Summary of Early Findings From a Second Generation Information Monitoring and Diagnostic System

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Synopsis

Private sector commercial office buildings are challenging environments for energy efficiency projects. This challenge is related to the complexity of business environments that involve ownership, operation, and tenant relationships. This research project was developed to examine the environment for building operations and identify causes of inefficient use of energy related to technical and organizational issues. This paper discusses a second-generation Information Monitoring and Diagnostic System (IMDS) installed at a leased office building in Sacramento, California. The underlying principle of this project is that high quality building performance data can help show where energy is being used and how buildings systems actually perform. Such data are an important first step toward improving building energy efficiency. This project has demonstrated that the IMDS is valuable to the building operators at the Sacramento site. The building operators not only accept the technology, but it has become the core of their day-to-day building control concepts. One objective of this project was to evaluate the costs and benefits of the IMDS. The system cost about $0.70 per square foot, which includes the design, hardware, software, and installation, which is about 30% less than the previous IMDS in San Francisco. A number of operational problems have been identified with the IMDS.

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Background

Building operators in large office and similar buildings have limited tools to understand the energy use and performance of the building systems they manage. The paper reports on recent research to develop and assess such tools. This research builds on nearly a decade of previous research. During the 1990s a multi-disciplinary research team led by Lawrence Berkeley National Laboratory completed an analysis of the performance of a first-generation IMDS in a commercial office building in San Francisco at 160 Sansome Street (http://imds.lbl.gov, see also Piette et al., 2001). The Sansome Street project showed how sophisticated performance monitoring and data visualization tools can be useful to building operators and property managers. This technology can save energy, reduce operating costs and improve comfort. The IMDS concept consists of high quality sensors, a data acquisition system that provides high quality performance measurements archived each minute, data visualization software, and web-based data retrieval and analysis capability. Commercially available Energy Management and Control Systems (EMCS) have limited performance-monitoring capabilities compared with the IMDS. The Sacramento IMDS, however, is not used for control, only monitoring.

Table 1: IMDS Project History

Year	Project Phase	Activities	Pilot IMDS* San Francisco	2nd IMDS Sacramento
1993	Phase 1	Detailed scoping study, market assessment, & technology evaluation		
1994				
1995				
1996				
1997	Phase 2	Pilot IMDS installation	Site selected, system specified	
1998			Installation completed	
1999	Phase 3	Pilot IMDS evaluation		
2000	**Phase 4**	**2nd Generation IMDS**	RFP released for controls retrofit	**Site selected, system specified**
2001			Controls retrofit based on IMDS completed	**System installed, preliminary investigation**
2002			Savings reported	

The IMDS was used to identify and correct a series of control problems at Sansome Street. It also helped to improve building comfort, which potentially improved occupant health and tenant organizational productivity, though this is harder to measure. Following the completion of the Sansome project, the building management initiated a project that retrofitted the IMDS to become the primary HVAC control system (Smothers and Kinney, 2002). The number of sensors was doubled. Prior to performing the control enhancements in San Francisco, the research team estimated that $20,000 in annual savings was available from improvements identified with the IMDS. Such costs could provide a simple payback for the $100,000 first-generation IMDS in five years. This paper focuses on the bold items in Table 1, which outlines the research history.

Goals of the Second Generation IMDS

The overall goals of this project are to refine the IMDS concept and to evaluate the value and usefulness of the IMDS in a more general context. The success of the demonstration at 160 Sansome Street is due in a large part to the high level of innovativeness and capability of the building operators and their dedication to learning, using and adopting the technology. Following the Sansome project, several questions remained which the 925 L Street IMDS project addresses. For instance, *will other building operators have similar dedication and appreciation of the IMDS technology?* Also, the existing EMCS at 925 L Street is far more sophisticated than the original EMCS used at 160 Sansome Street. *Can a modern EMCS be used for the majority of the diagnostics and data tracking tasks conducted at 925 L Street, or is IMDS-type technology essential to achieving the benefits obtained at the 160 Sansome Street project?* The primary diagnosis at Sansome Street could not have been done with the EMCS at that site. The on-site comparison of the IMDS with a state-of-the-art EMCS is critical to a definitive evaluation of the technology characteristics. Follow-up questions that this project addresses are: *How effective is the IMDS platform for deploying automated, model-based diagnostics, and how can such systems be made useful to the building operators?* Earlier papers (Xu amd Haves, 2002, and Haves and Khalsa, 2000) report on automated diagnostics research related to the IMDS.

Methodology and System Description

This project began during the final phases of the previous IMDS project at Sansome Street. The Sacramento Municipal Utility District expressed interest in sponsoring a second IMDS, and the research team identified a candidate site in Sacramento. The selection of Jones Lang LaSalle (JLL) as a test subject was influenced by JLL's status as the largest third-party property management company in the world. Their willingness to employ a full-time team of engineers and architects provides them with in-house technical expertise. This company is large and well respected in Sacramento, operating over 4 million square feet of Class A office space. Several buildings were proposed and evaluated. This step was a high risk for the research team. Third-party property managers do not typically own the buildings they operate. Building owners can be fickle and managers may change frequently. Building owners' reactions to changes they are experiencing elsewhere may make for capricious local decisions. A cooperative property management company can help select the site, but they cannot guarantee rational behavior from the owners. The mechanical systems in the building selected for the project are listed in Table 2.

The Park Executive Office Building is a "Class A" Office Building constructed in 1970. It has a gross floor area of approximately 175,000 square feet. There are 14 leased floors at approximately 12,160 square feet each, and an additional 4,200 square feet of tenant space on the main floor and mezzanine levels. The central plant is located in a rooftop mechanical room (penthouse). The building is in downtown Sacramento, directly adjacent the north side and one block west of the State Capitol building. A large portion of its tenant space is leased to State of California agencies as well as media and other organizations related to State governance.

Table 2: Building Description and Systems Overview

Building Size	175,000 sqft (14 floors, 1 mezzanine and basement)
Chillers	Two @ 300 tons each (centrifugal)
Cooling Towers	Two-cells
Air Handlers	17 AHUs, 20 Hp Supply Fan, no return fan
Boiler	Natural gas, 65,000 kBtu input, 80% efficient, two firing stages
Controls	1998 vintage EMCS, primarily pneumatic controls with some DDC
HVAC Distribution	Dual Duct CV systems, 2 duct zones per floor, ~35 boxes per floor
Lighting	Compact fluorescent and T-8 lamps

The project team customized the IMDS design by examining the HVAC, lighting, and other systems at 925 L Street and discussing monitoring objectives with the operations staff. The overall aim of the project was to maximize the usefulness of the IMDS in improving building performance. The building has 14 floors and 17 single fan air handling units (AHUs), with each AHU serving two zones on each floor. The following measurements were considered for inclusion in the IMDS directly or linked to the IMDS via a gateway to the EMCS (one item marked * was considered but not included because of budget limitations):

- Fan status (with manual measurements of true power, accompanied by flow rate)
- AHU air temperatures: return, outside, mixed, supply discharge, hot and cold duct supply
- Control signals to mixing dampers, heating coil valve and fans
- Return and outside air humidity
- Entering and leaving water temperatures for both coils
- Cold deck humidity*
- Hot and cold duct air flow rates for each zone
- Terminal box hot and cold duct temperatures at inlets (compare with deck temperatures leaving AHU to estimate duct losses/gains)
- Terminal box leaving temperature
- Zone temperature sensors (same location as control sensor). The EMCS has two temperatures per floor.
- Control signal to terminal box dampers and/or damper position. Note: most of the dampers on the AHUs are controlled pneumatically.

Installation, Commissioning, and IMDS Training

The building operations staff was the primary installer of the supplied equipment. While the building staff repeatedly expressed interest and commitment to the project and an increasing level of enthusiasm as the project developed, the realities of property management resulted in the IMDS installation receiving a low priority in day to day tasks. The first priority of the building operations staff is to maintain the comfort of its tenants. Some of the issues that derailed the staff away from the IMDS include budget cuts and lease negotiations. Additionally, faulty water heaters flooded, causing major damage, requiring over six months to repair. Scheduling of the installation of power monitoring equipment on the 7th-floor required a power shutdown in tenant space and was delayed several times. Several staffing changes resulted in a significant amount of delay as new personnel had to be brought up to date on the project and also were expected to have the same commitment.

IMDS Description and Costs

Table 3 lists the primary components of the IMDS. The system value is approximately $50,000, but the costs to the project were $38,000 because of discounts and in-kind contributions obtained from industry partners. The system costs were brought down from $63,000 for the pilot IMDS due to the drop in prices for computer and network technology and the use of lower-grade sensors outside the chiller plant. Standard commercial-grade sensors were used where higher accuracy did not provide value in the pilot IMDS installation. As listed in the table below, the IMDS consists of:

- A data acquisition server and software
- Data acquisition networked controllers
- A web server and user workstation
- A data visualization package, including both a local and a web-based interface
- 44 new sensors located in the basements, 7th floor air handler, and plant room.

The data acquisition component uses 16-bit analog-digital conversion and has better accuracy than typical 8-or 12-bit EMCS systems in the field. The higher resolution and accuracy adds stability and longer-term reliability. The system is high speed with capability to trend all points at 1-second intervals. Both retail and actual costs are shown in Table 3. Electric Eye Pte, Lte. (www.eeye.com.sg) in cooperation with EN-WISE donated the data visualization system, plus the local and web interface.

Table 3: IMDS Component Costs

Data Acquisition and Visualization	**Retail Value**	**Cost to Project**
Data Acquisition Server and Software	$6,788	$5,903
Data Acquisition Networked Controllers (10)	$6,198	$5,389
Web Server and User Workstation	$2,645	$2,300
Data Visualization Package, local and web interface	$9,000	$0
Peripherals (monitor, UPS, RAID, etc)	$3,824	$3,325
Total	**$28,455**	$19,917
Sensors Total	**$23,404**	$18,495
IMDS Equipment Total Cost	**$51,859**	$38,413

The points include power, temperature, air flow, and water flow monitoring. The costs to install the system were about $0.7 per square foot. This is lower than the $1/sqft estimate for the original IMDS demonstration in San Francisco; however, the total cost is slightly higher. This is due in part to a more accurate accounting of labor costs. Many of the labor costs for the installation at the San Francisco site were never accounted for.

Evaluation of IMDS Use, Savings, and Benefits

LBNL's objective for the case study was to evaluate the costs and benefits of the IMDS. This task consisted of compiling data from at least 6 months of use of the IMDS to evaluate the benefits over time. These benefits could include energy savings, labor and operations savings, comfort improvements, and other such items. We conducted periodic on-site interviews with the operations staff to evaluate how they used the IMDS. These interviews were used to identify building performance problems found using the IMDS.

Energy Management Control System Trending

There is minimal trend logging with the EMCS for a number of reasons. First, the EMCS has few trend logs set up for building operations analysis. Setting up new trends requires high-level EMCS programming that is not done by on-site staff, but is done through the local company who supports the control system. As a trend runs, it overwrites previous files on the hard drive and there is no historic archiving of the HVAC data. Another factor that limits the use of trend logs is the limited hard drive space and system memory. When the system resources are set to trend, loss of primary control or impacts to communications on primary operation can be created. Earlier attempts to gather data for comparison to the IMDS filled up the buffers and caused the OS2 (Operating System 2, IBM PC) interface to lock up. The EMCS continued to operate, but the system did not fully operate and the local service provider needed to make a site visit to clear the trends and reset the interface. This is a key finding regarding the capability of the EMCS to be used for data analysis.

Historical Energy Use

LBNL performed extensive analysis of the historic energy use data prior to and during the project. The purpose of this analysis was to establish baseline energy use against which energy savings due to measures taken in response to IMDS data can be evaluated and to understand the overall energy use intensity compared to other buildings, thus providing some reference point for energy efficiency opportunities. We also examined the peak demand data and the major drivers of energy use including weather and occupancy.

The operations staff began using the IMDS in mid-2002. The utility data prior to that time can be used to establish a baseline energy usage profile against which future energy use can be compared to evaluate energy savings. For this building we have a large amount of data to use as SMUD was able to provide us with several years of 15-minute data collected under a separate program. This is useful for understanding the long-term energy use of the building; however, other major changes in building use have to be accounted for, such as weather and occupancy.

The building uses about 91 kBtu/sqft-year. In establishing the potential for energy savings, it is useful to compare the building's energy use to that of other buildings. We used a benchmarking tool, Cal-Arch, to determine that the building has an EUI that is higher than 75 percent of California office buildings (see poet.lbl.gov/cal-arch, see also Kinney and Piette, 2002). While there are many factors, such as extended operating hours, that can help to explain this, it still suggests there is room for improvement. The dual-duct CV HVAC system at the building is energy intensive with extensive use of simultaneous heating and cooling, and no economizer cooling.

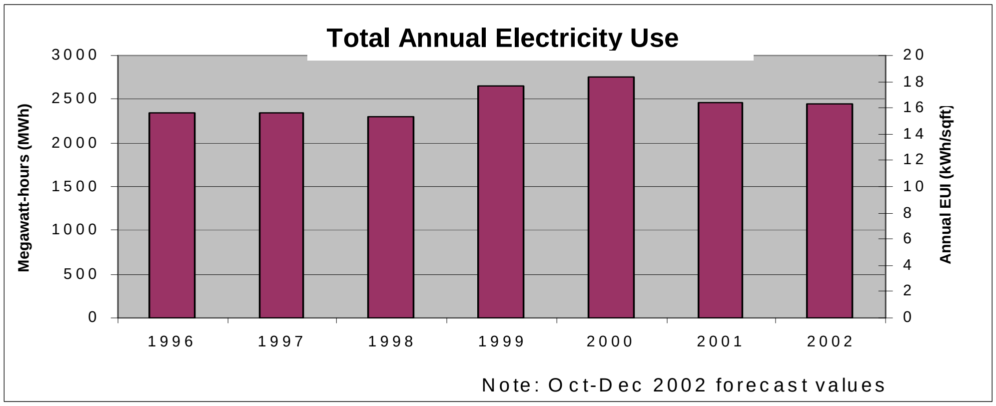

Figure A. Total Annual Electricity Use

Figure A shows seven years of electricity use, which reached a maximum in 2000 of 2700 MWh, and dropped 10 percent in 2001 and 2002. In light of recent events relating to California's energy supply, peak loads are of great interest. Over the last several years, the annual extreme has come down. The energy use data also illustrates a drop in daily peak, i.e., full-load operation, after the chiller retrofit in 1999. Also evident are changes in operating schedules. Nighttime and weekend operating hours have increased since 1999, as has occupancy of the building. Two years of cost data were available for both electricity and gas use. Electricity costs during this time, for peak and off-peak periods, were relatively stable. In contrast, gas costs for Winter 2001 were extremely high. The average annual expenditure for the main building account is nearly $243,000, or $1.6 per square foot per year, based on 147,750 square feet, and nearly $29,000, or $2.4 per square foot per year, for the 12th floor, based on 12,250 square feet. Combined, the total cost is $271,000, or $1.7 per square foot per year. On the gas side, annual costs are $70,000, or $0.45 per square foot per year. Figure B shows the average costs per day for 24 months of data. The increase in summer electric costs is evident, as is the dominance of electric over gas costs.

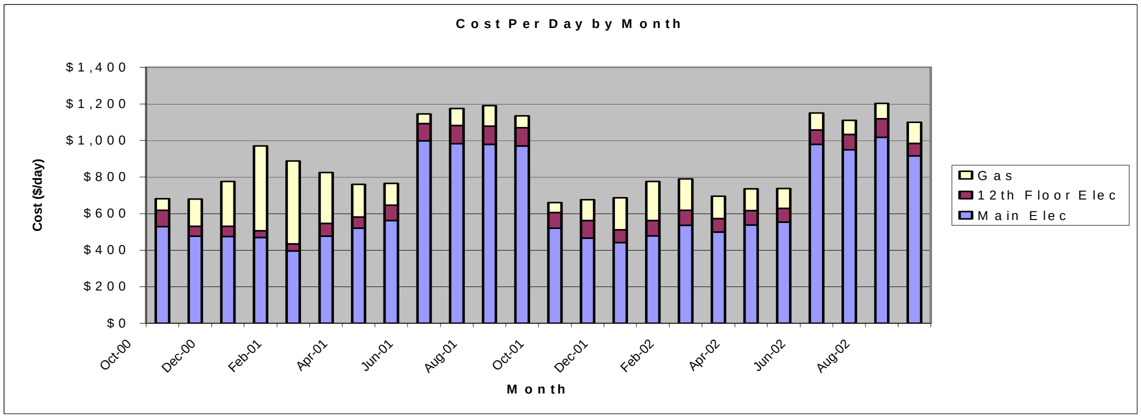

Figure B. Utility Costs Per Day, By Month

Use of the Information Monitoring and Diagnostic System

The building's current chief engineer took over in 2001, as the IMDS installation was underway. He has been using the IMDS as an integral part of daily operations since August 2002. Initially, as part of his daily routine, the on-site engineers used the Web interface "Operator Page" (Figure C) on the Electric Eye server. This page is customized and provides most of the system data he needs to file in his daily activity logs and system status report to JLL. The page helps him quickly ascertain if the controls are operating correctly. LBNL conducted periodic interviews with the operations staff beginning September 2002. In the interviews we discussed system performance, system problems, obtained copies of his Activity Reports and provided assistance as needed.

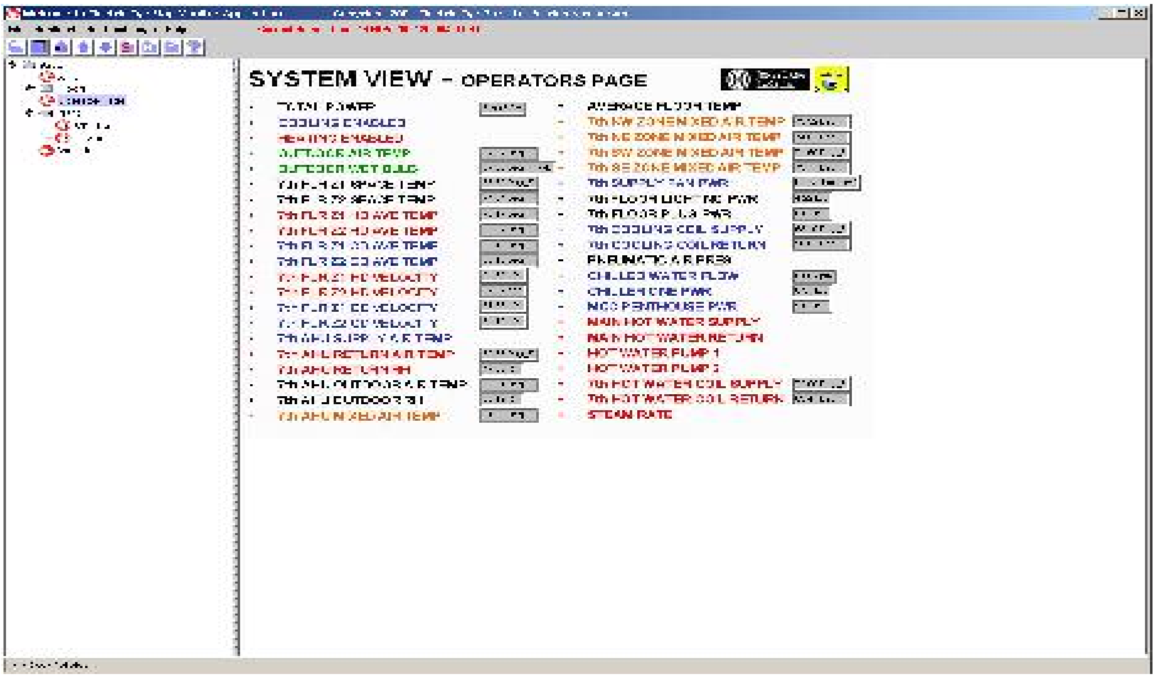

Figure C. Operator Page on the Electric Eye Web interface

In October 2002, the engineer requested training on the local user interface, which provides more analysis capabilities than the web interface. He had not been fully trained on Electric Eye because the IMDS installation was not complete; however, the operator wanted the project to move forward even if the EMCS-IMDS connectivity could not move forward as planned. He now uses the visualization capabilities of this software as part of his daily routine. The main reason for this request was his discovery of an unusual oscillation in the whole building power plots he saw on the web Electric Eye graphs.

Both the current and the original building opreators report that the IMDS sensor accuracy is far better than the EMCS because of the quality of the sensors, their location, and their recent commissioning of the sensors. As a result, they monitor the building operation with readings from the IMDS and implement the control changes on the existing EMCS terminal. Both operators are impressed with the accuracy and visualization capabilities of the IMDS, and report this as the most important benefit they have derived from the IMDS. They report that the IMDS is becoming increasingly indispensable as a system resource, largely displacing the EMCS sensor readings and relegating the EMCS interface to the role of an “elaborate manual control switch.” The control is, however, still done by the EMCS.

Building Operations Problems found with the IMDS

To date, the IMDS has helped to identify four key problems in the building HVAC system. Corrective measures are in progress and resulting energy savings have not yet been quantified.

Problem 1. Variable Frequency Drive Operation. The first day the IMDS was online, JLL was identified a variable frequency drive (VFD) overheat condition for the cooling tower fans.

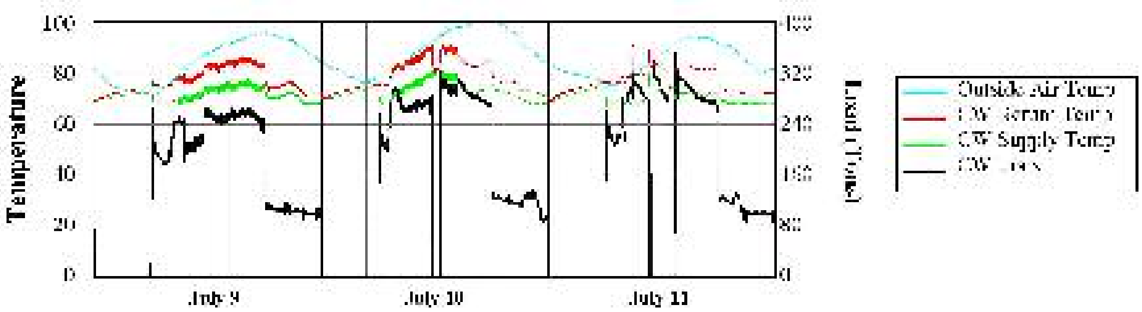

Figure D. Condenser Water Temperatures Fluctuations, July 9 and 11, 2002.

When temperatures soared over 110 ° F, high condenser water temperatures shut down the chiller and cooling tower fans ran intermittently. The tower fans did not operate. With no air circulation across the VFD controller, the VFD shut down on a thermal safety. The IMDS tools were used to diagnose the problem and obtain tower control. **Figure D** shows the condenser water temperatures fluctuate on **July 9 and 10**. On **July 10** the operator controlled the condenser temperatures by taking the door off the VFD panel. On **July 11,** during the installation of the new fans, he bypassed the VFD (observe the chiller shut down).

Problem 2. Temperature Control. Using the IMDS data, JLL found a possible explanation for the building’s long history of temperature complaint calls from occupants located in the NW corner of each floor. The condition is related to duct zoning, airflow rates, and differing solar load conditions. Corrections are in progress.

Problem 3. Outside Air Sensing. The IMDS weather station allowed JLL to identify a gross error of +12°F in the EMCS measurement of outside dry bulb air temperature (OAT). Because OAT is used in several control system reset schedules, the energy impact from modified control will likely be significant.

Problem 4. Chiller Control. Another significant discovery was that the 300-ton chiller was restarting for a brief period several minutes after shutdown.

JLL is interested in using the IMDS to obtain information to develop a capital budget for needed HVAC system upgrades. Two upgrades in consideration are 1) Constant Volume (CV) to

Variable Air Volume (VAV) retrofit of all AHUs, and 2) the addition of a plate-and-frame heat exchanger for a waterside economizer cycle. It is important to note that the involvement of the building operators in the IMDS installation has influenced their knowledge and perceived value of the system. They report, "We helped build it, so we know it!" JLL plans to present their findings and benefits of the technology at the upcoming annual JLL Engineer Conference. They are interested in quantifying the savings obtained from the use of the IMDS. LBNL has not conducted this important step because the system has only been in use for a few months.

As mentioned above, the research project at 925 L Street is the second IMDS installation. The first project began with an industry innovator in San Francisco (Shockman and Piette, 2000). The new issues studied in this project phase are the use of the IMDS by an early adopter, and the dissemination or diffusion of the information about this type of technology within JLL and the wider industry. We present findings in both of these areas. This test has been technically successful, but slow in execution.

The JLL operators report that they have a good understanding of the IMDS. The data interface has no automated diagnostics or annunciation of alarmed conditions; the operator must decide what data to view and compare. According to the JLL operators, they believe the data are trustworthy and are using it to make decisions about building operation. Interpretation of the results is in its early stages.

The IMDS is highly valued by the building staff, as expected by the research team. We have observed that they have quickly mastered the computer software and are confident navigating through the screens. Typically, the characteristics of the technology that the early adopters will try are relative advantage, compatibility, complexity, and ability to be observed. These characteristics of an innovation are well understood for smaller, less complex products. The IMDS provides a unique opportunity to follow the adoption process and diffusion of a more complex technology. A major advantage of the IMDS compared to existing systems that monitor, control or monitor and control, is that that the system uses open communication protocols. Mr. Colbert will need to test his ability to access and program to all parts of the system software before recommending it for wider adoption. Another criteria for JLL to adopt the technology is demonstrated compatibility with existing values, past experiences, and future needs. The technology must be capable, for example, of being built up using small annual equipment budgets, rather than requiring a large, one-time procurement. The technology must be installable by local building engineers. Complexity of new systems is a major obstacle for new system adoption. Any technology must be operable by regular building engineers. The buildings industry is reluctant to require "Information Technology" professionals as staff. New technology must not be so complex that it is impossible or time consuming to use.

Summary of Research Results

Evaluation of IMDS performance, Costs and Benefits

One objective of this project was evaluate the costs and benefits of the IMDS. The system cost about $0.70 per square foot, which includes the design, hardware, software, and installation, which is about 30 percent less than the previous system in San Francisco. A number of operational problems have been identified with the IMDS as described in the report. Potential energy savings from addressing problems identified by the application of the IMDS have not yet been quantified, although the IMDS has been an important tool to the operations staff to help better assess planned future retrofits. We have found that the IMDS has become an integral and highly-valued tool in the daily operation of the building. The data provided by the IMDS are considered more valuable and useful than those provided by the EMCS. The sensors are more accurate and reliable, and the time-series data visualization tools provide a useful way to understand the performance of the HVAC systems. **The building is now operated using the IMDS to monitor the building operation and the EMCS to implement control changes, such as changing schedules and set points.** The IMDS was used to identify four key operational problems with the HVAC system. In addition to the use of the IMDS for operations, JLL is excited about the use of the IMDS for retrofit planning and believe the high-quality data will accelerate retrofit plans and reduce the need for audit investments. Thus the technology enables the adoption of additional building improvements.

Evaluate Decision-Making and Adoption Processes

Through a continuing set of interviews, the research team has successfully demonstrated that there is significant value and interest in the IMDS to the early adopter building operators at the building site. JLL is interested in continued use and further investment in the technology. We have confirmed that such tools are of interest and of value to building operators. Questions remain regarding how to disseminate this technology more broadly. Enhancing this partnership with industry is of interest to the researchers and JLL.

Outstanding Issues and Future Directions

The IMDS demonstration is intended to show that there are significant opportunities to improve building performance with continuous monitoring systems that provide more accessible and reliable HVAC and energy use data than a typical EMCS. The IMDS technology concept is nonproprietary and other combinations of hardware and software could provide similar functionality. LBNL has been reviewing several web-based Energy Information Systems to understand how the IMDS features compare with other products, technologies, and services in the market (Motegi and Piette, 2002). LBNL is interested in continuing to track the use of the IMDS in Sacramento to understand how the system will be used in ongoing operations and if energy savings are identified. Several building performance issues have been identified that could reduce energy savings, but the energy savings have not been yet been quantified. The IMDS data have been used to evaluate and prioritize retrofit opportunities. The data were used for this purpose at another site in San Francisco site as well. The benefit and value of the IMDS as a diagnostic tool is currently limited by the amount of time the operator can spend reviewing graphs and data. Outstanding research questions include:

- How can these data be made more useful?
- At what point does the time required to examine the data become burdensome?
- How could these data be best organized in automated diagnostic tools?

Another implication of the IMDS findings is that we need to understand the value of advanced energy information systems beyond the limited demonstrations that have been conducted in San Francisco and in Sacramento. JLL has expressed interest in developing a multi-facility demonstration. A key area for future work is to better understand the role of continuous monitoring systems in ensuring persistence of savings from retro-commissioning or building tune-up activities. LBNL will be examining the persistence of savings from retro-commissioning in a forthcoming project with SMUD. LBNL will characterize the use of monitoring systems in several of the SMUD buildings that have been retro-commissioned.

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