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Environmental Energy Technologies Division

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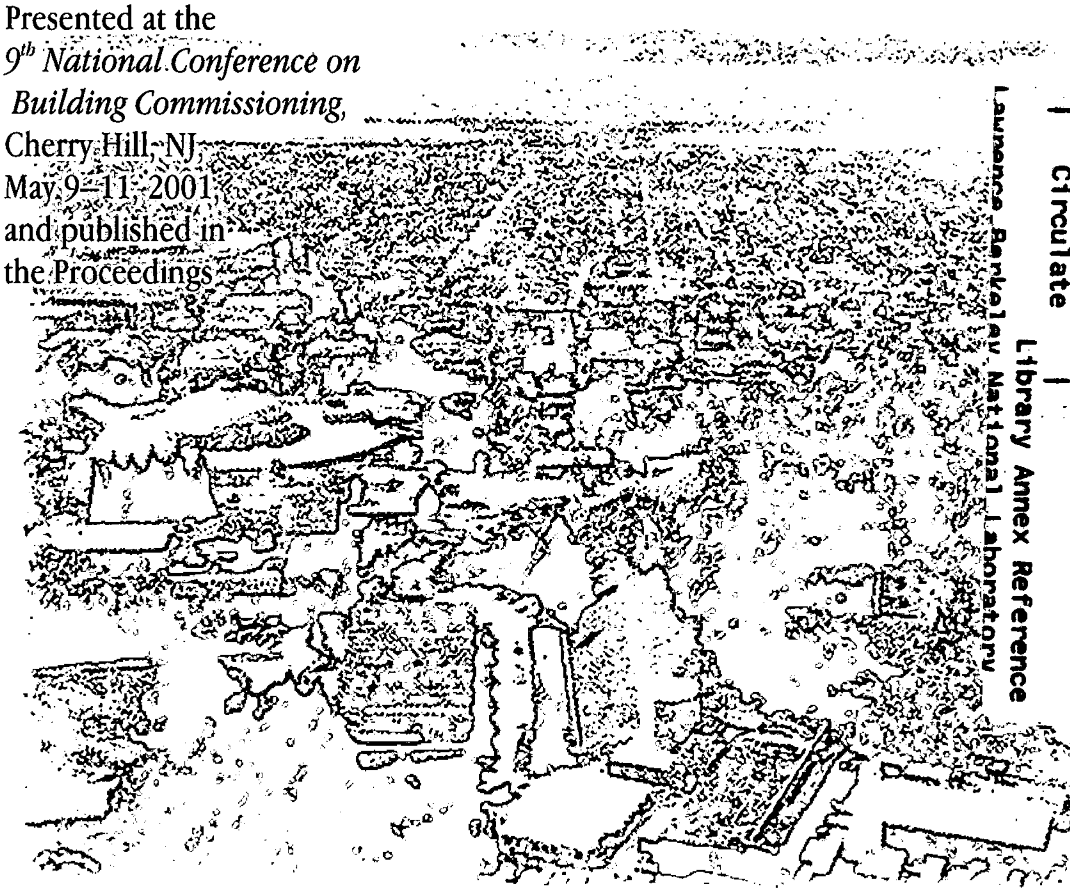

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EMCS and Time-Series Energy Data Analysis in a Large Government Office Building

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SYNOPSIS

Energy Management Control System (EMCS) data are an underutilized source of information on the performance of commercial buildings. Newer EMCS's have the ability and storage capacity to trend large amounts of data and perform preliminary analyses; however, these features often receive little or no use, as operators are generally not trained in data management, visualization, and analysis. Whole-building hourly electric-utility data are another readily available and underutilized source of information. This paper outlines the use of EMCS and utility data to evaluate the performance of the Ronald V. Dellums Federal Building in Oakland, California, a large office building operated by the Federal General Services Administration (GSA). The project began as an exploratory effort at Lawrence Berkeley National Laboratory (LBNL) to examine the procedures operators were using to obtain information and operate their buildings. Trending capabilities were available, but in limited use by the operators. LBNL worked with the building operators to use EMCS to trend one-minute data for over one-hundred points. Hourly electricity-use data were also used to understand usage patterns and peak demand. The paper describes LBNL's key findings in the following areas:

- Characterization of cooling plant operations
- Characterization of economizer performance
- Analysis of annual energy use and peak demand operations
- Techniques, strengths, and shortcomings of EMCS data analysis
- Future plans at the building for web-based remote monitoring and diagnostics

These findings have helped GSA develop strategies for peak demand reduction in this and other GSA buildings. Such activities are of great interest in California and elsewhere, where electricity reliability and demand are currently problematic. Overall, though the building's energy use is fairly low, significant energy savings are available by improving the existing EMCS control strategies.

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BACKGROUND

Buildings rarely perform as well in practice as anticipated during design. Reasons for this include improper equipment selection and installation, lack of rigorous commissioning and proper maintenance, and poor feedback on operational performance, including energy performance. A recent evaluation of new construction commissioning found that 81 percent of the building owners surveyed encountered problems with new heating and air conditioning systems (Wisconsin Energy Center 1998). Systematic procedures to address these problems are beginning to emerge. Texas A&M's continuous commissioning methods have saved an average of over 20 percent of total energy costs (over 30 percent of the heating and cooling cost) in over 80 buildings (Claridge, et al. 1998). New software tools to organize EMCS time-series data, display plots for performance analysis, and evaluate equipment performance are emerging as well (Friedman and Piette 2001).

This paper provides an overview of recent research at the Dellums Federal Building in Oakland, California regarding EMCS monitoring for performance analysis. This project supports our previous finding that building operators can greatly benefit from improvements in tools to collect and analyze building performance data (Sebald and Piette 1997). LBNL has examined the benefits of continuous monitoring systems that are installed in parallel with the EMCS (Piette et al. 2000). We have found that EMCS data are an underutilized source of information on the performance of commercial buildings. However, the ability of the EMCS to collect such data has been problematic in many legacy systems. Newer EMCS's have the ability and storage capacity to trend large amounts of data and perform preliminary analyses. However, these features often receive little or no use, as operators are generally not trained in data management, visualization, and analysis.

The paper begins with a review of the project history and motivation, followed by a description of the data collection and analysis activities. Next we review a series of findings regarding the building performance. We conclude with an overview of current and future directions. The Dellums Federal Building is now the subject of a series of projects regarding diagnostic tools, EMCS remote monitoring, and load shedding strategies.

PROJECT OVERVIEW

Staff from Lawrence Berkeley National Laboratory have been working with GSA on energy-related issues at the Oakland Federal Building since its opening in 1993. In a meeting during the Fall of 1999, the building energy manager reported that energy use (both electricity and gas) had been increasing for the last few years (**Figure 1**). This phenomenon is common in new buildings, however, the source of the energy increase at the Oakland facility was unknown. The building has a fully operational EMCS. To determine how we might evaluate the building performance we examined the EMCS points list. Whole-building power, chiller power, chiller flow, and cooling plant temperature measurements were listed on the points list, but they had never been analyzed. These data were collected as part of LBNL's Remote Building Monitoring and Operations (RBMO) project which involved an internet gateway to the EMCS (Olken 1999). However, because of the emphasis of the RBMO project on the design of the database and communications system, the data were not carefully analyzed. We evaluated the RBMO data and found that many of the values were erroneous.

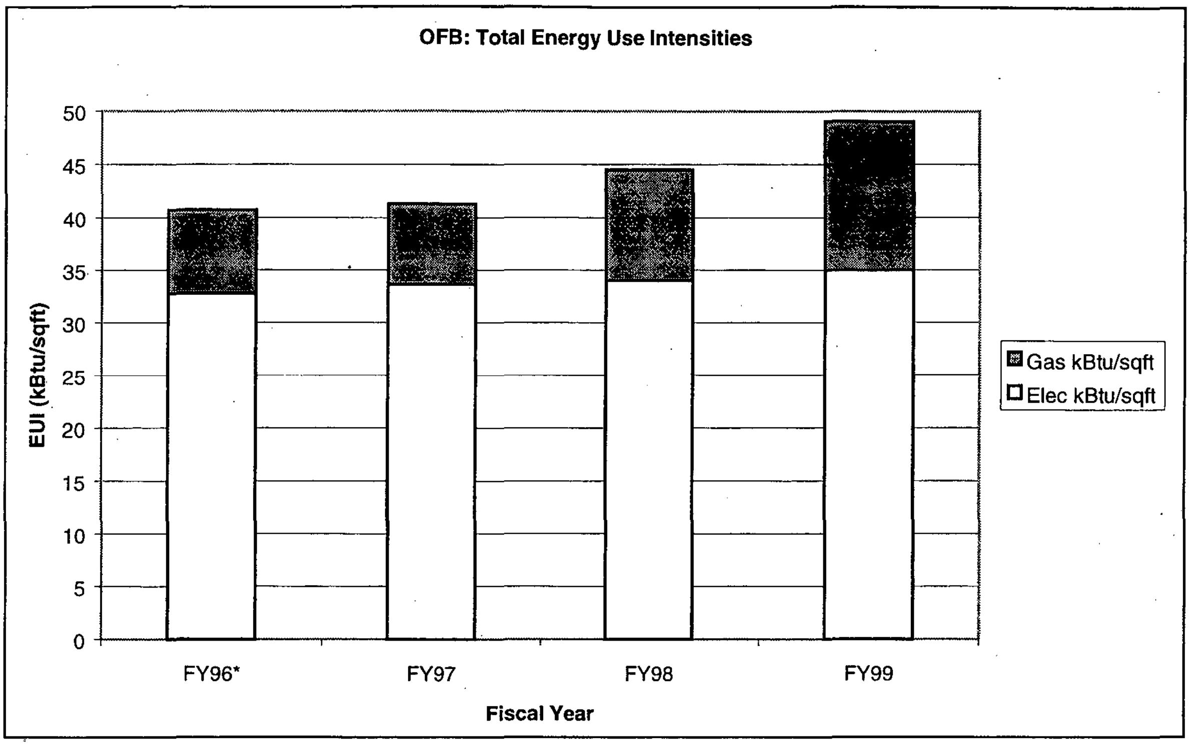

Figure 1: Multi-year whole-building site energy use at the Oakland Federal Building.

Following the RBMO project, LBNL has been evaluating the building's operations data. The objective of our analysis is to:

- Evaluate the EMCS as a building monitoring tool
- Examine building performance, based on the available monitored data
- Assist building staff in using existing systems and analysis techniques
- Evaluate the performance of diagnostic tools using data from this building
- Evaluate load shedding strategies for peak demand reduction

Energy Management Control System Monitoring

Prior to LBNL's involvement, the on-site staff used EMCS trend logs from data collected by the network control module (NCM) stored in the EMCS network buffer. None of the data were archived for later analysis. LBNL examined which trend logs were active and set up the trending capabilities to include a reports destination summary, which sends the data to the EMCS's PC hard drive. LBNL began trending a few points, and added more points over time. This approach was taken to ensure that the logging did not overload the EMCS. High levels of logging can clog the control communications and slow down operations. Up to a hundred points were trended at once, at one-minute intervals. There were some minor problems with the EMCS trending, but these problems did not noticeably affect building control. When the system was busy, there were periods of missing data. LBNL examined the size of the data files created by the trend logs to ensure that excessive disk space was not used up. Trending and purging tests were done on LBNL's own EMCS prior to testing at the Oakland Federal Building since LBNL has a similar EMCS.

Building Characteristics

The building consists of twin towers with a gross floor area of 1.1 million square feet, including 971,000 square feet of office space, a 7,200-sqft computer center, and a 36,000-sqft parking garage.

- **Cooling Plant**: Oakland Federal Building has five chillers in a primary-secondary configuration. Three chillers were originally rated at 980 tons (Chillers 1, 2 & 3), and two smaller ones (Chillers 4 & 5) at 450-tons. These chillers were derated as the R-11 refrigerant was changed to a non-CFC refrigerant, R-123. This reduced the chiller capacity by about ten percent. There are four cooling tower cells, with a variable frequency drive (VFD) on one of the cells. A plate-and-frame heat exchanger was added in early 2001, and the control strategy is currently being developed. This retrofit will allow the cooling towers to be used to cool the building directly, without the use of the chillers, when ambient conditions permit.
- **Air Systems**: The building has 11 main air handlers and 47 smaller supply fans. There are VFDs on many of the fans.
- **Distribution**: The system is a dual-duct/VAV (variable air volume) with reheat on the perimeter; and single-duct VAV in the core (without reheat).

KEY FINDINGS

Whole-Building Performance

LBNL collected four years of utility bill energy data to evaluate whole-building energy use trends (**Figure 1**). Overall, the whole-building energy use, or energy use intensity (site kBtu/sqft-yr) is low compared to similar buildings, with consumption at around 50 kBtu/sqft-year. Average energy use for office buildings in the local utility's service territory is 68 kBtu/sq-yr (PG&E, 1999). Efficient equipment at the building include T-8 fluorescent lamps with electronic ballasts, optical reflectors, and VFDs on the air handling units and one cooling tower.

The building achieved the ENERGY STAR Label for Buildings in 2000 without major retrofits or additional commissioning. In addition to monthly utility bill data, we evaluated the whole-building half-hour electric demand data provided by the electric utility. These data, along with the EMCS data, showed the HVAC systems starting at 3 a.m. (Figure 2). By examining the average hourly electric load shapes for each month we estimated the following savings from employing an optimal start algorithm. Such algorithms consider outside air conditions to determine when to bring on the HVAC equipment. (using $0.10/kWh, which is more than the current $0.08/kWh, but increases are expected):

- HVAC 3 a.m. start delayed to 5 a.m. saves 117,700 kWh/year (about $12,000, or 1% of whole-building electricity use)
- HVAC 3 a.m. delayed to 6 a.m. saves 260,700 kWh (about $26,000, or 2% of whole-building electricity use)

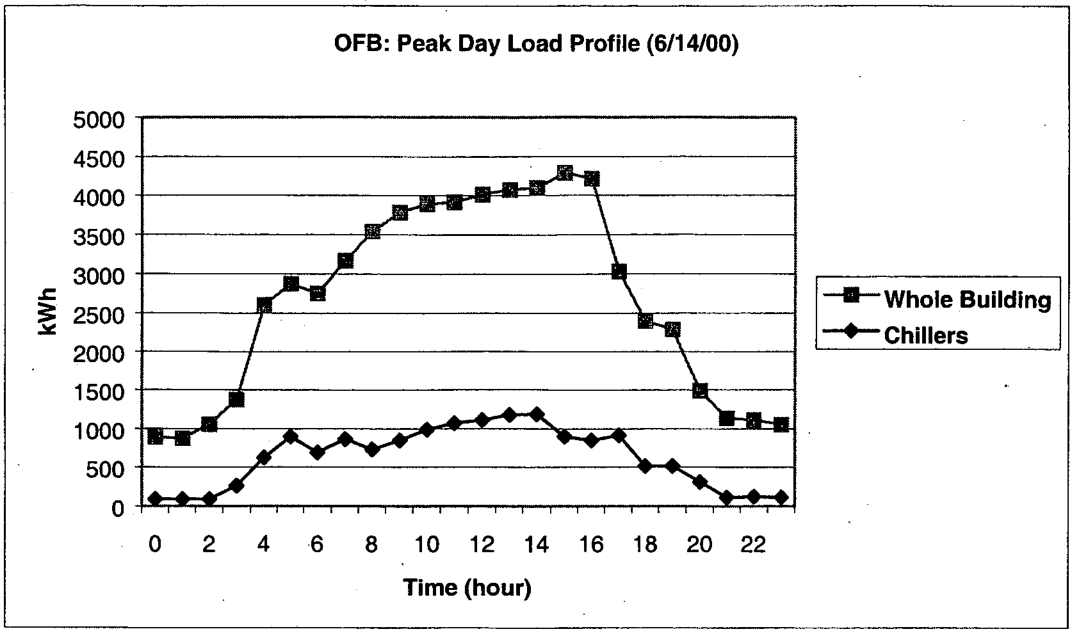

Figure 2. Whole building and chiller peak-day electric load profile (note: some uncertainty remains with the chiller power data).

The second finding from the whole-building electric data is the temperature sensitivity of peak demand. **Figure 3** shows that hourly peak demand is significantly correlated with outside temperature. These data cover the maximum peak electric demand for each weekday between June 1 and July 30. The average daily temperature (x-axis) is the daytime average between 11 a.m. and 6 p.m. On the hottest day of the year, the peak demand was nearly 1.5 megawatts higher then a typical day. This finding is significant in understanding the load-shedding potential since there is a strong interest in load shedding in California.

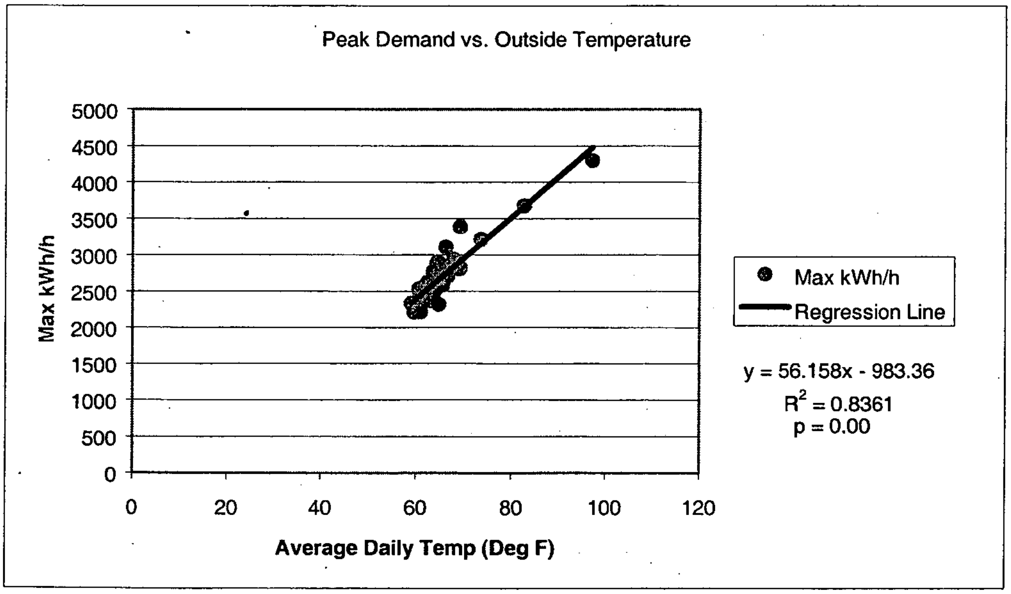

Figure 3. Peak demand vs. outside temperature.

Cooling Plant Operation

LBNL collected one-minute EMCS data from about 115 points. On June 8, 2000 LBNL presented eight graphs to the operations staff. The purposes of these graphs were to:

- demonstrate the type of information that can be collected from the EMCS
- illustrate some of the problems with the EMCS data collection
- discuss the cooling plant performance issues associated with these graphs

In general, the EMCS has been useful for collecting data, though there have been some problems with missing data and sensor accuracy. The data we first collected and analyzed were measurements for the two smallest chiller (kW, tons, chilled water supply and return temps, condenser water supply and return temperatures for chillers 4 and 5) and whole-building power. The cooling duty calculation on the individual chillers was found to be implemented in the JCI system based on the assumption of constant chilled water flow rate (though the secondary system flow measurement and related tons calculation is based on magnetic flow metered data).

In examining the whole-building power data listed as an EMCS point, LBNL and the building operators discovered that the meter produces a null reading. It appears that the local electricity utility and the controls company provided parts of the metering connection, but the final connection was never completed. The following observations regarding the cooling plant operations were provided to the building staff:

Data Problems

- **Erroneous data (load with no power)**—For some limited periods the measured chiller power dropped off to zero although the chiller continued to operate (as indicated by the ton and temperature measurements). It is not clear if this is a meter problem or a problem with using the EMCS for monitoring.
- **Unreasonable power measurements and high kW/ton**—We found several instances when the value of the power (kW) is more than twice the value of the cooling duty (tons). It is unlikely that the actual efficiency of the chiller is so poor; thus it is probable that one or more of the measurements is incorrect. Again we see chiller power reaching over 700 kW, with ton measurements reaching only slightly over 300 tons.
- **Missing data**—There were several gaps in the archived data files. Strangely, not all of the data are missing; the cooling duty is available for some periods when the temperatures were not available (the tons measurement would have been calculated from missing temperatures).

Cooling Plant Operational Problems

- **Load profiles and tonnage**—The cooling provided by Chiller 4 reaches about 300 tons during the peak hours. This peak is 33% less than its original rated capacity of 450 tons, which may indicate a measurement problem. Such measurements were assessed for several of the chillers, with peak tonnage and chiller dispatching reviewed by LBNL.
- **Oscillations**—We identified several periods when Chiller 4 duty fluctuated significantly through the day.

- **Nighttime chiller cycling**—The chillers cycle during the night time because of ongoing, yet low cooling requirements for some computer centers. The chillers cycle between 100 and 200 kW at a five-minute frequency, which is hard on the chillers. This was confirmed by the building operator from his examination of the nighttime start-stop logs during recent discussions about these graphs. Retrofitting these areas with smaller, dedicated cooling units is worth investigating. The new plate-and-frame heat exchanger should also help address this problem, taking advantage of cooling nighttime weather and bypass compressor cooling.
- **Oscillations in condenser water temperatures**—The oscillations in the condenser water supply and return temperatures are significant. Chiller 4's condenser water supply and return temperatures oscillated in the afternoon, but not in the morning.

These findings are being used to develop new strategies for the cooling plant operation. The cooling plant sensors will also be calibrated. Even the uncalibrated measurements, however, provide some evidence of performance problems. **Figure 4** below shows the chiller operation on the peak day in 2000. Significant energy reductions could have been achieved by better sequencing of the chillers. It appears that the chillers were not fully loaded before additional chillers were brought on. Improvements in the chiller dispatch algorithm are being examined.

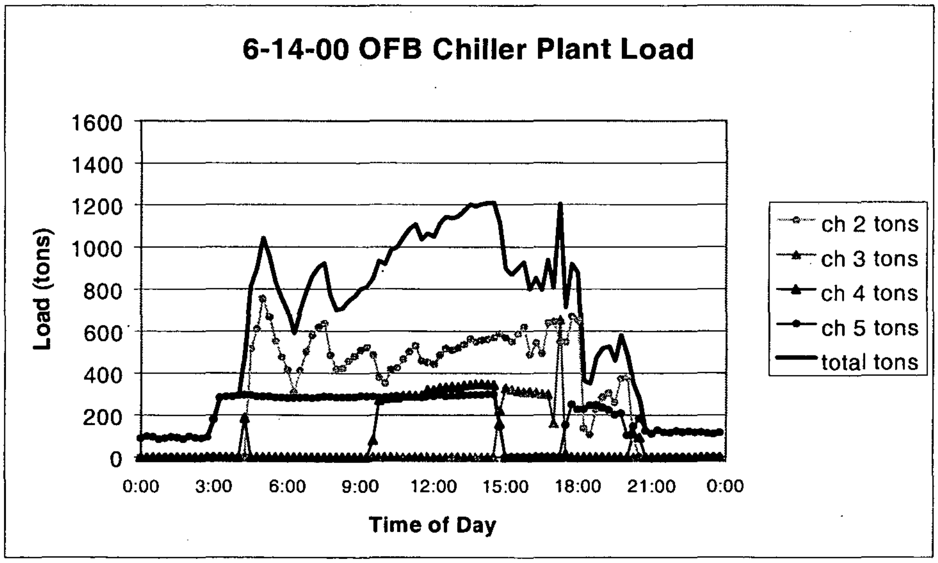

Figure 4. Peak day chiller loads (overall shape of cooling plant operation is shown, but absolute value of loads are uncertain from measurement problems).

Economizer Analysis

One of the most well known diagnostic techniques for HVAC systems is to assess the performance of the economizer using mixed air temperature (MAT), return air temperature (RAT), and outside air temperature (OAT) from the EMCS. LBNL performed such analysis for one of the four large air handlers. We were also performing some evaluation of current diagnostic software tools (Friedman and Piette 2001). We identified three main problems during June and July 2000. First, there were at least six days when energy waste occurred because the outside air damper was fully open but outside temperatures were well above the supply air setpoint. During another five days, the RAT was greater than the OAT, but the outside air dampers were fully or partially closed. This energy waste would have been identified by several of the diagnostic tools we are examining. The second problem was cold-deck backdraft, which was caused by a lack of damper control at the fifth floor supply fan. There was a backdraft across the fan into the mixing box when the penthouse air handler was operational and the fifth floor fans were off. This problem could probably have also been detected by some diagnostic tools, but the cause of the problem could not have been diagnosised by the automated tools. The third problem was oscillating control for the mixed air and outdoor dampers. This condition might have been found using current diagnostic tools. These problems will be addressed by a controls re-commissioning project planned for Spring 2001.

FUTURE DIRECTIONS AND SUMMARY

Performance and Continuous Recommissioning Analysis Tool (PACRAT)

As mentioned, LBNL is evaluating emerging diagnostics tools, several of which are currently on the market (Friedman and Piette 2001). One such tool is the PACRAT. PACRAT is both broad and in-depth in its automated diagnostic capabilities (Santos and Brightbill 2000). PACRAT's automated diagnostics serve the air handlers, chillers, hydronic system, whole building, and zones. GSA has obtained a license for PACRAT and the Oakland Federal Building will be one of the first in California to use this new software technology. LBNL will evaluate the findings and savings PACRAT at the Oakland Federal Building and other sites.

GEMnet and Load Shedding

GSA is currently in the process of developing an Internet-based regional network called the "GSA Energy and Maintenance Network," or GEMnet. GEMnet consists of a remote-monitoring information infrastructure with a set of applications residing on a server using a common operating system and database engine. The applications will consist of an Internet-based building automation system (BAS) front-end, maintenance management software, and energy reporting tools. GEMnet will communicate over the Internet using DSL connections installed at each site. The objectives of GEMnet are to provide remote monitoring, data management, remote assistance, and diagnostics. GEMnet is a remote monitoring and control technology that builds on GSA's innovations with the successful BACnet (Building Automation Control network) demonstration at 450 Golden Gate, the Philip Burton Federal Building.

Four GSA buildings, including the Oakland Federal Building, will participate in the California ISO (Independent System Operator) Summer 2001 Demand Relief Program. GSA is enhancing GEMnet to implement demand-responsive strategies into specific GSA-owned buildings in California. Analysis of the historical time-series data at the Oakland Federal Building suggest that there may be demand savings available from improved chiller dispatch. The whole-building peak electric demand on June 14 was nearly 20% greater than any previous peak (**Figures 3 and 5**). The building has an oversized cooling plant. Monitoring of the cooling plant showed that four of the five chillers were used on June 14 (**Figure 4**). Significant savings in chiller power could have been gained if the chillers were dispatched more carefully, turning off the smaller chillers as the larger ones were brought on line and fully loaded, where they are more efficient. Demand savings of about 300 kW are estimated for typical summer days, with as much as 800 kW during hot periods. Furthermore, plans are being developed to globally increase indoor temperatures to shed cooling and ventilation electric demand when requested by the ISO. GEMnet is being staffed with a system operator to develop and program a series of changes in the EMCS controls as part of the re-commissioning effort, which will also include demand-shedding strategies.

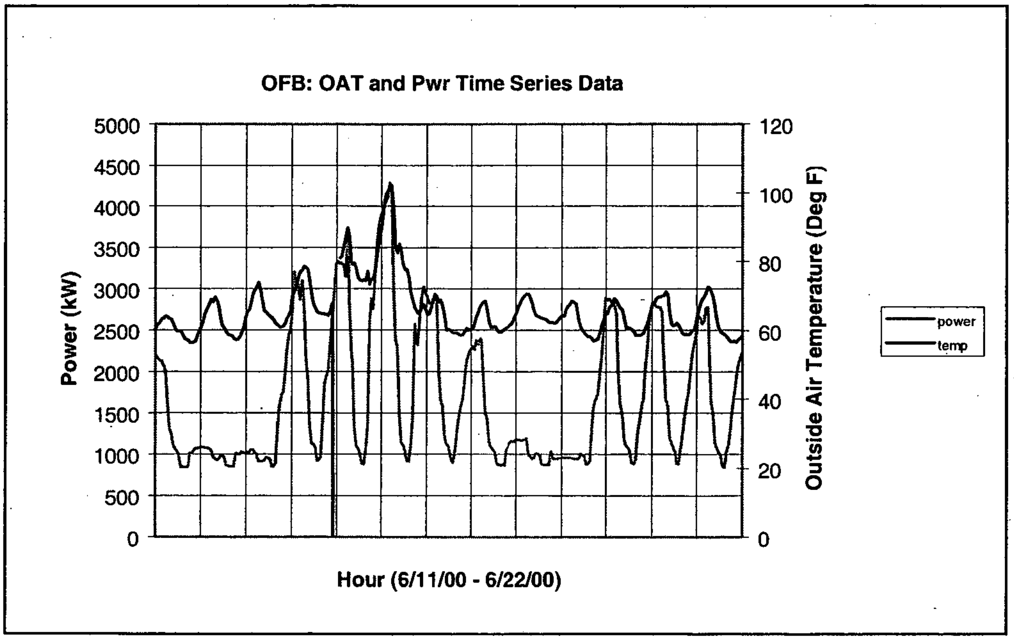

Figure 5. Whole-building electric and outside temperatures during the peak week and part of the following week.

Summary

In summary, the Oakland Federal building has demonstrated a number of important findings for commissioning and diagnostics. One methodological finding is that newer EMCS are quite capable of functioning as data acquisition systems. However, sensor accuracy must be evaluated and re-calibration may be required when using EMCS data. Second, the data collected and analyzed has proven to be extremely valuable for the operations staff to evaluate current opportunities for improving the overall efficiency of the building. We plan to track and document the savings from control and other improvements made over the next few years. Third, the findings to date suggest that not only are there many savings opportunities, but new technology being developed and tested at the site will offer load shedding capabilities to help control peak demands. This technology will allow multiple parties from remote locations to track and evaluate both energy and peak electric demand performance data. LBNL will provide additional analysis on the success and economics of the load shedding. GSA is continuing to provide leadership in advanced building controls with this new technology to improve and optimize building performance.

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