The Jury Is (Halfway) In: New Building Performance Contracting Results

Jeff Ross Stein, Taylor Engineering
Aditi Raychoudhury, Eley Associates
Charles Eley, Eley Associates

ABSTRACT

The design/build contract for the new Oakland Administration Buildings includes an energy performance bonus or penalty of up to ± $250,000 based on the measured energy performance of the buildings in the second year of operation. This paper covers four topics:

- **Performance evaluation procedures** – Evaluation involved (1) adjusting the target DOE-2.1E model based on factors for which the design/build contractor is not accountable, including weather, plug loads, occupancy, hours or operation, etc., and (2) comparing the model output to actual energy consumption data for all HVAC equipment.
- **Results for the first half of Year 2** – The buildings had a higher energy cost than the target model in the first quarter but a lower cost than the model in the second quarter. Recent improvements in HVAC operation appear to account for this performance improvement. Based on these two quarters alone the actual performance is within the $20,000 deadband and thus is not on track for a bonus or penalty.
- **Problems encountered** -- Most of the problems related to missing or clearly inaccurate monitored data for lights, fans, boilers, etc.
- **Recommendations** – The approach used in the Oakland project relies on the absolute accuracy of DOE2, which is asking a lot of the software and of the evaluation team. A relative accuracy approach is recommended for future contracts. This basically involves calibrating a model of the actual building, making a copy of the model and adjusting the copy for any discrepancies between expected and actual equipment efficiency and operation.

Introduction

The difficulties in achieving truly energy efficient, and lowest lifecycle cost buildings are well documented (Lovins 1994). The problems are on both the design side and the implementation side and they include the perceived higher first cost of more efficient designs and the lack of incentive for key players like engineers and contractors to strive for efficiency. New building performance contracting is an exciting new concept for giving the proper incentive to the people who have the ability to insure that buildings achieve their true potential for efficiency and lifecycle cost-effectiveness (Eley, Syphers Stein 1998).

The Oakland Administration Buildings Performance Contract is a groundbreaking experiment in new building performance contracting. Many eyes in the research, utility, design, construction, and building owner communities have been on this project. The Oakland Administration Buildings consists of two separate buildings that were constructed under a single design/build contract: the Dalziel building and the Broadway building, which consists of a new construction portion and an historic preservation portion. The total gross area is 540,000 ^{ft2}, which includes 37,000 ft^2 of retail and 90,000 ft^2 of parking garage. Construction was completed in spring 1998 and occupancy began in the summer of 1998.

The main HVAC system is central VAV with hot water reheat. Main air handlers in both buildings are served by a single chilled water plant in Dalziel. Each building has its own hot water boilers. Broadway also has an air-cooled chiller serving three computer room AC units. Dalziel also has a fluid cooler serving heat pumps in a TV studio and in the retail spaces.

Performance Evaluation Procedure

Target Model

The DOE2.1E target model was developed by Eley Associates in 1994 based on the building program before the RFP was issued to design/build contractors. Most of the data needed to develop the model were available in the program (e.g. building size, shape, orientation, HVAC system type). Eley Associates, the City and its consultants agreed on other modeling assumptions that were not available in the building program. The unadjusted energy performance target ($1.08/$ft^2$-yr) as well as the relevant energy efficiency modeling assumptions were included in the RFP (e.g. lighting power density, chiller efficiency, glazing properties). The contractor was not required to implement any of the specific energy efficiency measures modeled in the target (they were presented simply as the basis for the target) but the contractor was required to model the proposed design at four milestones in the design process and demonstrate that the proposed design used less energy than the target model. Modeling by the winning design/build team during the design process indicated that the proposed design was more efficient than the target model in a number of areas (e.g. chiller efficiency, fan efficiency) and was on track to receive a performance bonus.

Monitoring Requirements

The performance contract calls for the Energy Management System (EMS) to record and permanently store 15 minute interval data for a large number of points including: total and boiler natural gas; kW and kWh for all pumps, chillers, cooling towers, supply and return fans, heat pumps, etc.; plug loads, interior and exterior lighting loads per building; and outdoor climate conditions including drybulb, wetbulb, wind speed, wind direction, atmospheric pressure, ground temperature and total solar radiation.

Other monitoring requirements included most water and air flows and temperatures. The performance contract also included requirements for a full energy commissioning process including a commissioning agent, commissioning plan (with proposal), design intent document (design phase), commissioning static and functional test plans (design phase), and final commissioning report (acceptance phase)

Model Adjustments

The purpose of the performance contract is to hold the Contractor accountable for the efficiency of the HVAC, envelope and lighting systems, i.e. the Contractor is not accountable for the demand placed on the building systems, but only for how efficiently that demand is satisfied. Thus the efficiency of the HVAC, envelope and lighting systems are held constant in the target model (e.g. chiller efficiency, HVAC controls strategies, roof insulation, and lighting power and controls). The model is adjusted for all the variables for which the Contractor is not responsible, including occupancy patterns, hours of operation, lighting schedules, plug loads, and weather.

HVAC schedules and settings. The City provided Eley Associates with the desired standard schedules and thermostat settings. Any changes are reflected in the model. The HVAC system also has the ability to allow occupants to adjust zone-level thermostat settings by up to ±4°F and the ability for occupants to request after-hours HVAC. The model must be adjusted to account for any such changes in demand. Although not specifically required in the specification, the Contractor agreed to provide thermostat offset data and after-hours request data for a representative sample of zones. To date, there have been problems collecting the data and questions regarding accuracy. Preliminary analysis has not indicated any significant thermostat variations or after-hours usage. Other HVAC control information such as minimum outside air ventilation rates and minimum supply air flow rates were taken from the specifications in the design/build contract. For example, the specifications call for a minimum air flow to all zones of 0.6 CFM/ft^2.

Plug Loads. Plug loads place a demand on the cooling system for which the Contractor is not responsible, thus they are treated as a "pass through". A single hourly average equipment power density is calculated for both buildings based on the monitored data. The model reads in the average equipment power density every hour and assumes that it is uniformly distributed across all zones.

Lighting. The energy target for lighting in the model is based on 1.0 W/ft^2 (this includes occupant sensor credits) and widespread use of daylighting controls in perimeter zones, which was modeled explicitly in the original target model. The Adjusted Lighting Power Density in the model (using California's Title 24 approach to daylighting controls credits) comes out to 0.88 W/ft^2. The Contractor is responsible for lighting efficiency but not for lighting demand (i.e. when and where lighting is desired). Unfortunately, there is no way, based on a single hourly lighting KWH value for each building, to calculate the demand for lighting. Thus the monitored data was not used to evaluate the energy performance of the lighting system. Instead, a two step approach was used:

1. **Lighting Takeoffs**. Actual connected lighting power and adjusted lighting power were calculated based on final electrical drawings for the building. It just so happened that the adjusted lighting power density calculated based on the takeoff was also about 0.88 W/ft^2.
2. **Spot Measurements**. Spot measurements were taken in July 1999 to verify that the daylighting controls were installed and operating properly. Light intensity meters were installed near windows (to measure natural light entering the space) and in perimeter zone light fixtures to test daylight controls in about 5 locations. 4 of the 5 tests clearly showed that the lights were dimmed when sufficient natural light was available (See Figure 1.). Based on these spot measurements, we felt it was reasonable to conclude that the daylighting controls are working sufficiently well.

Based on the lighting takeoffs and spot measurements, it was determined that the Contractor has exactly met the lighting performance target and is not eligible for an incentive or penalty based on lighting. In order to accurately represent the cooling load from the interior lights, lights are treated as a simple pass-through in the model, exactly the same way as plug loads.

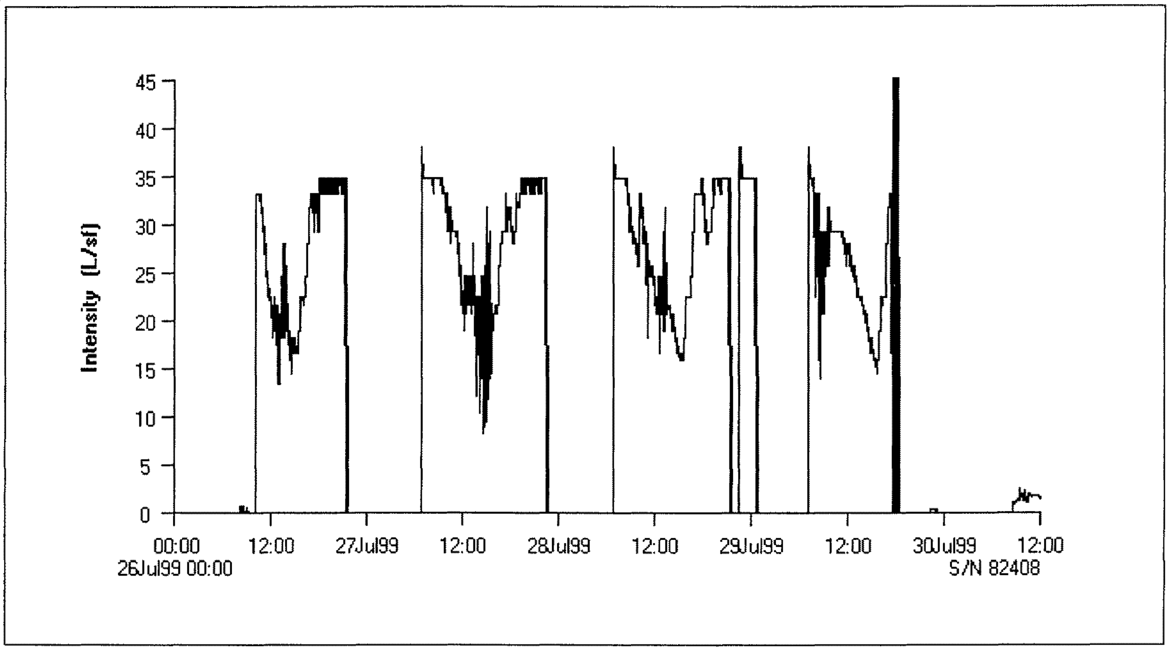

Figure 1. Light output from a fixture controlled by daylighting controls

Occupancy. The City reported that 1050 people work in the buildings, which works out to density of about 336 ft^2/person. A typical occupancy schedule was assumed for all zones. It is based on ASHRAE Standard 90.1-89, with input from the City on how administrative buildings are operated in Oakland.

Weather. The monitored data for drybulb, wetbulb, wind speed, wind direction, atmospheric pressure, and total solar radiation were used to modify a DOE-2 weather file for the run period.

Incentive/Penalty Calculation

Ideally, the best way to calculate the incentive/penalty is to compare the gas and electric utility bills to the adjusted model results. However, some of the data necessary to fully adjust the model was either not included in the monitoring requirements (e.g. trash compactor, elevator AC, mechanical room exhaust fans) or not accurately reported by the EMS (e.g. exterior and garage lighting). Furthermore, there was considerable difficulty getting the utility bills and considerable confusion about what was included in the bills (Hitchcock, Piette and Khalsa 2000). Therefore, we decided to manually apply the relevant utility rates to both the monitored and the simulated HVAC hourly KWH and therm data. This is reasonable given that lighting and everything else is a pass-through. The applicable electricity rate in PG&E A-10 and the gas rate is G-NR1. According to the performance contract, if the actual energy cost for Year 2 exceeds the adjusted target cost by more than $20,000 then the Contractor will compensate the City an amount representing fifteen times the additional energy cost up to a maximum penalty of $250,000. If the actual energy cost is under the adjusted target by more than $20,000 then the City will pay the Contractor an amount representing five times the additional energy cost savings, up to a maximum bonus of $250,000.

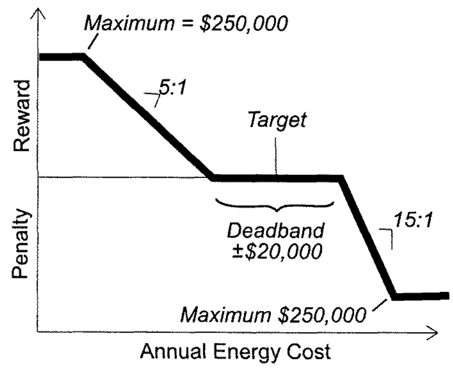

Figure 2. Incentive/Penalty Calculation

Results

Year 2, or the evaluation period, runs from August 1, 1999 through July 31, 2000. As of this writing, results are available for the first half of Year 2. Because of missing data and data quality problems September 1999 was used to represent the first quarter of Year 2 (August-October 1999) and similarly January 2000 was used to represent the second quarter (November 1999-January 2000). As Figure 3 shows, actual electricity costs was slightly less than the adjusted target in the first quarter and considerably less (about half) of the target in the second quarter. However, actual gas cost is several times what the model predicts in both the first and second quarters. Figure 4 shows a breakdown of electricity HVAC end uses for the model and actual buildings by period. (Actual Cooling includes chillers, heat pumps, and computer room AC. Actual heat rejection includes cooling tower and fluid cooler fans. Actual pumps includes HW, CHW, and CW pumps. Actual fans includes supply, return, and some exhaust fans)

Extrapolated to a full year, the actual energy cost would be about $7,000 more than the model. This is within the "±$20,000 deadband" and there would be no penalty or incentive. There are a number of encouraging signs, however, and there is reason to believe that the actual performance could be considerably better than the model in the second half of Year 2, possibly resulting in an incentive bonus to the Contractor. Encouraging signs include the following:

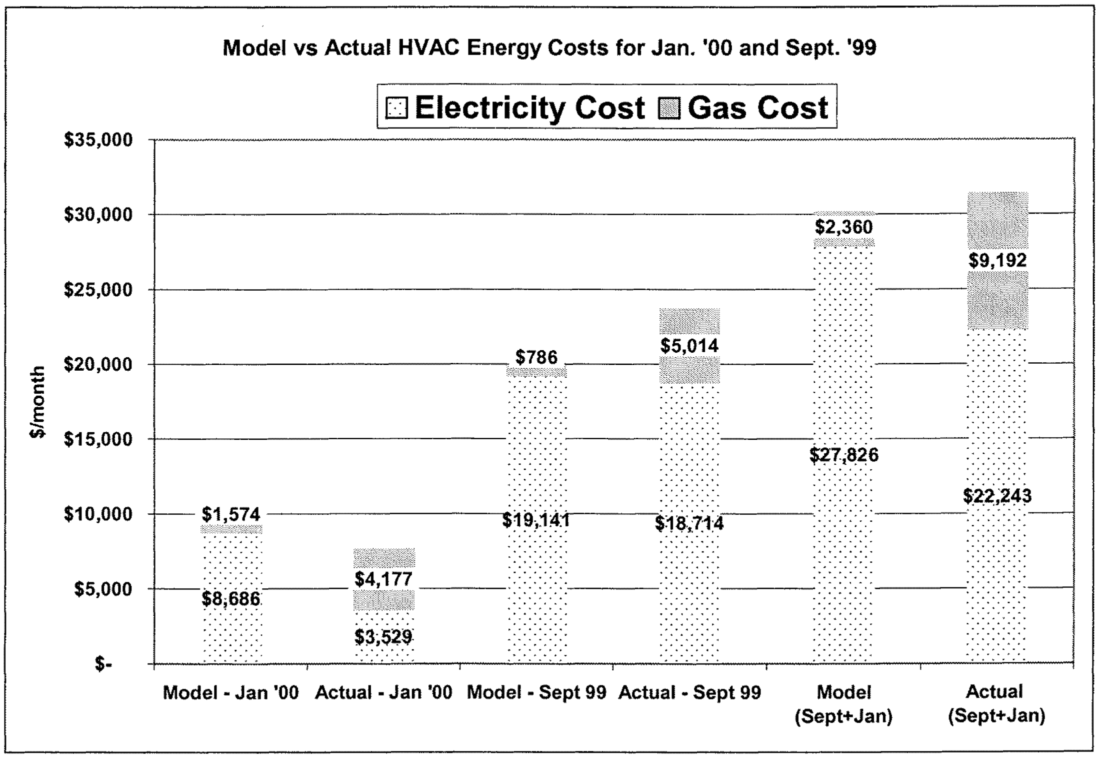

Figure 3

- For over one year after occupancy the Contractor was unable to satisfactorily demonstrate to the City's indoor air quality specialist that the HVAC systems was able to meet the minimum ventilation requirements at all times. As a result the supply and return fans were running 24 hours per day until December 1999. The model, however, uses the City's desired HVAC schedules. This helps explain why electricity performance improved dramatically, relative to the model, from the first to second quarter.
- Because of the problems getting IAQ approval, both buildings were in 100% outside air mode at all times in the first quarter. January data indicates that the Broadway building is still operating in 100% outside air mode in the second quarter but that Dalziel has been switched to proper economizer operation. The 100% outside air, especially in combination with the 24 hour fan operation, helps explain why actual gas cost is several times higher than the adjusted target in the first quarter and why the gap between actual and target gas cost is smaller in the second quarter.
- It appears that most of the HVAC equipment is significantly oversized, at least for the time periods we have analyzed. Generally, oversized variable speed equipment, such as fans and pumps with variable speed drives, are extremely efficient at low loads.
- The building operators are clearly making an effort to operate the building as efficiently as possible. For example, according to the EMS there are occasional periods in the winter when the chilled water valves in the air handlers open up slightly. Normally this would bring on the chiller, chilled water pumps and condenser water pumps. However, the operators have determined that the chillers can be locked out and the space temperatures can still be maintained, as long as the OA temperature is below a specific temperature.

- The specifications call for a minimum air flow to all zones of 0.6 CFM/ft^2. This requirement has been included in the model, although it is not clear if it is being followed in the design or operation of the buildings. This could be a significant source of energy savings.

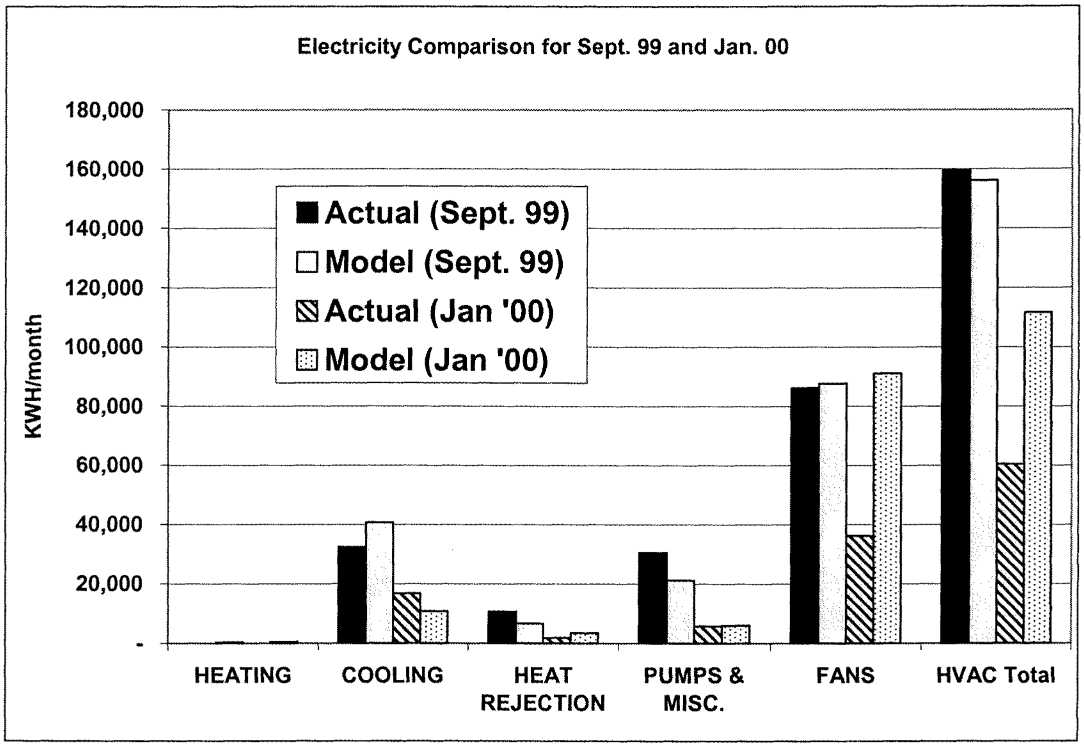

Figure 4

Data Analysis Problems

The performance evaluation is dependent on the monitored data, particularly the sub-metered electricity data. Unfortunately, the data collection system has been plagued by missing data and clearly inaccurate data. Fortunately, the performance contract calls for the incentive/penalty to be calculated in the second year because the first year was almost completely a wash in terms of useful data. Dealing with the data problems has consumed considerable time and expense for the City, the Contractor and Eley Associates. Data problems encountered include:

- **No data**. Either the metering equipment was not installed or the trend log was not created so that no data files were created. One of the most serious omissions was gas consumption, which was not available for Dalziel until the second quarter of Year 2 and is still not available for Broadway.
- **Zero data**. Some files showed that the equipment never drew any power even though it was clear from inspection or from related equipment that the equipment was operating at least some of the time.
- **Negative data**. For example, condenser water pump data for at least the period of 12/15/98-12/17/98 was constant at negative 75 KW.

- **Spikes**. For example, Dalziel supply fan data was generally in the expected range of 50 to 150 KW except for hours when the value shot up to 500 KW which is clearly erroneous.
- **Out of range**. For example, data for Cooling Tower 1 for June 1999 exhibits a reasonable profile but the data peaks around 50 KW while the nameplate power for the tower is only 30 horsepower or about 22 KW.
- **Suspicious load profile**. Data for many pieces of equipment simply did not exhibit believable hourly or daily variations.
- **Conflicting kW and kWh data**. The performance contract calls for 15 minute KW and KWH data. In order to reduce the data manipulation burden (DOE-2 uses an hourly time step) we asked the Contractor to provide hourly data instead. Hourly KWH and average KW data should be the same. However, this was not always the case. The Contractor has been unable to explain or resolve this inconsistency.
- **Missing hours**. Many data files are missing random periods of data (e.g. Dalziel fan data is missing from 12/13/99 5:30am to 12/15/99 2:30am).

According to the Contractor, many of the early data quality problems (in the beginning of Year 1), were due to meter setup mistakes that were quickly corrected (e.g. a 10 amp current transducer was used but the KW meter was programmed for a 100 amp transducer). Other problems, with the chillers, lights and plugs for example, were related to power factor problems. A large number of meters were relocated or replaced in Year 1. Despite these and other efforts by the Contractor, many of the data problems remained unresolved as of this writing.

In order to evaluate the energy performance a number of steps were taken for dealing with bad data. Obvious spikes or gaps in data were filled in by repeating data from similar periods for missing periods. For data that was missing entirely, reasonable "worst-case" assumptions were made based on nameplate power and expected operation. Another step was to pick the month from each quarter that seemed to have the fewest data problems.

Data processing problems. In addition to data quality problems, processing the raw data also turned out to be more difficult than anticipated. The data is stored by the EMS system in dozens of cryptic text files, with little or no documentation. KWH is cumulative (random resets), KW is not. Some is 15 minute, some is hourly data. Some points are only logged when the equipment is running (e.g. boiler water flow and temperature) making it nearly impossible to plot against time. Analyzing the data was a fairly time consuming process of importing chunks of dozens of files into database and/or spreadsheet software, then graphing and sorting to find problems and ways to deal with them.

Independent verification. Aside from clearly bad data (spikes, out of range, all zero, negative, etc) there was no clear indication of accuracy (i.e. calibration reports) and no way to compare the sum of the monitored data to the utility bill since not all end-uses were monitored. In order to improve our confidence in the data, Eley Associates and the City did some independent verification of a couple of the KW meters using a hand-held KW datalogger. While not entirely conclusive, these tests seemed to indicate that the KW meters were reasonably accurate.

Recommendations

Recommendations have been divided into two categories: (2) recommendations for future performance contracts following the model of the Oakland project and (2) a proposed alternative methodology for new building performance contracts.

For Similar Projects

Better specifications for data collection. The specification should say exactly what data should be in each file, in what format, how it should be labeled, what time periods should be covered , etc. For example, the specifications should say that KWH data shall be for that hour only (not cumulative) and should be accurate to 0.1 KWH. Putting a sample data table in the in the specification might be a good idea.

Data visualization. The specification should include detailed requirements for data visualization capabilities and for pre-programmed automatic data plots. For example, the specification could require weekly plots of hourly data for chiller, CHW pumps , CW pumps, and tower fan KWH and outside air temp (separate scale) all on the same page. Again, sample plots in the specification would help.

Data access. Raw data and data visualization should be easily accessible by the evaluation team via internet access.

Minimize meters. There are two basic ways to reduce the burden of data collection. One method is to reduce the points requirements. Theoretically, the Oakland project only requires two KW points: total HVAC KW, and total interior lights and plug loads. (Of course submetering particular HVAC equipment is necessary for commissioning.) In Oakland, for example, the dozens of KW meters monitoring lights and plug loads on each floor could easily be reduced to one lights+plugs meter per building. The other way to reduce the number of meters is to meet with the electrical contractor before design begins and explain how segregating end-uses by electrical riser will greatly reduce metering needs. For example, if separate lighting and plug load data is desired, then all lights should be served off of a single riser and all plug loads by another riser.

Automatic cross-checks. Although it seems to contradict the previous point, a few extra meters should be installed to confirm the accuracy of downstream meters. For example, a KW meter on the riser serving all main HVAC equipment should confirm the total output from KW meters on each piece of main HVAC equipment. A whole building cross-check is also a good idea, i.e. an hourly meter just inside the utility meter should equal the sum of the HVAC, interior lights and plugs, and exterior lights and plugs.

Link with commissioning. While energy commissioning was required in the design/build specifications, the performance evaluation team was not responsible for commissioning and did not have access to commissioning data. Much of the data and analysis for the performance contract could have been useful for commissioning and vice versa. It is not clear what if any energy commissioning took place, since the specifications lacked sufficient detail and no independent commissioning agent was required. For future projects, if an independent commissioning agent is hired by the owner, then the commissioning agent can and should also evaluate energy performance. However, if commissioning agent is hired by the performance contractor, then it is probably too much of a conflict of interest for that person to also evaluate the energy performance incentive/penalty.

Fee retention. While the +/- $250,000 was clearly an incentive, it is still a relatively small amount compared to the total $80 million design/build contract, and it was fairly clear that the Contractor would not have been as cooperative in the process had the City not invoked other sections of the contract that allowed the City to withhold a significant portion of the Contractor's fee pending resolution of the data quality and other problems.

Daylighting monitoring. As we found, a simulation model may not be the best approach for evaluating lighting performance. In addition to the lighting takeoffs approach, the specifications should require KW metering of a random sample of individual lighting ballasts that are controlled by daylight sensors as well as light intensity meters near adjacent windows. This way, it will be possible to know when the light is on, the level of natural light and the amount of actual dimming, which can then be compared to manufacturers data.

Alternative Approach

There is at least one other fundamentally different approach to performance contracting for new buildings that is worth consideration. We will call it the Relative Accuracy Approach.

The approach used in Oakland, call it the Absolute Accuracy Approach, is basically to compare a simulation model to an actual building. This is highly dependent on the absolute accuracy of the model. This means that careful attention must be paid to getting all of the assumptions exactly correct, which is onerous in a large, complex building. It is necessary to know the exact plug loads, thermostat schedules, hours of operation (including after-hours HVAC), weather, areas of conditioned and unconditioned spaces, etc. There is also no way to calibrate this model. In the case of Oakland, a great deal of time has been spent on issues that are needed for the model but are not relevant to energy efficiency, such as why the plug load KW and KWH are inconsistent. The Oakland target model was created over 6 years ago, in which time it was edited by several people and the actual design requirements have evolved. Insuring absolute accuracy is quite a challenge. A Relative Accuracy Approach would have the following basic steps:

1. A rough target model is created before the design process to determine the sizes and efficiencies of the "accountable" energy efficiency systems, i.e. it is needed to determine things like fan size, fan efficiency, pump size, pump efficiency, glazing properties, etc. It is also used to fine tune the target control strategies (e.g. supply air reset). These properties of the "accountable" systems become the "target properties" which are listed in the specifications as the basis of the target but not necessarily as strict requirements.

2. An actual model of the final design is created based on the final plans and specifications.

3. The actual model is calibrated after some period of occupancy based on utility bills, submetering data and post-occupancy commissioning data. The

submetering/commissioning data is primarily needed to determine if the relevant HVAC and lighting systems are operating according to their design intent. For example, if a review of the commissioning data shows that an economizer is not working correctly, or that the minimum zone flow in most zone is 50% not 30%, or that the chiller part load efficiency (based on KW, flow, and delta T data) is better than assumed based on manufacturers data then the model is adjusted accordingly. Any discrepancies between design intent and actual operation are put into the model. Then the calibration is performed by adjusting the "non-accountables" (like plug loads, occupant schedules, fan schedules, weather, etc) based on whatever information is available. It is not necessary to have submetered data for all of these things. All that is important is to approximate the total load on the HVAC system in order to match the utility bill.

4. An Adjusted Target Model is then backed out of the Calibrated Model by holding the non-accountables fixed and replacing the accountable properties with the target properties. For example, the target chiller properties are used and a properly functioning economizer is assumed even if the actual one is not working properly.

This is basically the whole building approach prescribed by the International Performance Measurement & Verification Protocol (IPMVP) Section 6.0 Measurement and Verification for New Buildings (Kats 1997).

While the absolute accuracy approach used in Oakland is not dependent on good commissioning, the relative accuracy approach is dependent on commissioning. This is not necessarily bad. A performance bonus gives an incentive for efficiency but energy efficiency cannot be achieved without adequate evaluation tools, which is what commissioning is all about. Thus the relative accuracy approach focuses attention on important variables like HVAC control strategies and not on unimportant variables like plug loads and weather. For this approach to be accurate, the specifications must include extremely detailed commissioning requirements including a list of all points to be monitored; monitoring accuracy requirements; sensor calibration documentation; data storage and visualization requirements; design intent documentation; very detailed functional testing and reporting requirements for all major pieces of equipment and a specified sample of all repetitive equipment, like VAV boxes; detailed post-occupancy testing and reporting requirements. The most successfully commissioned buildings have detailed commissioning specification and employ an independent commissioning agent.

One disadvantage of a relative accuracy approach as compared to the absolute accuracy approach used in Oakland is that it does not give as much of an incentive to pursue envelope-related energy efficiency design options. For example, in the Oakland case, the performance contractor might have proposed an alternative orientation or building shape that is more efficient when compared to the target model. With a relative accuracy methodology it would be hard to the contractor to get credit for this innovation. The reality, however, is that those sorts of decisions are usually made by the owner for aesthetic and other considerations and not left up to a potential performance contractor. If however, the owner does want to give the design team the incentive to be more creative then the absolute accuracy approach may be more appropriate.

Another possible methodology for executing new building performance contracts is to use utility data from comparable buildings during an evaluation period. For example, the

Oakland Administration Buildings could have simply been compared on a $\$/ft^2$-year basis to other City of Oakland office buildings. Of course, the difficulty with a "comparables" approach is finding sufficiently similar buildings and/or normalizing for differences in building use, hours of operation, site shading, ventilation codes, etc.

Conclusions

The Oakland Administration Buildings Performance Contract has demonstrated that this approach to performance contracting is a viable approach. The project demonstrated that a reasonable target could be set, the target could be adjusted for factors outside of the Contractor's control and an incentive/penalty could be calculated. The performance contract and performance evaluation process has clearly been a strong incentive (among other incentives) for the Contractor to pay attention to energy issues that might otherwise have been ignored. Indeed we have seen a dramatic improvement in energy performance during the evaluation period.

The Oakland performance contracting process, however, turned out to be more costly and time consuming, for both the Contractor and the evaluation team, than originally anticipated. Some of the lessons from the Oakland project could be used to simplify and reduce the cost of the process in future buildings. One way to reduce the level of effort required to evaluate performance and to eliminate some of the potential sources of uncertainty in the results is to use a relative accuracy approach along the lines of the IPMVP whole building approach for new buildings.

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