Development and Testing of an Information Monitoring and Diagnostic System for Large Commercial Buildings

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ABSTRACT

Large commercial buildings generally do not operate at economically achievable levels of energy efficiency. Performance monitoring projects have shown whole-building energy savings of 20% or more through improved operation and maintenance practices. The opportunity for O&M savings is related to systemic problems associated with the lack of feedback available from current Energy Management and Control Systems (EMCS). Today's EMCS are designed for control, with limited capabilities in sensing, archiving, data analysis, diagnostics, and data visualization. This paper discusses a multi-year, multi-institutional project to develop and demonstrate an Information Monitoring and Diagnostics System (IMDS). The system is designed to address common O&M problems and the needs of office building owners and property managers to address these problems. The IMDS includes about 50 points of whole-building and cooling plant data, plus a set of standard diagnostics plots to evaluate key performance metrics and curves. Five unique features of the project are (1) sophisticated building operators and engineers as users, (2) permanent installation, (3) high-quality sensing, (4) high-frequency data archives, and (5) top-down design (i.e., whole building, system, and component data). The system does not provide control functions. We review the installation and early results from the use of the IMDS. An office building demonstration site was selected because of the technical reputation and interest of the chief engineer and on-site operator. We also discuss the technology adoption process and decisions involved in such innovations.

Introduction

Buildings generally do not perform as well in practice as anticipated during the design stage. There are many reasons for this, including improper equipment selection and installation errors, the lack of rigorous commissioning and proper maintenance, and poor feedback on ongoing performance, including energy performance. These problems are prevalent in most building systems, and frequently found in dynamic systems such as heating, ventilation, cooling, and lighting controls.

This paper summarizes results from the development and early field testing of an Information Monitoring and Diagnostic System (IMDS, see also Sebald & Piette 1997). The project was conceived to develop and introduce state-of-the-art information technology in buildings in order to substantially enhance building energy performance by continuously improving operations and maintenance (O&M). The project is being conducted by an interdisciplinary team to assess the current state of technology, develop a performance monitoring and diagnosis capability, and test it in real buildings. The system is being designed to improve operations in large Class A commercial office buildings. Class A buildings are the most prestigious buildings in a particular market, with above-average rents, high-quality finishes, state-of-the-art systems, exceptional accessibility, and a definite market presence. Large property management companies usually manage these buildings. There are potential "innovators and early adopters" among these companies, who have been identified for demonstration of the IMDS.

The project is in its second phase. Phase 1 included a detailed scoping study, market assessment, and technology evaluation, while the current phase focuses on the installation and initial testing of the IMDS. The Phase 1 market assessment activities included in-depth interviews with six technical managers who had been identified as among the most sophisticated in California. These interviews included a review of their perceptions of operations and maintenance problems with all major building systems, including controls. We found it difficult to identify a single system or component that was most problematic. Rather, there are systemic problems associated with the lack of feedback available from current Energy Management and Control Systems (EMCS). Today's EMCSs are designed for control, with extremely limited capabilities in sensing, archiving, data analysis, diagnostics, and data visualization. The purpose of the current demonstration is to deploy and evaluate the IMDS. The specific objectives are: (1) To save 15% of the energy used in a large commercial building by applying sophisticated monitoring and data visualization techniques with generalized rules to identify and correct problems in various building system, and (2) To develop diagnostic tools and data sets which create a specification for a diagnostics system.

The IMDS differs from previously developed systems in several important ways. First, it is specifically targeted toward sophisticated building operators and engineers. Most related research efforts or techniques are targeted toward a remote expert user (Liu et al. 1997; Honeywell 1998). Second, the proposed system is designed to be installed permanently. Some related approaches that are known for ease of use are built around short-term rather than continuous monitoring systems (Waterbury et al. 1994). Third, the monitoring system is based on high-quality sensors that are more accurate and reliable than sensors found in most commercial building systems. Fourth, the proposed system continuously archives data each minute. Most current systems do so every 15 minutes or longer, lacking the ability to catch problems such as equipment short cycling (Liu et al. 1997; Waterbury et al. 1994). Fifth, the diagnostic system has a top-down design that logically flows from the general whole-building analysis to system and component diagnostics. This is in contrast to bottom-up approaches that attempt to detect performance failures associated with specific individual devices (Hyvarinen & Karki 1996).

The remainder of this paper is organized as follows. First, we discuss the O&M problems discussed in building case study literature and results from our detailed surveys on problems. Second, we discuss the technology innovation and adoption elements of the project. We then present details of the IMDS design, followed by a description of the pilot demonstration site. Prior to the summary and conclusions is a brief discussion of the system costs and benefits.

Operations and Maintenance Information Problems

One of the important activities in Phase 1 was to identify major O&M problems in commercial buildings. We focused on O&M issues that cause an increase in energy use relative to the expected performance of a building system. For example, a cooling tower that operates when the chillers are off causes unnecessary energy use. The expected performance is for the tower schedule to be coordinated with the chiller schedule. Such problems are common in commercial buildings. Fixing O&M problems can also produce non-energy benefits, such as extending equipment life or improving comfort. These benefits will be tracked in the project as well.

Literature on related building case studies suggest that virtually all buildings have some sort of O&M problems, and the vast majority of buildings are not carefully commissioned (Claridge et al. 1994; Piette et al. 1994; Piette et al. 1996). Similar case studies indicate that careful review of hourly end-use and whole-building energy performance data can result in savings equivalent to about 15 percent of annual operating costs (Herzog & Lavine 1992; Claridge et al. 1994). These savings are much greater (up to 50 percent) in some cases (Liu et al. 1997).

The Phase 1 effort included detailed interviews and direct feedback from building owners and operators. These interviews were based on an extensive, 50-page questionnaire designed to tabulate O&M problems and characterize building owners' and operators' experiences with diagnostic and control technologies. The idea was to identify their most important O&M problems. Instead of generating these kinds of seemingly straightforward results, the underlying problem turned out to be more complex. The difficulty with identifying common O&M problems is that reports of these problems tend to be anecdotal rather than statistically based. Instead of identifying a detailed set of problems, we found a more critical and diverse set of problems that need to be addressed by a successful diagnostic system.

The key problem we identified is that **building operators lack good information on major building systems.** Information tools currently in use in these buildings severely limit a building managers' ability to assess their own O&M practices in a comprehensive manner. The questionnaire given to operators included asking about continuous information systems, such as Energy Management Control Systems (EMCS), as well as one-time and short-term diagnostics such as vibration analysis and thermography. EMCS limited capabilities to diagnose problems, or help evaluate the economic benefit of modifying O&M practices or changing existing equipment with more efficient equipment.

Technology Innovation and Collaboration with Expert End-Users

An important element of the project is the analysis and application of technology innovation and adoption theory (**Figure 1**). We selected Class A building operators because of their role in the commercial building market as "innovators and early adopters" of advanced technologies. These operators typically work for third-party property management companies whose businesses are growing under the current trend toward outsourcing. We purposefully worked with the Building Owners and Managers Association to identify the most sophisticated and innovative building engineers and operators in California. The analysis is based on the classic work by Rogers (1983) who suggested that technology adoption can be described by five categories: innovators, early adopters, early majority, late majority, and laggards. As an example of how the categories differ, "innovators" pursue technology and sometimes make a purchase simply for the pleasure of exploring a new idea or device, while "early adopters" are interested in new technology for its own sake and are quick to understand and appreciate the benefits of new products.

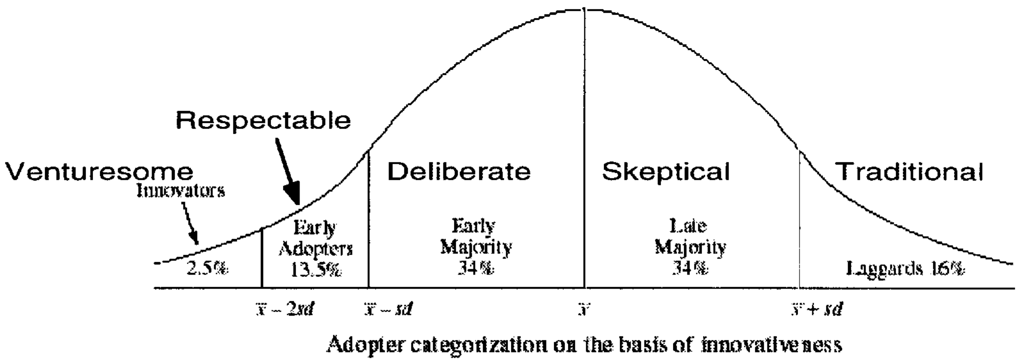

Figure 1. Technology Adoption Categorizations

The people selected for the O&M surveys had the characteristics that Rogers deemed important. First, they had some organizational "slack" to pursue new ideas and had developed a method to analyze innovations utilizing this slack time. This influences the way they budget for their test of the innovation. Second, they specify someone in their organization responsible for the technology strategy. Although they do not have formal R&D departments, they have identified a technology evaluator. Finally, they had demonstrated by past performance that they could think creatively and would act on new information in previous innovations we evaluated.

After identifying the innovative operators we sought to identify the process used to adopt related technology innovations. These "scouting" studies resulted in an understanding of the business and technical constraints and incentives for innovations. Specifically, we found that the technical managers responsible for innovation frequently conducted pilot studies with their own operating budgets. Furthermore, we found that the technical managers responsible for innovations were limited to evaluating simple components and were unable to undertake large-scale studies of potential "system-wide" technologies because they could not justify the cost and time for such studies.

Figure 2 shows the five stages in the innovation-decision process (Rogers 1983). The current demonstration site's chief engineer (who is responsible for operations in more than 100 buildings) evaluated a variety of information we presented about the IMDS prior to making a decision to implement the system. This information included a detailed engineering specification that outlined the sensor suite, software systems, and standard plots.

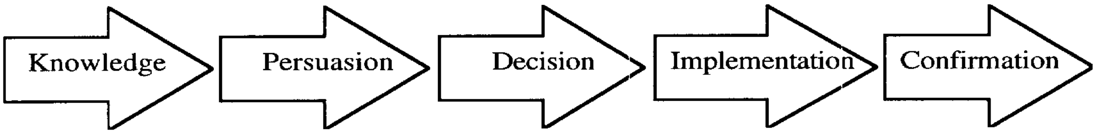

Figure 2. Stages in the Technology Innovation-Decision Process.

The collaboration with a leading chief engineer allows us to assess his informational needs, computing environment, and willingness to learn new systems. Our ability to automate diagnostics is linked to evaluating the ease of use necessary for the operating environment. We will work with the property managers to collect and review results presented in the form of standard graphics. The chief engineer is looking for technology that gives him a competitive advantage in managing the building. The system will allow evaluation of how the building performs in real time, with reliable and understandable monitoring technology.

During the pilot project selection process, we completed interviews of five third-party property management companies whose technology manager was selected as innovative. We are preparing a written analysis of the interviews for these five companies, who will be brought in to comment on the IMDS at the pilot site. We are studying the five steps (Figure 2) in the decision process for the pilot site demonstration, and are currently looking at the implementation and confirmation stage. The implementation stage has been complicated by a take-over in the property management business. There is a trend toward mergers and consolidation of property management firms, which have influenced most of the property managers we've been tracking. This turmoil is a barrier to research such as ours that benefits from stable ownership and management. Significant turnover in operational staff also hampers the development of long-term knowledge about an individual building's energy performance.

Diagnostic Technology and IMDS Design

Phase 1 included an investigation and evaluation of diagnostic methods, tools, and techniques for inclusion in the current project. Our analysis considered issues such as sensor and communications technology, bottom-up versus top-down diagnostics architecture, and the design of temporary versus permanent systems. We also examined the status of techniques from the field of intelligent systems (e.g., artificial intelligence, fuzzy logic, neural networks) and diagnostics used in process control industries.

A diagnostic system comprises the components depicted in **Figure 3**. We have installed the system in the building, with the set of sensors, data processing, and standard graphics already specified. We are currently training the building operator to use the system and will be closely monitoring their actions taken as a result of the system, which we expect to result in energy savings. There are difficult tradeoffs between advancing the automation of the diagnostic systems versus designing the system for optimal human-based diagnostics. The current emphasis in this project is to provide reliable and easily interpreted standard performance graphs that the operator can use for "human-based" diagnostics. The project also includes research on automated diagnostics, which include methods to detect faults and identify fault sources. Automated diagnostic systems generally include model-based (e.g., simple functions, physical, or black-box) fault detection and classifiers (knowledge or association based). The development of automated diagnostics can be justified by the recognition that building systems are becoming more complex over time and are difficult for the average operator to understand (Hyvarinen & Karki 1996). One study found that after a few months of strong enthusiasm, building operators lost interest in standard energy use plots provided by a utility research project that provided detailed energy data to building operators (Behrens & Belfer 1996). Thus, some automation of diagnostics are needed to set alarms that can tell an operator when the diagnostic system has identified a performance problem or deviation from normal operation. When such an alarm is sounded, the operator can than query the standard plots to look at the nature of the problem. We have chosen to work with the most sophisticated operators we can find, and will explore how to automate some of their "expert diagnosis" so that the system could be developed for a broader set of users.

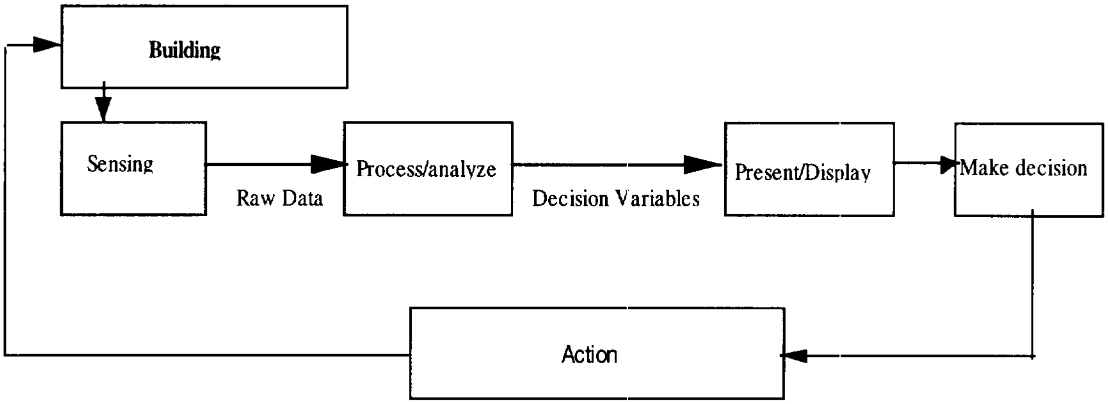

Figure 3. Components of a Diagnostic System

The basic architecture for the automated diagnostics has been defined and the approach for constructing the appropriate fuzzy-logic maps has been specified. We have begun to build a prototype of the basic routines needed to implement the system, which will use some of the project's basic plots (listed below) as test beds. The ideal automated diagnostic system should have the following capabilities:

- Easily automate the diagnoses incorporated in the project's nine basic (or other related) plots. This means automating the test regarding whether data in each plot is in the range corresponding to appropriate performance.
- Test for specific faults found by the research team or building operators.
- Learn new diagnostic patterns from experience and take hints or new information from humans (team or operator).
- Permit the human operators to understand the system's reasoning, and answer questions like "Why did the problem occur?"

The automated diagnostics analysis will include an assessment of how applicable the techniques tested at the demonstration site are to other buildings.

Figure 4 compared an IMDS and an EMCS. EMCS typically focus on scheduling and controlling building HVAC systems including air temperatures and flows and monitoring zone conditions. By contrast, the IMDS measures energy, weather and water-side variables (temperatures, pressures and flows). As mentioned, sensors commonly used in buildings are typically not adequate due to durability (frequent failures or falling out of calibration) and accuracy problems (e.g. measuring flows accurately is crucial, but typical systems either do not measure flow or do so with inadequate accuracy). Less accuracy is needed for day-to-day control than for diagnostics and evaluation of equipment performance because EMCS tend to use relative as opposed to absolute measurements.

The installed system consists of about 50 points and several dozen calculated, or virtual fields (such as load or efficiency) which are based on sensors such as high-grade thermistors, power meters, magnetic flow meters, and aspirated psychrometers. The monitoring equipment is listed in **Table 1**.

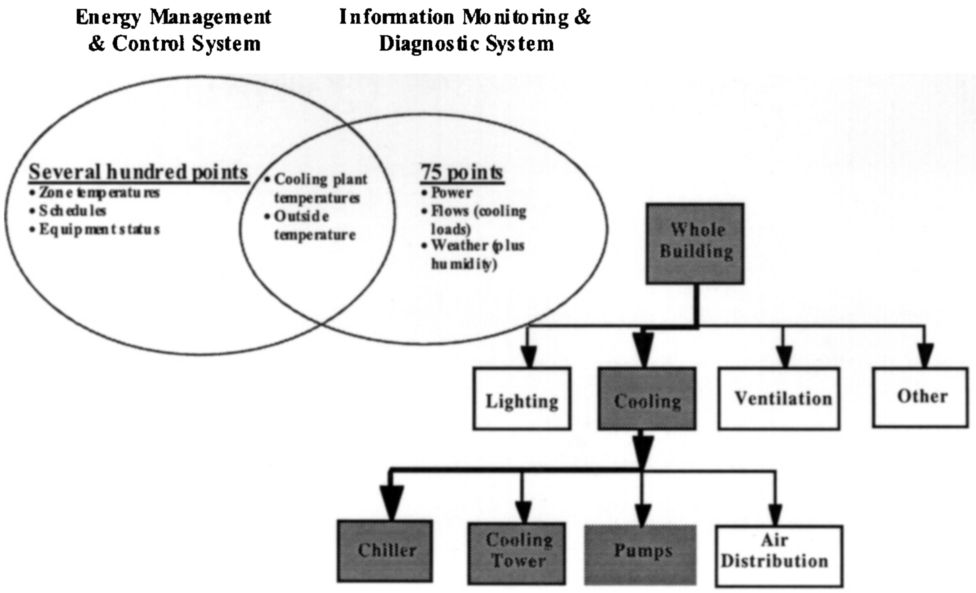

Figure 4. Comparison of EMCS and IMDS

Table 1. Systems and Sensors in the IMDS

System to be Evaluated	Measurement	Accuracy (@ full scale or °F)
Whole Building	Power	+/- 1.50%
Chillers	Differential Pressure (water) Water Temperatures Flows (water) Power (to chillers)	+/- 0.25% +/- 0.01 °F +/- 0.50% +/- 0.50 %
Pumps	Differential Pressure (water) Power	+/- 0.25% +/- 0.20%
Cooling Tower	Dry Bulb Temperature Wet Bulb Temperature Water Temperatures Power Flow	+/- 0.01 °F +/- 0.01 °F +/- 0.01 °F +/- 0.50% +/- 0.50%
Local Micro-Climate	Dry Bulb Temperature Wet Bulb Temperature	+/- 0.01 °F +/- 0.01 °F

The rationale for the selection of the systems is as follows. First, the selection of whole-building diagnostics is the starting point of the proposed diagnostic system. Whole-building data contain the basic yardsticks by which a building operator can get an overall set of metrics to evaluate building performance. The rationale for the selection of the cooling system is related to the benefits of working with it relative to the difficulties related to other candidates for the diagnostics, such as lighting or ventilation systems. Great improvements in cooling plant efficiency measurements can be gained with magnetic flow meters and high-quality thermistors. Chillers are the largest single energy-using component in large office buildings, and are thus a logical item to examine. Evaluating the entire cooling plant will allow us to understand the overall system performance, which is more important than examining a component in isolation from the system.

For comparison, the measurement issues associated with ventilation and lighting are more distributed -- literally distributed throughout a building. Measuring air flows is particularly problematic. A similar confounding issue with ventilation systems is that ventilation requirements in individual zones vary because of duct configurations and thermal variations. These were determined not to be good candidates for the initial demonstration, but are suitable for future research. The IMDS, by contrast, is restricted to monitoring cooling plant equipment that is located either in the central plant or on the rooftop.

The components selected for the analysis are chillers and cooling towers. Both of these components were targets of complaints from building managers about poor sizing. Chillers are often oversized, thus they require more power per ton than optimal because they are less efficient at low partial load. Cooling towers are often undersized. Larger towers allow the chiller to operate at cooler condensing temperatures. The diagnostic system will explore major failure modes for these components.

The IMDS is designed to be a permanently installed and continuously active system. This is necessary because buildings continuously change. For example, some problems reoccur, such as those from modifications to schedules to handle special events. These modifications often lead to equipment being left on when not needed. The diagnostic system is designed to operate in parallel with any existing EMCS, rather than expanding or modifying the EMCS. The IMDS is therefore not constrained by EMCS data collection capabilities, which can be problematic with 50 points of one-minute data. This technology may, however, be incorporated in future EMCS.

Failure Modes

The research has included an analysis of performance metrics and benchmark data to characterize the fundamental principles of the selected building, system, and components. We developed a series of standard graphics that will allow the metrics to be displayed in a manner that assists in the diagnosis. These graphs were analyzed to determine benchmark signatures for good performance, such as where measured values should fall on a given analysis plot, or what the curve shape should look like if the system or component is performing properly. We developed a series of measurements and sensing requirements to evaluate the systems and components. We also listed common modes of failure that one can diagnose with the given metrics and graphics based on case study data and related literature. The discussion of failure modes is not an entirely exhaustive list of failures, but covers common and critical modes of failure. The proposed knowledge base is designed to be modular, with a set of standard graphs and standard information. These graphs also serve as a tutorial that is designed to orient the building operator on how best to understand the system or component's energy performance. A list of the nine plots and associated diagnostics are listed in **Table 2.** The whole-building data are fairly straightforward but we provide some additional details on the cooling system and component data.

Cooling System Diagnostics. The entire cooling system efficiency can be evaluated using the efficiency versus load analysis (kW/ton vs. cooling tons). The total cooling system performance in kW/ton is affected by the kW/ton for each component. The shape of the efficiency versus percent load curve is dominated by the chiller, so the entire cooling system kW/ton curve tends to look like the chiller curve. Chillers should ideally operate near their rated efficiency (purchase point). Various problems (oversizing, improper scheduling, control problems, etc.) exhibit signatures on these plots.

Chiller and Cooling Tower Diagnostics. The chiller monitoring will capture key parameters in the chiller operation such as water flows and temperatures, pressure drop, and power. These data will allow determination of chiller efficiency (Figure 5) and loads. We will also measure the pressure drop across the chiller heat exchangers to determine the extent of fouling. The cooling tower monitoring will also include water temperatures and flows, plus local outdoor weather data and cooling tower fan power. A temperature measurement station including an aspirated psychrometer will be installed on the top of the building as far away from the cooling towers as possible. Data from this psychrometer will be used to evaluate "nano-climate" effects at the building scale, which and are smaller than well-known city-wide micro-climates. Cooling tower intake conditions will be compared with outdoor air conditions to evaluate re-circulation of cooling tower exhaust.

Table 2. Standard Plots and Failure Modes

Building Component	Standard Diagnostic Plots	Example Failure Modes, Problems & Opportunities
Whole building	1. 2D - Outside Temperature/ Power (24 plots for each hour of the day) 2. 2D - Power/ Outside Temperature 3. 3D - Day/Time/Power	• Sudden changes in consumption • Weather impacts on consumption • Higher consumption than similar buildings • Opportunities for alternative electricity rates - load shapes, • Load management strategies, • Unusual nighttime loads or start-up peaks
Cooling System	1. 2D - Cooling System Load (tons)-kW/ton 2. 3D - Day/Time/Cooling System kW	• Comparison to other similar systems • Changes in consumption or efficiency of cooling system due to such things as improper pump operation, tube fouling, component malfunction, or tower set points. • Scheduling problems such as excessive time on or short cycling
Chiller	1. 2D - Chiller Load (tons)-kW/ton	• Degradation in efficiency of the chillers away from manufacturer's specs. • Efficiency improvements from changes in operational parameters, i.e. part-loading, and condenser and chilled water temperatures • Efficiency degradation due to refrigerant charge, tube fouling, etc. • Full load or part load performance and chiller oversizing or undersizing
Cooling Towers	1. 3D - Day/Time/Cooling Tower kW(excluding condenser pumps) 2. 2D - Approach (CWS-WB)/Cooling Tower Tons* 3. 2D - Corrected Cooling Tower Tons/Condenser Flow	• Degradation of tower efficiency due to fouling, excess flow, too few cells running, or recirculation of saturated air leaving tower • Cooling system excess energy use due to tower undersizing • Scheduling problems due to tower not modulating or not interlocked to condenser pumps, temperature control problems

*CWS - condenser water supply and WB - wet bulb

The classic example of chiller diagnostics is depicted in **Figure 5**. Here, efficiency (kW/ton) is plotted versus load (tons). Chillers should ideally operate near their rated efficiency (purchase point). Various problems (oversizing, improper scheduling, control problems etc.) exhibit signatures on this type of plot.

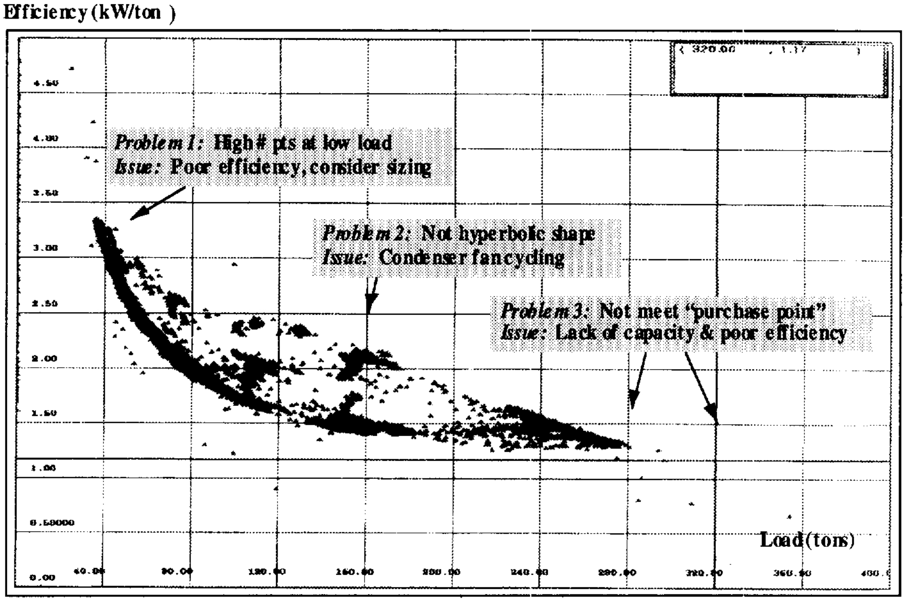

Figure 5. Chiller Efficiency versus Load and Sample Problems Diagnosed

IMDS Structure and Data Access

The data collection and distributed analysis environment are shown in **Figure 6.** A simple flat-file database has been developed to archive the monitored data. We are testing the first PC version of the graphics software, which was previously only available for use with high-end graphics workstations. Data from each sensor are archived in the PC server at the demonstration building. The data acquisition and graphical analysis software are located on the PC, allowing the on-site operator and chief engineer direct access to the data. The IMDS generates nine standard plots available for viewing, plus it offers a series of more sophisticated browsing and statistical analysis tools. These more sophisticated tools will likely be of greater use to the remote researchers. Researchers in several locations will have access to the data, plus the identical analysis software, allowing them to analyze the building performance and test the automated diagnostic systems. The PC server will offer a subset of the real-time analysis graphics from the demonstration site to the public over the World Wide Web. The purpose of these graphs are to demonstrate the technology to interested organizations and potential future service providers such as Energy Service Companies, utilities, and control companies.

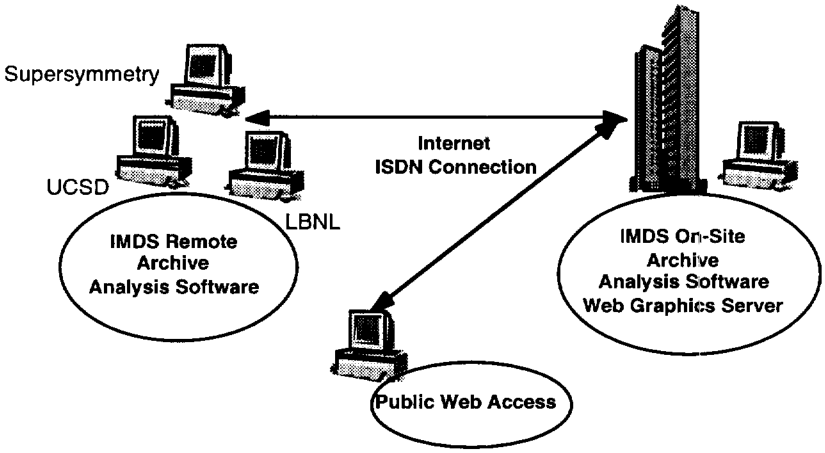

Figure 6. Remote Data Access for the IMDS

Pilot Demonstration

The building selected for the demonstration is a 100,000 sqft office building at 160 Sansome Street in San Francisco, also known as the Hong Kong Bank Building. The building is about 30 years old, with two 200-ton chillers that are also 30 years old. **Figure 7** shows that the site annual energy use intensity (EUI) is typical compared with related benchmarks. The building used 90 kBtu/sqft-yr in 1996, which consisted of 64 kBtu/sqft-yr for electricity and 24 kBtu/sqft-yr for purchased steam. The first of the comparison data sets is the EUI for a 100,000 sqft large office building from a Northern California simulation prototype developed from energy analysis of 74 similar buildings (labeled **CEC No.Cal**, Akbari et al. 1993). The second EUI is the west-coast large office building average from the US Department of Energy's Commercial Building Energy Consumption Survey (labeled **CBECS-West**, CBECS, EIA 1995). The third, and most similar, is the average EUI for San Francisco office buildings from BOMA (labeled **BOMA-SF,** Energy User News 1995).

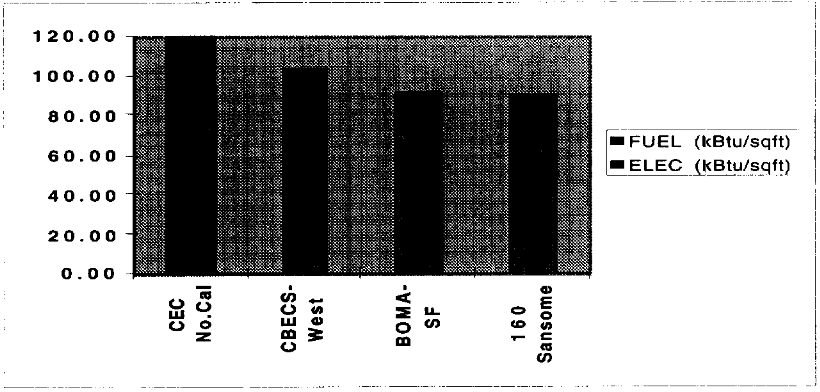

Figure 7. Annual Site Energy Use (kBtu/sqft-yr) of Demonstration Site and Comparison Buildings

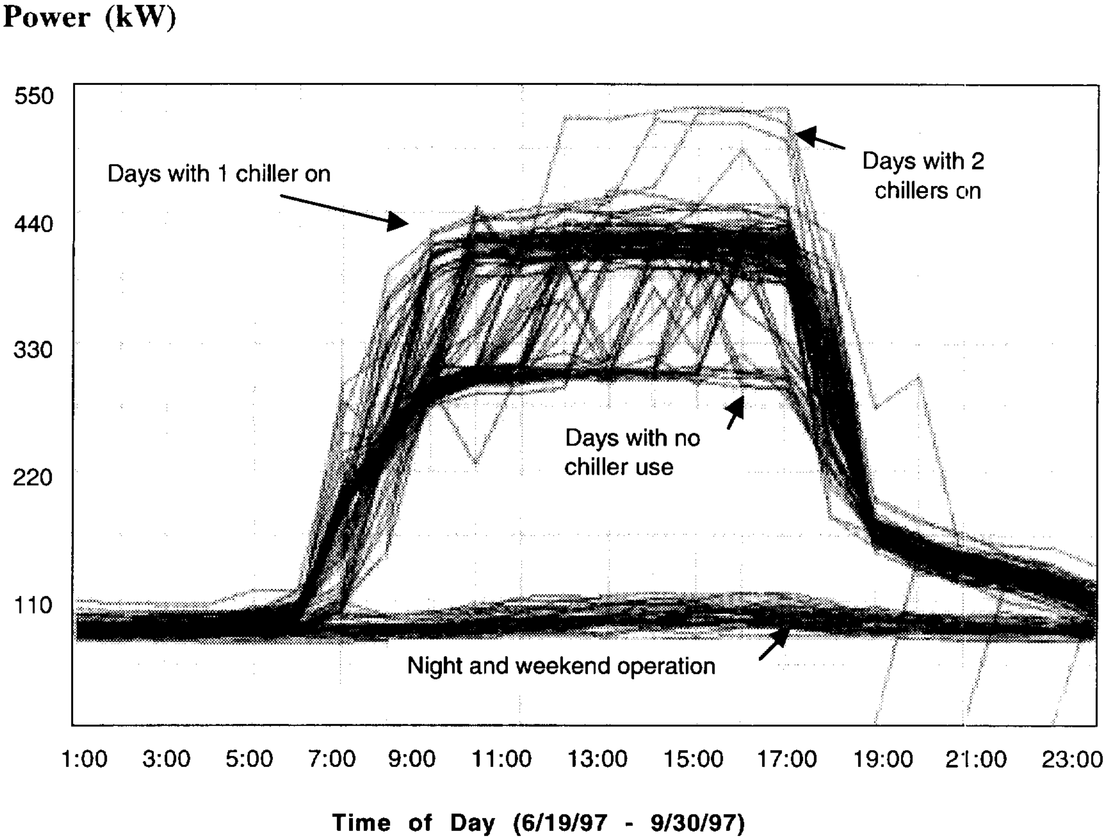

Figure 8. Hourly Electric Load Profile for 160 Sansome St.

Figure 8 shows the hourly electric load profiles for about three months (June 19 through September 30, 1997). The load profiles show that the building is extremely regular in its usage pattern. Nighttime energy use is extremely low. All HVAC systems and most equipment tend to be off at night, with HVAC coming on at about 6 AM. Although we do not yet have end-use data, there appear to be four distinctive day-types that can be easily identified. First, weekends and holidays are days with low power similar to nighttime power. (There are few nighttime and weekend occupants; after-hour HVAC services are available at a relatively high price.) Next, there appear to be typical workdays that are those when the chillers are not needed. The next higher load shape represents days when one chiller was used. Finally, the highest power days are those when both chillers are used. These days correspond to the periods with the warmest weather.

The highly regular and well-controlled building systems suggest that basic equipment scheduling will not be where we will find energy savings. Rather, we expect that the IMDS can be used to improve chiller and cooling tower control. *We will only explore these changes after we first give the on-site staff time to use the system without our intervention!* The current outdated EMCS, unlike most for this type of building, does not provide any information about the chilled water supply temperature or condensing water temperature. We also expect that the overall cooling plant has poor efficiency (kW/ton). We provide some examples here of the opportunities for improving the cooling tower performance. The cooling towers are blow-through towers with centrifugal fans, which are inherently inefficient. We will consider the savings possible with a variable frequency drive for the tower fans. We will examine the general conditions of the cooling tower, such as the fill water treatment and air flow rate (by working backwards from water side enthalpy). We will consider alternatives to the current cooling tower operation, such as changing the fill or water treatment, or perhaps increasing the louver area. Another possibility might be to increase the condenser flow by removing obstructions (such as the strainer, globe and balancing valve, and orifice plates, etc.) and possibly running two pumps to one chiller.

Since high-quality sensors are a critical element of the diagnostic system design, the demonstration will include an evaluation of the costs and benefits of data accuracy and relative value of each data point. This task will also include evaluating the life-cycle costs (first costs and maintenance costs) of high-quality, high-end sensors versus alternative, more common sensor and comparisons of the EMCS data with the IMDS data.

Costs and Benefits

The property managers that we have approached have all expressed a strong interest in participating in this research. The pilot collaboration is structured as follows. The research project's budget covers the cost of the hardware and software at the building site. The property management company covered the cost of the system installation. This arrangement worked fairly well in practice, but required some assistance from the research team in the installation process in order to keep to the tight project schedule. We have spent approximately $65,000 for the hardware and software (including ISDN services) with a similar level of in-kind support from the property managers.

The non-energy benefits of the IMDS are major drivers for the high level of interest in this technology. The "innovators" we are working with recognize the general value of having high quality information about building performance. Perhaps the primary non-energy benefit the IMDS offers is vast improvements in data about the general operating conditions of major building equipment. Field studies have found that equipment is often on when not needed, plus we commonly see equipment cycling too frequently (Piette 1996). Both of these examples bring about premature end of life or equipment failures. The IMDS data may also lead to better comfort conditions and tenant satisfaction given the improved ability to evaluate the performance of the cooling plant. These benefits will be difficult to quantify, but will be tracked in our evaluation. Our target of 15% energy savings translates into about $0.30/sqft-year for a 100,000 sqft building consuming about $2/sqft, or $60,000/year for the pilot building. This would offer a simple payback time of about two years when considering the current system with today's costs. Our expectation is that the first costs will decrease significantly as the technology matures.

Summary and Conclusions

The primary objective of this project is to introduce state-of-the-art building monitoring and diagnostic information systems into Class A buildings for use by sophisticated building operators. This objective is based on our background research, which suggests that the proposed system meets the needs of operators and that they support the system we've designed. The concept is to deploy a permanent system to assist in continuous improvements in O&M to reduce energy use and operating costs. Our overall goal is to work with building owners and property managers in demonstrating the cost effectiveness of the proposed diagnostic system, thereby creating a market demand for such technology. We hope to demonstrate that the system could be cost effective when commercialized by the private sector.

The IMDS demonstration is oriented toward deploying the basic infrastructure for an advanced information system, including field tests of initial applications. This demonstration will allow the controls industry to examine the value of such systems that greatly exceed today's current EMCS technology. Such a system is the starting point for more advanced, automated diagnostics, such as those based on fuzzy logic or neural networks.

The diagnostic system will meter various building systems and components to provide feedback on building performance. The users of the system will be building operators and property managers. The project involves working with innovative experts a) to assist in developing new technology and b) to use them and their peer groups to develop a technology pull strategy as they provide feedback on the technology. The suppliers could be electric utilities, other third-party experts such as ESCOs, or control companies. The service would ideally be paid through savings in the operating budget. This technology gives the owners and managers a quantum leap in improving management in their buildings. It could reduce operating costs and make their spaces potentially more comfortable. It also gives them the choice of local or remote building diagnosis. The IMDS is an example of an entire wave of information based technology, giving customers a direct entree into this entire new field. We hope to extend the IMDS demonstrations to additional buildings, and will be exploring modifications to the current monitoring suite. See http://eetd.lbl.gov/EA/IIT/diag/ for more information.

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