From Design Through Operations: Multi-Year Results from a New Construction Performance Contract

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ABSTRACT

As part of the High Performance Commercial Building Systems program, LBNL has been working with the City of Oakland to understand the ongoing performance of the Oakland Administration Buildings. The primary objective of this research is to understand the performance targets and ongoing performance of two buildings that were the subject of a new construction performance contract. Secondary objectives include examining the building performance information systems developed as part of the new construction performance contract and evaluating the role of the energy management and control system (EMCS) as a data acquisition tool to provide recommendations for future new construction projects. We examine the results of the performance contract in detail, and provide additional performance metrics that go beyond what was required in the performance contract. We found that the energy cost intensities (ECI) linked to the project ranged from \$1.08/ft^2 to \$1.44/ft^2. Changes in floor area, energy costs, rate schedules, and energy use complicate the evaluation of the performance because of the lack of tracking of underlying data and assumptions. Overall, Oakland has two large office buildings with relatively low-energy use (50 kBtu/ft^2-yr site electricity and gas use). We compare this energy-use intensity with a number of related benchmarks. Additional end-use, HVAC performance, and diagnostics data are discussed.

Background

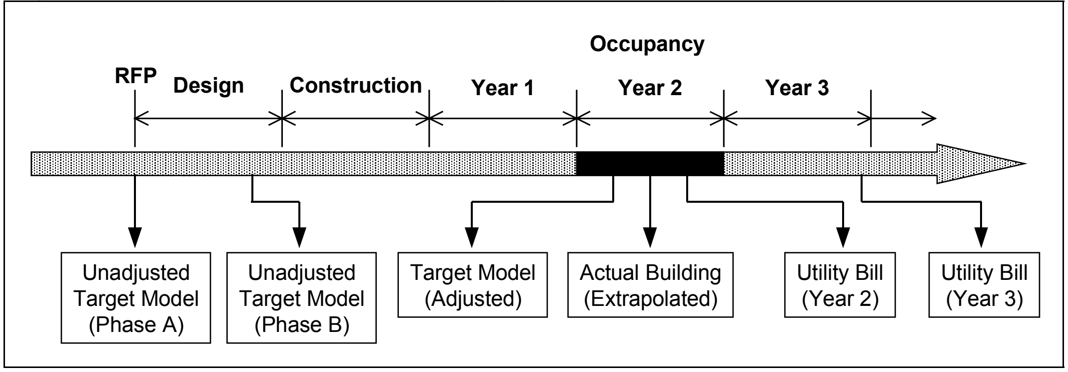
In 1994, the City of Oakland embarked on a project to utilize a novel new construction performance contract to deliver superior energy efficiency for two new buildings. This paper presents a brief history of the project, along with the final results of the performance contract. We present some details from HVAC (heating, ventilation and air conditioning) and end-use performance monitoring, and additional utility bill data that were not included within the purview of the performance contract. We also discuss some of the process issues with the performance contract methodology and the information systems used in the monitoring and analysis of the data.

Project History

The basic concept of the New Building Performance Contract was to create financial incentives for the design/build contractor to construct building that is superior to a pre-defined performance target. This project has been described in several previous papers. In 1996 Busch and Diamond described the initial concept of the performance contract and the results of interviews with developers and contractors who bid on the project. The City had set aside an \$80 million budget for two new buildings, which totaled about 450,000 ft^2

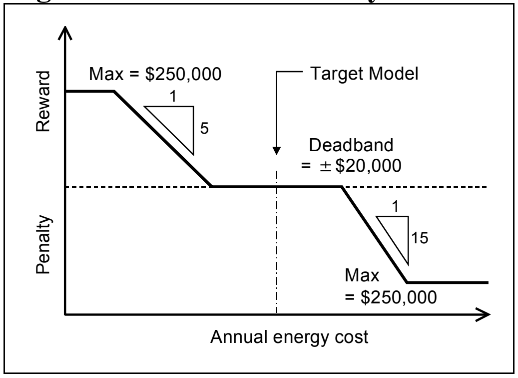
(\$178/ft^2). Eley Associates worked with the City of Oakland to develop a model using DOE-2.1E to simulate a new building that would beat the state energy code (Title 24, circa 1996) by about 25%. The ECI target from the simulation was set at \$1.08/ft^2. The target was increased to \$1.32/ft^2-yr when the ventilation specification changed from 0.4 to 0.6 cfm/ft^2. This increase, and the underlying ventilation metrics, is an example of metrics that are important to track to help explain changes in performance targets and the underlying assumptions explaining such changes.

Figure 1. Timelines for New Building Performance Contract



The performance contract followed the procedures shown in Figure 1. First, Eley Associates developed an energy target for the building (Unadjusted Target Model Phase A. which was revised in Phase B as discussed below). Second, the Architect and Engineer (A/E) provide a model of the proposed building design that must use less energy than the Target Model. After the building was built, the EMCS was used to collected performance data for two years of occupancy. After the 2nd-year, the DOE-2 Target Model was adjusted based on the monitored data to reflect actual operations (Adjusted Target Model). LBNL has continued to collect the utility bills and EMCS data to compare how ongoing performances compare with the contract results.

Figure 2. Incentive/Penalty Calculation



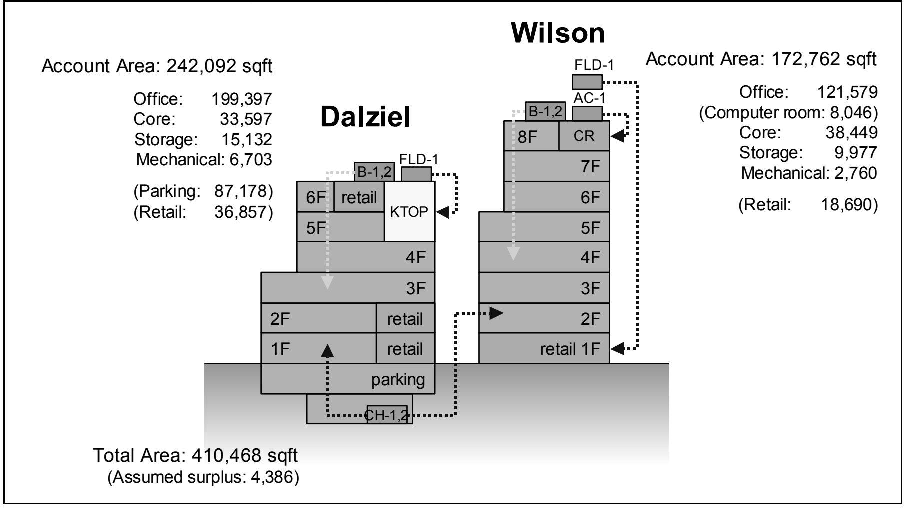
The adjustments to in Year 2 accounts for items that the A/E and contractor are not responsible for, such as changes in energy costs, occupancy schedules, plug loads, and weather. If the actual energy cost for the second year exceeds the revised target cost, then the design-build contractor (DB) must compensate the owner with a penalty of fifteen times the additional energy cost (Figure 2). If the actual energy cost is under the Revised Target Model, the owner will pay the DB an incentive of five times the additional energy cost savings.

Busch and Diamond (1996) questioned whether the process for selecting winning bidders resulted in an efficient design based on interview from project participants. The teams who bid on the project had to ensure that the project simulations "met" the energy cost target. There was skepticism by the teams about the ability of DOE-2 to accurately model their designs. Bush and Diamond provided 18 suggestions for new performance contracts, covering issues such as not requiring bidders to perform detailed modeling at such an early stage, to the need for owners to use both explicit and implicit goals for energy efficiency. That is, a feebate is useful, but efficiency goals must be reinforced during each stage of the design review and commissioning.

In 1998, Eley et al. report on their experience with new construction performance contracting, comparing the Design-Build model, which was used in Oakland, with the plan and specification model, and the construction management model. While the evaluation period was underway, Stein et al. (2000) reported on the details of the performance contract process, along with a series of suggestions for improvements. Stein described the details of the performance contract method, and provided an overview of the EMCS-based monitoring. The use of the EMCS as a data acquisition system was highly problematic. We describe some of these problems below.

Building Description

Figure 3. Building Summary



The Oakland Administration Building Project consists of two separate buildings that were constructed under a single design/build contract: the Dalziel Building and the Wilson Building. The Wilson building (previously known as Broadway Building) consists of a new construction portion and an historic preservation portion. Construction was completed in spring 1998 and occupancy began in the summer of 1998. As shown in Figure 3, Dalziel Building has six stories including a 24-hour operated TV studio, and Wilson has eight stories including 24-hour computer rooms. The area excluding the retail space (which is not in performance contract) is 412,000 ft^2, plus 87,000 of parking. The main HVAC system is central variable-air-volume with hot water reheat. A single chilled water plant in Dalziel, which consists of two 500-ton chillers, serves the main air handlers in both buildings. Each building has its own hot water boilers. Wilson also has an air-cooled chiller (ACH-1), which serves three computer room AC units, and a fluid cooler serving retail spaces that is not in the contract. Dalziel also has a fluid cooler serving heat pump in a TV studio and in the retail spaces.

Data Collection and Analysis

Monitoring Requirement and Collected Data

The performance contract required the EMCS be capable of recording and storing 100 points planned to be used in calibrating the revised DOE-2.1C model for the "as-operated" baseline. Over 500 points were logged on 15- to 60- minute intervals. Table 1 shows a summary of collected points.

Table 1. EMCS Monitoring Points

Chilled water system	Chiller electricity CHW Btu CHW supply temp CHW return temp CHW flow rate CW to CT temp CW from CT temp Building CHWS temp Building CHWR temp Chiller start/stop
Cooling tower	CT electricity CW to CH temp CW from CH temp CT fan start/stop
Boiler system	HW gas HW Btu HW supply temp HW return temp HW flow rate Building HWS temp Building HWR temp Boiler start/stop
Thermostat	Indoor air temp Schedule offset
Pump	Electricity Start/stop
Air distribution	Fan electricity SAT RAT OAT Mix box damper CHW valve Duct statistic pressure VFD speed Fan start/stop
Weather	OAT OA humidity Wind speed Wind direction Solar radiation
Lighting	Interior light elec
Plug load	Each floor Computer room
Electricity Misc.	Exterior light Garage Ex fan Elevator

In addition to the EMCS data, LBNL collected the following documents to capture the details of the performance contract and ongoing energy performance.

- Contract Documents - Division 1 General Requirements & Energy Requirements
- Measurement and Verification Plans **-** developed by Eley Associates
- Architectural As-Built CAD Drawings
- DOE-2 Models
  - Original model - initial target model from Eley Associates
  - Target model - modified DOE-2 model with minor corrections
  - Rebate model - target adjusted for a utility rebate for efficiency measures
  - Code-compliance model - code compliance model with Title-24 schedules
  - Adjusted model -modified to allow input of monitored data
- Quarterly Comparisons Documents - between actual and modeled energy use
- Final Performance Contract Evaluation

- Utility Bills - from the local utility

We included the utility bill data for the energy performance evaluation, which are beyond the scope of the performance contract. Utility bills are popular source of whole-building data for benchmarking which can be performed at no cost. Even though all the end-use electricity is collected, utility bills are meaningful for cross checks to ensure monitored data accuracy. Furthermore, linking the performance contract results to the actual utility bulls helps communicate the building performance translate into costs.

Data Issues

Data management was highly problematic. EMCS vary greatly in their data collection and archival capabilities (Sebald and Piette, 1997). Stein et al. described a number of problems with the building automation system (BAS) data, such as missing data, erroneous values, and conflicting kW and kWh data. He also described the data management issues, along with recommendations for data visualization tools and cross checks. We echo some of these suggestions in the discussion below.

The EMCS processor time for acquiring these data was extremely demanding, resulting in problems with other BAS functions. This problem was so extreme that the economizer strategy failed when the control signal closed the outside air damper quickly while closing the return air damper slowly. As it turns out, the outside air damper processes its signal locally, while the return air damper signal is processed through the central processor. The central processor works more slowly because it is simultaneously acquiring from 300 to 500 points every few seconds. This problem is a noteworthy example of challenges faced with EMCS trend logging. To resolve the problem, the DB contractor installed additional outside air fans, without dampers, that turn on whenever outside air is needed. The City was obligated to accept the solution because it did not compromise the energy performance results enough to put the contractor into the range of unacceptable performance.

As is common in new construction projects, utility bill data were highly problematic over the first few years of operation, hampering our ability to compare the EMCS data with other whole-building cross checks. The local electric utility read both the electric and the natural gas meter sporadically.

The EMCS monitoring was discontinued following the completion of the performance contract. LBNL reviewed the points list and reduced it by about 150 points. The monitoring has been revived to continue performance monitoring. LBNL recommended the addition of several points that can be used to evaluate the economizer operation. Thus, we are modifying the monitoring to support ongoing energy management as opposed to simply using the data for the performance contract analysis. Another reason to continue the monitoring is to support the future retro-commissioning project, which is being planned. It is unclear, however, how to maintain this level of monitoring over time because the current EMCS monitoring is laborious, and not well automated.

Whole-Building Benchmarking, Diagnostics and End-Use Data Analysis

LBNL conducted a series of analyses of the data to examine the building performance beyond what was required in the performance contract. The original scope of the performance contract was to evaluate the contractors' performance to achieve energy-efficient design and construction. That is, it is focused on the comparison between the results of Adjusted Target Model and actual usage data, which doesn't require detail data mining for the building diagnostics. However, these trend data are also valuable to examine the energy performance of various building systems in detail, and performance diagnostic analysis (Friedman and Piette, 2001). LBNL collected, organized, and analyzed the EMCS data for diagnostic analysis and whole-building benchmarking. The EMCS data used for the analysis were from 11/05/1999 to 9/11/2000. The entire history of utility billing data was acquired for whole building analysis and to develop energy use intensities (EUIs). Performance metrics from both the performance contract and the utility bills were compared. We also developed key end-use breakdowns from the EMCS data. Chiller performance (kW/ton) was analyzed using hourly cooling load and energy use data. Miscellaneous equipment and plug load were analyzed. We also examined hourly electricity use in June 2000 during an extreme heat storm.

Performance Metrics

Building on the results of previous data analysis by Eley Associates, LBNL defined a set of performance metrics that can be tracked along the key phases of the performance contract and on into operations. It is important to understand how these metrics differ during each phase of the building life cycle. Performance Metrics should be identified in order to explicitly represent project objectives, using quantitative criteria, in a dynamic, structured format that provides value across the life cycle of a building project (Hitchcock et al, 1998). Ideally, sets of both benchmarking and assessment values are archived for each performance metric over the life cycle of a building project. There may be an initial benchmark value established in pre-design planning, updated benchmarking values and predicted assessment values determined during design, short-term measurement from commissioning, and long-term monitored values. The Oakland Administration Building data were archived by various aspects of data in each key phase (shown in Figure 1).

Results and Performance Metrics

Whole-Building Metrics

The performance contract results for the City Administration project were favorable. The Eley Associates' final report showed that the building's energy costs were slightly lower than the adjusted target energy consumption. Final energy costs for the actual building were \$441,339 (\$1.08/ft^2-yr) as compared to the \$458,298 target (\$1.11/ft^2-yr). The DB firm did not receive a premium performance incentive because the energy costs were within the deadband for the performance payment. It is somewhat remarkable that the final ECI from the performance contract analysis is exactly equal to the original, unadjusted target.

Figure 4 lists the five versions of the area-normalized energy cost metrics that present the entire history of the energy costs. Details for these data are presented in Table 2. The first two bars show the original unadjusted targets before the building was built, of $1.08/ft^2 for the first target (Phase A), which was increased to $1.32/ft^2 as the ventilation levels changes from 4 cfm/ft^2 to 6 cfm/ft^2 (Phase B). The third bar shows the Adjusted Target of $1.11/ft^2 that resulted from the extensive revision of the target model simulation after two years of EMCS data collection and remodeling of the baseline. The fourth bar, the "Extrapolated Actual" shows the actual energy costs/ft^2 from the end-use metering of $1.08/ft^2. The word "extrapolated" is somewhat important because there were some extensive gaps in the monitoring, and there were some periods where energy use, and related costs, was extrapolated to develop an annual total. The final bar shows the utility bill total of $1.44/ft^2 from August 2000 to July 2001. Although the utility bill data were problematic in the first two years, most of the data from the 3rd year (August 2000 to July 2001) were available to analyze. These are the only 12 months where a full set of utility bill data was available. This total is 25% greater than the extrapolated Actual. It is, however, based on a different rate schedule, as noted in Table 2. Notice also that the floor area data reported for each project phase differ somewhat as well.

Figure 4. Area Normalized Energy Cost Intensities (ECI)

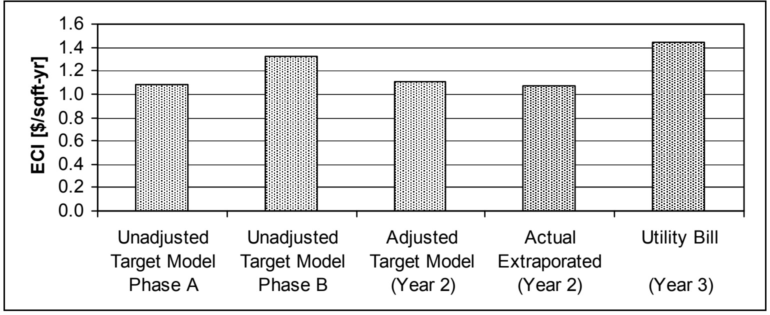


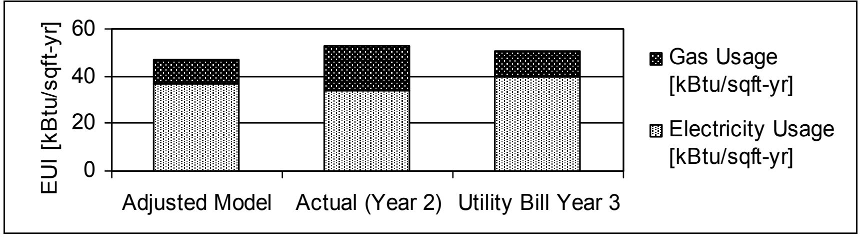
Table 2. Comparison of Performance Metrics and Data in Each Phase

	Pre-Construction Unadjusted Target Model		Target Model (adjusted)	Actual Building (extrapolated) Aug99~Jul00	Utility Bill Year-2: Aug99~Jul00	Utility Bill Year-3: Aug00~Jul01
	A	B				
Gross Area	392,569 ft^2		411,923 ft^2	410,468 ft^2 (1st quarter: 391,114 ft^2)		
Electricity Rate	A10			A10	A10 (Wilson) E19 (Dalziel)	
Gas Rate	GNR1			GNR1	GNR1 (Wilson) GNR1, ABAG (Dalziel)	
Electricity Usage	N/A	N/A	4,467 MWh	4,095 MWh	N/A	4,787 MWh
Gas Usage	N/A	N/A	39,947 Therm	74,411 Therm	N/A	41,965 Therm
Energy Usage (Total)	N/A	N/A	19,367 MBtu	21,654 MBtu	N/A	20,667 MBtu
Energy Cost	N/A	N/A	$458,298	$441,353	N/A	$592,854
EUI [kBtu/ft^2-yr]	N/A	N/A	47.02	52.75	N/A	50.35
ECI [$/ft^2-yr]	$1.08	$1.32	$1.11	$1.08	N/A	$1.44

See Figure 1 for description of each phase.

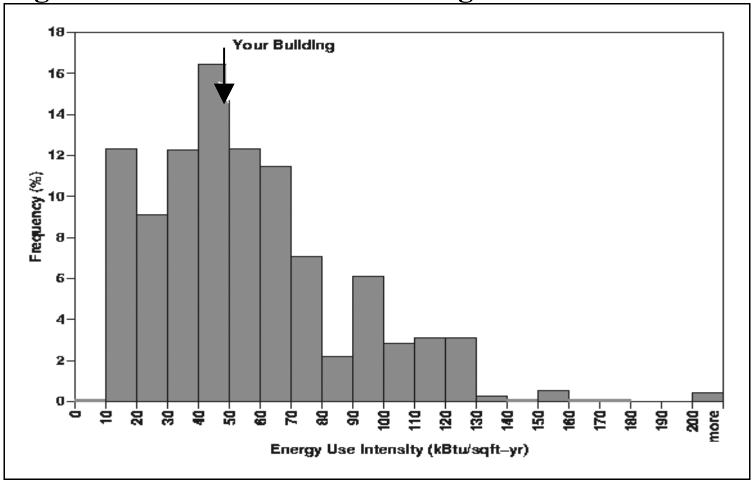
Although the "Extrapolated Actual" ECI was below the Adjusted Target ECI, the energy usage of the actual building was higher than target model. The EUI of the actual building was 52.75 kBtu/ft^2-yr, while that of the target model was 47.02 kBtu/ft^2-yr (Figure 5). This is because of the differences between gas and electricity costs, as shown in Table 2. The EUI in Year 3 at 50.4 kBtu/ft^2-yr was lower than the EUI of the actual building at 52.75 kBtu/ft^2-yr (Year 2). However, as mentioned, the ECI was 25% greater because the differences in rate schedules and electricity rates were much greater in summer 2001. Although the gas rate was high in Year 3 (almost tripled), it was not as significant because gas usage was approximately half as much as the Year 2 actual building.

Figure 5. EUIs of Adjusted Target Model, Actual Performance, and Utility Bills



Since the energy rates for both electricity and gas, have been fluctuating dramatically in California, it is difficult to evaluate ECIs. The performance metric tracking would have been far more straightforward if the entire set of data shown in Table 2 were tracked for each phase of the project. The question remains: is this an efficient building? The EUI of the Oakland Administration buildings is similar to the median within the distribution shown in the figure below, but well below the average EUI for offices in PG&E territory of 67 kBtu/ft^2-yr (43.7 kBtu/ft^2-yr electric, and 23.8 kBtu/ft^2-yr gas, PG&E, 1999). Figure 6 is a benchmarking plot from Cal-Arch (http://poet.lbl.gov/cal-arch), showing the EUI of 50 kBtu/ft^2-yr (Kinney and Piette, 2002). The building EUI appears low relative to other benchmark data.

Figure 6. Cal-Arch Benchmarking Plot

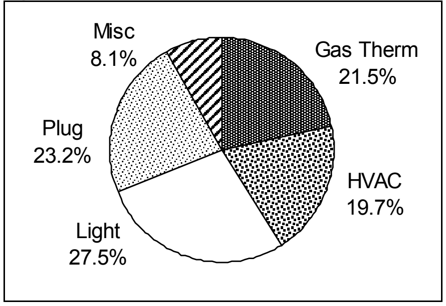


(Cal-Arch also presents source energy use comparison.)

End-Use and Performance Metrics

The electricity use of the building can be divided into three main end-uses. Lighting, the largest end-use, was 36% of the total, followed by equipment (miscellaneous and plugs at 35%), and HVAC (30% for fans, pumps, chillers, and cooling towers). It is interesting to note that the lighting and miscellaneous and plug equipment loads were considered pass-throughs in the model, although they account for such a large portion of the electric energy use. (Lighting was not initially a pass-through, but was treated like a pass-through because one-time measurement of lighting power densities confirmed that the design met the DOE-2 target.) Figure 7 shows the end-use break down for the building with the gas (for space and water heating) included. Here we separate "plug use" from miscellaneous. "Plug" electricity use is the second largest end use.

Figure 7. Annual End-Use Breakdown for Electricity and Gas



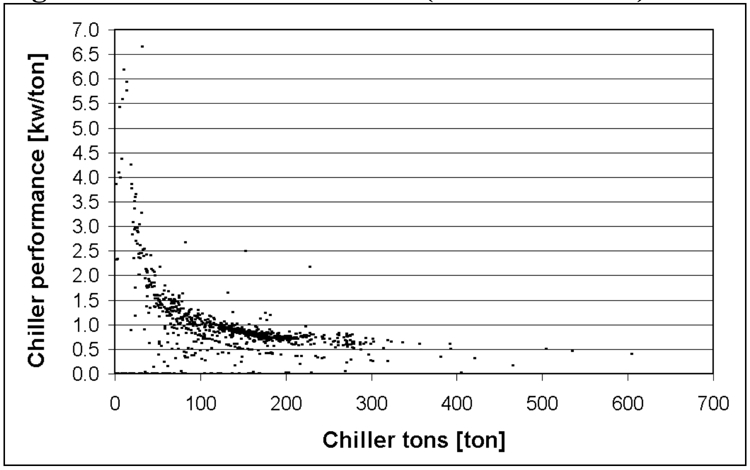
Percentages based on total site kBtu.

(source kBtu)
(Gas Therm: 7.5%)
(HVAC: 23.2%)
(Light: 32.5%)
(Plug: 27.3%)
(Misc: 9.5%)

HVAC performance. In addition to examining the whole-building data, LBNL has examined the detailed EMCS, HVAC, and end-use data. One interesting finding is the performance of the cooling plant. As is common in office buildings, the cooling plant was dramatically oversized. During nearly a full year of operation (11/5/1999 to 9/11/2000, 7463 hours), the chillers where used only 812 hours. While the manufacturer specification of chiller performance is 0.44 kW/ton, the measured performance averaged around 0.8 kW/ton (Figure 8). One reason the average kW/ton is different is that the chiller run only partially loaded. Each chiller has 500 tons of capacity (totaling 1000 tons for the cooling plant), but the system rarely requires more than 200 tons. The maximum load was 604 tons measured at 3:00 PM, 6/14/2000, which occurred during a hundred-year outside temperature high of 103° F. Simultaneous operation of two chillers occurred only 27 hours, and 15 of these hours occurred during the week of 6/14/2000.

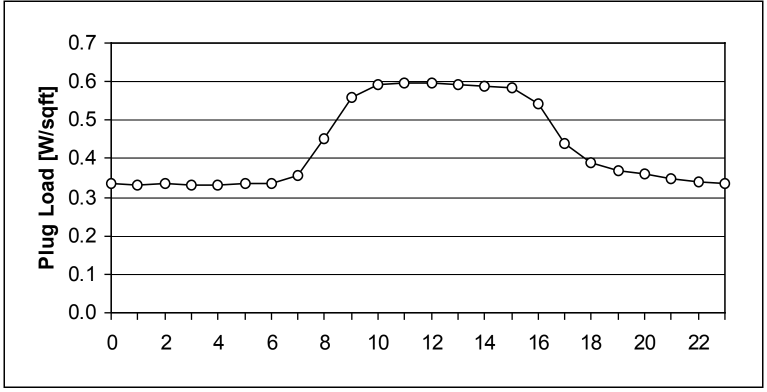
In reviewing the data LBNL found a number of operational problems. For example, the boilers were operated every morning during summer seasons because they were not locked out. The boilers start at 6 AM to heat up the buildings, with chillers starting at 11 AM, and boilers shutting down. This "pre-heating" increases cooling electricity peaks in afternoon peak time. Interestingly, the monitoring system includes a cement slab temperature at the top, middle and bottom floors of each building. Plans are being developed to use these sensors to developed pre-cooling summer peak load management strategies.

Figure 8. Chiller Performance (kW/ton vs tons)



Plug loads. We provide results of the submetering of plugs loads because of the value and difficulty of obtaining such data in commercial buildings, and the growing importance of this load. Daytime (9AM – 6PM) average plug load density was 0.57 W/ft^2, and 0.35 W/ft^2 in nighttime (using the gross area of 410,468 ft^2). The plug loads consumption was 3.4 kWh/ft^2-yr (11.7 kBtu/ft^2-yr). The computer room in the Wilson Building accounts for a large part of the load with an average of 19.6 kW, or 2.4 W/ft^2 (floor area of the computer room is 8,046 ft^2). The computer room causes the high nighttime load (Figure 9).

Figure 9. Plug Load Density (Nov. 99 – Sept. 00 Weekday)

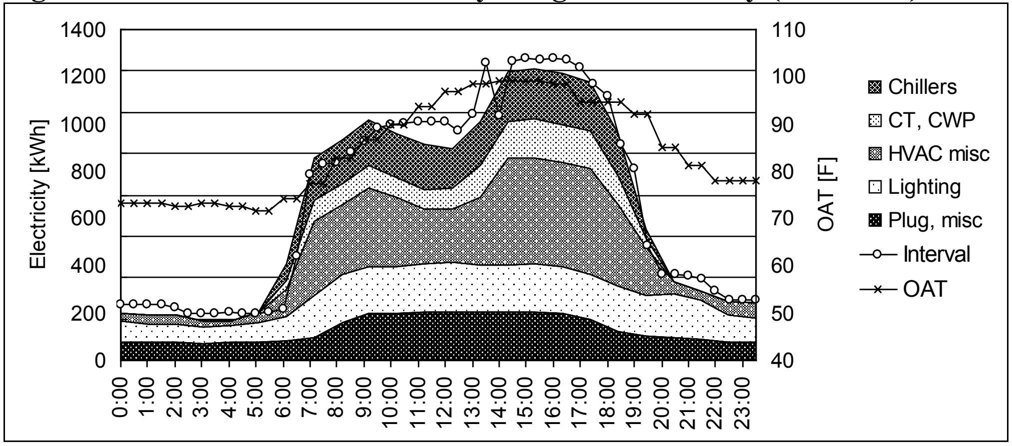


Peak day analysis. The building complex's greatest electricity peak occurred at 3 pm on June 14, 2000, reaching 1748 kW, or 3.78 W/ft^2. Figure 10 shows the electric end-use data and outside temperatures in the Dalziel Building. In analyzing these data one must remember this building supplies cooling to the Wilson Building. At peak time 3PM, about 60% of electricity was air-conditioning. Figure 10 overlays 30 minutes utility interval meter data LBNL recently analyzed. These data are close to the end-use metered total, confirming their accuracy.

Conclusions and Future Directions

This paper has presented a series of performance metrics that describe the energy performance of two new buildings in Oakland, California, which were designed and built under the first new construction performance contract. This paper has shown that the building beat the performance target Energy Cost Intensity, but consumed slightly more energy than the target. This discrepancy is due to fluctuating energy cost rates over time. Overall the building is a relatively low-energy building, requiring about 50 kBtu/ft^2-yr (site electricity plus gas use).

Figure 10. Breakdown of Electricity Usage on Peak Day (6/14/2000)



One key lesson from this project is that it is important to track both energy and cost targets. Cost targets were used so that TES and other load management strategies would be properly credited. But under the highly fluctuating energy rate, cost-base analysis may lead confusion to understand actual energy savings. Since energy rates change, energy units can help track the history of energy consumption rates. Furthermore, it is important to track the floor areas associated with these rates.

More careful tracking of the data underlying higher-level performance metrics can help building owners understand how the performance contract process changes the metrics and targets. We also conclude, as others have before, that a stronger linkage of the performance contract methodology to utility bills would facilitate more careful actual energy use and costs tracking.

One outstanding issue is determining the value of the ongoing, intensive submetering. The metering was designed to support the performance contract, but needs to be reviewed to support ongoing energy management. Such data can be extremely useful for diagnostics, but the current EMCS-based monitoring is laborious and hard on the EMCS. The performance monitoring should have included the development of standard performance metrics and diagnostic feedback graphics, summary metrics, and data management methods. These improvements are still needed.

We recommend that future project develop more detailed data management plans. Since EMCS are better than others with data management. Data management should include data collection, archival, and analysis systems.

The City of Oakland is working on an enhanced, next-generation performance-contracting framework for its future public works construction projects. The goal is to use past experience to achieve synergies that dramatically reduced life cycle costs and improves energy efficiency to levels 20% to 50% below today's more stringent state code (Title 24). The City plans to hold the contractor responsible for superior building performance through prescriptive and performance criteria, along with information and supporting collaboration that provide boundaries and supports that steer the project to the maximum favorable result. the City of Oakland is working to put better utility bill tracking information system into place. Plans are also underway to perform retro-commissioning of the Administration buildings. Future energy use will likely be lower than the EUIs discussed above.

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