6,60.0,60.0,69.7,75.2,60.0,0.5,0.5,60.0,43
.8,78.8,62.1,70.0,75.3,  72.1
"03-04 am",827.0,220.0,740.0,0.0,0.0,0.0,0.0,14.4,55.0,57.2,63.4,68.5,75.0,25.0,777.0,0.0,
33.0,575.0,0.0,0.0,50.6,100.5,14.0,52.0,75.4,73.5,60.0,60.0,69.5,75.5,60.0,0.5,0.5,60.0,43
.8,79.0,61.7,70.0,75.2,  72.0
"04-05 am",874.0,230.0,740.0,0.0,0.0,0.0,0.0,12.6,54.8,57.0,62.6,68.2,75.0,25.0,777.0,0.0,
33.0,575.0,0.0,0.0,50.6,100.5,14.0,52.0,75.6,73.4,60.0,60.0,69.5,75.6,60.0,0.5,0.5,60.0,43
.8,79.1,61.4,70.0,75.1,  72.0
"05-06 am",920.0,241.0,740.0,0.0,0.0,0.0,0.0,11.6,54.7,56.9,62.0,67.9,75.0,25.0,777.0,0.0,
33.0,575.0,0.0,0.0,50.6,100.5,14.0,51.8,75.9,73.3,60.0,60.0,69.4,75.9,60.0,0.5,0.5,60.0,43
.8,79.2,61.2,70.0,75.0,  71.9
"06-07 am",966.0,252.0,740.0,0.0,0.0,0.0,30.0,10.6,54.5,56.8,61.5,67.7,75.0,25.0,777.0,0.0
```

Figure VI-39. File Format for EMCS Monitoring. Data are collected in a fairly concise format, aside from the bulky header information. The file is easy to process.

MO	DY	YR	HR	MN	SC	TSR	VFUON	KW0|MO	KW1|MO	KW2|MO	KW3|MO	KWH0|MO	KWH1|MO	KWH2|MO	KWH3|MO		
7	6	94	0	0	0	664	V	9.685	105.482		-0.017	20.223	172309	1512559		160600	520631
7	6	94	1	0	0	665	V	9.057	106.152		-0.021	20.262	172318	1512665		160600	520651
7	6	94	2	0	0	666	V	8.162	107.407		-0.022	20.183	172326	1512773		160600	520672
7	6	94	3	0	0	667	V	8.011	108.245		-0.024	20.079	172334	1512881		160600	520692
7	6	94	4	0	0	668	V	7.995	108.412		-0.024	20.079	172342	1512989		160600	520712
7	6	94	5	0	0	669	V	8.005	107.575		-0.022	20.039	172350	1513097		160600	520732
7	6	94	6	0	0	670	V	8.000	107.910		-0.023	20.039	172358	1513205		160600	520752
7	6	94	7	0	0	671	V	8.037	106.821		-0.022	20.039	172366	1513312		160600	520772
7	6	94	8	0	0	672	V	9.962	105.566		16.387	20.118	172376	1513417		160616	520792
7	6	94	9	0	0	673	V	12.903	112.765		13.332	20.223	172389	1513530		160630	520812
7	6	94	10	0	0	674	V	18.020	128.922		13.039	21.164	172407	1513659		160643	520833
7	6	94	11	0	0	675	V	22.833	136.708		16.136	22.904	172430	1513796		160659	520856
7	6	94	12	0	0	676	V	21.641	139.973		11.500	23.637	172451	1513936		160670	520880
7	6	94	13	0	0	677	V	21.641	139.052		16.387	20.733	172473	1514075		160687	520901
7	6	94	14	0	0	678	V	22.247	137.880		11.773	24.016	172495	1514213		160699	520925
7	6	94	15	0	0	679	V	22.854	142.987		17.057	22.917	172518	1514356		160716	520948
7	6	94	16	0	0	680	V	23.147	129.006		12.620	22.512	172541	1514485		160728	520970
7	6	94	17	0	0	681	V	21.389	122.476		16.126	20.824	172563	1514607		160745	520991
7	6	94	18	0	0	682	V	15.759	118.709		13.133	20.131	172579	1514726		160758	521011
7	6	94	19	0	0	683	V	10.203	112.347		11.155	20.236	172589	1514838		160769	521031
7	6	94	20	0	0	684	V	8.827	111.007		12.861	19.477	172598	1514949		160782	521051
7	6	94	21	0	0	685	V	8.209	108.412		-0.063	18.574	172606	1515058		160782	521069
7	6	94	22	0	0	686	V	8.926	110.086		-0.018	18.692	172615	1515168		160782	521088
7	6	94	23	0	0	687	V	9.324	111.091		-0.021	18.928	172624	1515279		160782	521107

Figure VI-40. File Format for Dedicated Monitoring. The data are collected in a fairly concise format which is easy to process. The file contains other information that is not needed, however, increasing its size and transmission time.

Data Time Stamping: Does the system system record the time 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?

The hourly data report uses timestamps with the format: "09-10 pm". This clearly indicates that the average represents data from the top of the hour to the bottom of the hour. 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 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 am.

Remote Connection: Can users connect to the EMCS remotely, using generic communications 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 is run. Hence, 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 in order to transfer the file, but this software is fairly common, and not specific to a single EMCS maker.

Since LBL 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. This phone line was used by the contractor in Houston for monitoring. For the purposes of the dissertation's case study, however, access to the EMCS was accomplished quasi-remotely, through another computer on the local area network, in another building within the same complex. In an earlier demonstration of remote data monitoring using the EMCS at LBL Building 62, however, this system was monitored remotely from a conference center in Asilomar, CA, in August 1992.

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?

Once the remote control connection is made, it should be 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 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.

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?

The method of transferring data, described in the previous section, is very 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 were discussed in the previous section. They 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?

Partly because the data files are relatively compact, the transfer process should be fairly quick. The baud rate of this network connection is 9600. 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. The data file is shown in Figure VI-39. Using an EMCS on the network, it took about ten 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. It includes monthly cumulative energy consumption, and hourly average reactive power as well as real power. The data file is shown in Figure VI-40.

Transmission Error Detection: Are data transmission errors automatically detected and corrected?

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 (Symantec 1991).

Data collection from the dedicated datalogger has error detection, and when too many errors occur, transfer is halted.

4. Evaluation of EMCS for Monitoring

Having identified the constraints for monitoring in this case study, and the resources available in the EMCS, the next step is to evaluate the use of this EMCS for remote monitoring for evaluation of energy savings. Each of the technical issues is now discussed.

- *Data points:* Many very interesting points were monitored, including four end-use energy channels. The end-use energy channels would provide data necessary to calculate energy savings from the retrofit. However, there was not a whole-building electricity channel. Assistance was required from the EMCS operator to determine what points were available. Operational data were very useful as a substitute for—or supplement to—energy data. Operational data were used to determine easily when the building was in occupied-mode, and to confirm the EMCS sequence of operations. The type of analysis that was done on the operational data could be done internally to the EMCS, by defining rules for alarms for inappropriate operation, (for example, during minimum-outdoor-air economizer mode, an alarm should be generated if there is a large difference between the mixed air temperature and outdoor air temperature; if two pumps are running simultaneously; or if the economizer is in outdoor-air mode while heating is on). Proxies for energy consumption might also be very useful. Proxies were calculated using both hardware points (actual measured data) and software points (outgoing control signals, or setpoints). For example, proxies were calculated using outgoing on/off signals, measured ("proof") status, chiller loading, and VFD speed control (both constant and linear relationships).
- *Data accuracy:* 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. Since there were problems with both EMCS and dedicated equipment, it is concluded that quality control is an essential factor both in EMCS and dedicated monitoring equipment. 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).
- *Sensor calibration:* Sensors were not calibrated in this building. The temperature sensors were an integrated circuit type that typically does not require calibration. Calibration was performed with different temperature sensors in other buildings on site, and a small fraction were found to be out of calibration.

- *Data recording:* There were several mechanisms for recording data. One was used, and it worked quite successfully. Hourly data collection had never been used at this site. Monthly data were used as the basis for savings payments, but since the data were so aggregated, it was impossible to review their quality. Only during review of hourly data did problems with the data become apparent.
- *Data averaging:* This EMCS collected hourly averages of a cumulative kWh point, making interpretation of the data quite difficult. It would have been possible to create an additional point that noted the value of the accumulator at the end of each hour (the appropriate way to collect cumulative data), but this would have required additional operator effort, and was not done in this study.
- *Data storage:* The host computer had a large disk drive, and data storage was sufficient in this system.
- *Data format:* The data files had a bulky header, but they very clearly identified what the data points were. The data were comma separated, making them simple to process, and missing data were identified as "None."
- *Data time stamping:* Averaging over an hour was very reliable.
- *Remote connection:* This EMCS used a remote control program for remote connections. There were no problems with remote connection. Since one does not have to log onto the EMCS to download data, there is less of a potential to interfere with control.
- *Remote data transfer:* An automatically stored data file was transferred from the host computer to a remote computer. Using this method, it was not necessary to actually log onto the EMCS software, so it would be possible to allow monitoring personnel access to data without allowing access to the EMCS control software. One problem occurred when memory constraints were encountered on the host computer. Data collection continued manually for a short time, and a longer-term solution may have been found if it were needed, requiring additional operator effort.
- *Simple process:* The remote connection and data file transfer used a very clear, simple, easy-to-use menu-oriented interface. This remote control program allows automation of the transaction, although this was not tested in this study.
- *Rapid process:* The transfer was fairly rapid, owing to the fact that the data file was fairly concise, it was not generated as it was being transferred, and the connection had an acceptably high communications speed.
- *Transmission error detection:* The file transfer had different levels of error detection.

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. However, the problems with the kWh data were very troublesome. 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, shared savings program manager, retrofit contractor, EMCS vendor, and instrumentation subcontractors, it was quite difficult.

5. Conclusions

This chapter illustrated and demonstrated the use of the framework and guidelines presented in Chapters III and V. The objectives of this study were to demonstrate and evaluate the use of the guidelines for assessing EMCS for monitoring, to evaluate the process and effectiveness of collecting data with an EMCS, and to demonstrate other potential benefits of EMCS monitoring which could be further developed. The building selected for this demonstration was the subject of a pilot study of shared savings for the Department of Energy. The building already had an EMCS and a dedicated monitoring system installed, and thus it was a good opportunity to compare the processes of collecting data from each, as well as the data themselves. The guidelines were followed to collect information about the building and EMCS, and to evaluate the capabilities according to the categories of issues embodied in the guidelines. This involved first defining the constraints for the monitoring project, and then assessing the resource represented by the EMCS.

The guidelines were a useful way of determining whether or not the EMCS could be used for monitoring. They made it easier to organize the collection of information, and to make comparisons between what was needed and what was available. The guideline methods were effective in evaluating EMCS monitoring capabilities in most respects. Even with the use of the guidelines, however, accuracy and calibration were two issues that took a significant amount of effort to assess. For these two issues, the guidelines initially suggested that EMCS monitoring should be satisfactory. After much effort, problems with accuracy and calibration were resolved, but in many cases this amount of effort would not be acceptable.

While there were several significant problems with this monitoring study, there were also several interesting advantages. 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. Although the system eventually provided acceptable end-use energy data, however, given the objectives of the dedicated monitoring, one could not recommend the EMCS at this site as the sole monitoring tool unless the project hardware budget was very limited.

VII. SUMMARY AND CONCLUSIONS

1. Summary

Monitoring for the evaluation of savings from energy conservation efforts is an important undertaking. Since EMCSs exist in many commercial buildings, and contain much of the same instrumentation that is required for monitoring, it would seem intuitive to use them for monitoring. EMCS-based monitoring is a very straightforward matter conceptually: if all the required hardware and software are present at a site, they can be used for monitoring. This dissertation has shown, however, that in practice it can become more complex. Although there has been considerable interest in EMCS-collected data on the part of building researchers, this application has never been methodically demonstrated, and its use bears closer investigation.

The hypothesis of this dissertation was that an in-place EMCS can serve as an adequate alternative for long-term, remote, third-party monitoring for evaluation of energy savings from HVAC retrofits in commercial buildings. The primary objective of the dissertation was to prove that hypothesis by assessing that adequacy. In order to do so, several other intervening objectives had to be met:

- provide a framework for assessing the needs for monitoring tools for different monitoring applications,
- assess the needs for monitoring tools in the particular application of remote, third-party monitoring for evaluation of energy savings, and
- provide metrics and methods for assessing the use of in-place EMCSs for use in remote third-party monitoring for evaluation of energy savings.

These objectives were achieved by:

- analyzing the technical characteristics of EMCSs;
- analyzing the technical characteristics of currently available tools that have been used for this monitoring application, and evaluating how they compare to the characteristics of EMCSs;
- analyzing different monitoring applications to determine what constitutes an appropriate tool for a given application;
- analyzing, in particular, what constitutes an appropriate tool for the specific application of remote, third-party monitoring for evaluation of energy savings;
- carrying out several exploratory case studies of EMCS monitoring for this application to identify the specific capabilities that are needed;
- developing guidelines for evaluating specific installations; and
- carrying out an in-depth case study of EMCS monitoring for this application to test these guidelines and provide more rigorous evidence of capabilities and lackings.

The generic characteristics of EMCSs were defined in Chapter II. The different types of systems in use were described, and the specific characteristics of several commonly used systems were described. This same sort of analysis was used to define the characteristics of currently used monitoring tools, describe the different types of tools used, and describe the specific characteristics of several commonly used tools.

As a result of this analysis, it was found that EMCSs and dedicated monitoring have very similar technical characteristics. Both typically contain similar sensors and transducers, wiring from sensors to device, wiring between devices, signal and data processing, storage, operator interface, and communications. The methods that can be used for EMCS-based monitoring were outlined in Chapter II, and Table II-5 evaluated their relative advantages and disadvantages. For different projects, any of the methods might be appropriate, but the introduction of systems that support multiple users will provide the greatest potential for monitoring. The chapter also suggested that comparison of technical characteristics alone is insufficient to evaluate the appropriateness of the EMCS as a tool for monitoring. Thus, assessment of more basic monitoring needs is necessary to determine the other criteria with which to evaluate the tool.

An analysis of the needs for monitoring projects was carried out in Chapter III. The approach was to categorize monitoring programs according to four sets of attributes: objectives, constraints, resources, and approaches. Table III-1 outlined these attributes for different types of monitoring efforts. These four sets of attributes, taken together, can determine what tools will be appropriate. This type of analysis enables the fair assessment of a proposed new monitoring tool, such as the EMCS.

For remote third-party monitoring for evaluation of energy savings, the important attributes are the lack of intimate connection to the site, the fact that the building does not benefit from the monitoring, the need for reliability, the "hands off" nature of the monitoring, the large scale and long term, the strong need for standardization, and the prior specification of the way that monitoring and analysis must be done. These needs and resources must be matched with the attributes of EMCS monitoring. These attributes are too generic to be useful in specifying or evaluating potential monitoring equipment. More specific requirements are needed. These specific requirements are difficult to analyze in a theoretical treatment, however, and case studies were necessary to identify the important issues.

In eight case studies, EMCS monitoring was investigated and in most cases implemented. These case studies found several advantages and several significant problems associated with using EMCSs for third-party remote monitoring of energy savings. In almost all cases, it was possible to collect data without installing any additional hardware or software, but other procedural issues were important. Table IV-2 summarizes the evaluation of the use of the EMCSs in these buildings, according to several criteria that became evident throughout the study. This table shows that each case had at least one drawback. Some problems were more serious than others, and some could be more easily solved than others, as is discussed in the next section.

The evaluation criteria—identified in carrying out the eight case studies with a specific, bounded, monitoring application—were distilled into thirteen guidelines, shown in Table V-1. The guidelines discussed the issues with much more specificity and included specific methods for evaluating capabilities. These guidelines served as a tool in evaluating the use of an existing EMCS in order to use it for monitoring. They can also be used as a guide in specifying EMCSs if it is known in advance that they will be used for monitoring, and they can be used to guide the design of new EMCS models that will be used for monitoring.

In a detailed case study, designed to illustrate the use of the guidelines and to demonstrate their benefit, several advantages and several quite significant problems appeared. A detailed comparison of the EMCS monitoring with conventional monitoring was possible in this study, and it was found that the EMCS was capable of providing data that were quite close to the data collected by the dedicated monitoring tool. In fact, in some cases, the data provided by the EMCS were *more* reliable than those provided by the dedicated monitoring. However, for three out of the four electric power points, the data were meaningless until a great deal of effort was spent on repairing them. Some of the points that would have been necessary to carry out a whole-building energy analysis were not measured, and there were problems with monitoring interfering with control functions (these problems were ultimately remedied). On the other hand, much of the operational data collected by the EMCS were useful in confirming the sequence of operation of the building, and in serving as proxies for monitored energy consumption. The process for monitoring and the format of the data that were collected were both equivalent to dedicated monitoring. The guidelines provided useful methods for carrying out the evaluation.

2. Conclusions

Tools to be used in remote third-party monitoring for evaluation of energy savings must be accurate, reliable, use available hardware, allow a quick startup, be standardized, avoid intrusion into the building, have low liability, and allow the monitoring team control over the data. EMCS monitoring can address many of these needs, and have advantages over conventional methods, as documented in several case studies.

- *"Free" data:* The most obvious advantage of EMCS monitoring is that it can make use of existing hardware and software. It is often possible to make use of existing equipment, and to install absolutely no hardware. Since no protocols exist for EMCS monitoring, each EMCS is a unique case, and time will be required to learn how to use the existing capabilities, in coordination with building personnel. Time will also be required to ensure that the EMCS is capable of monitoring, and possibly for some reconfiguration. This time may be significant, although it may represent the only costs involved in starting up the monitoring. It is difficult to estimate how much time was required to obtain data from the case study sites, due to the fact that this project was research oriented, and intended as a proof of concept rather than a realistic example of the implementation of this technology. However, as a rough estimate, it should not take more than the equivalent of two to three weeks of effort by a knowledgeable person to make a system functional for monitoring (often much less—on the order of hours). At a rate of $100 per hour, the three week effort would cost roughly $12,000, regardless of the number of points being monitored. If ten points are monitored, this corresponds to about $1200 per point. If 40 points are monitored, as was the case in the detailed case study, this corresponds to $300 per point. As a comparison, dedicated monitoring can cost on the order of $1000 per monitored point. If EMCS monitoring becomes more routinely applied, and EMCS manufacturers begin designing their systems with remote monitoring in mind, the time and costs involved will be greatly reduced. This is particularly a consideration when cost is a limiting factor in monitoring. It may be possible to collect data from an EMCS, when no data collection would be possible otherwise. Or one might be able to increase statistical sample sizes by monitoring more buildings, if the per building cost can be brought down by using EMCSs.
- *Amount of data:* In addition to mimicking the monitoring capabilities of dedicated data acquisition systems, part of the power of EMCS-based monitoring comes from the different data and computing capabilities that it offers. It is possible to obtain much more information about the building operation than is typically economically feasible in a dedicated monitoring project. In dedicated monitoring, the number of points that can be monitored is usually limited by the number of available input channels on the datalogger, and the cost of hardwiring the connections from the sensors to the logger. With an EMCS, however, many points of interest are monitored in order to control the building, and the network connecting the sensors to the data storage medium is already in place. In one of the case study

buildings, for example, over 10,000 points were available for the building. Many new systems will always automatically store the last 24 hours' worth of hourly data. This is a beneficial feature, because often one does not always know beforehand what will be the most important data to monitor. This was the case in one of the case studies: no heating data were monitored, but to diagnose economizer operation, it was realized that heating information was needed. One and a half days of data were immediately available for analysis. This is also an advantage because often monitoring has a short lead time, and there is not sufficient time to gather pre-retrofit data: perhaps the data are already there with an EMCS.

- *Type of data:* Beyond allowing monitoring of more data, the EMCS has an advantage in the type of data it monitors. A typical EMCS measures temperature, energy, and flow (pressure) for many different pieces of equipment. It will also, however, measure values such as valve or damper position, setpoints, and status. These kind of operational control data are valuable. Operational control is an important determinant of energy consumption, and it is important to understand if one wants to know not just how much energy the building is consuming, but why. In the detailed case study building, 36 operational control variables were monitored, and they were found to be quite useful in understanding the operation of the building, and even in serving as proxies for energy consumption. Conventional energy monitoring systems could monitor these operational data, but this is not common due to cost constraints.

In the case studies, using existing in-place EMCSs had several limitations in meeting these requirements. The specific problems that occurred in some of the case studies were:

- *Hardware deficiencies:*
  - EMCS telephone lines or modems were in use by system;
  - several different EMCSs were in use in the complex, but they were not interconnected;
  - network communications constraints precluded extensive monitoring;
  - memory on the host computer was limited and monitoring overloaded available memory—several days of data were lost;
  - the necessary points were not included in the EMCS system; and
  - several kWh meters failed.
- *Software deficiencies:*
  - Hourly data storage was limited to 24 hours, so daily downloading was required;
  - data could not be accessed remotely;
  - remote transfer of data was very slow;
  - proprietary, EMCS model-specific software was necessary to connect to the system;
  - 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 either did not restart at the top of the hour or it did not restart at all.

- *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.

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.

Use in other Applications

If the types of problems outlined above can be solved, there is tremendous promise for using EMCSs in other monitoring and conservation efforts as well. Table III-1 showed what attributes are significant in other types of programs, and these are discussed here. Some of the programs in which EMCS monitoring might be most applicable are savings verification, commissioning, operation and maintenance (both troubleshooting and improvements), building optimization, identification of conservation opportunities, and technology assessment. The primary differences between these types of programs and third-party savings evaluation programs are the fact that they take place on site and the building management benefits from the results, the smaller scale, the reduced need for standardization, and the relaxed need to use a specific method for monitoring or analysis.

EMCSs can play many other roles in conservation efforts:

- *Supplements to conventional monitoring:* In some cases it may be appropriate to supplement submetered energy data, collected using a datalogger, with information collected by the EMCS. Hundreds or thousands of control points are often accessible in an EMCS. This type of operational information—such as temperature setpoints, outdoor air fractions, and variable-frequency drive control signals—can aid in understanding the patterns behind the energy consumption, or providing clues to be used in simulation tuning.
- *Diagnostics, optimization, and performance targets:* The on-site processing capabilities of an EMCS would enable the system to provide immediate feedback to the building operator on the performance of energy conservation measures or equipment, and to compare that actual performance to baseline assumptions. For example, the EMCS could calculate savings realized from night setback, or heat recovery, based on temperatures and other operational data. The system could also compare current building performance with predicted and historic values, or calculate new energy consumption targets that were specific to the current or anticipated operating conditions and objectives. EMCSs are installed to optimize control of building systems. With the addition of data monitoring and analysis, the operation of the building can be further optimized. Understanding which systems use the most energy or power could help building operators decide which conservation measures to

implement. Whole-building demand monitoring is important to help operators with building load management and demand limiting. Data monitoring could also be integrated with building control so control algorithms could be reprogrammed to operate the building in an intelligent way. A knowledge-based control system can optimize control of building systems by automatically analyzing data to evaluate past performance and anticipate future needs. In addition, a knowledge-based control system can help to solve the problem of data reliability. An EMCS programmed with the building operator's "expertise" could automatically distinguish between bad data and out-of-the-ordinary building operation and either flag data that seemed erroneous or alert the building operator to possible equipment failures.

- *Commissioning:* EMCSs could contribute to commissioning of buildings, building systems, and EMCSs themselves. Commissioning usually includes two tasks: taking the building through its expected range of operations, and monitoring its performance; the EMCS can be a powerful tool for both of these tasks. For example, the EMCS can be used in commissioning a variable speed fan by controlling the speed, varying it from minimum to maximum speeds while monitoring flow rates. The monitoring capabilities can also be used to collect operational data to confirm that the EMCS is managing the speed appropriately.
- *Alternative evaluation methodologies:* Some methods of analyzing building performance rely almost entirely on monitored whole-building and end-use energy consumption. However, the availability of operational data may suggest modifications of these methods or entirely new methods. For example, knowing what the building "thinks" it is doing may be very useful in analyzing what it actually did. Simply knowing the temperature setpoint and the reason for that setpoint may provide a great deal of information. As another example, the EMCS can match equipment hourly runtime with hourly energy consumption to obtain a more accurate representation of energy consumption during equipment operation. Or the status of motion detectors might be aggregated across the building, and used to automatically normalize energy consumption for occupancy. Operational data may confirm or provide inputs to simulation models or savings estimates.
- *On-site data processing:* It is possible to collect large amounts of data with an EMCS, but often more data are not necessarily preferable. A monitoring program can be quickly overloaded with too much data, and large monitoring programs sometimes must employ database and computer specialists to deal with the large amounts of data that are collected. Since there is usually a sophisticated microcomputer present on site, the EMCS could be used not only as the source of raw data, but as a tool to carry out the data analysis. The EMCS also has access to a different type of data—operational data—since it is controlling the building. With an EMCS it may be possible to collect raw data on-site, determine a few key factors that are of interest to the monitoring program, and transfer only these values to the monitoring personnel. The computational capabilities of EMCS processors are quite extensive and often underutilized. This kind of processing might include things like calculation of chilled water energy consumption or of heat recovery energy savings from flowrates and temperatures, and different kinds of averaging. Using this type of information, along with the monitored energy consumption, it might be possible, for example, to evaluate the performance of individual energy conservation *measures,* rather than monitoring the energy consumption of *end uses.* The operational data would also be useful for validating estimates made during building audits, or for providing clues needed in calibrating simulations to match measured consumption.

Solving the Problems

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. An example of a specification of such a "monitoring ready" EMCS, for the application of remote third-party monitoring for evaluation of energy savings is shown in Table VII-1. This specification should not be difficult for most manufacturers to meet.

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

Table VII-1. Sample Specifications for a "Monitoring Ready" EMCS for Remote Monitoring for Savings Evaluation.

System shall be capable of collecting long term data for the following points:

- kWh or Btu for all relevant end uses (those covered by retrofits),
- whole building kWh,
- outdoor air temperature, and
- status/runtime for all relevant end uses.

The system shall also be capable of collecting short term data for variables that characterize operation of relevant end uses.

The resulting data collected shall have the following accuracies:

- temperatures to ±0.5°F,
- flow to ±5% at lowest expected flowrate, and
- kWh to ±5% at lowest expected hourly demand.

Those sensors that are not factory-calibrated shall be field-calibrated. Space sensors, or VAV-box temperature sensors, shall be spot inspected, and no more than 10% shall fail inspection. All flow sensors and kWh meters shall be inspected, and none shall fail inspection.

System shall be able to collect average data at intervals from one minute to one day—including 15-minute and hourly averages. Electrical data shall be total energy consumption for the interval or average power for the interval.

The system shall store long term data from all required points at required intervals for at least one month. Short term data shall be able to be stored for more than one week.

The collected data shall be reported in a format with comma separated numerical variables. All text shall be in quotations. The data file should consist of one column for each point monitored, and one row for each time interval. Each line shall be date- and time-stamped, using a format such as "DD MM YYYY HH MM," and hours shall be shown from 01-24, where 01 indicates the hour between midnight and 1:00 am. Missing data shall be indicated with "9999". A header line shall be included, showing the point name and engineering units.

The data shall be able to be viewed and retrieved remotely. This access shall allow use of non-proprietary communications software on the remote end. Request for data shall be a simple one line command, indicating the interval of data to be collected, the name of point or group of points, and beginning and ending dates or times; for example: ">hourdata kWh 01-01-94 06-30-94". Access shall take place at at least 2400 baud, and the data shall be transmitted using a common file transfer protocol, such as kermit, which includes error detection and correction. The data collection shall be password protected such that monitoring cannot be disabled or altered, and data cannot be retrieved, except by the monitoring entity or the chief EMCS operator. The monitoring entity shall not have any capabilities beyond data collection.

complexity of most systems. This type of problem is not easy to solve; conferences have been devoted to discussion the causes and possible solutions to building quality control problems (PECI 1994). 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 this dissertation 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.

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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