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Final Report

Early Evaluation of a Second Generation Information Monitoring and Diagnostic System

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Executive Summary

Project Overview

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. Whether it is poor quality design, inefficient operations, degradation of equipment over time, or merely the increasing use of energy by tenants and inattention from landlords, commercial office building energy use continues to increase. 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 report discusses a second-generation Information Monitoring and Diagnostic System (IMDS) installed at a leased office building in Sacramento, California. The report begins with a brief summary of the IMDS research at the previous building, followed by a discussion of the building selection process, the IMDS design and installation, recent use of the IMDS, costs and benefits, and fault detection and diagnostic research using the IMDS. A web site describes the IMDS in detail (see imds.lbl.gov).

The underlying principle of this research project is that high quality building performance data can help show where energy is being used and how buildings systems actually perform is an important first step toward improving building energy efficiency. The project utilizes a high-quality monitoring system that has been developed during the past decade by a partnership between LBNL and private industry.

The IMDS consists of the hardware and software required to support the collection, archival, visualization, and analysis of high frequency, high quality building data. At the Sacramento project site, a 175,000 square-foot commercial office building, over 50 new sensors, a secondary data acquisition system, and local and remote visualization tools have been installed. The system is also being configured to read additional data from the EMCS and chiller control panel.

This project is concerned with evaluating what an acceptable level of sensors, and data collection and visualization systems are needed to efficiently operate commercial office buildings. While sensors and monitoring systems are available with a broad spectrum of capabilities at varying costs, good engineering seeks efficiencies in determining optimal costs for procuring, installing, and use of such products. The IMDS used in this project incorporates standard components that are widely available. The operators at the building installed the IMDS with technical assistance from the research team. The purpose of having the operators install it was to bring to their attention the nuances and composition of the technology that full service engineering, installation, and set up often by outside vendors often obscure. The project is concerned with working with the building operations staff to determine the best products and installation techniques for a continuous monitoring system. To do this they must understand, as fully as possible, the underlying technology used in the monitoring system.

Technology does not operate in a vacuum and even the best technology can fail to serve its intended functionality if the user does not install and operate it correctly. This project involves evaluating the relationship between the technology and the people using it. We have developed this project to learn more about what building operators want and need in order to understand how performance-monitoring systems might be used in a fully developed mature market. There is a great explosion of performance monitoring tools being brought to the buildings sector from diverse markets. These markets include electric utilities and aggregators, control companies, Energy Service Companies, and software developers. Determining the value and importance of the IMDS is an important step in understanding the important features of new performance monitoring systems.

Another concept of this research is that it explores the idea that high quality time series HVAC, energy use, and related data allows building operators to construct mental models of building operations that are the precursor of expert systems and automated diagnostics. The IMDS provides a window into building operations data that far surpasses what is available from today's control systems. This resource will be the foundation of additional research efforts into advanced uses of the data for automated fault detection and diagnostics research, as described in the report below.

Results

This research project has been successful in demonstrating that the IMDS is tremendously 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. The innovative property management company, Jones Lang LaSalle, is interested in installing more sites to determine if the system could provide an economic platform for regional operations.

One objective of this project was to install the IMDS and evaluate the costs and benefits of its use. The costs have been evaluated. The system cost about $0.70 per square foot, which includes the design, hardware, software, and installation, which is about 30% lower 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.

Future Directions

A key implication of the IMDS findings is that we need to understand the practical value of advanced energy information systems beyond the limited demonstrations in San Francisco and Sacramento. The property management company considers the IMDS to be a success and have expressed interest in a multi-facility demonstration. Future research will also continue to utilize the IMDS for automated fault detection and diagnostics research.

1. Introduction

1.1. Background

Building operators in large offices and similar types of buildings typically have limited tools to understand the energy use and performance of the building systems they manage. Between 1993 and 1999, (see Table 1.1 below), the California Institute for Energy Efficiency (CIEE) funded the background research, engineering design, installation and testing of a first-generation Information Monitoring and Diagnostics System (IMDS). A multi-disciplinary research team led by Lawrence Berkeley National Laboratory conducted this research. Additional team members included, EN-WISE, Supersymmetry, Shockman Consulting, UC San Diego, and Kennedy-Wilson Property Management.

With PIER funding provided by the California Energy Commission through the CIEE Transition Program, the project team completed an analysis of the performance of the 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). Following the completion of this project, the IMDS was used by the building management as the basis for a new control system, as further described below (see Smothers and Kinney, 2002). Jones Lang LaSalle (JLL), Incorporated, a leading property management company, managed the 160 Sansome Street property during a significant portion of this first-generation IMDS demonstration and agreed to be our commercial partner in the proposed second-generation IMDS project in Sacramento.

The 160 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 IMDS, however, is not being used for control, only monitoring.

The IMDS was used to identify and correct a series of control problems at 160 Sansome Street. It allowed the operators to make more effective use of the building control system, thereby freeing up time to take care of other tenant needs. The IMDS helped to improve building comfort, which potentially improved occupant health and tenant organizational productivity, though this is harder to measure. As mentioned, the original project led by LBNL involved parallel operation of the EMCS and the secondary IMDS used for passive monitoring. Following the completion of the LBNL project at Sansome Street the building management initiated a project that retrofitted the IMDS to become the primary HVAC control system. The number of sensors used by the IMDS was doubled.

Prior to performing the control enhancements to the IMDS in San Francisco, the research team estimated that $20,000 in annual savings were potentially available from reducing building operating costs. Such costs could pay for the $100,000 first-generation IMDS in about five years.

Lawrence Berkeley National Laboratory (LBNL) has conducted a series of research projects related to continuous performance monitoring, commissioning and diagnostics. This work includes developing tools, analysis frameworks, and demonstrations of advanced techniques and systems in actual buildings. Further work in this area is described on the High Performance Commercial Building System's web site at buildings.lbl.gov/hpcbs. LBNL is also assisting General Services Administration (GSA) in the development and use of GSA Energy and Maintenance Network (GEMnet) (Levi et al., 2002).

This report focuses on reporting on the items listed in bold in Table 1.1, which outlines the 10 year project history of the IMDS research.

Table 1.1. IMDS Project History.

Year	Project Phase	Activities	Pilot IMDS* San Francisco	2^{nd} IMDS Sacramento
1993	Phase 1	Detailed scoping study, market assessment, and 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**	**2^{nd} 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	
2003	Phase 5	Model-based diagnostics		Diagnostics testing

**Phase 4 activities at the San Francisco IMDS site were not part of the research, but took place on the initiative of the building management.*

1.2. Report Overview

The rest of the report has seven additional main sections.

- **Section 2. Project Overview and Research Goals –** presents overall project goals and an overview of technology innovation and adoption theory.

- **Section 3. Methodology, Recruitment, and IMDS Implementation** - provides an overview of the IMDS site selection process, project research methods, plus the IMDS design and installation process.

- **Section 4. Description of Building and Building Energy Use History -** provides an overview of the building systems and multi-year energy use data.

- **Section 5. Use of the Information Monitoring and Diagnostic System -** describes how the IMDS has been used as an integral part of building operations.

- **Section 6. Lessons in Technology Innovation and Adoption -** describes the use of the IMDS within the context of technology adoption theory.

- **Section 7. Model-Based Diagnostics -** describes the activities under the model-based diagnostics research and future plans for expanding that work.

- **Section 8. Discussion and Future Direction -** a review of the research results as related to the original objectives and concepts for continuing this research.

Two final sections, are included, Acknowledgements and References. A series of appendices are included in a separate document and provide additional detail.

2. Project Overview and Research Goals

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. This value was demonstrated to the building operators at 160 Sansome Street in San Francisco, where the IMDS became the basis of a technical specification for a new control system that incorporated IMDS capabilities. 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 EMCS used at 160 Sansome Street prior to the IMDS project. *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 more recent vintage EMCS is critical to a definitive evaluation of the technology characteristics. Follow on 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?*

The emphasis of the work to date has been on manual, or human-based diagnostic techniques, with people interpreting data with the assistance of analysis and visualization software. We have also examined automated and model-based diagnostic techniques. The main conclusion of the model-based chiller fault detection work is that simple steady-state models can be used as reference models to monitor chiller operation and detect faults. The ability of the IMDS to measure cooling load and chiller power with 1% accuracy and a one-minute sampling interval permits detection of additional faults.

The project has also studied two technology adoption processes to understand decision-making methods. We have examined routine and radical innovations and adoption. In routine adoption, managers enhance features of existing products that are already well understood. In radical adoption, innovative building managers introduce novel technology into their organizations without using the rigorous payback criteria used in routine innovations.

2.1. Research Objectives

Specific project objectives were as follows:

- **Develop custom IMDS specification.** The IMDS specification for 925 L Street was developed in partnership with SMUD and the operations staff. Experience gained at 160 Sansome, San Francisco permitted some costs to be reduced compared to the San Francisco site. While costs were reduced, the scope increased, allowing one representative air-handler to be instrumented and monitored in addition to the chilled water plant, at a lower overall cost. Results from 160 Sansome showed that both chilled water plant and air-handler measurements are of critical importance. The potential for cooling energy savings was expected to be greater in Sacramento because of the more severe summer climate.

- **Evaluate IMDS performance, costs and benefits**. The objective is to make a quantitative assessment of both the energy savings and the non-energy benefits of IMDS use. Several studies have shown that performance monitoring and tune-ups can identify no cost and low cost measures that result in energy savings in commercial buildings averaging about 20 percent. A key objective of this project is to determine what level of energy savings and other non-energy benefits can be identified at 925 L Street using the IMDS. This project allowed us to perform a more detailed comparison of the data collection capabilities of a newer vintage EMCS with the IMDS than could be done at 160 Sansome Street.

- **Develop and demonstrate techniques to automate the diagnostics.** One aim of this project was to develop and demonstrate a hybrid approach to building diagnostics in which manual, human-based diagnostic tools are supplemented by automated fault detection tools. These ‘smart alarms’ can be used to alert the operators to potential faults and problems, which can then be confirmed and further investigated using the manual tools. Model-based automated diagnostic routines for chiller and air handler systems were to be developed and tested.

- **Evaluate decision-making and adoption processes**. Many new energy savings technologies fail to be adopted in the marketplace. There are many reasons why a product may not be adopted. Only rarely are innovation-derived first-generation technologies immediately and directly adopted. The objective of this aspect of the project is to provide a description of the innovation adoption process and a road map for the adoption of new energy technology in practical, business applications in the buildings industry. This effort will focus on market transformation opportunities arising from partnerships with third-party property managers.

2.2. Overview of Technology Adoption Theory and Research Goals

Understanding the technology research evaluation methodology requires an understanding of the type of individual and organizations of an early adopter. Rogers (1983) identifies ideal types of adopters and places them into categories. The categories used by Rogers are shown in Figure 2.1.

Innovators – These adopters are know for their “venturesomeness”, they are risk takers pulled through by the technology and their own desire to be the first to see something. Often they are outsiders on the edge of their local community, but wide readers and thinkers.

Early Adopters – Early Adopters are known for their cautious optimism and respectability. They are known as leaders throughout their industry and they are proud of it. They look for technologies that are practical and will perform a useful function. Early adopters tend to be able to deal with abstractions and demonstrate this by greater rationality and intelligence. Able to cope with uncertainty and risks, they also have higher career aspirations than the majority of people in their field, and more contact with other people. They are not difficult to identify, as they are widely known for their information seeking. These are the people to ask about new ideas and technology for an intelligent and thoughtful answer.

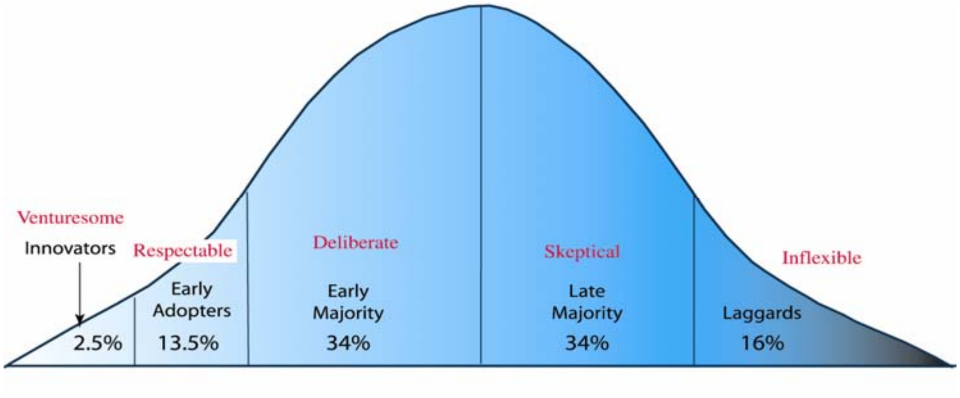


Figure 2.1. Technology Adopter Characteristics

Majority and Laggards - These types are not studied here although careful selection of the site was done to avoid these types of careful and more timid adopters.

This project focuses on early adopters who are often most easily identified by their respected position in their industry. A positive affirmation from a respected industry leader such as JLL is expected to present other opportunities for industry-wide dissemination. As mentioned above, the IMDS has been under research and development for nearly ten years. While the technology has matured, the original research goals remain the same. The broad goals of the technology innovation and adoption research are:

1. To select a specific energy market and understand the barriers and incentives to innovation. This goal is based on the idea that one must understand decision-making processes in technology adoption.

2. To select and test a technology that would encourage energy efficiency as an integral part of building operations as the technology matures, and in its mature phase would require little or no incentives to penetrate the market. This goal is based on the premise that advanced monitoring and control technology will not be adopted on the basis of energy savings potential alone.

A variety of building markets were studied in the first project phase, including educational markets, institutional markets and retail sales. The decision to work with large "Class A" office buildings, which are those that provide high-end services and amenities to tenants, was made for a variety of reasons. One reason for this decision is that Class A building operators have high demands on their time to produce comfortable, well controlled buildings. Another reason is that Class A office buildings are an underserved market in the energy efficiency business because operating costs for the buildings are passed through to the tenants. Since landlords do not pay energy costs there is a low awareness or concern about energy efficiency. Early in the study we learned that as long as the energy costs did not become high relative to their peers, which were often tracked through Building Owners and Managers Association data, the engineers were not particularly concerned about them. Although the market for lighting retrofits had been active, little research had been done with third party property managers beyond component replacement. Following a seminar with property managers, energy managers and operators in 1994, the research team decided to pursue a demonstration to evaluate this technology. The technology was placed with a widely known industry innovator in a medium sized office building in San Francisco. The demonstration at Sansome Street has been the subject of several papers (see for example, Piette et al 1998, Piette et al. 2000, and Piette and Shockman, 2000, see also the publications link at imds.lbl.gov). The results were promising and the industry innovator confirmed the original hypothesis that this technology is useful and desirable. The building manager at 160 Sansome upgraded the IMDS system at his own cost to become the central control system. Many technical upgrades and additions to the user friendliness of the technology were developed.

3. Methodology, Recruitment, and IMDS Implementation

This section describes the major tasks within the research project. It also describes the site selection process and the IMDS design and implementation. This project began during the final phases of the previous IMDS project at 160 Sansome Street. SMUD expressed interest in sponsoring a second IMDS, and the research team identified a candidate site in Sacramento.

3.1. Site Selection

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 (see www.jll.com). The merger in the late 1990s of Jones Lang Wooten and LaSalle Properties made the company truly international. They are a dominant presence in Europe, Australia, the Far East and the United States. 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.

The selection of a site was a secondary consideration. Jones Lang LaSalle's former regional area technology chief, Larry Hjulberg, had a strong desire to locate the test project near his home office in San Francisco. Once he had determined the desirability of the technology, he wanted to gain personal knowledge of the IMDS to report to his company. SMUD and the project team insisted that the IMDS be placed in Sacramento. Mr. Hjulberg was informed that he would be able to see the IMDS data over the web, and he agreed to a Sacramento demonstration site.

Several buildings were proposed and evaluated. This step is high risk for the research team. Third-party property managers do not own the buildings they operate. Building owners can be fickle and building 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 research team requested a long-term commitment from JLL to pursue the IMDS technology and asked JLL to install the IMDS hardware. Unlike the innovator at Sansome who proceeded with the IMDS installation on a verbal agreement, JLL asked for a detailed contract ensuring that their needs were recognized. While no money was exchanged, the research team negotiated a written and formal agreement. No penalties were anticipated for failure to perform and we assured them that we would not be suing them. We asked for their willing cooperation and continued support. They asked for liability insurance. The contract was a statement of understanding and an action of good faith on the part of both parties.

Three potential sites were identified in Sacramento. The final selection of JLL at 925 L Street was based on the proximity of the building to the center of life in Sacramento (the State Capitol building), the onsite engineer's interest in participating, and the perceived need for this type of technology for this building. Additionally, Shockman Consulting determined that the original engineer at the site (Larry Colbert) was a strong candidate for promotion within JLL. After completion of the IMDS design (described below), equipment was ordered and installation began. At the same time, the on-site engineer was moved to a different building and a new engineer took over. A third engineer was brought to the building in 2001. The technology required the substantial participation of the third on-site engineer and the original senior engineer.

3.2. Finalizing IMDS Design

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 (together with occasional manual measurements of true power, preferably accompanied by flow rate).
- AHU air temperatures: return, outside, mixed, supply fan 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. The floor is split into 15 areas that have pneumatic temperature controllers that use compressed air to modulate the branched mixing valve for the hot and cold ducts.
- Control signal to terminal box dampers and/or damper position. Note: most of the dampers on the AHUs are controlled pneumatically.

3.3. Installation, Commissioning, and IMDS Training

En-Wise worked with the building operations staff over a period of about two years to install the IMDS. The building operations staff (Larry Colbert and Jack Bostick) were the primary installers of the supplied equipment. This task included coordinating with SMUD and the operations staff to ensure that the sensors, data acquisition system, and IMDS software were properly installed. LBNL worked with EN-WISE to review the remote monitoring systems. LBNL is remotely archiving the data.

The kickoff for this project took place in August 2000. This project was scheduled for completion in Fall 2001 and has experience significant delays for several reasons. First, the majority of the installation process was expected to be completed by JLL and its contractors. This required a great deal of commitment and time from the building staff. The reason for their participation in the installation is to allow them to be fully knowledgeable and trust the installed system (Shockman and Piette, 2002).

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 lower priority. 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, in November 2000 and February 2001 faulty water heaters flooded and caused major water damage to six floors, taking over six months to fully 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.

The primary innovator, Larry Hjulberg in San Francisco, suffered a stroke during the second year of the installation process, which also hampered the team's ability to bring in additional resources from within JLL. The IMDS site has also been subject to a series of staffing changes. The building engineer at the time the project began (Larry Colbert) was the primary site contact in the initial discussions to locate the project at 925 L Street. When the property manager came into the building the project was nearly underway. At the time of the official project kick-off, the building engineer was already on his way out; however, his intent was to remain involved in the project. The engineer brought in to replace him (Ken Phelps) was himself replaced in a matter of months (to the existing engineer, Jack Bostick). The new engineer has remained on since then; however a new property manager was brought on in 2001.

These 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. The chief engineer was fully aware of the project when he started; however, he was not aware of the extent to which he would be expected to operate independently or the amount of extra work involved. The initial building contact was unable for much of the installation period to provide a high level of project support. Additionally, the chief engineer had never installed monitoring equipment before, not typically required of building operators, and thus a great deal of additional training, oversight, equipment, and installation work by En-Wise was required beyond the original scope of work.

Additional delays were incurred with the projects suppliers and in-kind contributors. The building does not have a service contract and their EMCS service provider was undergoing significant staff turnover. They agreed to provide assistance related to connections with the EMCS, but this assistance never materialized. The key contact person left the company in early 2001. In addition, some of the critical data acquisition equipment was delivered six months behind schedule.

3.4. IMDS Description and Costs

Table 3.1 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 three areas:
    - Basement – Section A – 1 point
    - 7th Floor – Section B – 25 Points + Three Power Meters
    - Plant Room – Section C – 18 Points + Two Power Meters

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. The interface to the EMCS will be limited by what the EMCS can safely export without data corruption, which can occur when the communications system is overly taxed by heavy network traffic. Both retail and actual costs are shown in Table 3.1. 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 3.1. 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 monitoring
- Temperature monitoring
- Air flow monitoring
- Water flow monitoring

The three locations communicate by using open and proprietary protocols. Several diagrams of the system architecture are included in the appendices. RS-485 Enflex protocol communication was used for distributed I/O to a central data server and controller. The distributed three-phase power meters also communicate by RS-485, but use a ModBus RTU driver to send measured parameters to the same central Data server and controller. The IMDS also includes two Linux

Computer Servers. The equipment and the IMDS Software were provided by Electric Eye Pte Ltd. The equipment and software were configured on-site by EN-WISE. Jones Lang LaSalle has made an approximate $11,200 investment in the IMDS. During the initial recruitment process JLL agreed to spend up to $10,000 for system cabling, water flowmeter installation, and hardware, and they later added $1200 for an electrical contractor. The staff estimates that they spent about 180 hours of their own personal time, primarily early morning hours, to install the IMDS. The JLL staff usually bill out at about $120/hr, thus estimating the value of their contribution at about $22,000. In addition to the time spent by JLL, approximately $40,000 worth of labor effort was provided by EN-WISE to manage and contribute to the IMDS installation. Additional in-kind contributions of equipment and labor were provided by the EMCS manufacturer and service provider to connect the chiller panel and EMCS to the IMDS. Contributions from Invensys and Yamas include hardware and labor to upgrade the EMCS communications so additional equipment could be added. This portion of the IMDS has not been completed and is not included in the total cost estimate. EN-WISE had a major role in the system installation. EN-WISE designed the wiring configuration on the penthouse, plus they configured most of the sensors. JLL performed some of the penthouse wiring termination. EN-WISE also mounted and installed all the basement equipment. The system costs can be considered two ways:

Low Estimate: $38,000 + $11,000 + 22,000 + 40,000 = $111,600
High Estimate: $52,000 + $+ $11,000 + 22,000 + 40,000 = $125,200

These costs translate to $0.64 to $0.71 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.

3.5. Develop and Deploy Automated Fault Detection Systems

As mentioned in the project introduction, LBNL lead the task to develop automated fault detection algorithms for the chilled water system and air-handling units. The algorithms were to be based on simple models of the physical processes and equipment characteristics and would alert the operator to a possible fault condition when the actual performance of the HVAC system differed significantly from the performance predicted by the models. The models were to be configured initially using design information and manufacturer's performance data and used to re-commission the appropriate subsystems. The models would then be fine-tuned to match the performance of the re-commissioned subsystems and used to monitor them for faulty operation. Results of this research are described in Section 1.

3.6. Evaluate 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.

4. Description of Building and Energy Use History

The IMDS was installed at 925 L Street in Sacramento. This building, known as 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 mezzanine also contains storage, maintenance, telephone and electrical equipment spaces. The building has an unconditioned basement, where the main electrical meter is located. The building is located 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 4.1. Building Description and Systems Overview

Building Size (gross)	175,000 sqft (14 floors, 1 mezzanine and basement)
Chillers	Two @ 300 tons each (centrifugal), Chiller #1 is currently non-operational, primary only CCW loop w/ 20 HP pumps
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, primary only HHW loop w/ two 3 HP pumps
Controls	1998 vintage EMCS, primarily pneumatic controls with some DDC
HVAC Distribution	Dual Duct CV systems, 2 duct zones per floor, approx. 35 mixing boxes per floor
Lighting	Compact fluorescent and T-8 lamps

4.1. Building Construction and Site Details

The building has a steel-frame with concrete floors and façade. There are four elevators serving the above-ground floors. An adjacent building up to the 12th floor shades the West-facing façade. The lower seven floors on the Northern façade will be shaded when a neighboring construction project is completed. The Eastern and Southern façades are open to solar and wind exposure. The buildings opposite L Street on the East, provide little shading or glare to 925 L. The floors have windows with tinted glazing and use task lights and overhead electrical lighting. The typical floor has perimeter private offices with office cubicles and common spaces in the interior zones.

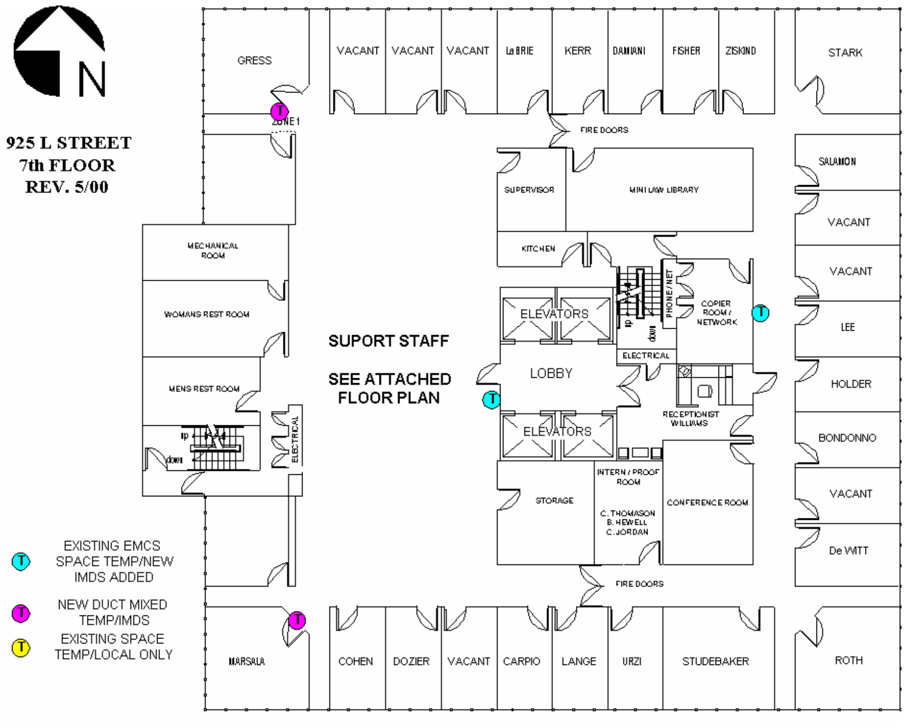


Figure 4.1. Typical Floor Layout

The tenants expressed interest in de-lamping lighting fixtures during the 2001 energy emergency. Many three-lamp fixtures are now operating with two lamps. There are some simple lighting controls connected to the building EMCS such as lobby and hallway lighting. The tenants have custom systems that include occupancy sensors, timers and dual-zone switching systems supplied by the building management. The restrooms use occupancy sensors. Most utility spaces have manual switches. All lights have been retrofitted to CFL or T-8 fluorescent. An upgrade of the existing fire alarm system is scheduled to start in 2002.

4.2. Occupancy

The operating schedule is typically from 7 am to 5:30 pm five days a week; however, tenants often request night and weekend services, particularly when the California legislature is in session. The tenants use a phone-based service for activating HVAC after hours in 4-hour increments. Each tenant has time allocated for after hour use and the building management invoices the tenant if the allotment is exceeded.

The large amount of after-hour occupancy in the building is an energy consumption issue. Due to the design of the airside systems, there is a significant amount of simultaneous heating and cooling in the facility. Even modest levels of after hours occupancy causes both boiler and chiller to turn on. More details are in Appendix E.

One major tenant leases an entire floor for automated telephone switching equipment and does not have any permanent staff in the building. This floor had its own dedicated direct-expansion cooling system, with the air-cooled condensers located on the rooftop; however, the tenant moved out in 2002. The central plant chilled cooling water (CCW) has been turned off to the existing air handler unit for this floor, which is now used for minimal ventilation and heating. There is no connection to the building EMCS at this time, but this connection is planned as part of the next phase of the research.

4.3. Energy Management Control Systems

The EMCS was installed in 1998. The system has the following sub-systems:

- **Workstation:** The workstation acts as a client to the control system. There are interactive functions that allow the operator to enter setpoints, schedules, and overrides and to view current operation. Logic and control changes have to be uploaded to the global control module (GCM) from the workstation or from a dial-up connection via analog modem. The EMCS has a control workstation that maintains time clock and related core functions. The micro-zones are installed on each floor and have a set number of input and output channels. The micro-zones can be programmed to operate independent of the workstation.

- **Global Control Module:** The GCM controls the time and logic functions of the control system. It controls the microzones.

- **Air Handler Control:** The AHUs mix air from the hot and cold ducts of the dual duct system to supply a fixed temperature to the tenant space. Each mixing box has its own thermostat. There are control dampers on the AHU the use a mix of DDC and pneumatic control.

- **Cooling Plant Controls:** A refrigerant monitoring system for the chiller is located in the penthouse. The monitoring system also controls an exhaust and alarm notification system. It is not known if it is integrated into the EMCS or chiller interlocks. Microzones and relay contactors are used to start chillers, pumps, and fans.

- **EMCS 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 RAM. 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.

- **Sensors**. Analog and electronic sensors are installed on the systems. Many of the building's HVAC sensors are not connected to the EMCS such as temperature, pressure and annubar flowmeters that require manual inspection. As a result, the building operators do not often use these sensors. The EMCS contains only temperatures used in the control loops and some major equipment relays, interlock, and alarm points. The original AHU installation included meters on both the cold and hot water coils throughout the building. The zone temperatures use thermistors. The sensors are not calibrated on a set schedule, but replaced if there are suspected problems.

A detailed description of the HVAC and electrical systems is presented in Appendix E.

Appendix E also lists HVAC observations and measures that could be used to improve the energy performance of the HVAC system. This list was developed by En-Wise and Supersymmetry, and discussed with the buildings staff during the IMDS installation.

4.4. Building Energy Use

LBNL performed extensive analysis of the historic energy use data prior to and during the project. In this section we describe the main historical energy use patterns. Additional detail is provided in the appendices. The purpose of this analysis is as follows:

- To establish baseline energy use against which energy savings due to measures taken in response to IMDS data can be evaluated.
- To understand the overall energy use intensity compared to other buildings, thus providing some reference point for energy efficiency opportunities
- To examine the peak demand data to understand how "peaky" the demand is.
- To understand the major drivers of energy use including weather and occupancy.

Table 4.2 summarizes the data provided to LBNL:

Table 4.2. Historical Energy Use Data Collected and Analyzed.

	1996		**1997**		**1998**		**1999**		**2000**		**2001**		**2002**	
Gas Utility Bills							▨	▨	▨	▨	▨	▨	▨	
Electric Utility Bills										▨	▨	▨	▨	
15-min Electric Power Data Building Main & Chillers	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
Electric Utility Bills - separately metered floor										▨	▨	▨	▨	

Shaded areas are those with data. Results from the data analysis are shown in Appendix B.

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 consumed 91 kBtu/sqft-year in the most recent year of energy data. In establishing the potential for energy savings, it is useful to compare the building's energy use to that of other buildings. We used Cal-Arch, a tool developed at LBNL, and found that 925 L Street has an

EUI that is higher than 75 percent of California office buildings (see poet.lbl.gov/cal-arch). 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.

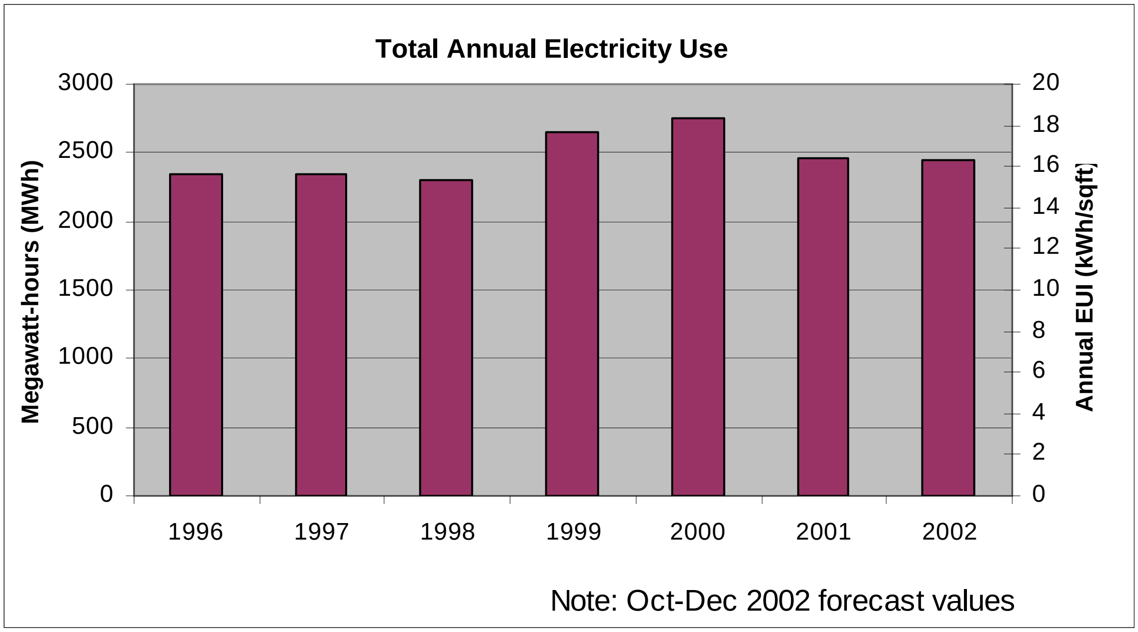


Figure 4.1. Total Annual Electricity Use

Figure 4.1 above shows seven years of electricity use, which reached a maximum in 2000 of 2700 MWh, and dropped 10 % 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 4.2 shows the average costs per day for 24 months of data. The increase in summertime electricity costs is evident, as are the dominance of electric costs over gas costs.

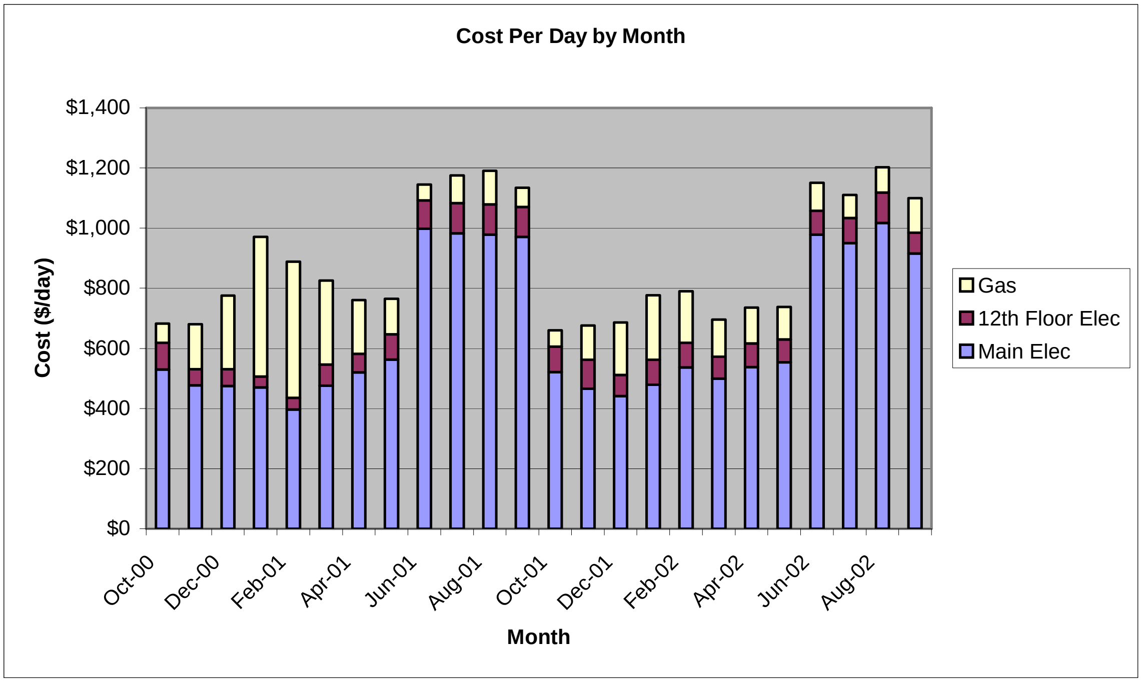
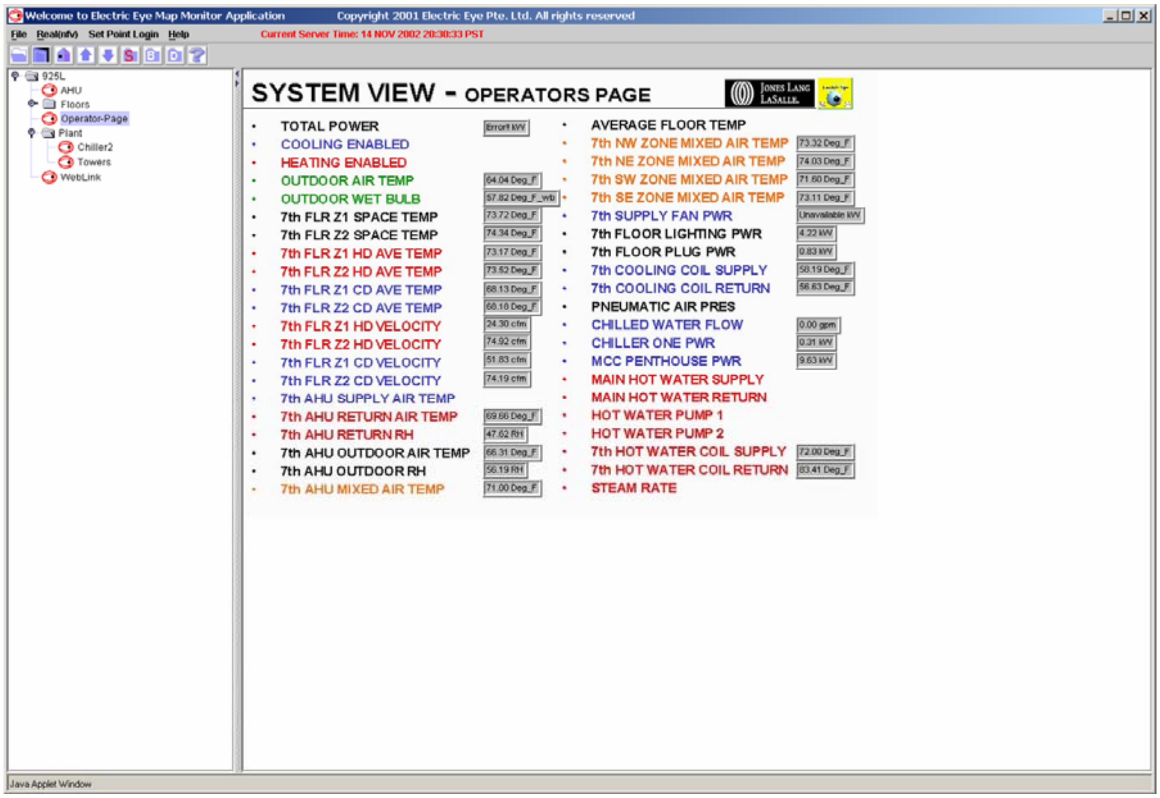


Figure 4.2. Utility Costs Per Day, By Month

5. Use of the Information Monitoring and Diagnostic System

The building's current chief engineer, Jack Bostick of Able Engineering Services, 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, Mr. Bostick uses the Web interface "Operator Page" (Figure 5.1) 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 bi-weekly interviews with Jack Bostick beginning September 10th, 2002. In the interviews we discussed system performance, system problems, obtained copies of his Activity Reports and provided assistance as needed. Appendix 6 lists the interview dates and summarizes the Activity Reports.



TOTAL POWER	Error! kW
COOLING ENABLED	
HEATING ENABLED	
OUTDOOR AIR TEMP	64.04 Deg_F
OUTDOOR WET BULB	57.82 Deg_F_wb
7th FLR Z1 SPACE TEMP	73.72 Deg_F
7th FLR Z2 SPACE TEMP	74.34 Deg_F
7th FLR Z1 HD AVE TEMP	73.17 Deg_F
7th FLR Z2 HD AVE TEMP	73.52 Deg_F
7th FLR Z1 CD AVE TEMP	68.13 Deg_F
7th FLR Z2 CD AVE TEMP	68.18 Deg_F
7th FLR Z1 HD VELOCITY	24.30 cfm
7th FLR Z2 HD VELOCITY	74.92 cfm
7th FLR Z1 CD VELOCITY	51.83 cfm
7th FLR Z2 CD VELOCITY	74.19 cfm
7th AHU SUPPLY AIR TEMP	
7th AHU RETURN AIR TEMP	69.66 Deg_F
7th AHU RETURN RH	47.62 RH
7th AHU OUTDOOR AIR TEMP	66.31 Deg_F
7th AHU OUTDOOR RH	56.19 RH
7th AHU MIXED AIR TEMP	71.00 Deg_F

AVERAGE FLOOR TEMP	
7th NW ZONE MIXED AIR TEMP	73.32 Deg_F
7th NE ZONE MIXED AIR TEMP	74.03 Deg_F
7th SW ZONE MIXED AIR TEMP	71.60 Deg_F
7th SE ZONE MIXED AIR TEMP	73.11 Deg_F
7th SUPPLY FAN PWR	Unavailable kW
7th FLOOR LIGHTING PWR	4.22 kW
7th FLOOR PLUG PWR	0.83 kW
7th COOLING COIL SUPPLY	58.19 Deg_F
7th COOLING COIL RETURN	56.63 Deg_F
PNEUMATIC AIR PRES	
CHILLED WATER FLOW	0.00 gpm
CHILLER ONE PWR	0.31 kW
MCC PENTHOUSE PWR	9.63 kW
MAIN HOT WATER SUPPLY	
MAIN HOT WATER RETURN	
HOT WATER PUMP 1	
HOT WATER PUMP 2	
7th HOT WATER COIL SUPPLY	72.00 Deg_F
7th HOT WATER COIL RETURN	83.41 Deg_F
STEAM RATE	

Figure 5.1. Operator Page on the Electric Eye web interface

In October 2002, Mr. Bostick 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 (which turned out to be a sensor problem that has been resolved).

Both Mr. Bostick and Mr. Colbert 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.

5.1. 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 identified a variable frequency drive (VFD) overheat condition for the cooling tower fans.

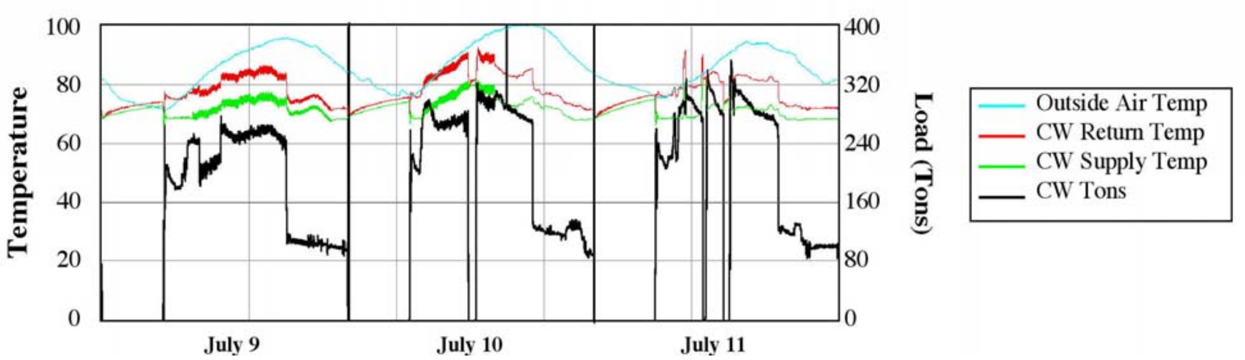


Figure 5.2. Evaluation of a Cooling Plant Problem

When temperatures soared over 110 º F, high condenser water temperatures shut down the chiller and cooling tower fans ran intermittently. The tower fans and with no air circulation across the controller, the VFD was shutting down on a thermal safety. The IMDS tools were used to diagnose the problem and obtain tower control. **Figure 5.2** 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.

5.2. Additional Plans for use of IMDS Data

JLL is excited about the prospect of using the IMDS to obtain information to develop a capital budget for needed HVAC system upgrades. This will help reduce or even eliminate the cost of an investment-grade energy audit. 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 with the use of the IMDS. LBNL has not conducted this important step because the system has only been in use for a few months.

6. Lessons in Technology Innovation and Adoption

6.1. Use of the IMDS in Sacramento

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 characteristics of early adopters are described in Section 2.3. Early adopters' cautious optimism presents challenges for the acceptance of new ideas and technology. Early adopters are not as tolerant of technical convolutions as innovators. They want to see the marketability of the technology and are unwilling to invest as much the time as a fearless innovator does in a new technology. Technology is pursued for an end and the journey cannot be too tortuous or the early adopter will bail out. This is a challenge for researchers as the early adopters rejection can taint industry acceptance of an idea that is presented when it is not yet ready. Although all researchers are interested in disseminating their results, failures are not as welcome as successes.

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.

6.2. Technology Evaluation Concepts

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.

Early adopters are known for their careful evaluation of new technologies; this leads to the innovation term of "trialability." Early adopters understand that they cannot evaluate and recommend an idea, but must evaluate and recommend real products and services that their company could eventually buy, make or sell. Trialability is the degree to which an innovation can be tested on a limited basis.

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.

Larry Colbert will prepare a report to JLL that will discuss the relative advantage of the IMDS to other technology that it would supersede. Mr. Colbert reported that one important criterion for adoption is if the technology can be built up out of competitive components. A major advantage of the IMDS compared to existing systems that monitor, control or monitor and control, is that the system uses open communication protocols that the operators can work with directly in future expansions of the technology. 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.

6.3. Multi-Facility Test Concepts

Larry Colbert has suggested that his company would be interested in a wider test of the technology in the Sacramento area. JLL has provided the research team with a list of some of the properties that might benefit from the IMDS, which is given in Appendix H. Dissemination of the IMDS could be enhanced if JLL had staff evaluating it at multiple buildings.

The research team believes that JLL's corporate offices are interested in contributing funds to this research project to further test the IMDS. Discussions with JLL have included a potential wide-scale test with several users located in one geographic area to facilitate communication. The technology is starting to be pulled through by industry leaders.

Larry Colbert has expressed an interest in acting as a change agent for the technology. JLL would positively influence innovation decisions by mediating between the change agency (researchers) and the social system within their organization (third party property management companies). The mutual benefit for the research community and industry could be substantial. JLL plans to disseminate the technology in several ways. First, by inviting other building engineers in the Sacramento area to visit 925 L Street. Second, to give a presentation to the Northern California JLL engineering staff. Third, to give a presentation on the IMDS at JLL's national engineering meeting in May 2003.

An unexpected benefit of the replacement of Mr. Colbert as the building's engineer is that the new engineer is a contract employee, employed by Able Engineering. Able is an industry-respected provider of engineering staff that employs a large number of engineers across the country. We are presently focusing on the JLL diffusion, but long-term dissemination of results would be appropriate using Able's resources as well. The introduction and education of Able engineers will be delayed so that it follows the JLL introduction. Later diffusion plans for Able will allow the engineer the opportunity to see and test the technology in place throughout the coming year before presentation of it to his peers.

7. Model-Based Fault Detection

7.1. Model Based Fault Detection Concept

This project has explored the use of high quality building data and manual visualization systems as a tool for building operators. It has also examined how such data can be used for model-based fault detection to assist operators in evaluating monitored data. The approach is to wholly or partly automate both commissioning and performance monitoring, using computer-based methods of fault detection and diagnosis (FDD). Component-level FDD, which is the subject of the work presented here, uses a bottom up methodology to detect individual faults by analyzing the performance of each component in the HVAC system (Hyvarinen 1997, LBNL 1999, Haves & Khalsa 2000).

For commissioning, a baseline model of correct operations is normally first configured and adjusted using design information and manufacturers' data. Next, the behavior of the equipment measured during functional testing is compared to the predictions of the model; significant differences indicate the presence of one or more faults. Once the faults have been fixed, the model is fine-tuned to match the actual performance observed during the functional tests performed to confirm correct operation. The model is then used as part of a diagnostic tool to monitor performance during routine operation. In each case, the reference model is used to predict the performance that would be expected in the absence of faults. A comparator, which is set of software algorithms conducting statistical analysis, is used to determine the significance of any differences between the predicted and measured performance, and hence the level of confidence that a fault has been detected.

7.2. Model Development

LBNL conducted a walk-through to examine the HVAC systems and talk with the building operators about the concerns and problems with building operation. Manufacturer's data and design information for the existing HVAC systems were collected from the site and this information was used in configuring the models.

HVAC performance data were copied for offline analysis and will be used to calibrate the models. Since the IMDS includes extensive instrumentation on the 7th floor air handler, the fault detection tool will be developed to characterize this air handler. The control signal from the EMCS has not yet been trended by the IMDS, but it will be necessary to do so to develop the models. Air handler models developed in previous research will be used as soon as these data are collected in the next research phase.

Component-level FDD Models. A component-level simulation model for fault detection has been constructed for this building. The IMDS sensor list (see Appendix G) was compared to the requirements of the FDD models. Since the building has a constant volume dual duct system with no static pressure measurement, the fan model lacks necessary measurements and it will be removed from the AHU models. The model will consist of a mixing section, a cooling coil, and a heating coil. The mixing section model has a fixed damper position, since there is no economizer damper control. Several chiller models were developed and tested in previous work; the Gordon and Ng model was found to provide as good a representation of performance as other models, and is easier to configure as it has fewer parameters.

Enflex and data transfer. One important component of fault diagnostics is evaluating the information infrastructure of controls and performance monitoring tools. LBNL's component-level fault detection model and supported software are programmed in C++. The Enflex Site Manager that the IMDS is based on supports a script-based computer programming program known as TCL, but does not support C++. It not feasible to reprogram the model in TCL. A programming environment supported by Microsoft Windows that will call the Enflex Site Manager is being built and an online FDD will be implemented. The fault detection executables will be executed on a separate PC that accesses the disk of the Linux Enflex host computer using Network File System (NFS). The fault detection tools will trigger an alarm when faults are detected.

7.3. Next Steps

LBNL was unable to complete the development of the FDD model because the IMDS installation was delayed. LBNL will be continuing this research as part of the High Performance Commercial Building Systems Project (buildings.lbl.gov/hpcbs). The following activities are being pursued that build on the previous work and extend it.

Online component-level model-based FDD. After the control signal trending is complete and the Enflex programming environment is developed, the online model simulation and fault detection will be deployed. The online model simulation will read the PC system clock to synchronize with the data collected through the IMDS NFS connection. The thresholds, or sensitivity of the fault detection and the steady-state detector will be closely based on the quality of the online data and accuracy of the model. LBNL will monitor the system performance remotely and interpret the alarm signals validating the method.

Online EnergyPlus FDD. The concept of using an online EnergyPlus (reference) simulation for building-level fault detection has often been suggested but never been demonstrated effectively. A well-calibrated EnergyPlus model should able to successfully predict the whole building energy consumption. The comparison of the simulated and the measured energy consumption will be used to detect faults at whole building level.

Based on information collected from a site visit and the design drawings, LBNL will build an EnergyPlus model to simulate the whole building energy consumption. Some site measurement may be necessary to determine the parameters of the models, such as the internal loads and the lighting power density. Lighting power is measured by the IMDS for the 7th floor only. Previous performance data will used to calibrate the model. Each floor will be divided into two zones according to the systems layout. (Some floors have one and some have up to three tenants sharing a two zone fan distribution system.) The simulated chilled water consumption of the AHUs will be compared with the measured chilled water consumption in the plant, assuming the internal heat gains track the value measured for the seventh floor. The 7th floor chilled water coil inlet and outlet are also measured and can be used to test the floor on a case-by-case basis.

A new real-time version of EnergyPlus executable that can conduct a simulation in synchronization with the PC system clock will be produced to run a building simulation online. The PC system clock will be used to read from files generated by Enflex at one-minute intervals and simulated and measured values of selected points will be displayed on the screen. Certain rules for fault detection that compare the simulated electricity consumption with the real electricity consumption will be developed by LBNL.

Relevance of automated fault detection. As discussed above, the building operator has identified a number of deficiencies in the building HVAC system that result in operational difficulties, e.g. lack of control valves on the cooling coils. These deficiencies require the operator to pay close attention to the operation of the building in order to maintain comfort in as many zones as possible. In this situation, automated fault detection is of limited value; however, upgrades to the HVAC system are planned that should obviate the need for continual manual monitoring. Once the building can be operated under completely automatic control, automated fault detection will become more valuable, since the operator will be spending less time manually observing the condition of the HVAC equipment.

8. Conclusions and Future Directions

This section begins with a discussion of the results of the research relative to the original research objectives. It then provides a summary of key lessons learned. The final section discusses future directions.

8.1. Discussion of Research Results

IMDS Design, Scope and Schedule. The research team successfully designed and installed the IMDS for use at 925 L Street within the original budget. The project was completed, though behind schedule. Reasons for the delay include personnel changes, delays in technology procurement, and an underestimate of the effort needed by JLL to install the system. While the installation has been completed, it does not meet all of the originally intended functionality. It does not connect to the EMCS and thus does not provide access to the data from the chiller panel, which was part of the original design concept. A collective decision was made by LBNL, EN-WISE and companies donating equipment to have a single interface into the IMDS. The donated EMCS equipment directly interfaces with the chiller control panel. The remaining step is to integrate the IMDS with EMCS so that data from the EMCS can be viewed and analyzed using the IMDS data visualization software.

Evaluation of IMDS performance, costs and benefits. One objective of this project was to install the IMDS and evaluate the costs and benefits of its use. The system cost about $0.70 per square foot, which includes the design, hardware, software, and installation, which is about 30% lower 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.

Develop and demonstrate techniques to automate the diagnostics. The research to develop model-based diagnostic techniques has been hampered by the lack of connectivity between the IMDS and the EMCS. LBNL has made progress in the development and use of these models at other building sites; however, progress at this site has been minimal. Plans are underway to accelerate and expand this work in early 2003.

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.

8.2. 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 issues 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?

This last bullet is the subject of continuing research to be integrated with part of the LBNL High Performance Commercial Building Systems Program.

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 performance monitoring systems in several of the SMUD buildings that have been retro-commissioned.

9. References

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Early Evaluation of a Second Generation Information Monitoring and Diagnostic System

APPENDICES

Appendix A. Project Staff

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Appendix B.   Utility Baseline Analysis

This appendix summarizes several years of utility metering data and billing data for 925 L Street. This purpose is to establish baseline energy use against which energy savings due to measures taken in response to IMDS data can be evaluated. The following data were provided to LBNL:

- Monthly gas utility bills dating back to January 1999. Gas use by calendar month was estimated from billing months.
- Summary gas and electric data dating back to 1996 – days per billing cycle were not included, data were of limited use
- Monthly electric billing data from August 2000
- Monthly electric billing data for one floor that is metered separately, dating from October 2000.
- 15-min whole-building electric demand data dating back to 1996
- 15-min chiller demand data dating back to 1996. The chiller power meter was installed by SMUD under a different program. The meter was commissioned by a SMUD technician and found to be off by a factor of 3, and the data were adjusted to reflect this.

There are some changes that will have to be accounted for when using the baseline data to evaluate savings:

1. The 2001 energy crisis prompted some permanent reduction measures, and could possibly have altered tenant behavior. It was noted by the operations staff that when they started to return lighting in some areas to previous illumination levels, they received complaints from tenants who still thought it was wasteful. Other than the installation of the heat exchanger, this is the only explanatory information we have currently for the reduction in energy use between 2000 and 2001 as seen in Figure B.1.
2. One floor is metered separately. The floor receives some shared services, such as ventilation. In the past this floor has not been occupied and only received services when requested. The separately metered space is 12,225 (12,168 used in Enflex Calcs) square feet out of a total of 168,000. Billing data for 2000-2002 for this floor were provided by SMUD.

B.1.   Annual Energy Use

Figure B.1 shows the change in annual energy use on the main building meter between 1996 and 2002. Similarly, Figure B.2 showns the corresponding data for the combined chiller usage. Note that whole-building electricity use increased in 1999 at the same time as chiller electricity use dropped. This is likeley due to major changes in building occupancy and schedules and a chiller replacement at that time. The changes in operational schedules can be seen in Appendix C.

Annual gas usage between 1999 and 2002 are given in Figure B.3. Gas usage increased in 2001 and 2002. From Figure B.4 it is evident that summertime gas usage has increased dramatically. Figure B.4 shows gas and electricity use by month for the same period.

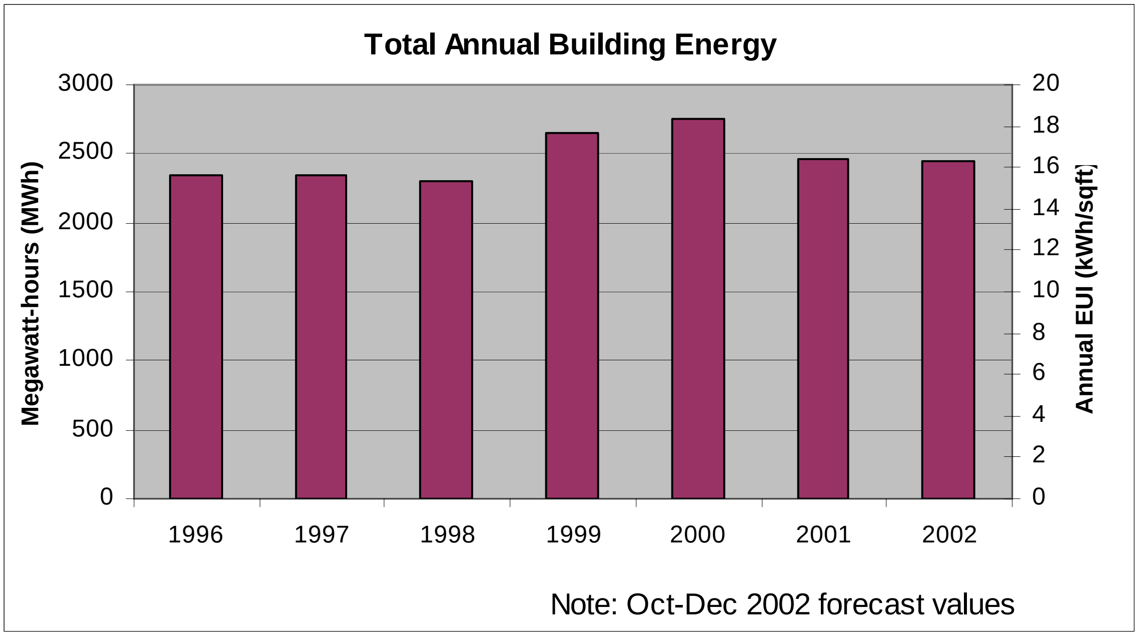


Figure B.1. Annual Energy Use by Year, Main Meter

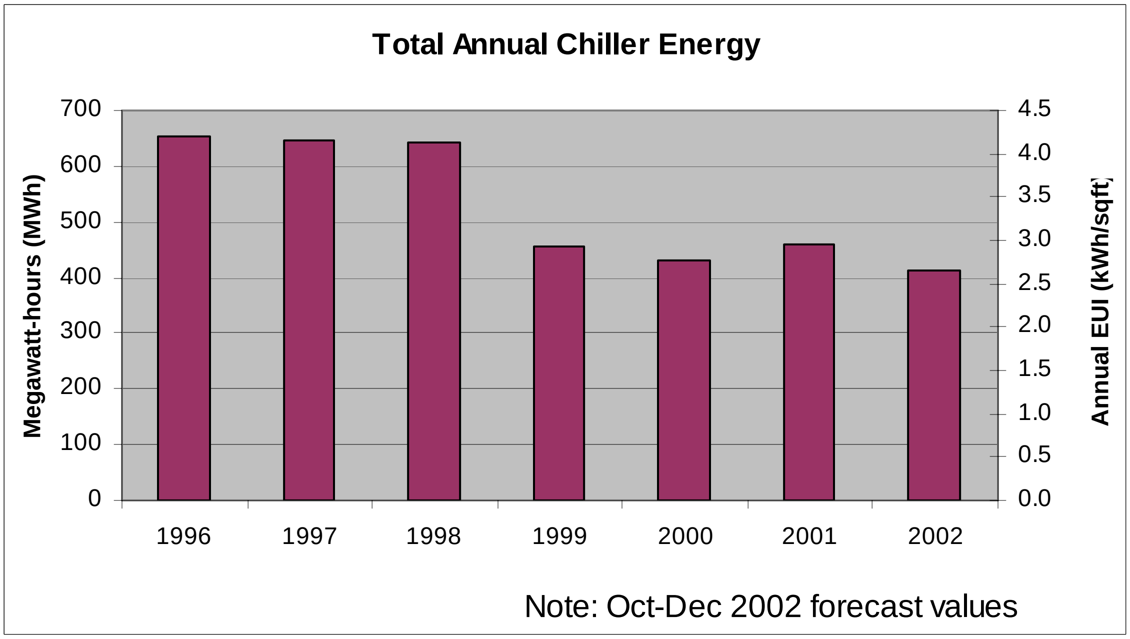


Figure B.2. Annual Chiller Energy Use by Year

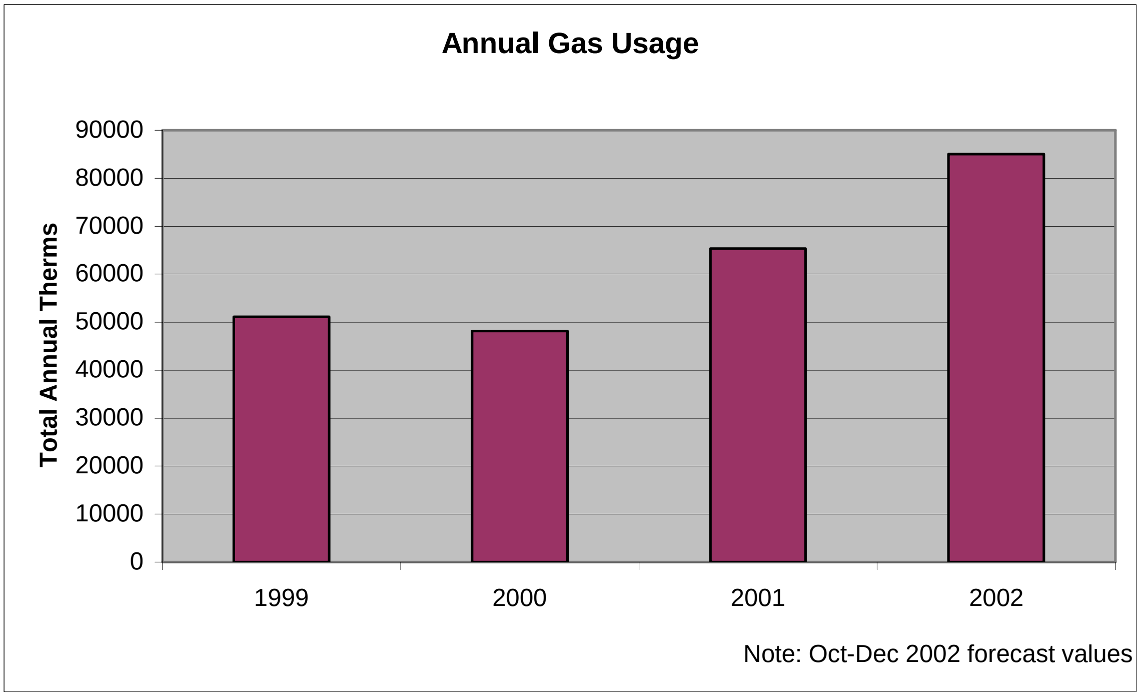


Figure B.3. Annual Gas Usage

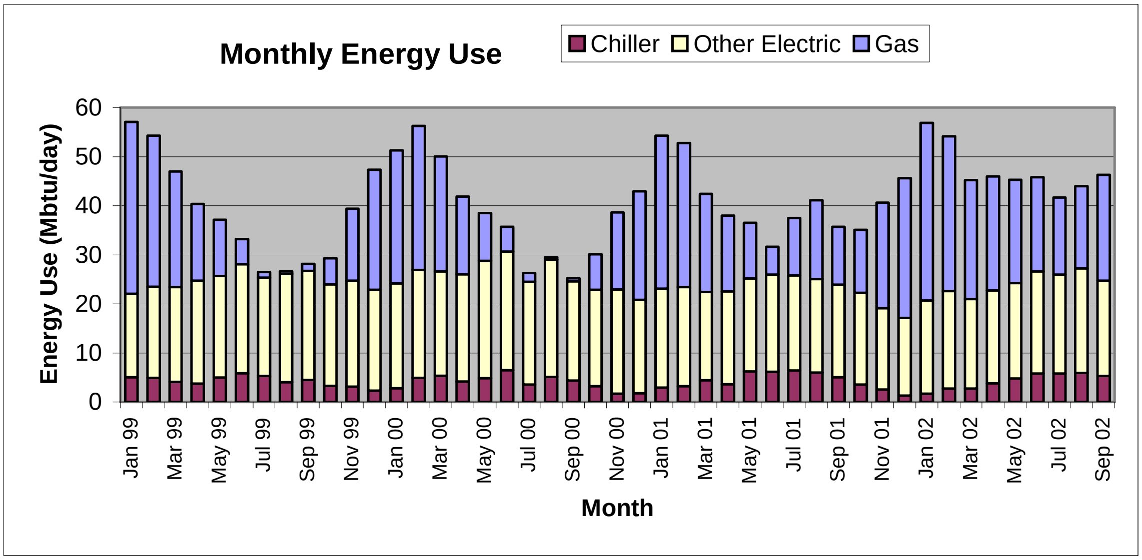


Figure B.4. Breakdown of total energy use

B.2. Weather Sensitivity

Temperature data were taken from an archive of average daily temperatures for the city of Sacramento. This archive is located at http://www.engr.udayton.edu/faculty/jkissock/weather/. Hourly temperature data were purchased from the National Weather Service for peak demand analysis under a separate project. The weather station is located at the Sacramento Executive Airport. Figure B.5 uses data from University of Dayton and Figure B.6 uses the purchased data.

Figure B.5 shows the relationship between weekday total energy use and average outside temperature, using University of Dayton temperature data, for 1996 to 2002. Statistically it is not a very strong correlation; however, this is still useful in understanding the general trend in energy usage with respect to temperature.

Figure B.6 shows a similar graph, using only the Summer peak hours; ie, 12-5pm, June 1 through September 30, 2000. The "Daily Average Temperature" is thus the average of only the hours 12-5pm. This shows a much stronger correlation, which is expected for the warmer months. Figure B.7 shows chiller electricity use by month versus temperature.

A significant increase in summertime gas use is evident in 2001 and 2002. The reason for this is not known but warrants further investigation. Figure B.8 shows monthly gas use vs. monthly average temperature. For the years 1999-2000, there is a strong heating slope. The cooler months in 2001-2002 follow the same linear trend as for 1999-2000; however, the warmer months do not. Thus the increase in gas use is not likely due to cooler summer temperatures.

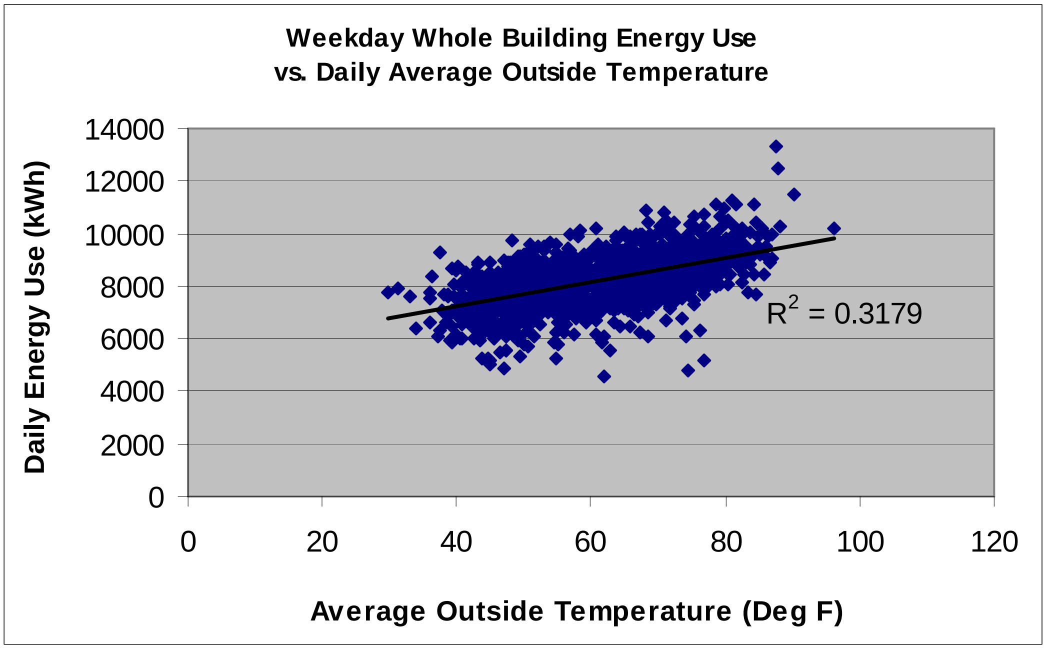


Figure B.5. Whole Building Energy vs. Outside Air Temperature

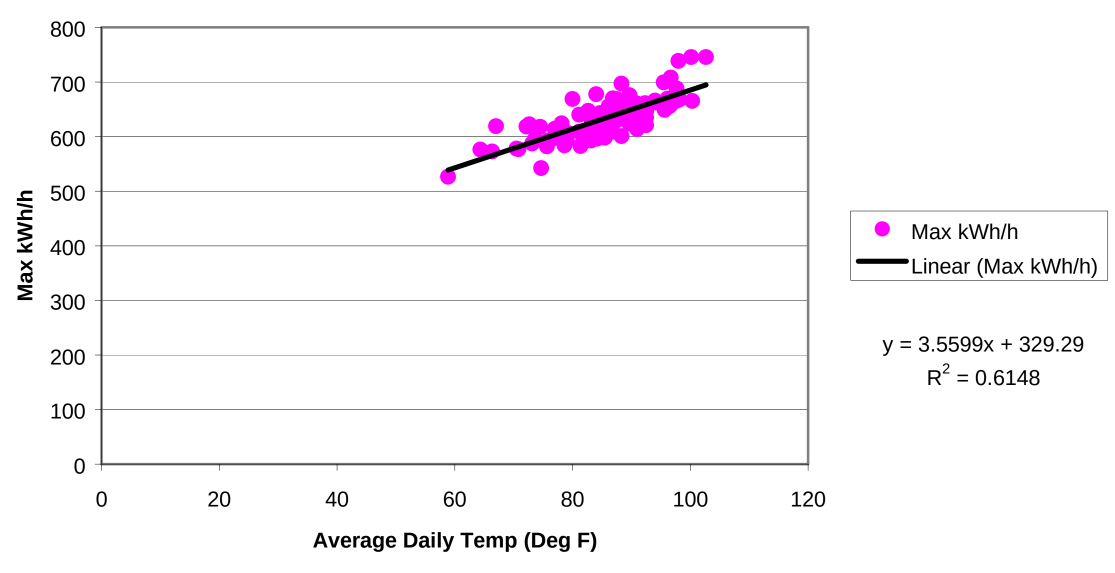


Figure B.6. Daily Peak Load vs. Outside Temperature, Summer Peak Hours

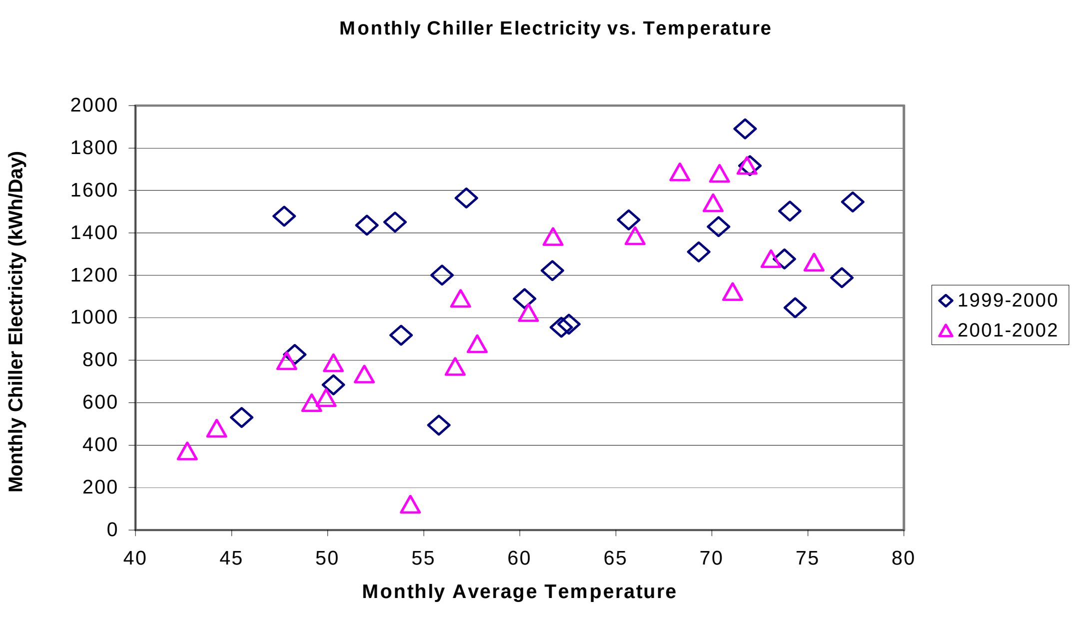


Figure B.7. Monthly Chiller Electricity Use vs. Outside Temperature

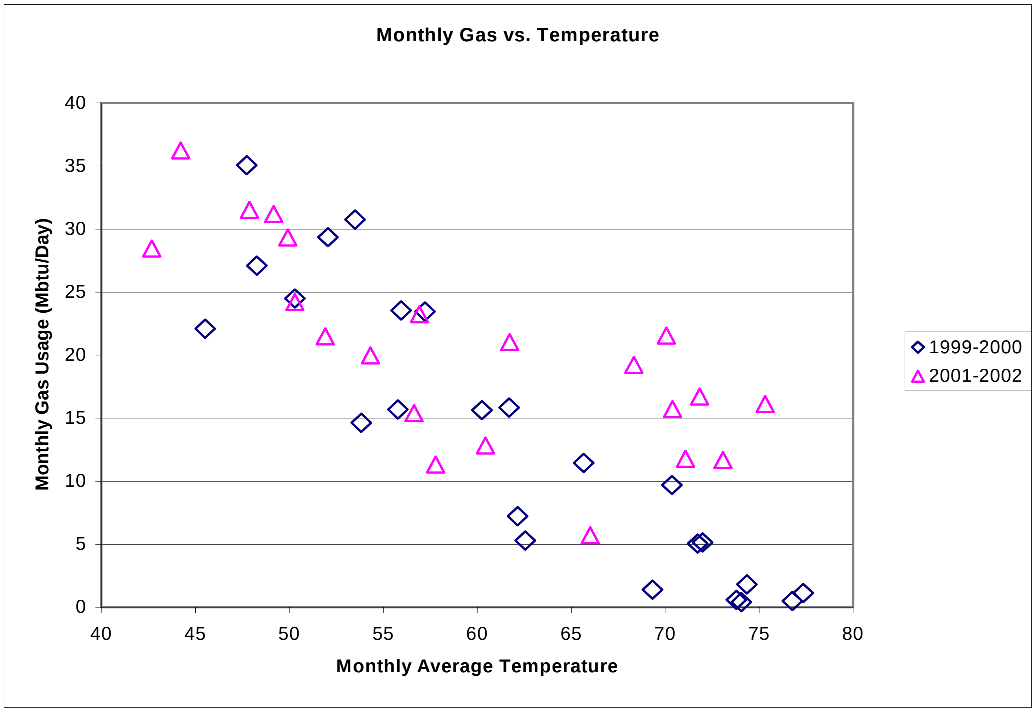


Figure B.8. **Monthly Gas Use vs. Outside Temperature**

B.3. Baseline and Savings Analysis

The operations staff first began to use the IMDS system in mid-2002. At this point there has not been sufficient time to observe the system or to expect any energy savings due to the IMDS. In the pilot IMDS, even after a year of monitoring and ample discovery of savings opportunities, no significant savings were realized until after the project's end, when the building staff upgraded the control system and began to implement recommendations.

The 2001 data, due to California's energy crisis, may not be a good representation of baseline operation. Using 1998 and 1999 may overestimate savings as energy use was higher in those years. Basically a savings analysis may require a more advanced analysis than used in evaluating the previous IMDS, ie, it will need to adjust for other factors affecting energy use besides temperature variations.

B.4. Cost Data

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 as shown in Figure B.9. In constrast, gas costs for Winter 2001 were extremely high. This is reflected in Figure B.10 and Figure B.11, which give monthly costs per kWh and per therm respectively.

Based on this data, 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.

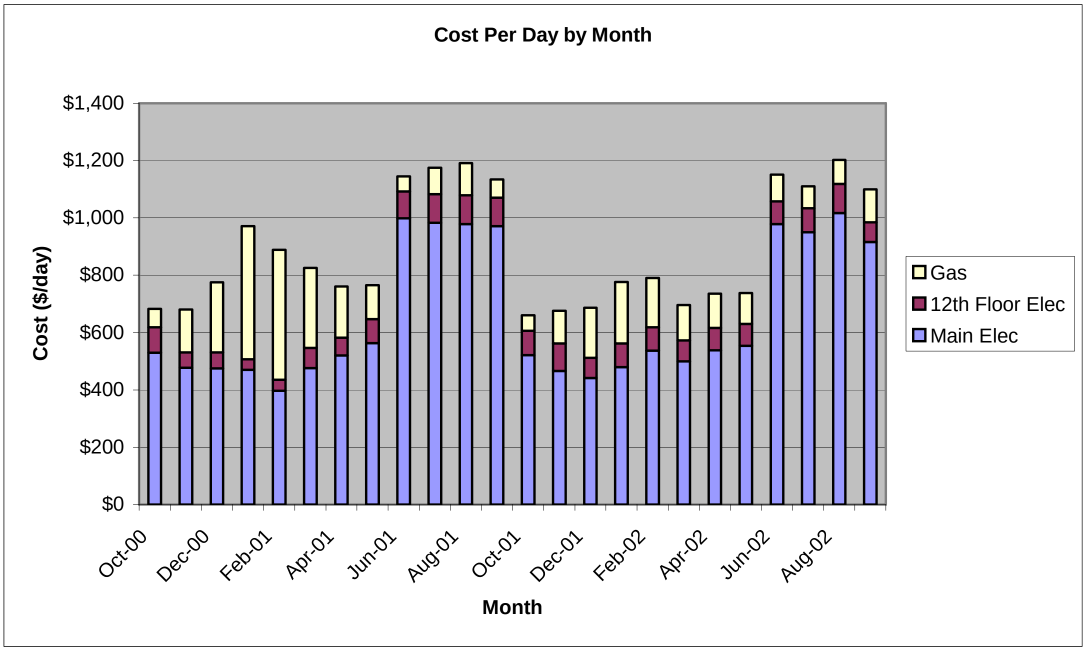


Figure B.9. Average Utility Cost per Day, by Fuel and by Month

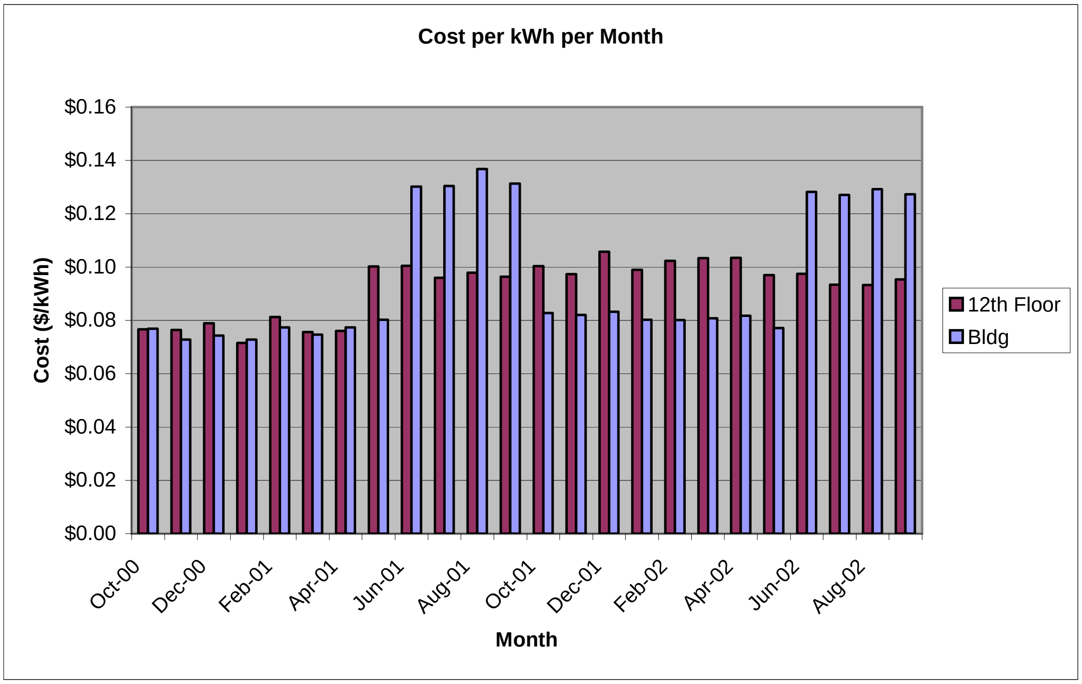


Figure B.10. Average Electricity Cost per kWh, by Month

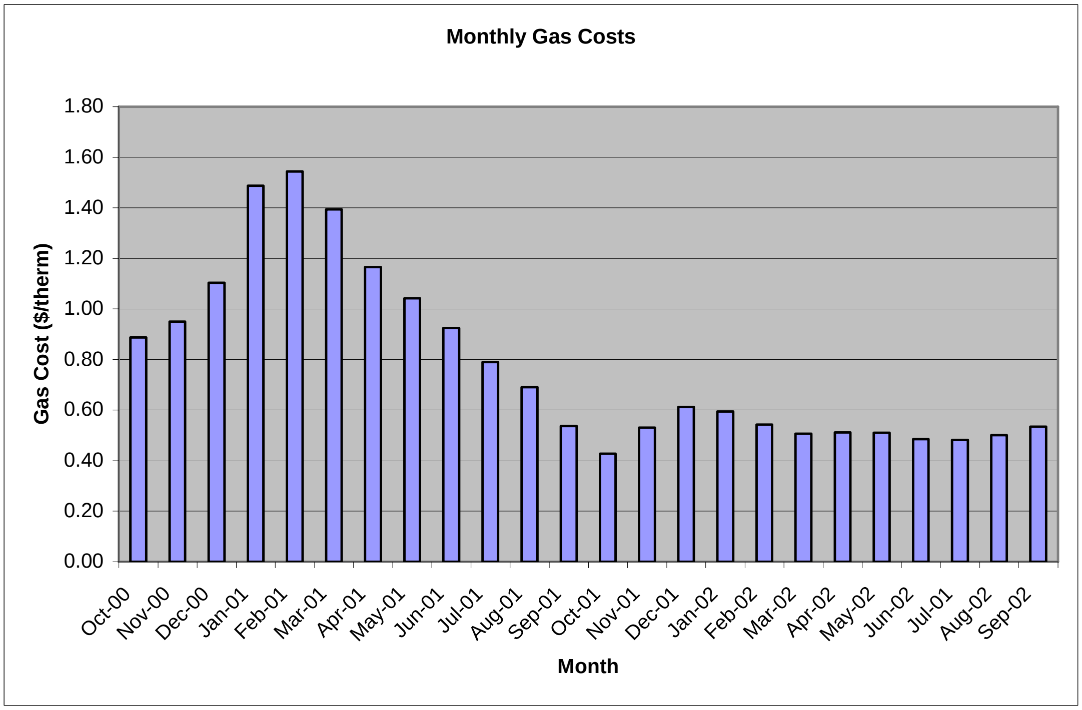


Figure B.11. Average Gas Cost per Therm, by Month

B.5. Peak Loads and Demand Reduction

Since 1999, the annual/summer extreme peak loads have come down slightly (Figure B.12) and the typical daily peak load dropped when the chiller retrofit was completed in 1999. The plots shown in Appendix Y summarize the past seven years of hourly data for whole building power and chiller power. These indicate a decrease in typical full-load operation.

In light of recent events relating to California’s energy supply, peak loads are of great interest. As part of a separate project evaluating demand shedding programs, analysis of peak loads at 925 L Street was done.

Figure B.13 illustrates the load reduction potential for the peak day, June 14, in 2000 according to a ten-day baseline. Typically these are calculated hour by hour, so this example uses only the hour 16 (4-5pm). The demand on the peak day was about 750 kW, and the average demand during the same hour for the previous ten days was about 600kW. Thus, if 925 L had been a participant in a demand shedding program and had been requested to shed load, a 150 kW reduction would have been necessary to meet the baseline. Any additional reduction below the baseline would have been considered curtailment.

Note that the peak day represents an extreme situation; on other demand reduction days, the amount of curtailment would likely be less. Although, to our knowledge, 925 L has no intention of participating in a demand reduction program, pre-cooling and other peak load management strategies could be used during extreme heat and energy usage periods.

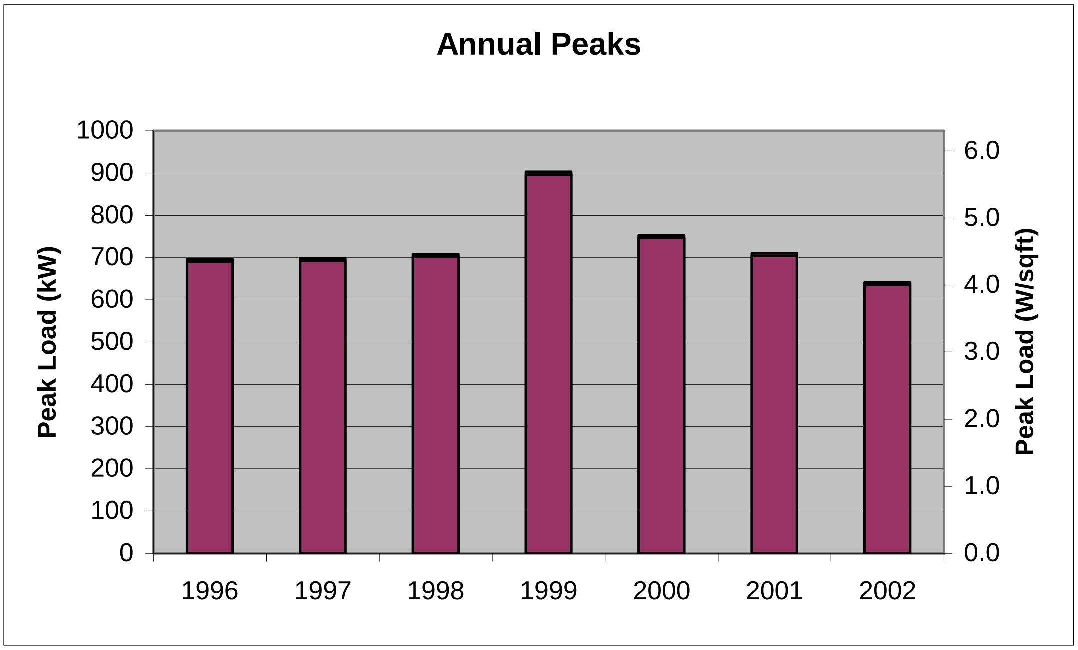


Figure B.12. Annual Peak Load by Year

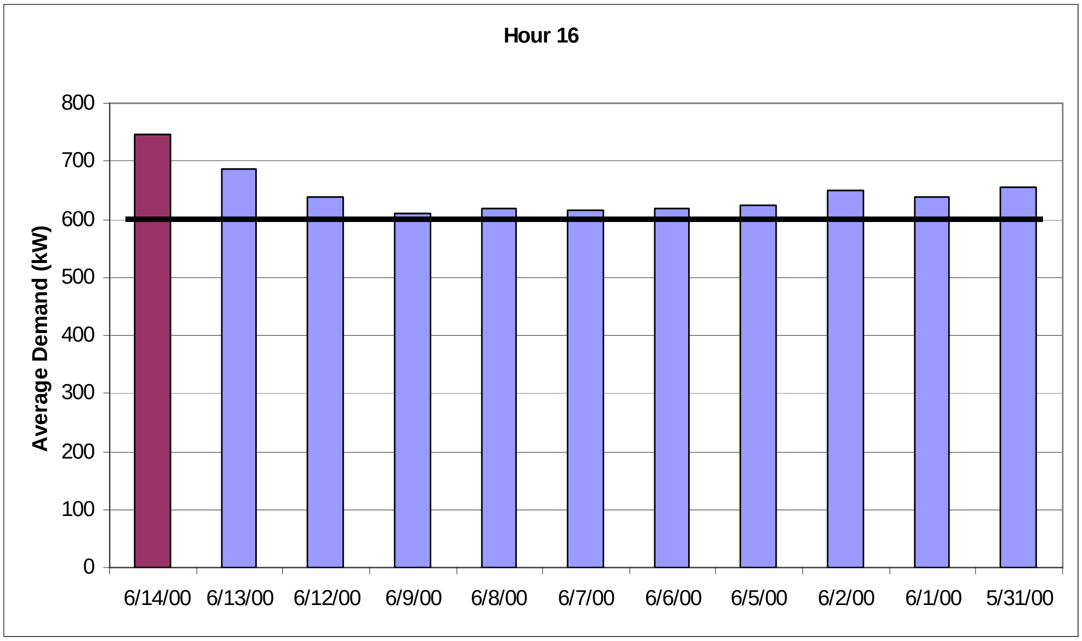


Figure B.13. Demand Reduction Scenario

B.6. Benchmarking

Benchmarking energy use is useful for evaluating potential energy savings. The results shown below are from Cal-Arch, a benchmarking tool for California buildings developed at Lawrence Berkeley Lab. While there is a lot of variation between the comparison buildings against which energy use is benchmarked, the building does not have a low energy use intensity (energy use per square foot) relative to the comparison population, at below the 50th percentile in energy use per square foot among California office buildings. Hence there is likely to be room for improvement. This is expected given the amount of simultaneous heating and cooling taking place.

With some additional information about the building, include space use, operating hours, number of occupants, and number of PCs, an Energy Star score can be calculated.

Appendix C.   Annual Summary Plots

Annual Summary Plots are a useful technique for evaluating long-term time series data. They summarize on one page a year of hourly data for one point. Each summary plot actually consists of 12 plots that are displayed on a single page, one plot for each month in a year. The monthly plots are created from hourly time-series data. Each month is divided into hours between 0 and 23, and the average hour for the month is computed. For each hour, the mean, median, maximum, minimum, and quartiles are calculated and displayed on the graph.

Displaying a year of data on one graph is advantageous as it allows identify major operating trends. It is also useful to filter out days that are not of interest; for example, we are primarily interested in weekdays only, though weekend energy use should not be ignored. In this appendix, separate plots are given for weekdays and weekends.

From these plots we can discern a reason for the rise in whole-building power in 1999 coincident with a decrease in chiller power and in peak load. Prior to 1999 the building operated a regular schedule of 6am to 6pm with very little shoulder-period operation as seen in Figure C.1. Contrast this with Figure C.3, whole-building power in a recent year, which shows an increase in night and weekend operating hourse. Similarly, a comparison of Figure C.4 and Figure C.5 reveals an increase in weekend energy use. Thus while peak loads are generally lower, the expanded hours of operation resulted in the net increase in annual energy use seen in Figure B.1.

Similarly, the change in chiller operation before and after the retrofit is apparent looking at Annual Summary Plots from before and after (Figure C.6 and Figure C.7). While there is some increase in nighttime operation, there is a dramatic decrease in peak load, resulting in an overall decrease in chiller energy use.

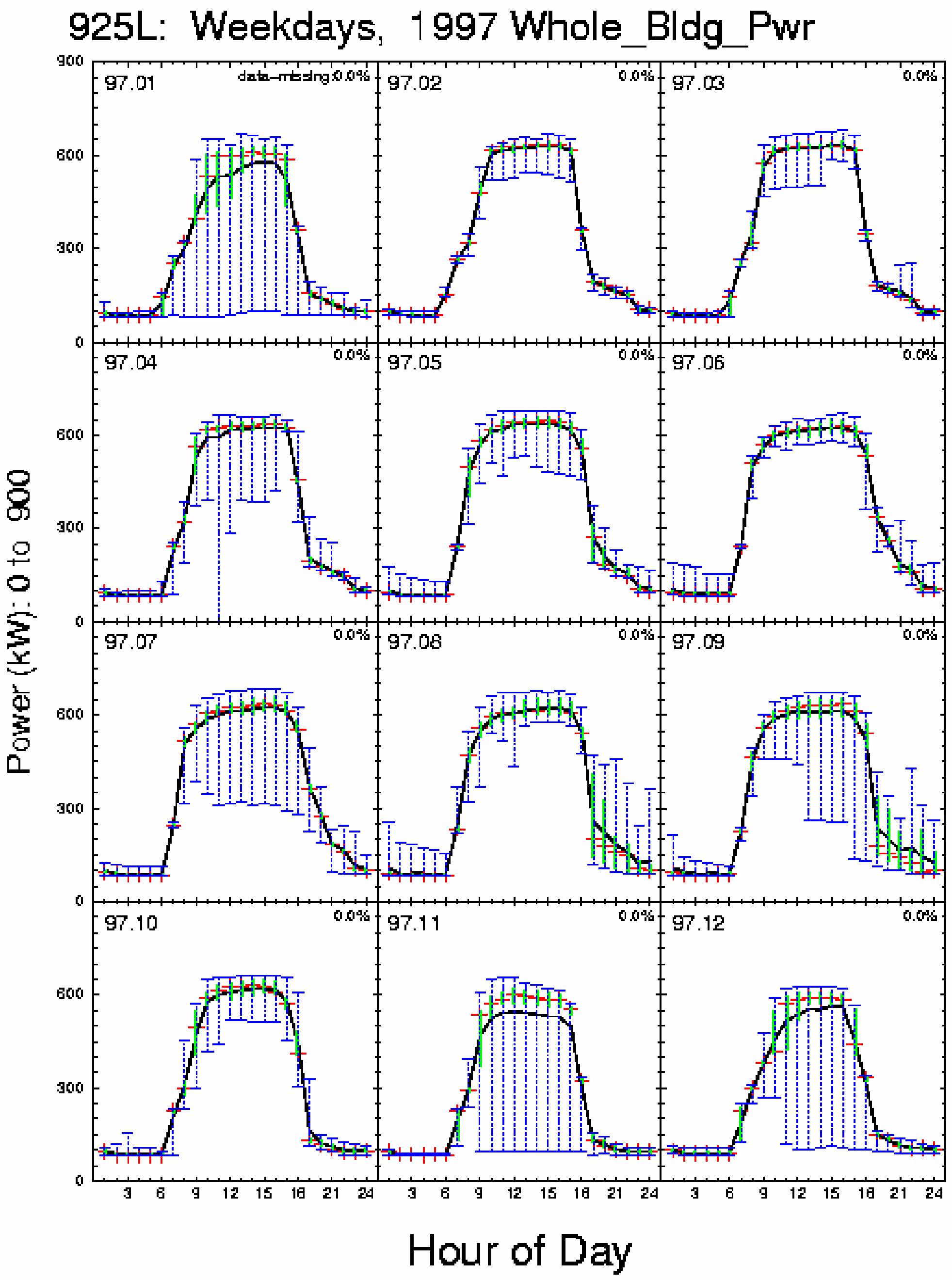


Figure C.1. **Whole Building Power, 1997, Weekdays**

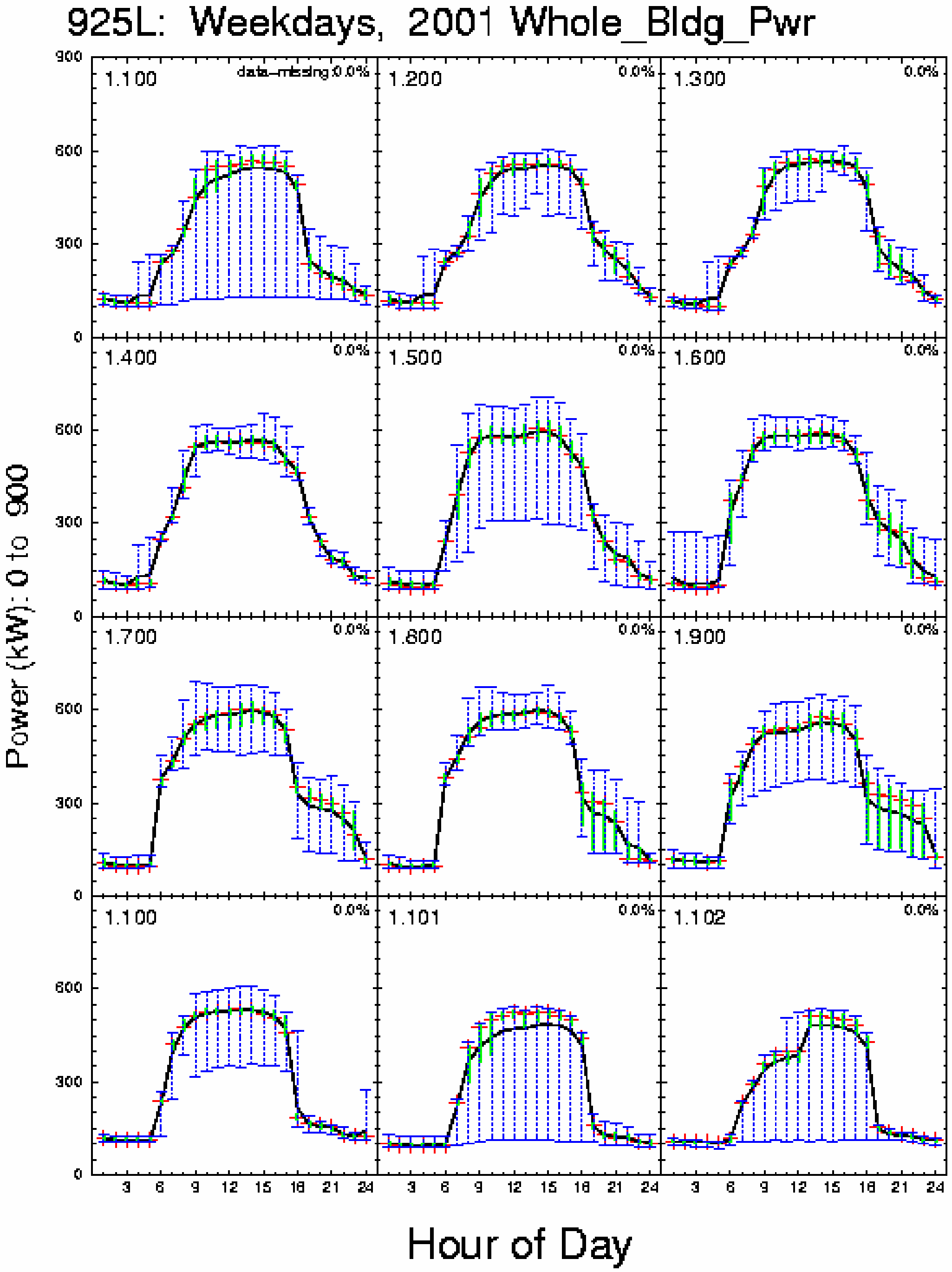


Figure C.2. Whole Building Power, 2001, Weekdays

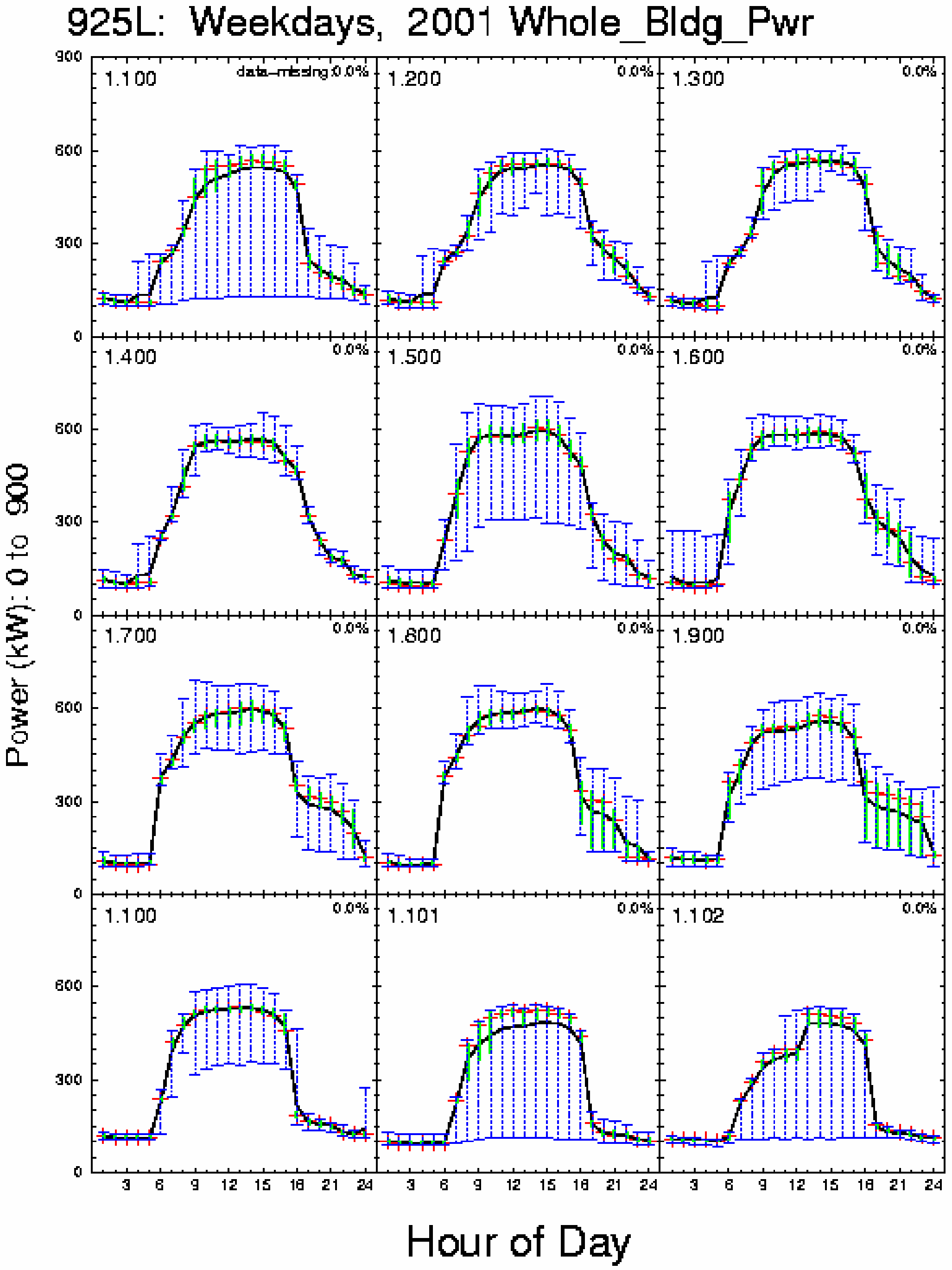


Figure C.3. **Whole Building Power, 2001, Weekdays**

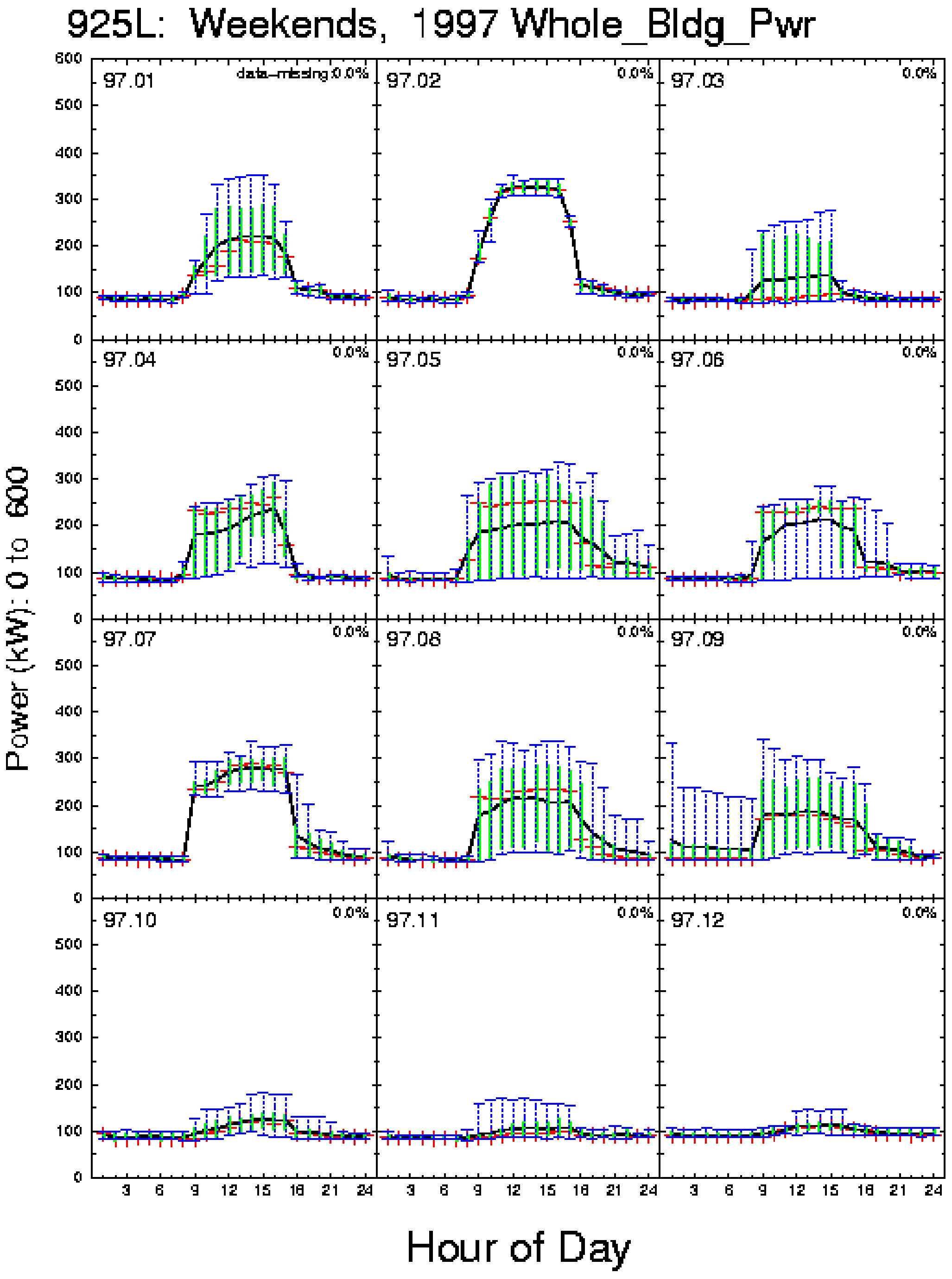


Figure C.4. **Whole Building Power, 1997, Weekends**

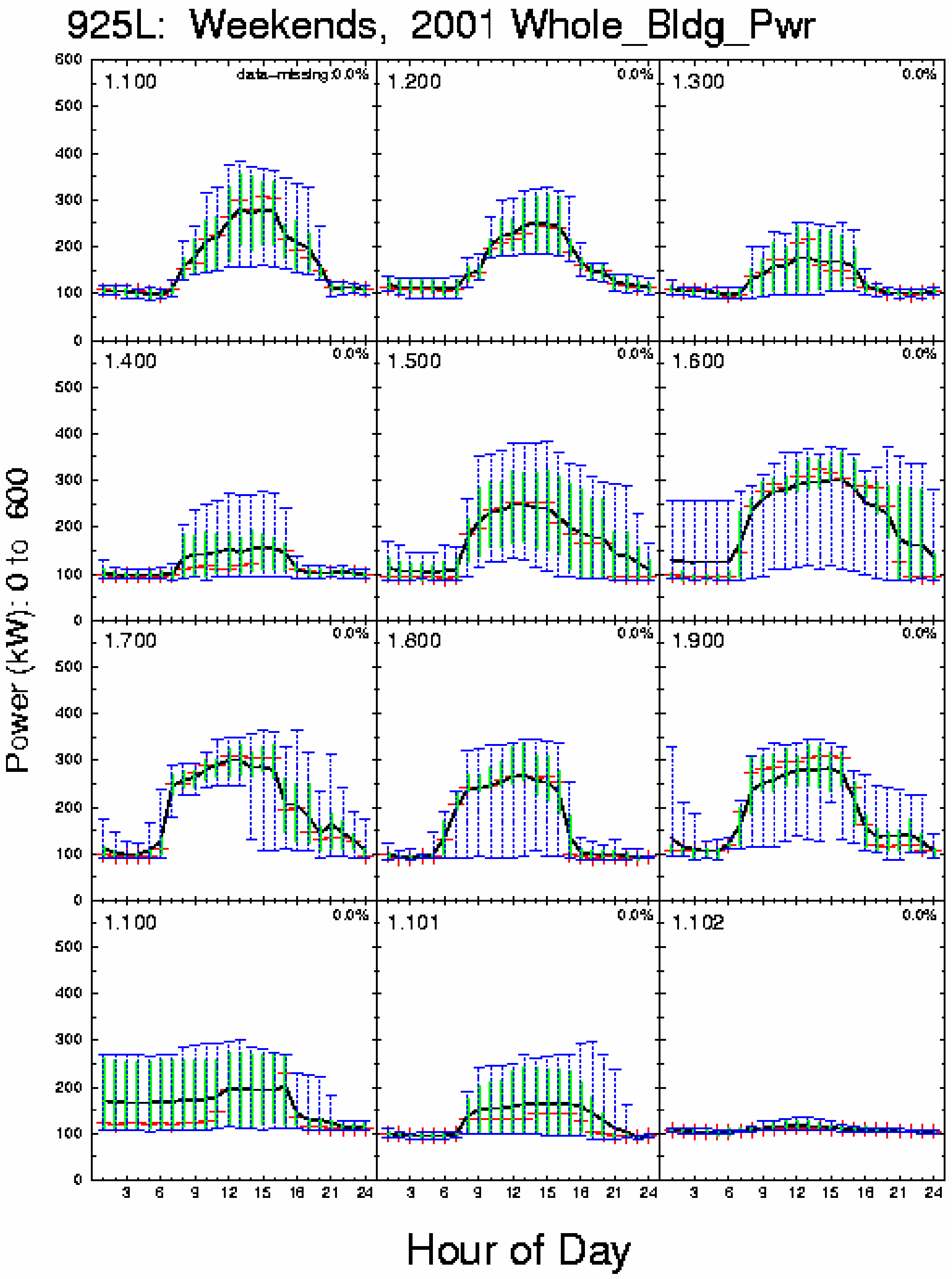


Figure C.5. **Whole Building Power, 2001, Weekends**

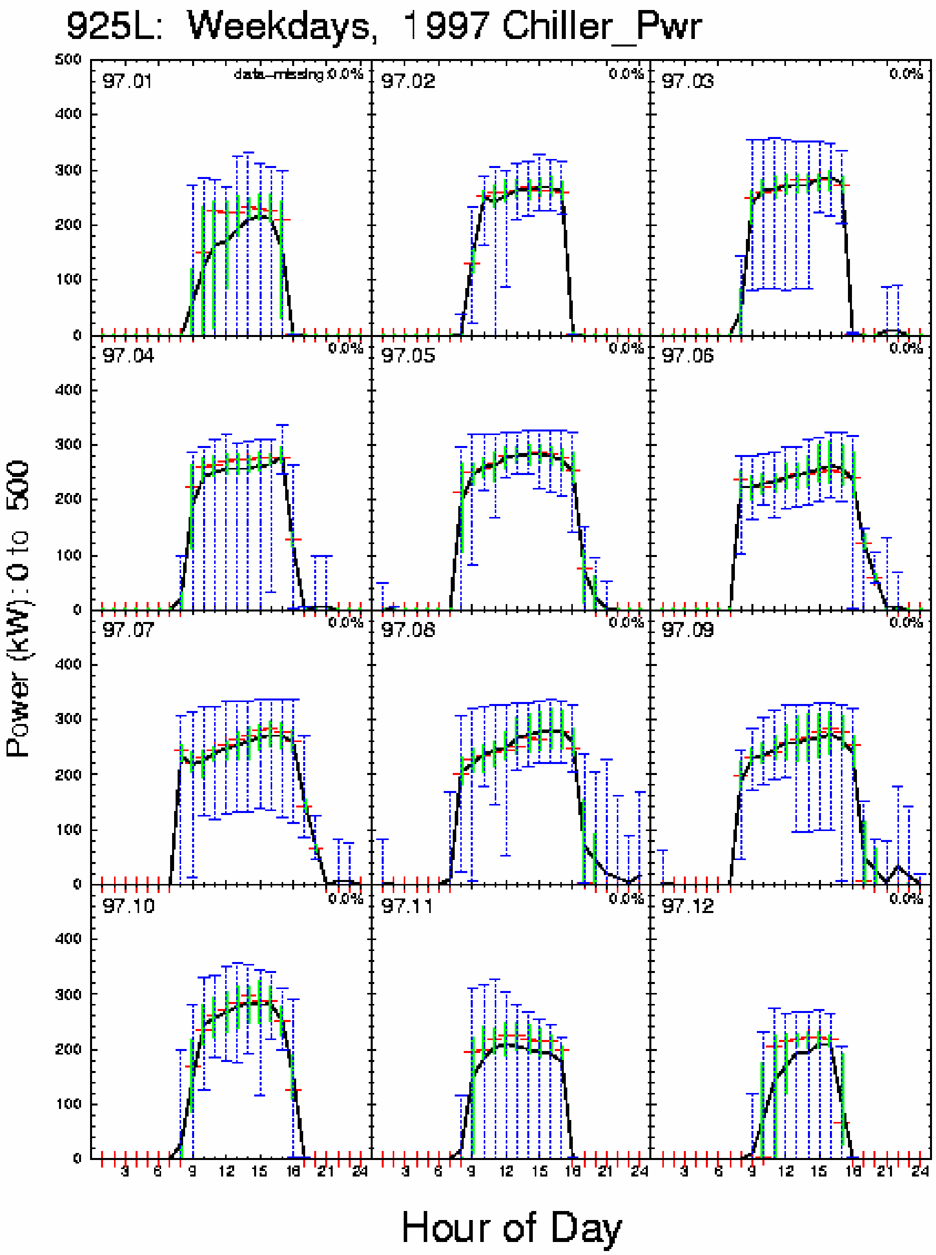


Figure C.6. Chiller Power Use, 1997, Weekdays

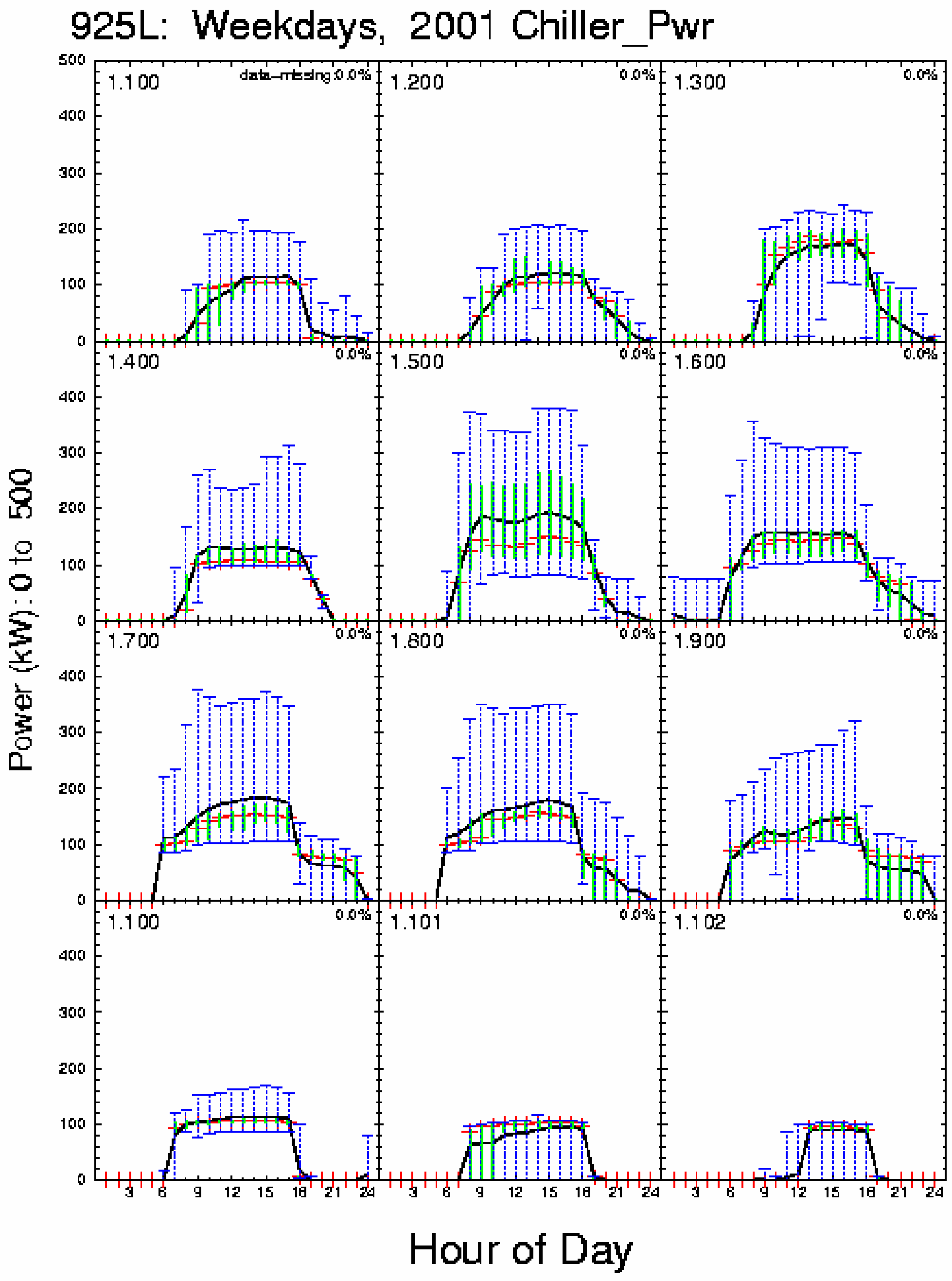
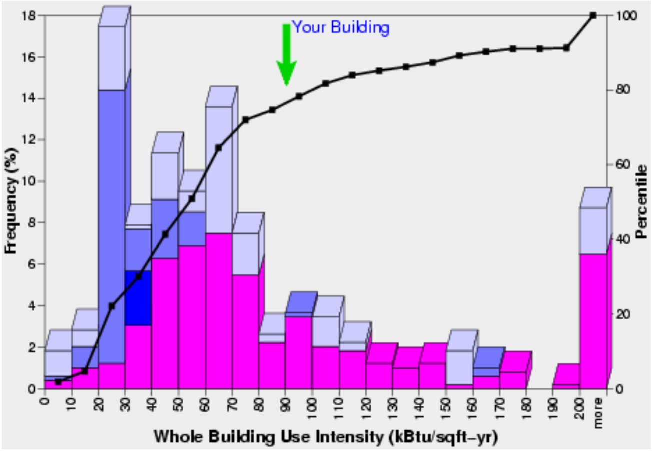


Figure C.7. Chiller Power, 2001, Weekdays

Appendix D. Cal-Arch Benchmarking Results

Whole Building Energy Use

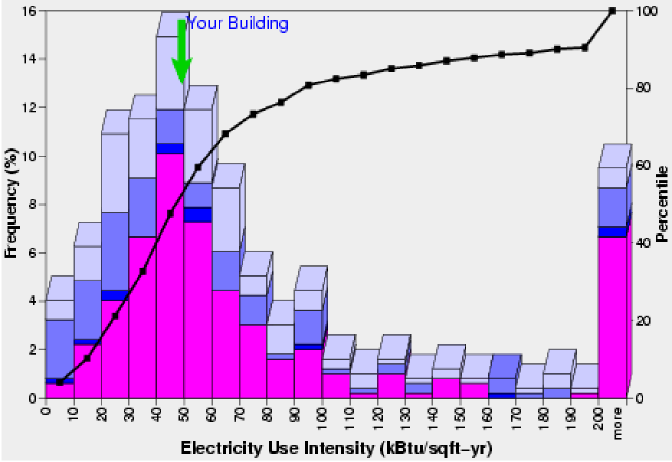


Your whole building EUI is 90.4 kBtu/ft^2-yr, which is higher than 75 % of comparison buildings shown.

EUI Summary	
%-tile	kBtu/ft^2-yr
25	34
50	58
75	90
Your EUI	90.4

more information

Electricity Use

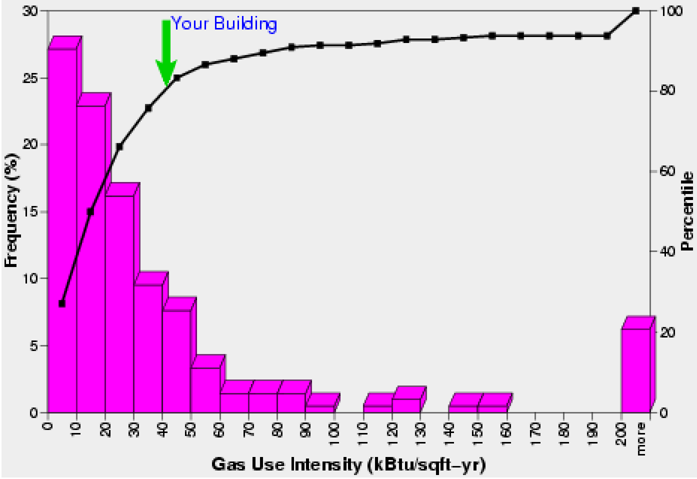


Your electric EUI is 49.1 kBtu/ft^2-yr, (14.3 kWhr/sf-yr) which is higher than 46 % of comparison buildings shown.

EUI Summary		
%-tile	kBtu/ft^2-yr	kWhr/sf-yr
25	32	9
50	51	15
75	84	25
Your EUI	49.1	14.3

more information

Natural Gas Use



Your gas EUI is 45.2 kBtu/ft^2, which is higher than 80 % of comparison buildings shown.

EUI Summary	
%-tile	kBtu/ft^2-yr
25	8
50	19
75	37
Your EUI	41.3

more information

LEGEND

Bar Color	Data Source	For further information:
🟪	PGE_CEUS	PG&E CEUS
🟦	SCE95L	1995 SCE Low-Res CEUS
🟦	SCE92L	1992 SCE Low-Res CEUS
⬜	SCE92H	1992 SCE High-Res CEUS

Description of Comparison Buildings

For this field:	You entered:	Comparison Buildings
Building Type	Office/Professional	Office/Professional
Zip Code	Not entered	All climate zones are shown
Floor Area	175,000 ft^2	
Filter by area?	No	Buildings of all sizes are shown
Site/Source	Site	Results are displayed as site energy use

Number of buildings on graphs:

	Whole Bldg	Electric	Gas
Unweighted:	267	423	210

Appendix E. HVAC Systems and Opportunities for Improvements

E.1. Central Plant

The central plant equipment is located in the rooftop mechanical room. A 6,500 kBtu/hr (input) natural gas boiler rated at 80% efficiency, serves the building heating hot water (HHW) demands. It uses a primary hot water supply loop with 3-way control valves at the air handler heating coils. The boiler has two firing stages and is larger than the building needs. It is possible that the boiler operation will need major changes if the building load is reduced by eliminating simultaneous heating and cooling (see Section E.2). There are two 3 HP circulation pumps for HHW, staged with the boiler's firing stages.

Figure E.1. Cooling Tower

In 1998, a two-cell cooling tower with VFD control was installed. The towers are operated as a single cell with dual VFDs with one speed signal. If one of both towers operates, only one speed signal is sent. The EMCS also controls the start/stop functions. Two existing 1976-vintage 20-hp turbine insertion water pumps are installed on the primary condenser water (CW) loop. The pumps were not replaced when the new chiller or tower was installed.

There are two electric chillers, of which only one (Chiller 2) operates. Chiller 1 is out of service and needs a major overhaul if it is to be used again. This 300-ton hermetic reciprocal chiller was installed in 1976. As of November 2002, JLL plans to begin the overhaul of Chiller 1 in early 2003. The work will include an upgrade to non-CFC R134 refrigerant.

Chiller 2, installed in 1998 during the EMCS upgrade, is a 300-ton chiller with R134 refrigerant. Chiller 2 is able to meet the current peak-cooling load at approximately 95% part load. There were several days when the IMDS showed the cooling load at about 300,

The chiller should be able to operate up to 115% of capacity if the condenser water is dropped. The building operators have experimented with dropping the condenser water supply temperature until there were oil-refrigerant problems. The condenser water flow was not varied at that test. The owners are evaluating the installation of a pony chiller to provide more cost effective chilled cooling water (CCW) during lower cooling load conditions. Plans are also under development for the installation of a plate-and-frame heat exchanger for a waterside free cooling cycle using the cooling tower. The tower is oversized to accommodate CW temperatures that will be adequate for CCW use during many hours of the year.
Two 1976-vintage 20-hp water pumps are found on the primary CCW loop. Both pumps are piped for operation on a single chiller.

The control system pneumatic control air compressor is located in the central plant penthouse. Relays and electronic-to-pneumatic transducers (E/P) execute the EMCS control sequences.. The system has dual compressors and maintains a building supplied pressure of approximately 20 PSI. Also located in the penthouse is a restroom exhaust fan which is a major cause of air movement in the building zones. Exhaust fans exhaust around 14 air changes per hour to create a negative presence on the zones. The AHU has to use outdoor air to make up part of that difference and add positive pressure to the floor.

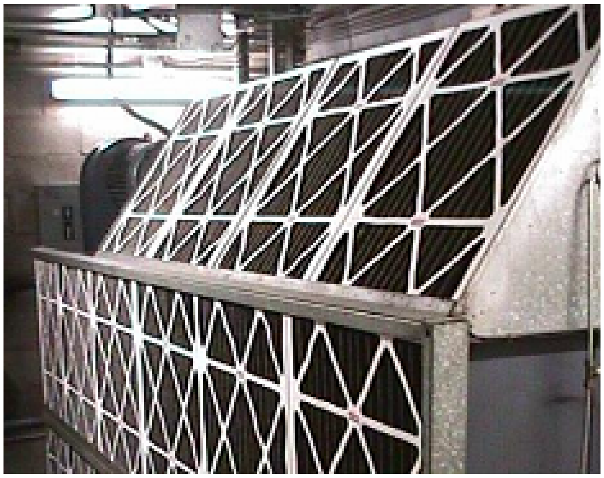


Figure E.2. Air Handling Unit

E.2. Air Handler Units and Ducts

The air distribution system is constant volume dual duct. Each floor has a single 1976-vintage Air Handling Unit (AHU). They are blow-through high pressure units with a 20-hp supply fan. The 17 units are individually set for airflow. It appears as though the belt and sheave setup was not completed during the original construction. As a result, airflow to the zone may not be balanced properly. There are two forward inclined blade fans driven by the constant-speed motor. The motor is mounted in the air path and rejected heat is in the air stream. The current motors are of standard efficiency. As motors are replaced, either inverter-ready high-efficiency motors or high-efficiency motors will be used as replacements.

Figure E.3. Air Handling Unit

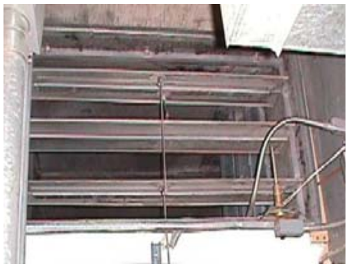


Figure E.4. Exhaust Air Dampers

The outside air intake is fixed at approximately 15 to 20% of total AHU flow, just enough to meet minimum ventilation rates. There is no way to implement airside economizer operation without major retrofit work. A possible alternative could be to pressurize the outside air duct with a vane axial fan, but that might cause pressurization or noise problems at the main fan.

There is a single hot water coil, with a 3-way control valve operated by the EMCS. This supplies approximately 110 °F HHW to the hot water coil. The hot deck is set to deliver 85 °F air. There are two cooling coils that have no automated flow control. The only flow control available is a manual butterfly-trimming valve in the CCW supply line. The cooling coil supplies about 53 °F CCW in the winter and about 50 °F CCW in the summer. The cold deck is set to deliver 58°F air.

The lack of cooling coil control is the main cause for considerable amount of simultaneous heating and cooling in the building. With the current configuration, it is not possible for the system to shut off the chiller when cooling loads are not present. Conversely, the boiler is not able to shut off when heating loads are low. As a result, both the boiler and chiller operate all year when the building is occupied. The current building operator is aware of the situation and is interested in using the IMDS data to justify a full VAV retrofit of the airside system.

The floors are split into two zones, corresponding to the North and South halves of the floor. The return air may short circuit over the two-zone system in some areas as the building construction and layout of the zones has been varied by tenant improvements. This should be reviewed on a floor-to-floor basis.

Each zone has 15 to 18 mixing boxes. The mixed air temp is different per space as delivered from the hot and cold ducts. The mixing boxes are controlled from individual pneumatic room thermostats. There are single and multiple boxes that are controlled in this fashion. This operation is separate from the EMCS and has to be dealt with directly if there is a complaint call. The building management does adjust setpoints where possible. The EMCS heating setpoint on the floor is adjusted for a heating call or all the cooling coils are adjusted for a hot call. This results in simultaneous heating and cooling as either chiller energy is added or boiler gas is burned to compensate all floors to satisfy one.

E.3. Electrical and Utility Systems

The main electrical service is located in the basement. There are two main electrical services, one for the building and the other for the 12th-floor tenant equipment.
There is one main natural gas service in the building. The primary use is the boiler. There are smaller natural gas domestic hot water heaters in the building as well.
The electrical system is a made up of a bus duct connection system with two risers. One riser is a mechanical riser and the other supplies power to step down transformers for lighting and plug loads. Both risers run the length of the building through the mechanical spaces.

The mechanical riser covers all floor AHUs and rooftop mechanical equipment.
The lighting and plug load riser use 277 volts for lighting and 120/208 Volts for plug and two-phase loads. The 120/208-Volt service is generated from dry type transformers. The power factor has shown to be good for these transformers. The transformers are mounted in the AHU room and are cooled by the mixed air. This placement adds load to the cooling system.

There are many small step down transformers used on the EMCS and other systems. Most are 110 primary, but some step down 480 volts primary to 24 VAC secondary. The 480-Volt transformers used for each floor control power to the EMCS may also be causing a power factor issue. The specifications of the transformer are not known, but the identified power factor on one AHU fan location was 0.62. The power factor at other monitored equipment was 0.9 or better.

E.4. Opportunities for Improvements

During the installation of the IMDS, En-Wise and Lee Eng Lock analyzed the physical plant. The Plate and Frame was evaluated. Opportunities for improvements are described below.

- **Cooling Tower: Change turbine pumps to end suction pumps.** The primary condenser water loop for two towers, two condenser pumps and two chillers can be improved. The current system uses turbine pumps that are applied incorrectly. Piping and valve settings should be adjusted to reduce the pumping pressure drop. The basin water entering angle is high and reduces performance on the current use.

- **Consider VFDs on condenser water pumps.** Consider opening the bypass valves and control the pumps to maintain chiller flow. The drive can allow for parallel or individual pumping depending on what is required. The reduced pressure drop and stability of water use will make more effective use of the chiller delta T and tower fill. The overall heat rejection should improve.

- **Consider a VFD chiller as an addition to the current system.** There are retrofit options that can be used to increase efficiency across the entire range of the chiller operation.

- **Consider an industrial head pump to produce hot water and chilled water at the same time.** There are also retrofit options that can be used to increase efficiency across the entire range of the need for chilled and hot water. This system will always have needs for both and must be combined with cooling coil control.

- **Consider VFDs on CCW (CHW) primary pumps.** Variable Frequency Drives are used in combination with adding 2-way valves across most of the coils and a 3 way valve at the end of the CCW pipe run. The 3-way valve ensures there is never a zero flow in the loop. A bypass valve is also added across the headers in the plant room to provide flow thru chillers. The pressure control can be built into the control valve for this purpose. The differential pressure is set to a value that opens the valve if the pressure goes up.

- **Close valves on non-operational equipment:** Two observations
    - CCW primary loop needs the non-used pumps to be isolated when not in operation. CW primary loop needs the chiller condenser bundle to be isolated also, so as to not add heat back into the evaporator loop.
    - This can also be applied to non-operational floors or floors that need only cooling or heating.

- **Add plate-and-frame heat exchanger to main plant equipment.** Two observations:
    - Add a plate-and-frame heat exchanger that can pre-cool CCW before the chiller is needed for start-up. It will reduce the startup current draw and extend the start time.
    - When outside weather conditions permit, use the heat exchanger to cool the CCW loop with CW from the tower. This would provide space cooling without chiller operation.

    - **How are tubes cleaned?** Is there room for access to Condenser? Need to modify the walls and/or piping to accommodate this. There is no filter system that will protect the chiller or performance. Condenser piping showed built up dirt and effects of improper chemical treatment. The interior face of the pipe probably creates conditions for higher pumping energy use.

    - **Insulate CW piping**. The condenser water pipes located on the roof with solar exposure could be insulated and/or painted white.

Appendix F. Summary of IMDS Activity Reports

Report Date & Time	Points Viewed	Point Description(s)	Time Interval	Time Period/Dates	Activity or Unusual Findings	Problem?	Action Taken
10/7/02 13:11	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 hr	10/7/02	Chiller Rounds	None	Recorded Data for JLL report
10/8/02 13:30	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 min	10/8/02	Chiller Rounds	None	Recorded Data for JLL report
10/9/02	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 min	10/9/02	Chiller Rounds	None	Recorded Data for JLL report
10/10/02	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 min	10/10/02	Chiller Rounds	None	Recorded Data for JLL report
10/11/02 13:34	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 hr	10/11/02	Chiller Rounds	None	Recorded Data for JLL report
10/15/02 08:48	kWhtokW.kW	Whole Building Power	1 min	During off hours over entire data set (July 02 to Oct 02)	Unusual graph pattern. 600 kW to 0 kW block.	Yes	Look into borrowing portable data loggers - SMUD
10/21/02 14:11	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 hr	10/21/02	Chiller Rounds	None	Recorded Data for JLL report
10/24/02 13:07	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 min	10/24/02	Chiller Rounds	None	Recorded Data for JLL report
10/28/02 14:08	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 min	10/28/02	Chiller Rounds	None	Recorded Data for JLL report
10/29/02 13:15	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 hr	10/29/02	Chiller Rounds	None	Recorded Data for JLL report
10/29/02 14:19	MCCPwr.kW Ch2Pwr.kW (EEye Bookmark)	Motor Control Center Power, Chiller 2 Power	1 min	9/27/02, 10/4, 10/11, & 10/18/02	Chiller surge on four consecutive Fridays	Need to investigate more	

Report Date & Time	**Points Viewed**	**Point Description(s)**	**Time Interval**	**Time Period/Dates**	**Activity or Unusual Findings**	**Problem?**	**Action Taken**
10/29/02 14:25	MCCPwr.kW Ch2Pwr.kW (EEye Bookmark)	Motor Control Center Power, Chiller 2 Power	1 min	7/27/02 & 7/28/02	Unusual pulse, could be restart on low load	?	
10/30/02 13:30	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 min	10/30/02	Chiller Rounds	None	Recorded Data for JLL report
10/31/02 13:10	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 min	10/31/02	Chiller Rounds	None	Recorded Data for JLL report
11/1/02 13:00	Io1211.wtroatdb & Io1211.wtroatwb (weather station bookmark)	Outside air Temps (DB & WB)	1 min	11/01/02	During Chiller Rounds, noticed the weather station at cooling tower wet bulb tracking dry bulb	Yes. Suggest checking cooling tower weather station wick.	Wet bulb sensor dried out due to siphon hose problem in water tank. Corrected problem & confirmed WB readings w/ EEye.
11/4/02 13:20	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 min	14/4/02	Chiller Rounds	None	Recorded Data for JLL report
11/5/02 13:15	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 min	14/5/02	Chiller Rounds	None	Recorded Data for JLL report
11/5/02 13:45	Io1211.wtroatdb & Io1211.wtroatwb	Outside air Temps (DB & WB)	1 min	14/5/02	Chiller Rounds	None	Recorded Data for JLL report

Appendix G. IMDS Equipment Inventory

SENSORS

IMDS Point Name	Description	Unit	Location Installed	Sensor Type	Quantity	Unit Cost, Retail	Total Cost, Retail	Total Cost to Project
ch2chws ch2chwr ch1chws ch1chwr	Chiller 1 Chilled Water Supply Temperature Chiller 1 Chilled Water Return Temperature Chiller 2 Chilled Water Supply Temperature Chiller 2 Chilled Water Return Temperature	Deg F	Evaporator Supply and Return	10K Ohm Calibrated Thermistors	4	$622	$2,486	$2,162
ch2cws ch2cwr ch1cws ch1cwr	Chiller 1 Condenser Water Supply Temperature Chiller 1 Condenser Water Return Temperature Chiller 2 Condenser Water Supply Temperature Chiller 2 Condenser Water Return Temperature	Deg F	Condenser Supply and Return	30K Ohm Calibrated Thermistors	4	$622	$2,486	$2,162
07ccstmp 07ccrtmp 07hcstmp 07hcrtmp	Cold Water Cooling Coil Supply Temperature Cold Water Cooling Coil Return Temperature Hot Water Cooling Coil Supply Temperature Hot Water Cooling Coil Return Temperature	Deg F	Hot and Cold water coils on 7th Floor	10K Ohm Thermistor	4	$54	$216	$86
07matmp	Mixed Air Temperature	Deg F	Air Handler Inlet	10K Ohm Thermistor, 25-foot averaging sensor	1	$213	$213	$170
wtroadb wtroawb ctroadb ctroawb	Ambient Outdoor Air Drybulb Temperature Ambient Outdoor Air Wetbulb Temperature Cooling Tower Drybulb Temperature Cooling Tower Wetbulb Temperature	Deg F	Weather Stations for outdoor air and at cooling tower intake	10K Ohm Thermistor	4	$54	$216	$172
				EWB Enclosures	2	$801	$1,601	$1,281
c1vtmp c2vtmp	Cooling Zone 1 Duct Average Temperature Cooling Zone 2 Duct Average Temperature	Deg F	Cold Air Ducts	10K Ohm Thermistor, 8-foot averaging sensor	2	$111	$222	$155
z1hvtemp z2hvtemp	Heating Zone 1 Duct Average Temperature Heating Zone 2 Duct Average Temperature	Deg F	Hot Air Ducts	10K Ohm Thermistor, 12-foot averaging sensor	2	$131	$262	$183
z1mtmp z1mtp2 z2mtmp z2mtp2	Zone 1 Mixed Air Temperature NW Zone 1 Mixed Air Temperatures NE Zone 2 Mixed Air Temperature NW Zone 2 Mixed Air Temperature NE	Deg F	Duct Supply to Zones	10K Ohm Thermistor	4	$41	$164	$131
sz1tmp sz2tmp	Zone 1 Space Temperature Zone 2 Space Temperature	Deg F	Zones	30K Ohm Thermistor	2	$5	$10	$0
ch2chflw	Chiller 2 Chilled Water Flow	gpm	Chilled water supply pipe between chillers, 8" pipe	Magnetic Flow Meter	1	$3,331	$3,331	$2,897
chhdrflw	Chilled Water Header Flow	gpm	8" pipe to chilled water coils,	Insertion Vortex Flowmeter	1	$1,428	$1,428	$1,242

			before chillers					
cwhdrflw	Condenser Water Header Flow	gpm	On 10" pipe on condenser supply back to chillers	Insertion Vortex Flowmeter	1	$1,428	$1,428	$1,242
oatrh ratrh	Outside Air Makeup Relative Humidity to AHU Return Air Makeup Relative Humidity to AHU	% RH	Outside air and Return Air Ducts	3% RH Meter	2	$298	$596	$417
07hz1cfm 07cz1cfm 07hz2cfm 07cz2cfm	Heating Zone 1 Duct Air Flow Velocity Cooling Zone 1 Duct Air Flow Velocity Heating Zone 2 Duct Air Flow Velocity Cooling Zone 2 Duct Air Flow Velocity	fpm	Zone 1 & 2 Hot and Cold Ducts	Hot Wire anenometer	4	$738	$2,954	$1,994
	7th Floor AHU Power	kW	Power Panels	True RMS Power Meter	1	$900	$900	$675
	7th Floor Lighting Power 7th Floor Plug Power	kW	Power Panels	True RMS Power Meter	2	$940	$1,880	$1,410
	MCC, CH1 and CH2 Power	kW	Power Panels	True RMS Power Meter	3	$940	$2,820	$2,115
bldgkw	Building Main Power	kW	SMUD Utility Meter	Transducer	1	$191	$191	$0
						TOTALS	$23,404	$18,495

Data Acquisition and Visualization	**Retail Value**	**Cost to Project**
Data Acquisition Server and Software	$6,788	$5,903
Data Acquistion 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

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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

Appendix H. Potential Future JLL Sites

300 Capitol Mall
383,328 RSF
Built in 1981
Tenant Base: Mix of State and Private
Central Plant Size: 1000 tons
Air Distribution System: Central

770 L Street
169,078 RSF
Built in 1984
Tenant Base: 35% state, 40% private, 25% Telecom
A/C & Ventilation: Package units on floors

925L Street (site of original system, could be enhanced further)
168,490 RSF
Built in 1970
Tenant Base: 75% State, 25% Private
Central Plant: 575 Tons
Air Distribution: Floor by Floor

801 K Street
336,104 RSF
Built in 1984
Tenant Base: 80% State, 20% Private
Central Plant: 900 Tons
Air Distribution: Central

Ziggurat
368,490 RSF
Built in 1997
Tenant Base: 100% state use – 15 year lease
Central Plant: 962 Tons
Air Distribution: Central

Senator
165,000 RSF
Building in early 1900s
Tenant Base: 80% State, 20% Private
A/C & Ventilation: Package units on each floor

Appendix I. IMDS Schematics

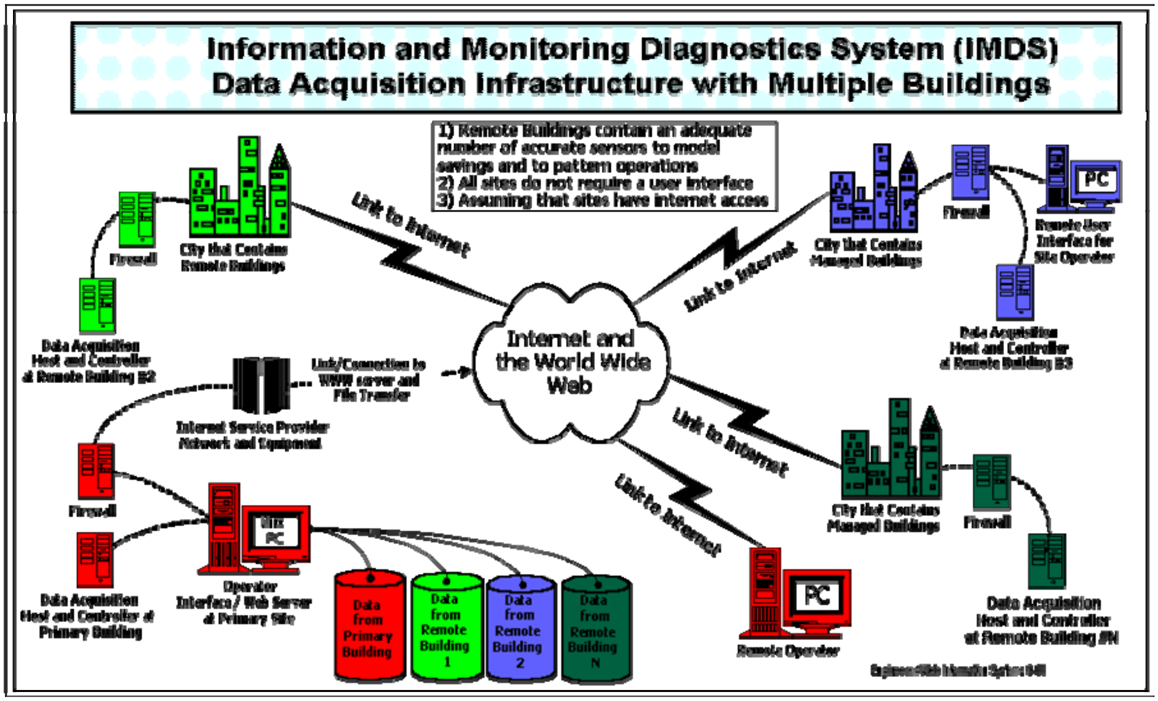


Figure I.1. IMDS Schematic

925 L Street Mezzanine Office
Local and Wide Area Network

Core Network is located on the Mezzanine level. CAT 5 cables will be used to connect the hardware components. Switches will be used to span the riser run that is used for setup and long term access The local network section shown below leaving the 8 port network switch unit one will be administered by EN-WISE. The domain 925l.925lstreet.com and firewall setup will be maintained and updated by existing JLL contractor

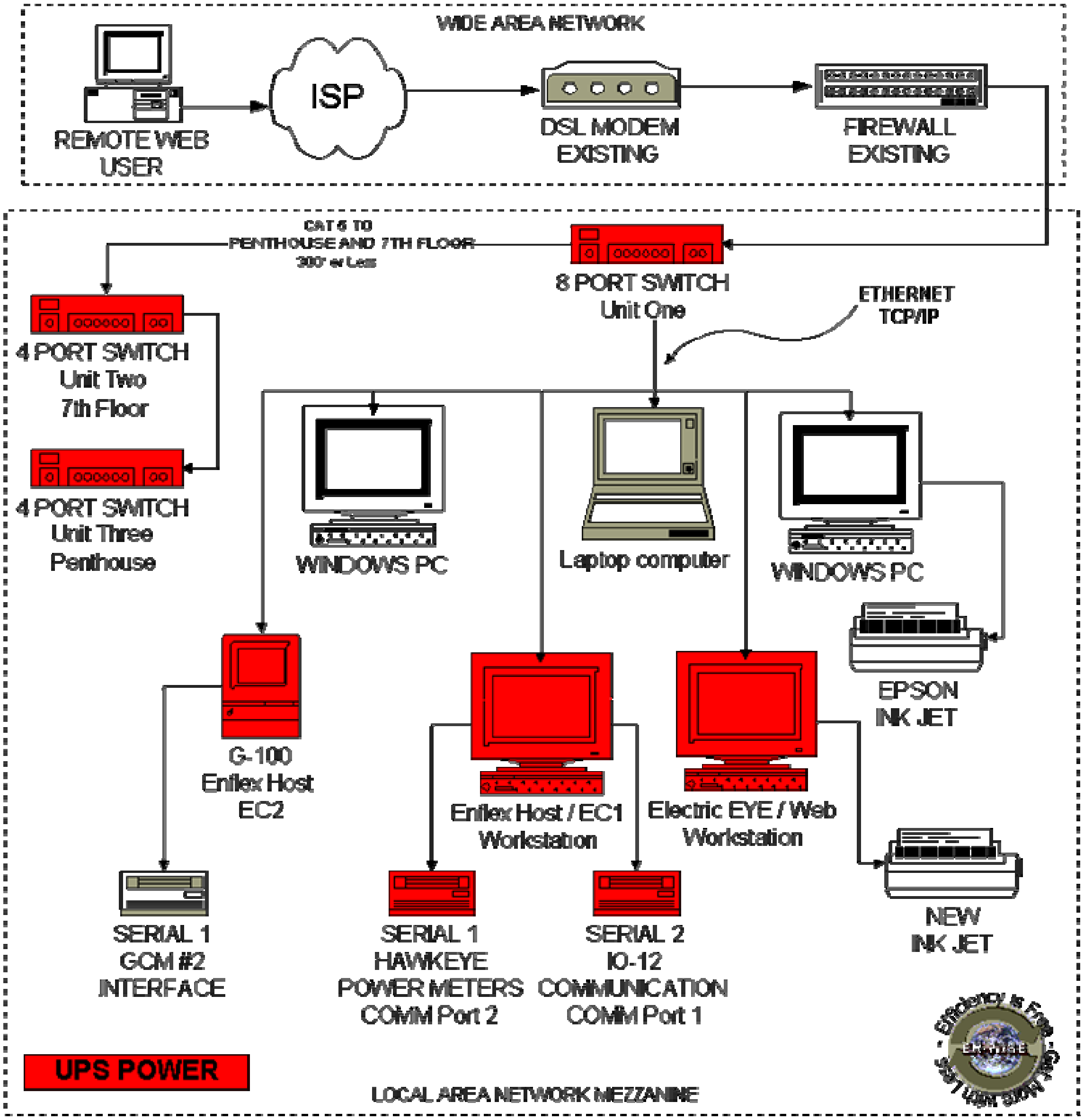
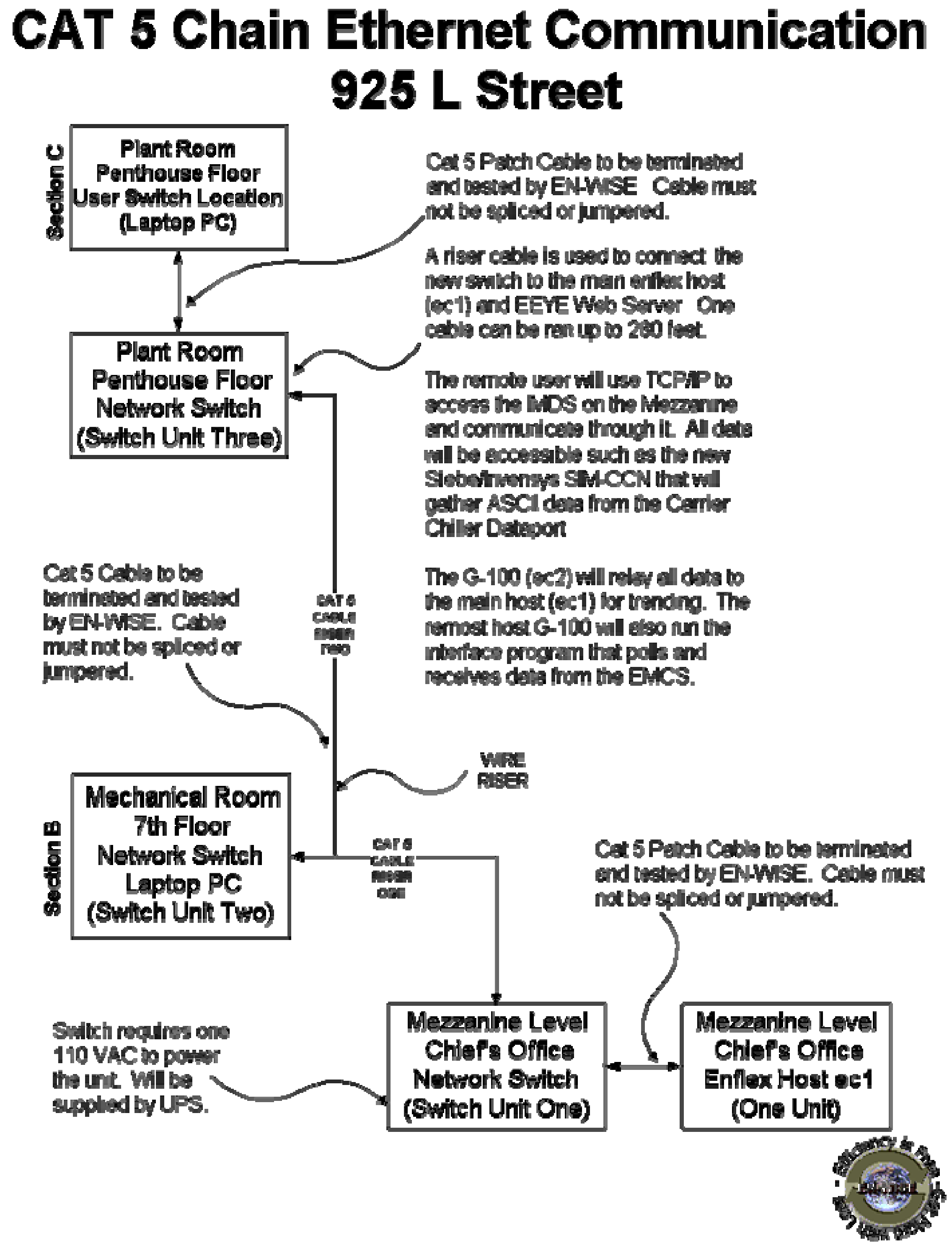


Figure I.2. **Networking Diagram**



Cat 5 Patch Cable to be terminated and tested by EN-WISE Cable must not be spliced or jumpered.

A riser cable is used to connect the new switch to the main enflex host (ec1) and EEYE Web Server One cable can be ran up to 280 feet.

The remote user will use TCP/IP to access the IMDS on the Mezzanine and communicate through it. All data will be accessable such as the new Siebe/Invensys SIM-CCN that will gather ASCI data from the Carrier Chiller Dataport

The G-100 (ec2) will relay all data to the main host (ec1) for trending. The remost host G-100 will also run the interface program that polls and receives data from the EMCS.

Cat 5 Cable to be terminated and tested by EN-WISE. Cable must not be spliced or jumpered.

Cat 5 Patch Cable to be terminated and tested by EN-WISE. Cable must not be spliced or jumpered.

Switch requires one 110 VAC to power the unit. Will be supplied by UPS.

Figure I.3. Ethernet Communication Chain

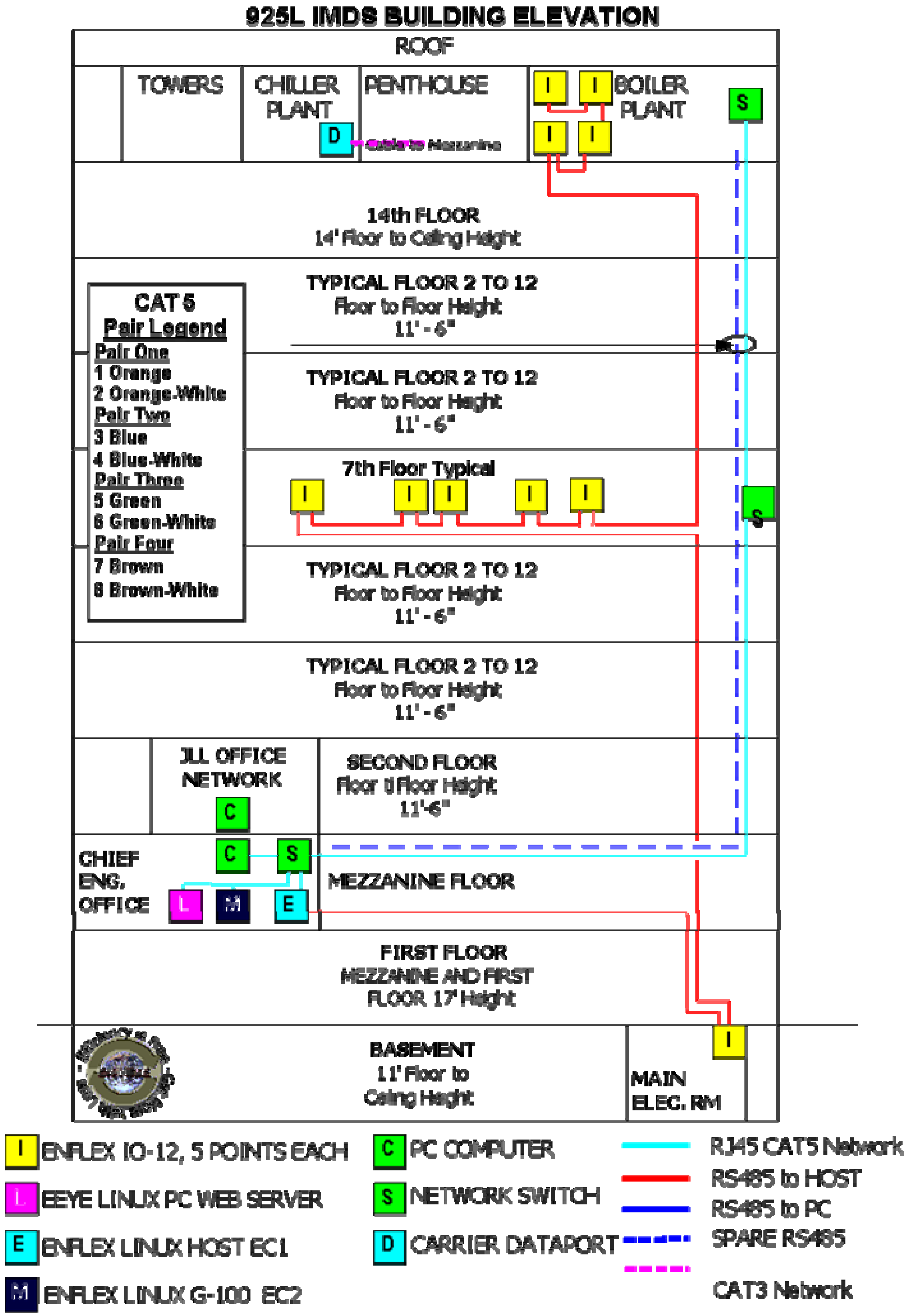
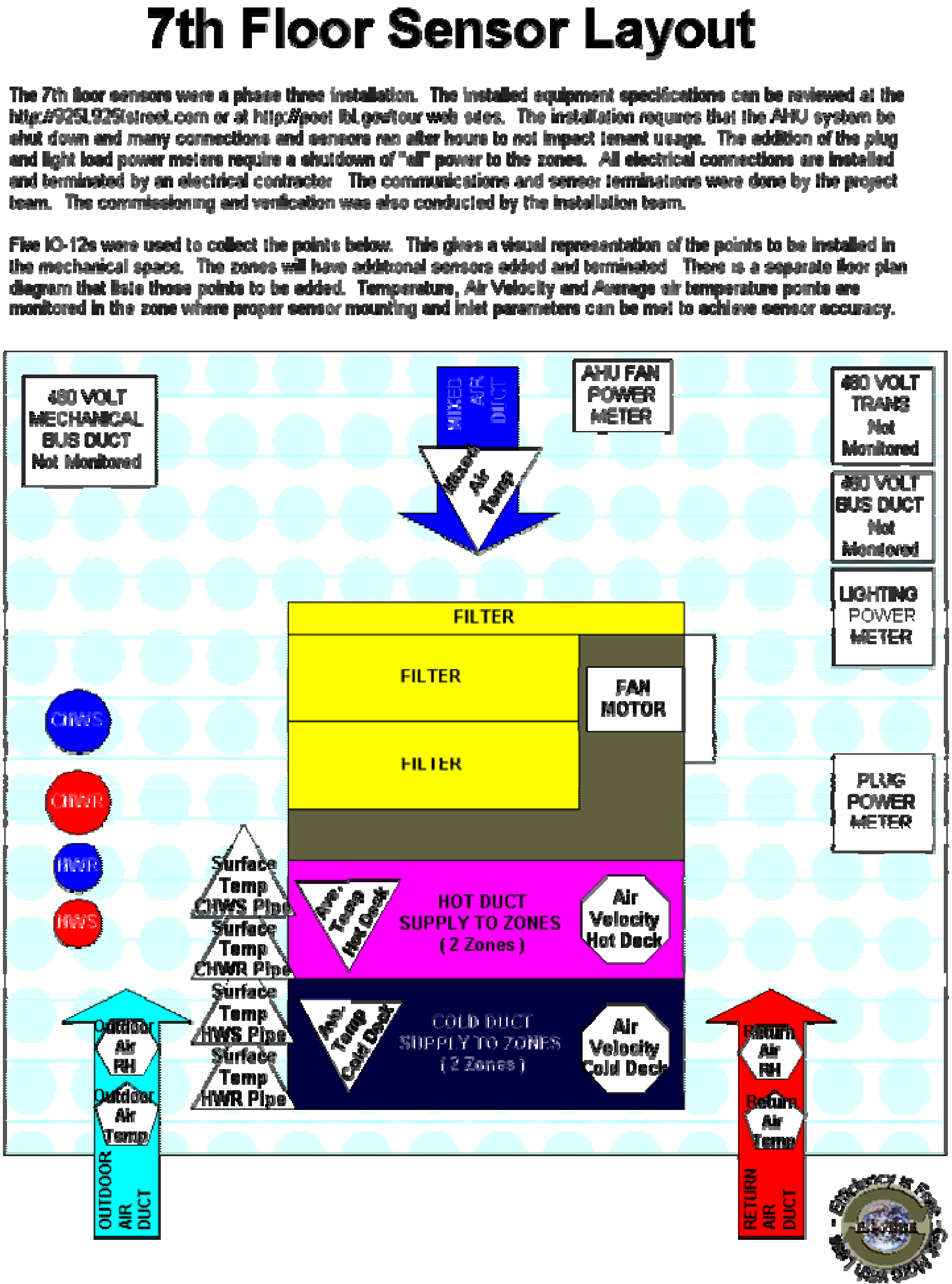


Figure I.4. Building Elevation

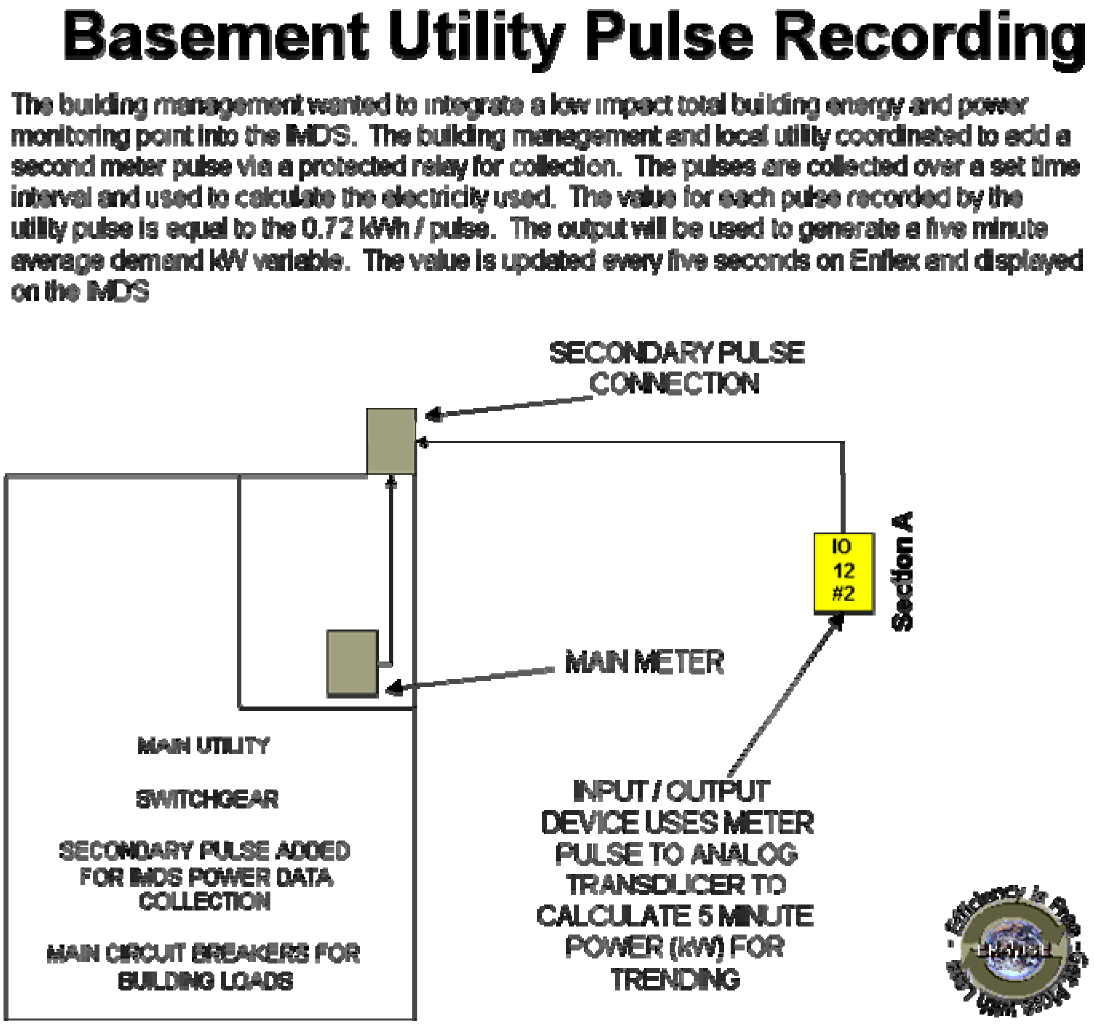


7th Floor Sensor Layout

The 7th floor sensors were a phase three installation. The installed equipment specifications can be reviewed at the http://925L925street.com or at http://poet.lbl.gov/tour web sites. The installation requires that the AHU system be shut down and many connections and sensors ran after hours to not impact tenant usage. The addition of the plug and light load power meters require a shutdown of "all" power to the zones. All electrical connections are installed and terminated by an electrical contractor. The communications and sensor terminations were done by the project team. The commissioning and verification was also conducted by the installation team.

Five IO-12s were used to collect the points below. This gives a visual representation of the points to be installed in the mechanical space. The zones will have additional sensors added and terminated. There is a separate floor plan diagram that lists those points to be added. Temperature, Air Velocity and Average air temperature points are monitored in the zone where proper sensor mounting and inlet parameters can be met to achieve sensor accuracy.

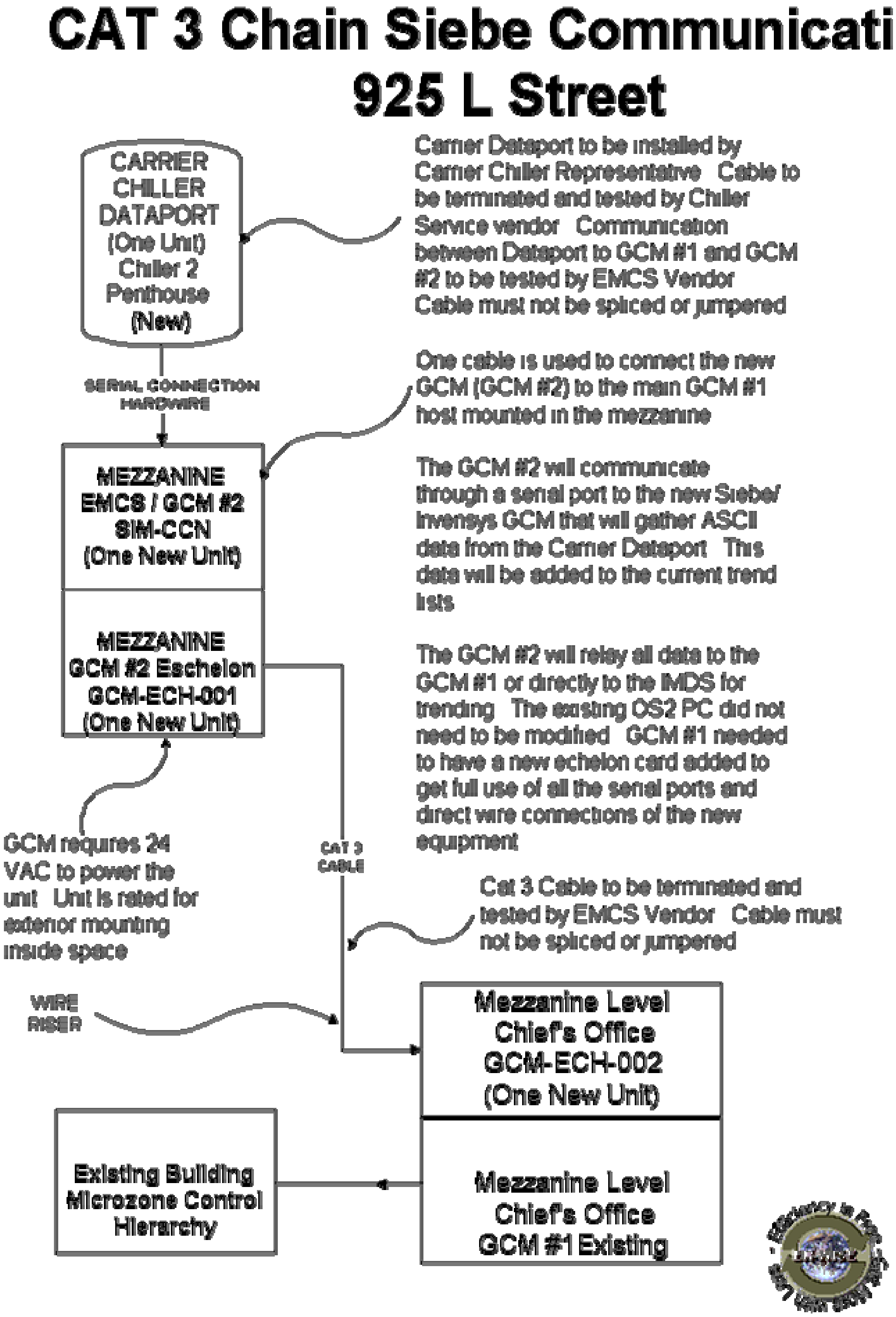
Figure I.5. 7th Floor Instrumentation



Basement Utility Pulse Recording

The building management wanted to integrate a low impact total building energy and power monitoring point into the IMDS. The building management and local utility coordinated to add a second meter pulse via a protected relay for collection. The pulses are collected over a set time interval and used to calculate the electricity used. The value for each pulse recorded by the utility pulse is equal to the 0.72 kWh / pulse. The output will be used to generate a five minute average demand kW variable. The value is updated every five seconds on Enflex and displayed on the IMDS

Figure I.6. Basement IMDS Connection to Utility Meter



CAT 3 Chain Siebe Communication
925 L Street

Carrier Dataport to be installed by Carrier Chiller Representative   Cable to be terminated and tested by Chiller Service vendor   Communication between Dataport to GCM #1 and GCM #2 to be tested by EMCS Vendor Cable must not be spliced or jumpered

One cable is used to connect the new GCM (GCM #2) to the main GCM #1 host mounted in the mezzanine

The GCM #2 will communicate through a serial port to the new Siebe/ Invensys GCM that will gather ASCII data from the Carrier Dataport   This data will be added to the current trend lists

The GCM #2 will relay all data to the GCM #1 or directly to the IMDS for trending   The existing OS2 PC did not need to be modified   GCM #1 needed to have a new echelon card added to get full use of all the serial ports and direct wire connections of the new equipment

GCM requires 24 VAC to power the unit   Unit is rated for exterior mounting inside space

Cat 3 Cable to be terminated and tested by EMCS Vendor   Cable must not be spliced or jumpered

Figure I.7.   IMDS Connection to EMCS

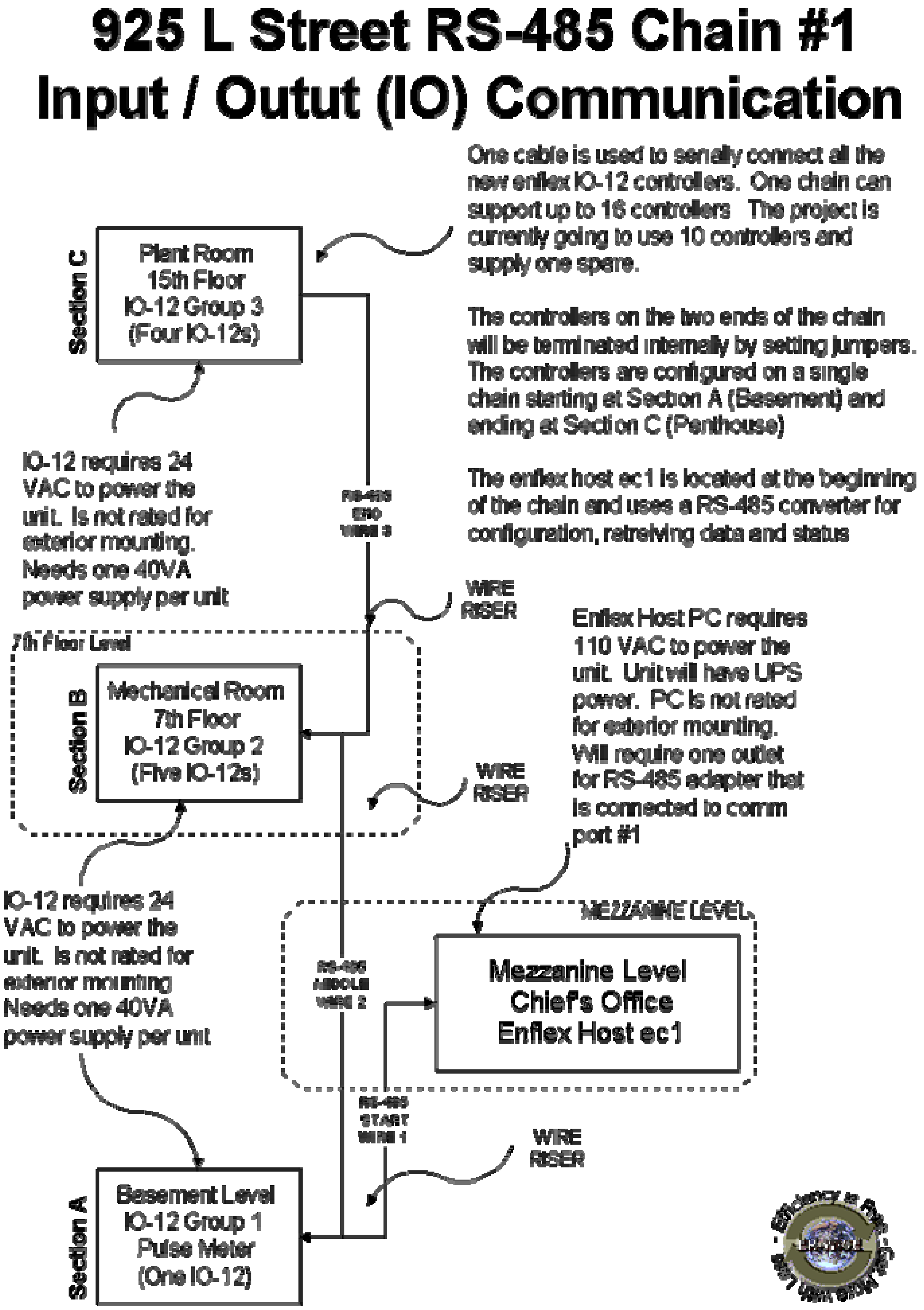
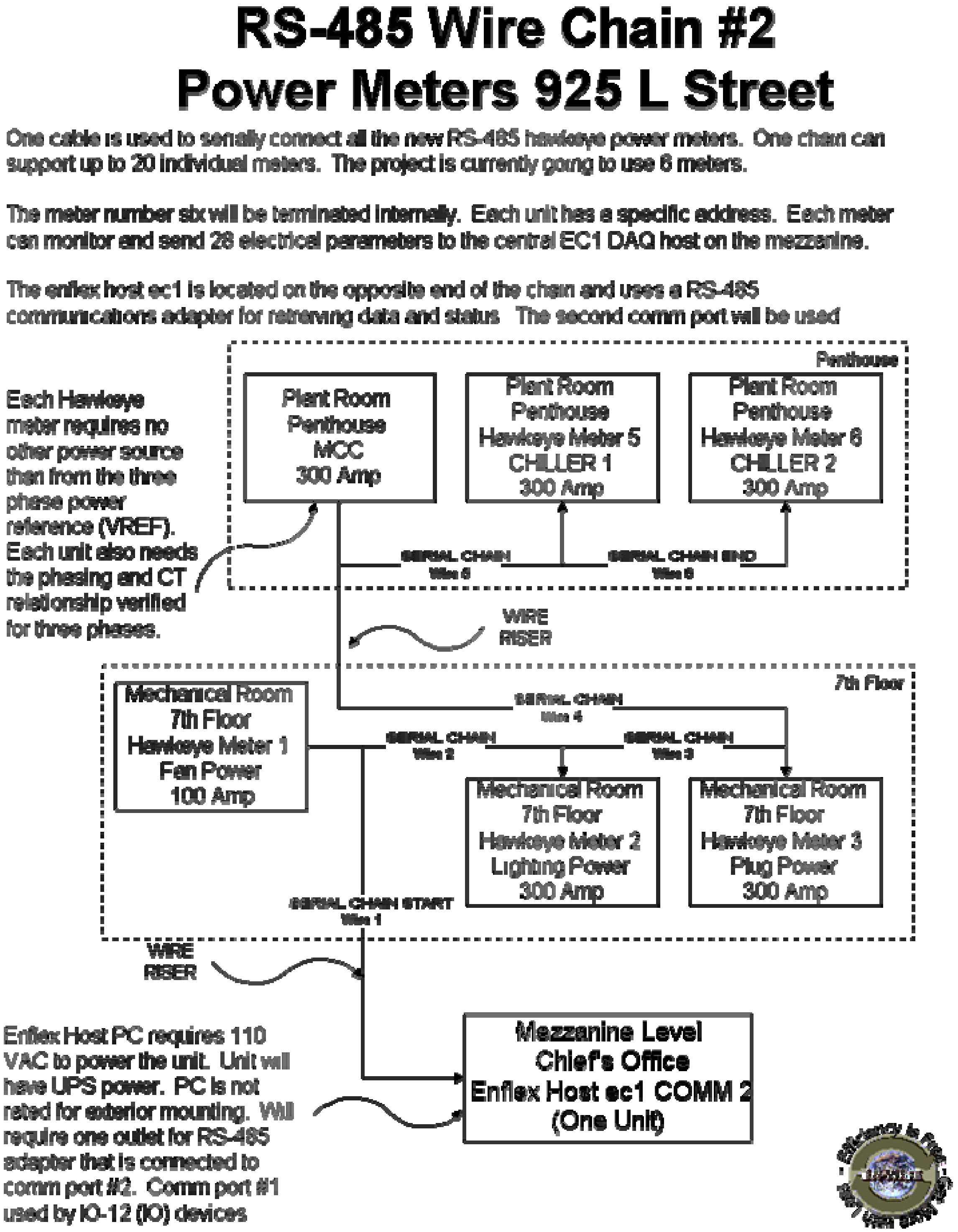


Figure I.8. **IMDS Data Acquistion System Communication**



RS-485 Wire Chain #2
Power Meters 925 L Street

One cable is used to serially connect all the new RS-485 hawkeye power meters. One chain can support up to 20 individual meters. The project is currently going to use 6 meters.

The meter number six will be terminated internally. Each unit has a specific address. Each meter can monitor and send 28 electrical parameters to the central EC1 DAQ host on the mezzanine.

The enflex host ec1 is located on the opposite end of the chain and uses a RS-485 communications adapter for retrieving data and status The second comm port will be used

Each Hawkeye meter requires no other power source then from the three phase power reference (VREF). Each unit also needs the phasing and CT relationship verified for three phases.

Enflex Host PC requires 110 VAC to power the unit. Unit will have UPS power. PC is not rated for exterior mounting. Will require one outlet for RS-485 adapter that is connected to comm port #2. Comm port #1 used by IO-12 (IO) devices

Figure I.9. IMDS Power Monitoring

925 L Street Siebe EMCS Network

Existing network is composed of a local control PC that uses OS2 as an operating system. The main system is an existing Global Control Module (GCM) Microzone controllers are installed in the field and collect analog or digital inputs and it also sends out control outputs

A new SIM-CCN will be added in the mezzanine to communicate with the IMDS and Carrier Dataport. The GCM echelon to SIM-CCN escheon communication requires CAT 3 cable. All other connections are RS-485 or RS-232 serial connections. The IMDS, Carrier Dataport and EMCS use a mix of available and propietary communications, drivers and protocols.

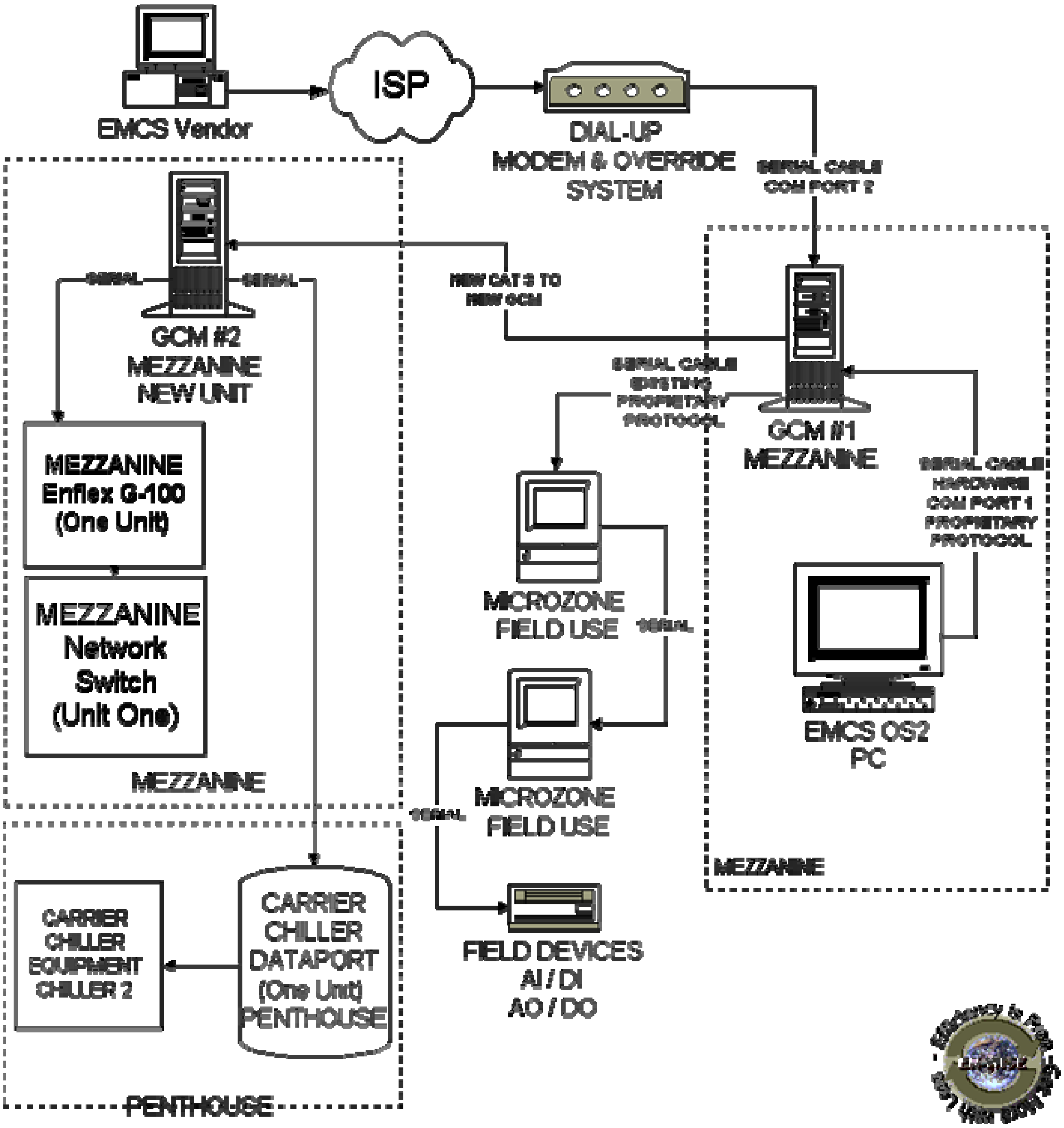


Figure I.10. EMCS Network

Penthouse Sensor Layout

The chilled water plant is the largest consumer of electricity in the building. The plant will be monitored to determine a baseline and gauge typical operation. Temperatures on the evaporator and condenser will be monitored. The chilled water and condenser water flow will be monitored as well. The true RMS power for the chillers will be monitored and the other plant loads will be monitored in a single group.

The load and efficiency of the plant will be a calculated metric that will be created and available on the http://925l.925lstreet.com web site. The information will help to optimize the operation and make full use of the capacity of installed equipment. The determination of the base load will also derive information needed for future upgrades or retrofits.

Chiller two will be upgraded to output the internal chiller Dataport parameters to the IMDS system. Visit 925l.925lstreet.com or poet.lbl.gov/tour for more specifics on the installed equipment.

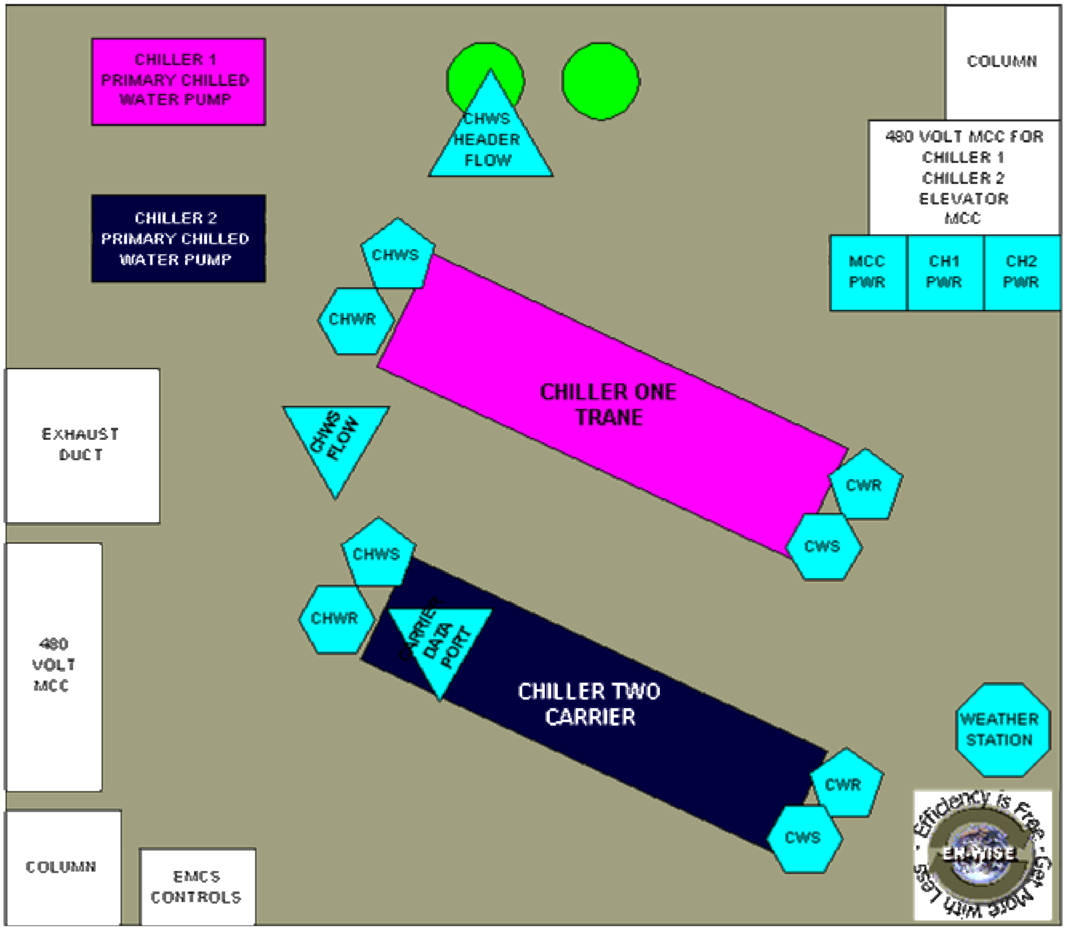


Figure I.11. Penthouse Instrumentation

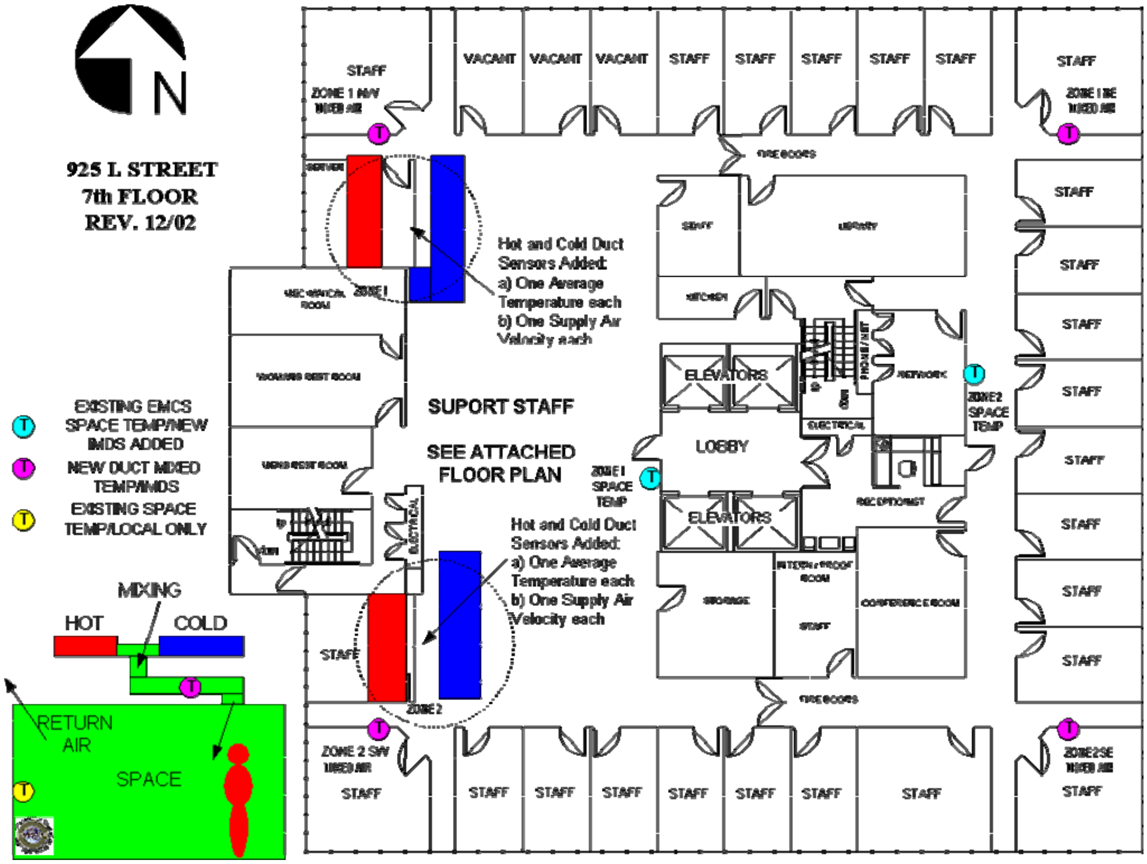


Figure I.12. 7th Floor Zone Instrumentation