Using Bulls-Eye Commissioning to Save Energy in Commercial Buildings

Will Price
Staff Engineer, Energy Services
Eugene Water & Electric Board
Eugene, Oregon

Reid Hart, PE
Engineering Supervisor, Energy Services
Eugene Water & Electric Board
Eugene, Oregon

ABSTRACT

Building system commissioning comes highly recommended by energy efficiency experts; however, it is rarely undertaken due to the cost and care needed to do a comprehensive job. Many existing utility meters provide whole-building 15-minute interval data that can be used to pinpoint fan control and HVAC schedule problems. Bulls-eye commissioning uses interval metering to focus detailed commissioning efforts.

This paper concentrates on a single customer and how bulls-eye commissioning can be applied to focus the commissioning process. Significant energy savings were found by using interval data in conjunction with outside air temperature to isolate problems with schedules and in the economizer controls. Evaluation of main meter profiles allows detailed commissioning work to be better focused and more effective without the wait and expense of full commissioning services. Bulls-eye commissioning can be applied on its own or can be coordinated with traditional commissioning. In either case, the main meter profile shows what will directly impact total energy use and the customer's bill.

INTRODUCTION

This paper focuses on the application of *bulls-eye commissioning* on a group of office buildings owned by a property management firm. Bulls-eye commissioning uses analysis of 15-minute interval consumption data from the main building meter for commissioning and energy management activities (Price & Hart 2002). In this case study it is used to augment the commissioning process of a utility sponsored energy efficiency retrofit. As utility-installed interval metering becomes more common, it will be beneficial for utility representatives, key account managers, energy analysts, facility managers, energy consultants, energy service companies, and commissioning agents to learn how to take advantage of bulls-eye commissioning.

While analysis of interval data is not new, the distinction for bulls-eye commissioning is that it focuses on whole-building data collected through interval metering that is usually installed for another purpose, typically billing (Piette et al. 1998; Alereza & Faramarzi 1994). In contrast, commissioning or monitoring-based energy analysis activities typically require the use of targeted short-term monitoring provided by data loggers or use of trends from multiple Direct Digital Control (DDC) points.

Bulls-eye commissioning is the process of uncovering building performance details from a single point—the building electric meter. This follows the Pareto principle: 80% of the benefits are produced by 20% of the effort. There is a clear trend in the electric utility industry towards Automated Meter Reading (AMR).[1] AMR meter and data recorder shipments grew by about 30% from 2000 to 2001. About 40 million units have been installed in North America to date. Many of these meters are installed on commercial and industrial sites.

BACKGROUND: COMMISSIONING GOALS

A review of various types of commissioning, M&V, and O&M activities finds many definitions, issues, and protocols (ASHRAE 1996). The general purpose of all these activities is to provide occupant comfort, energy efficiency, and reduced financial risk. The term *commissioning* can apply to new facilities or existing facilities and can include retro-commissioning, re-commissioning, and continuous commissioning (Claridge et al. 1996). An ongoing goal common to all these missions is to use cost-effective techniques that provide the necessary level of data accuracy.

Many of these goals or methods can be enhanced, optimized, or replaced through bulls-eye commissioning. Bulls-eye commissioning can be thought of as a competing variation of more traditional commissioning services; however, a more useful interpretation is to think of using whole-building interval data as an effective tool that can precede or compliment standard commissioning. Additionally, the energy professional can often obtain

[1] AMR typically includes 15 minute interval metering with a data storage device at the meter and a means to communicate data to the utility for billing. Interval metering typically collects consumption or other data for discrete periods. For electric meters, energy consumption (kWh) is usually collected for 15-minute intervals. This allows one register to contain both consumption data and 15-minute average kW demand data.

the interval data needed for bulls-eye commissioning from existing utility billing equipment.

BULLS-EYE COMMISSIONING: A CASE STUDY

A local property management firm purchased three office buildings. They had retained the existing building operator who described a building pressurization problem with one of their buildings. They decided to consult with an HVAC contractor and EWEB energy management staff. A site visit was conducted in April 1997 and subsequent analysis eventually let to a major energy efficiency retrofit of the lighting and HVAC systems partially funded through the utility energy program. After the retrofit was completed in 1998, the utility bills revealed that only about 30% of the predicted savings were being realized. Bulls-eye commissioning was started and resulted in an improvement to 90% of predicted savings.

1600 Executive Parkway: As Found Conditions

The building is a 40,000 square foot, four-story, masonry structure, built circa 1985. The glazing is tinted double pane with aluminum frames. In general, the building follows a typical office occupancy usage of 8:00 A.M. to 5:00 P.M., Monday through Friday with limited weekend use. Over the previous four years, the average annual electrical consumption was over 1,500,000 kWh or 128,000 Btu/sq.ft./yr.

HVAC description.

The building is mechanically cooled by a 40-ton packaged rooftop, variable air volume (VAV) cooling unit and heated with electric resistance coils located in the VAV boxes. Some of the perimeter boxes are fan-powered VAV boxes. Heating and cooling is thermostatically controlled and had no setback control. The cooling coil was set to discharge a constant temperature of approximately 60^{o}F. There are three 35 HP compressors with three stages of unloading each that maintain the set cooling temperature. The air handler is 42,000 CFM powered by a 40 HP motor with the air volume varied by a variable speed drive that is controlled by a static pressure sensor located down the supply duct. The static pressure set point is approximately 2 inches of water pressure in the ductwork.

During the initial site visit we discovered that the HVAC system was not operating as originally designed. For example, the economizer was disabled by being bolted shut and return-air flow back to the air handler was minimal. It appeared that most of the return-air flow is from the fourth floor. Maintenance staff indicated that the economizer was bolted shut to keep the front doors from pushing open. The result of these observations clearly indicated that the air distribution system was out-of-balance.

These observations only tell part of the story. Utility staff then set up monitoring equipment to measure supply air temperature, outside air temperature, cooling compressor power, and supply air fan power over a five-day period. This additional information indicates that the control strategy was ineffective and costly in demand charges and in annual maintenance.

Additionally, staff randomly checked one VAV box on the second floor and discovered that the box was out-of-control continuously swinging from full open to closed. This condition is another indication of poor system control.

DATA LOGGING

The following data points were measured over a five-day period.

1. Supply air temperature
2. Outside air temperature
3. Cooling compressor power (Three 35-HP, three-stage compressors)
4. Supply air fan power

The data was recorded in one-minute time intervals. The information gathered includes power factor (PF), kilo Watts (kW), kilo Volt-Amperes (kVA), kilo Volt-Amperes reactive (kVAR), and temperature (T). The results are shown graphically in Figure 1.

Several noteworthy observations are:

1. Compressor cycling. Compressors are energized for a couple of minutes and de-energized for a couple of minutes. This type of operation causes several negative results, high demand (kW), stress on the compressors, high maintenance costs, unstable supply air temperature, poor energy efficiency, and high energy costs. There are three compressors with three stages of unloading for a total of nine stages available to match the cooling load in the building. The control strategy did not optimize this capability.

2. Fan performance. The fan drew a nearly constant 25 kW. The fan performed as a constant volume fan, rather than a VAV fan. This indicates that the static pressure control operation was not working. The fan power draw should vary with the changing load on the building. For example, during peak cooling the fan should deliver higher flow (CFM) with a corresponding higher fan power draw and during off peak periods, the fan should deliver low airflow with a corresponding lower fan power draw.

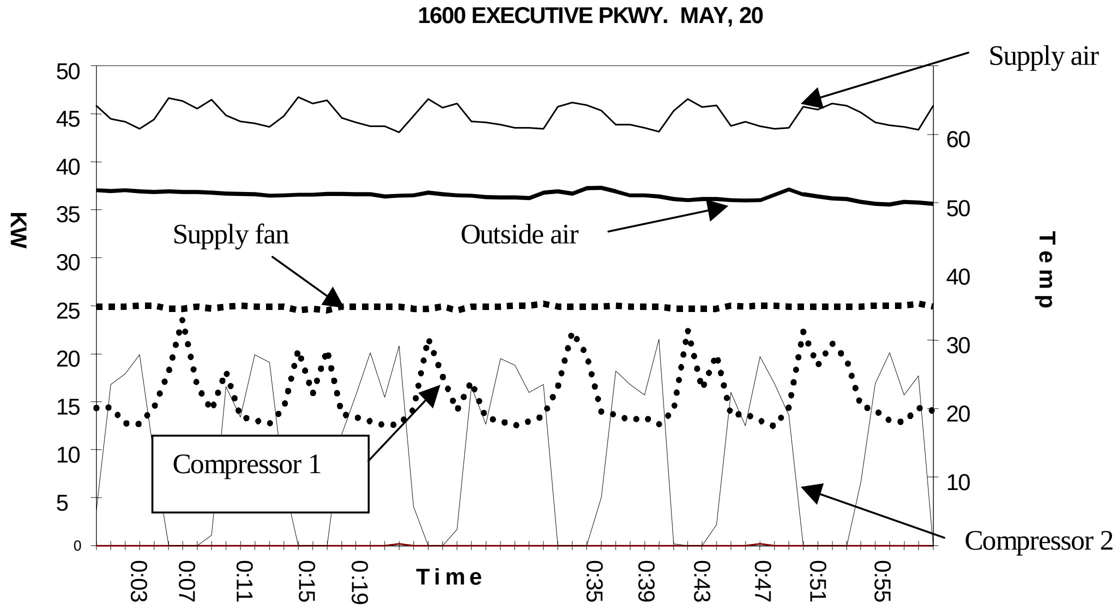

Figure 1. Short-Term Data Logging

3. Supply air. The supply air temperature was somewhat unstable. There was a 5°F change every two to three minutes. The supply air temperature is directly proportional to the compressor operation. Nine stages of compressor operation are cycled on and off to keep the supply air with in a 5°F dead band.

Figure 1 shows a one hour period of time from midnight to 1:00 a.m., Tuesday May 20, during an unoccupied period. Compressor #1 is cycling between about 15 kW (first stage) and about 23 kW (second stage) and compressor #2 is cycling on and off. The two compressors are driving the supply air temperature to between 60°F and 65°F. The supply fan is drawing a constant 25 kW (constant speed) and the out side air temperature is a constant 50°F.

Proper controls would keep the mechanical cooling compressors from activating by using two control strategies. During the early morning and early evening unoccupied periods, a setback control schedule reduces cooling need. During the later morning the outside air economizer could use cooler 50°F outside air in lieu of mechanical cooling.

When mechanical cooling is needed, proper compressor controls should provide staging with short-cycle prevention.

UTILTY RECOMMENDATION

Energy-use calculations were performed using the DOE 2.1E energy simulation computer program. The computer program models the thermodynamic characteristics of the building and the mechanical systems response for every hour of the year. A model of the existing building was built and calibrated to the existing conditions. The calibrated model was then changed to reflect various proposed changes and then was compared to determine potential annual energy savings. Several expensive retrofit solutions were discussed; however, the building owner decided that the air distribution system problems should be solved first. This work required re-commissioning the economizer and balancing the return air system. Heating and cooling control improvements were also recommended because the existing controls were inadequate. The control functions recommendations included:

1. Cold deck reset based on discriminator control loop.
2. Improved compressor staging controls with short cycle prevention.
3. Unoccupied period temperature setback.
4. Unoccupied outside air shutoff so ventilation air dampers close during unoccupied periods, including morning warm up.
5. Supply fan control. Re-commission so static pressure control allows fan to track building load as a VAV system is designed to do.
6. Controls to turn off or cycle fan during unoccupied periods.

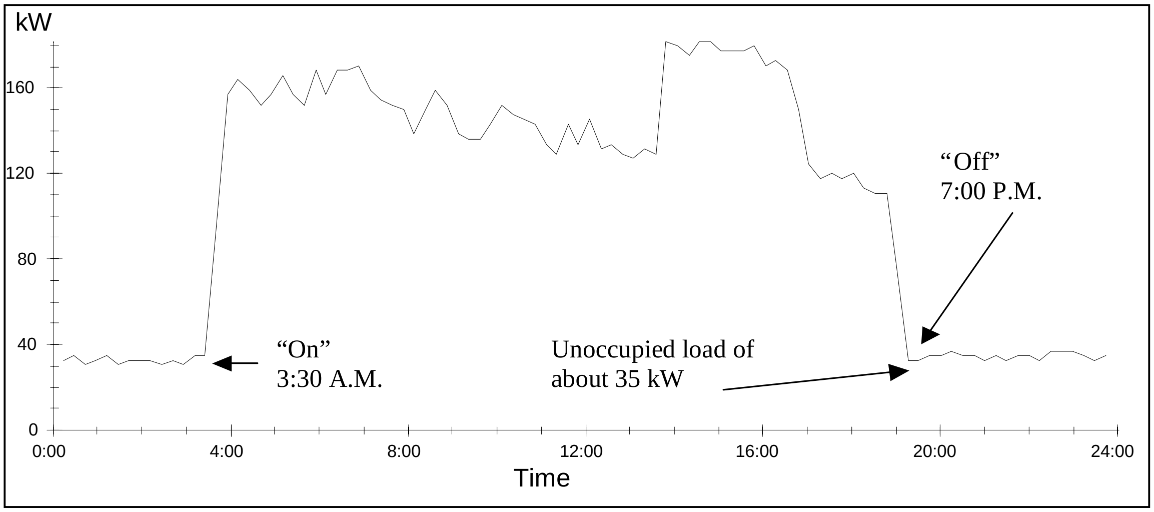

Figure 2. Daily View

To accomplish this a DDC system was recommended along with digital controls out to the VAV boxes. Due to costs constraints, building owners elected to retrofit 6 or 7 boxes per floor with DDC for primary air reset and leave the remaining boxes controlled pneumatically.

An additional recommendation was to retrofit the entire interior lighting system with T-8 lamps and electronic ballasts.

The estimated costs for the project was about $154,000 and the utility incentive was over $90,000. The estimated annual electrical savings was 45% or about 674,000 kWh.

<u>Implementation</u>

Three separate contractors completed the work. A HVAC contractor performed the re-commissioning work. A DDC system was selected and installed by a controls contractor and another completed the lighting.

WHERE THE RUBBER MEETS THE ROAD: USING BULLS-EYE COMMISSIONING

Are the promised energy savings really there? With bulls-eye commissioning the analyst does not have to wait for monthly utility bills to determine if the project is saving energy. With next day interval data, not only can one determine if the energy savings is on track, but how individual building systems are performing.

<u>Monitoring with Interval Data</u>

About a year before the project was started, the building meter was retrofitted with an interval data recorder as part of a utility load research effort. After completion of the re-commissioning, installation of a DDC control system, and the lighting retrofit, the building meter interval data was analyzed.

<u>Viewing the Interval Data</u>

Spreadsheet programs are useful and sometimes necessary to provide data visualization; however, utilizing spreadsheets is considerably more time consuming than using specialized applications. The profiling software used in this analysis allows the user to quickly zoom to the desired time interval (day, week, or month) and do focused analysis. They are designed to quickly import interval data and other data streams such as hourly dry-bulb weather.

Viewing daily profiles provides the greatest level of detail as seen in Figure 2. At first glance, the graphical data indicates basic on/off building operation, unoccupied load, and peak loads.

There is an unoccupied load of about 35 kW. With this information, some questions arise: Why does the building start up at 3:30 A.M. when occupancy starts closer to 7:00 A.M.? Does it really take three hours to bring the building to temperature? Can the building systems be turned off at 5:00 or 5:30 P.M.?

<u>Adding Comparative Information</u>

As described earlier, the graphical representation of AMR interval data provides the necessary backdrop for system analysis. Comparative data was added to help determine how individual systems were operating. The comparative data included an end-use analysis estimate, concurrent weather data, and other trend data points from the DDC system.

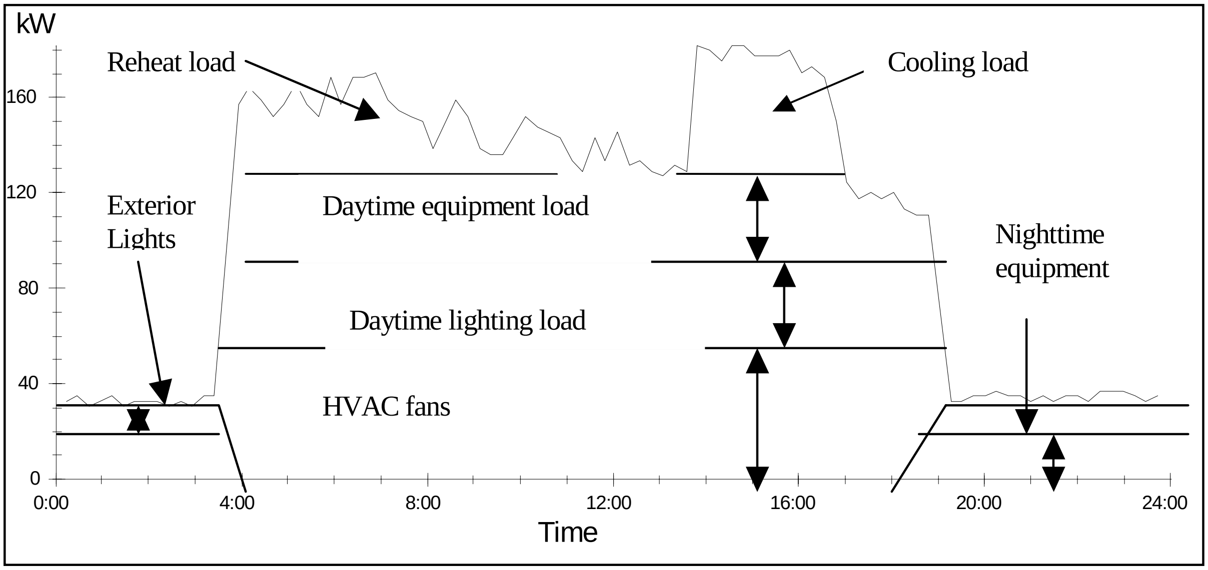

Figure 3. Daily View With EULA Overlay

<u>End-use Load Comparison</u>

To complete an End-Use Load Analysis (EULA), staff started with a facility survey of system loads (kW). Information gathered included the nominal power ratings of equipment such as: exterior lights, interior lights, HVAC (fans, pumps, compressors, cooling towers), hot water, and plug loads (computers, copiers, fax, space heaters, etc.). To keep with the 80/20 Pareto principle, existing drawings, engineer's estimates, and sampled surveys were used to give reasonable estimates of end-use. The analyst overlaid expected end-use information on the measured daily load profile. With it, the analyst can compare actual operation with an expected profile. Figure 3 illustrates about 40 kW of re-heat load that starts at 3:30 A.M. and tapers off around 8:00 A.M. The cooling system (50 kW) starts at about 1:30 P.M. and turns off at about 5:30 P.M.

<u>Weather Data Comparison</u>

An additional level of information was obtained by adding hourly weather data. The dry-bulb weather overlay lets the analyst see how the building responds to weather in a dynamic way. For example, with an overlay of hourly dry-bulb temperature, it was possible to see if the HVAC economizer cycle was working properly

<u>Comparison to DDC or Data Logger Trends</u>

The third level of added information was obtained by overlaying data streams from existing DDC trends (where available) or data loggers. Many data streams may be of interest, such as economizer position, discharge-air temperature, supply fan static pressure operation, etc. With additional trend information, the analyst can verify sharp changes in the main building load profile, and look for changes that do not make sense.

<u>Putting It All to Use</u>

After viewing the daily electrical profiles and doing a EULA, the operational questions were asked of the property manager, building operator and the controls contractor. Such as why does the building start up at 3:30 A.M. when occupancy starts closer to 7:00 A.M.? Does it really take three hours to bring the building to temperature? Can the fan system be turned off at 5:00 or 5:30 P.M.?

<u>HVAC Schedule Change</u>

The controls contractor input a HVAC operation schedule that was coordinated through the building operator. The building operator believed that it took three hours to warm up the building, based on his experience with the building. We decided to utilize the trending capability of the DDC system to see how long it really took to get the building up to temperature in the morning.

Trending of representative spaces in Figure 4 showed that morning warm-up took less than a half of an hour. This information provided the building operator the necessary confidence to allow a change in the HVAC schedule as seen in Figure 5.

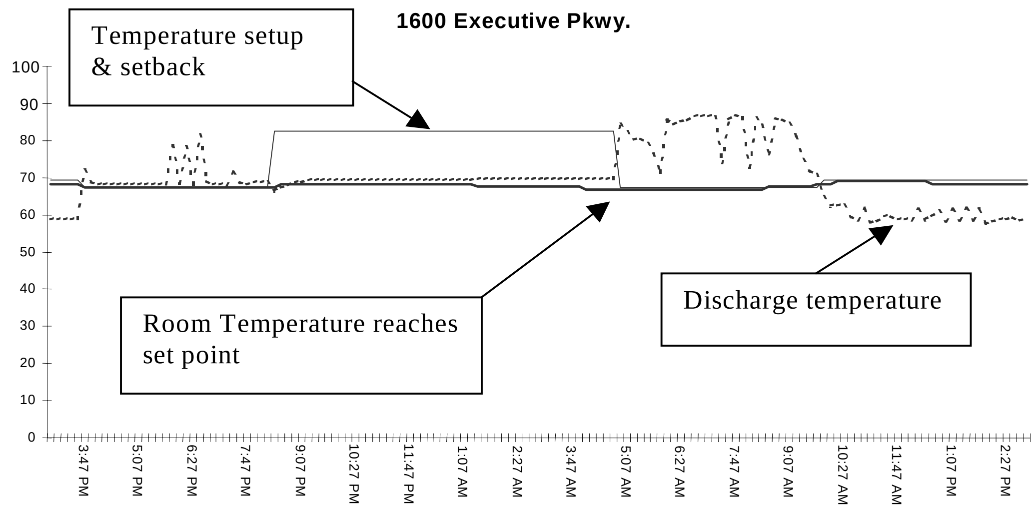

Figure 4. Trending of Morning Warm-up

The HVAC schedule could have been more aggressively altered, however, substantial savings were still achieved. Similar HVAC schedule changes were made to the other two newly purchased buildings.

Economizer Operation

Utilizing the dry-bulb weather overlay, as shown in Figue 6, it became apparent that the economizer was not operating as intended. Now staff could focus attention and utilize the DDC trending capabilities. One minute interval data as seen in Figure 7, showed an unstable economizer analog output. In addition, the economizer changeover or high temperature lockout set point was set at 55°F. Software operation logic was adjusted and the changeover set point increased to 65°F. This resulted in about 2 to 3% additional energy savings and more reliable and stable economizer operation as shown in Figure 8.

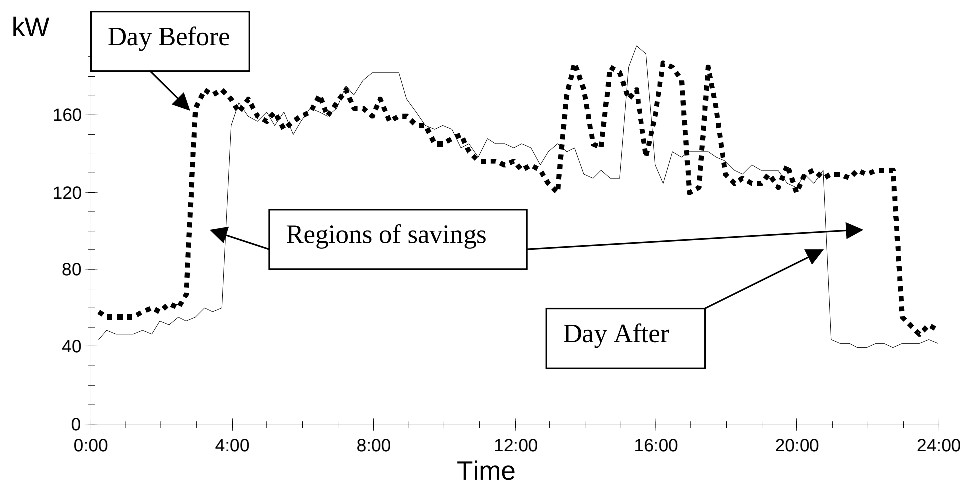

Figure 5. HVAC Schedule Change

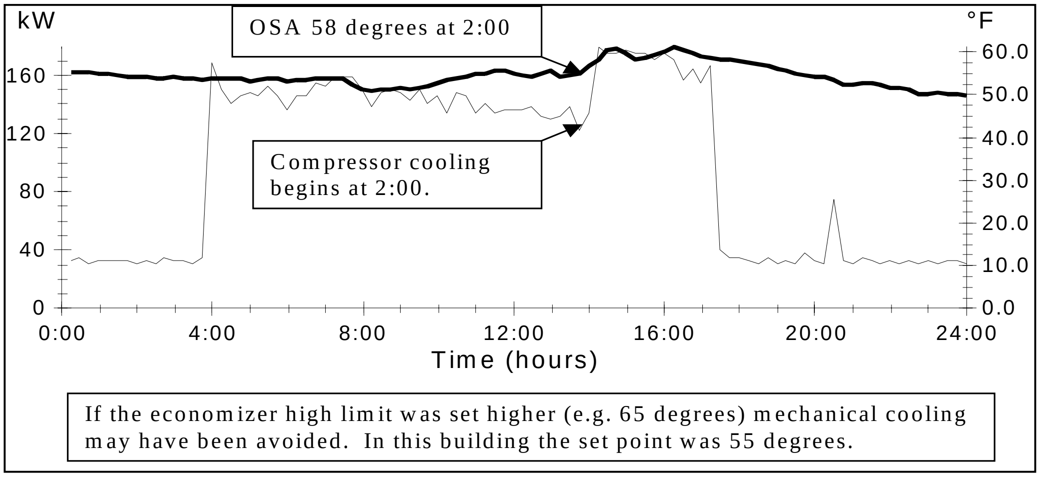

Figure 6. Daily View with Outside Air Overlay

<u>Supply Fan Operation</u>

The building meter interval data does not directly indicate how the fan pressure controls are operating. However the DDC system can. We expect that the fan control will follow the load requirements. Figure 9 shows the sum of the CFM from the control VAV boxes in the building versus the fan flow control output. The two graph lines should follow each other and they do not. The supply fan control throttles at about 95% full speed. Significant fan energy savings were not being realized. The fan control turned out to be a variable width wheel rather than a variable speed drive, and simple adjustment was not possible. Consequently, better tracking of the fan with airflow requirements was not implemented in the commissioning phase. This problem remains a point for further research.

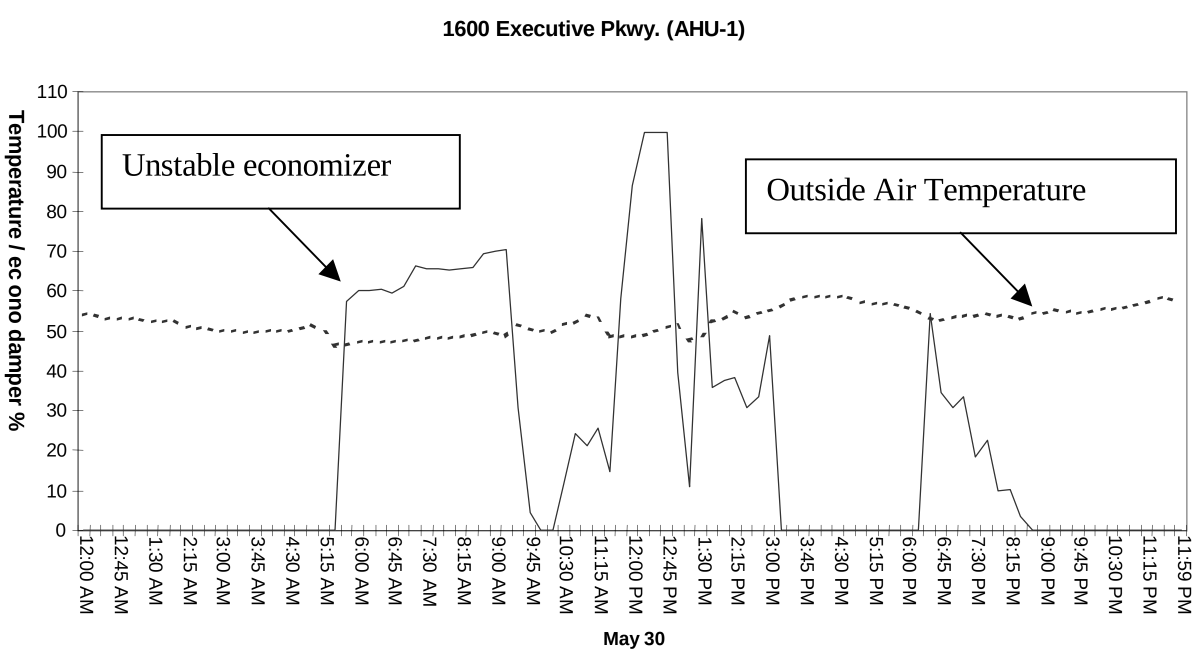

Figure 7. Unstable Outside Air Economizer

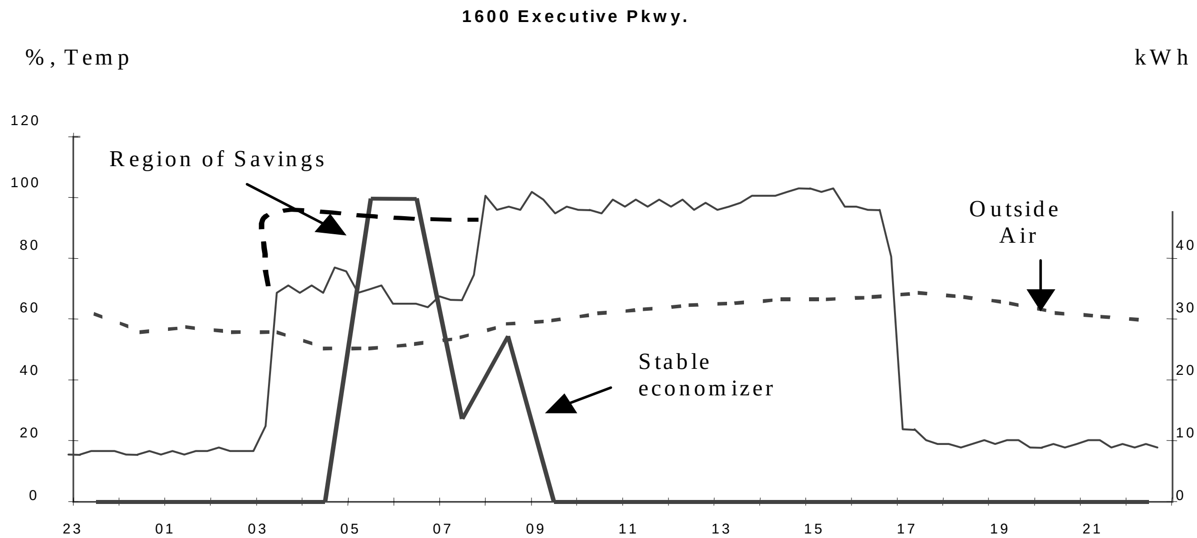

Figure 8. Stable Economizer

The Other Executive Parkway Buildings

The other newly purchased buildings were also examined in a similar way. In general, lessons learned in the first building (1600 Executive Parkway) were applied to the others (1200 and 1400 Executive Parkway). One noteworthy exception was the HVAC fan control for the 1400 building. The profile quickly demonstrated that the unoccupied loads were very high. After a quick end-use load analysis similar to the one shown in Figure 3, it seemed likely that the HVAC fan system was operating 24 hours per day. Phone calls were placed to the property manager and HVAC controls contractor. The controls contractor found the problem in about an hour. It turned out that the final transfer of scheduling to the DDC system had never happened. The building fans were still controlled by an old time switch with the trippers removed. After the HVAC fan systems were shut down at night, an additional 12% kWh savings was realized as demonstrated the next day by Figure 10.

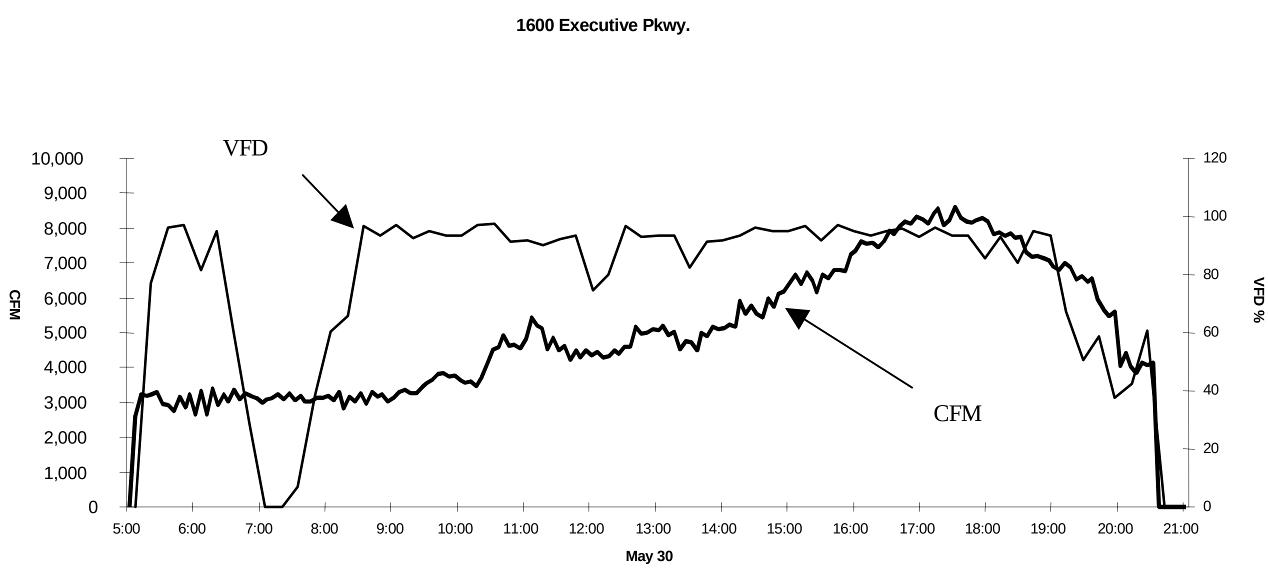

Figure 9. Variable Fan Control Signal v. Box Airflow

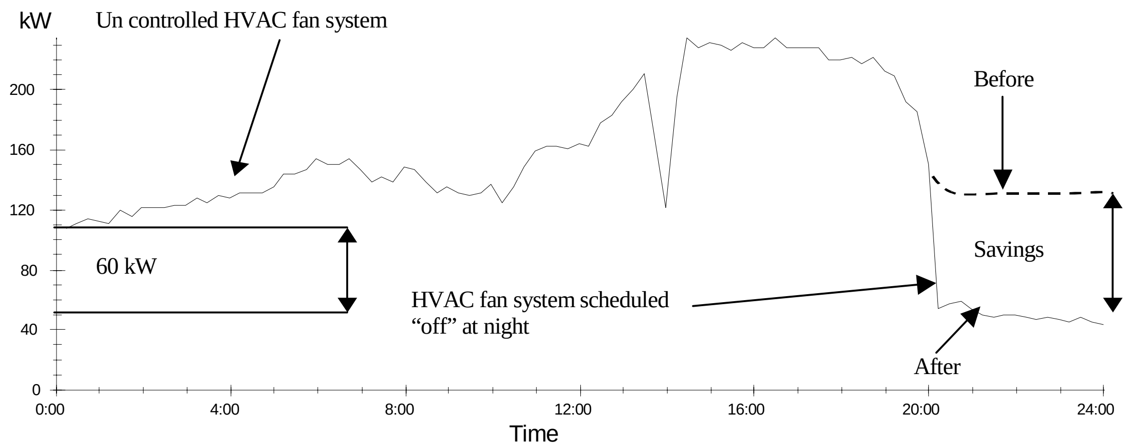

Figure 10. Verification of HVAC System Change

ADVANTAGES AND LIMITATIONS

Bulls-eye commissioning can be very effective in finding the right 20% of detailed commissioning needed under the 80/20 rule. Once profiles are reviewed with respect to outside air temperature or end-use load activity, the main-meter graphs will likely point to problems with equipment schedules or HVAC controls that can then be researched with spot commissioning activities. The major advantages of bulls-eye commissioning using whole-building interval data were:

- Analysis started with only one point to check: total building electrical usage. Data directly represents total electric energy use the customer pays for.
- The data visualization pinpointed events by time of day. This type of information is easy to comprehend, allowing further sleuthing into scheduling and controls.
- The process provided a quick feedback loop to see how equipment and operational changes impact building loads. The actual load profile resulting from changes in operation were reviewed the next day.
- Pictures make the point. Graphic profiles can be powerful evidence that motivates change by building operators and owners.

Bulls-eye commissioning limitations for this project relate to subtle issues such as compressor short cycling or improper VAV fan control. To deal effectively with these issues, shorter time intervals (one-minute or less) and more specific data were needed from short term data logging and the DDC system.

SUMMARY

The aim of bulls-eye commissioning is to quickly find when energy is being wasted and determine possible causes. The analyst does this by understanding the shape of the daily electrical profile of the building. Recommendations are made for further investigations, operational changes, hardware retrofits, or control retrofits. Graphical and statistical manipulation of AMR interval data can be a cost-effective means of discovering unnecessary energy use. Getting the highest level of understanding with the lowest level of effort and cost is the strength of bulls-eye commissioning. The initial energy efficiency retrofit had the following benefits:

- Reducing energy use from unneeded HVAC and lights.
- Reducing peak loads.

After the retrofit, the customer found cost-effective ways to save energy with bulls-eye commissioning by:

- Reducing unoccupied energy use through schedule changes to unneeded HVAC equipment.
- Reducing unnecessary mechanical cooling through economizer optimization.

Through the process of bulls-eye commissioning, the customer went from less than 40% of expected savings from the retrofit to over 90%. The other 10% of savings were not obtained because the building system start-up and shutdown schedule was longer than modeled. The extended schedule was necessary because of the business hours of a tenant that occupied most of the 4th floor and to the fact that there is only one HVAC system for the entire facility.

REFERENCES

Alereza, T., and R. Faramarzi. 1994. "More Data Is Better, But How Much Is Enough for Impact Evaluations?" *In Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings*, 2:11-19. Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE).

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). 1996 "The HVAC Commissioning Process." *ASHRAE Guideline 1-1996* Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Claridge, D., M. Liu, Y. Zhu, M. Abbas, A. Athar, and J. Haberl. 1996. "Implementation of Continuous Commissioning in the Texas LoanSTAR Program: "Can You Achieve 150% of Estimated Retrofit Savings" Revisited." *In Proceedings of the ACEEE 1996 Summer Study on Energy Efficiency in Buildings*, 4:59-75. Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE).

Piette, M.A., L. Gartland, S. Khalsa, P. Rumsey, L.E. Lock, A. Sebald, and C. Shockman. 1998. "Development and Testing of an Information Monitoring and Diagnostic System for Large Commercial Buildings." *In Proceedings of the ACEEE 1998 Summer Study on Energy Efficiency in Buildings*, 8:263-277. Washington, D.C.: ACEEE.

Price, W., and R. Hart. 2002. "Bulls-Eye Commissioning: Using Interval Data as a Diagnostic Tool." *In Proceedings of the ACEEE 2002 Summer Study on Energy Efficiency in Buildings*, 3:295-308. Washington, D.C.: ACEEE.