Bulls-Eye Commissioning: Using Interval Data as a Diagnostic Tool

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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. A Northwest utility recently installed interval meters to develop a cross sectional load study. Once installed, energy conservation staff used collected interval data for building load analysis.

During the course of investigating the disappointing savings from a recent control upgrade (funded primarily through utility incentives), staff used whole-building 15-minute interval data in conjunction with outside air temperature to pinpoint control problems in the economizer and fan schedule controls. The effort added about 15% to building energy savings, without the wait and expense of full commissioning services.

Since this initial effort, *bulls-eye commissioning* has been applied to over a dozen buildings. 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. Evaluation of main meter profiles allows detailed commissioning work to be better focused and more effective. Main meter profiles are also useful in evaluating the effectiveness of control changes and other energy measures. This paper documents the techniques and benefits of using bulls-eye commissioning.

Introduction

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.

This paper introduces the concept of *bulls-eye commissioning*. Bulls-eye commissioning uses analysis of 15-minute interval consumption data from the main building meter for energy management activities, including various forms of commissioning, Measurement and Verification (M&V), Operation and Maintenance (O&M), Energy Conservation Measure (ECM) evaluation, ECM feasibility analysis, and DOE2[2] model calibration. 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.

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[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.

[2] DOE2 is a computer program that uses an hourly method to model building system energy use.

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. In contrast, commissioning or monitoring-based energy analysis activities typically require the use of targeted short-term monitoring (data loggers) or trending of 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.

In this paper, general procedures and examples are included for bulls-eye commissioning. Case studies demonstrate how to achieve energy savings in situations where energy professionals can apply bulls-eye commissioning.

Background: Commissioning Goals

A review of various types of commissioning, M&V, and O&M activities finds many definitions, issues, and protocols. 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 (retro-commissioning, re-commissioning, and continuous commissioning).

An ongoing goal common to all these missions is to use cost-effective techniques that provide the necessary level of data accuracy. The list below illustrates some of the goals or methods discussed in the literature that are common to most of these activities:

- Data visualization (Stein, Raychoudhury & Eley 2000).
- Remote monitoring (Yoder & Kaplan 1994).
- Hourly energy use profile (Claridge et al. 1996; Verdict et al. 1990).
- Cost-effective monitoring (Jump, Johnson & Farinaccio 2000; Kromer & Schiller 2000).
- Quick feed back loop – one day later (Piette et al. 1998).
- Identify shut-down opportunities (Claridge et al. 1996).
- Weather normalization (Schueler 1990).
- DOE2 model calibration (Stein et al. 1998).

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 the services described above; however, a more useful interpretation is to think of using whole-building interval data as an effective tool that can precede or compliment all of these services. Additionally, the energy professional can often obtain the interval data needed for bulls-eye commissioning from existing utility billing equipment.

Bulls-Eye Commissioning: A Building Level Diagnostic Tool

Electric meter interval data provides good gross building-level diagnostic information (Alereza & Faramarzi 1994; Claridge et al. 1996). At about $600 per installation for hardware & software, an interval metering point compares favorably to typical DDC system points, which range in price from $500 to over $1,000. An added benefit is that the whole-building electric meter may be one of the most useful points because it tracks what the customer pays for.

AMR: Interval Data Collection System

Eugene Water & Electric Board (EWEB), a Northwest Municipal Utility with 72,000 residential and 4,000 commercial customers, started a strategic metering project in 1996. The original scope of the project was to collect interval meter data to support two business needs identified at that time: (1) load research for cost of service studies and (2) customer data services, such as on-line meter data. There are now approximately 250 commercial meters and 100 residential meters connected to the system. Two separate functions are required to get usable interval data to the customer:

- The first function is to collect and store the data. EWEB installed pulse output meters with Teldata meter recorders[3] that use landline and cell phone communications. Recorders call a host computer periodically to upload the meter data.
- The second function is to provide the information to the customer or analyst through various platforms. In June 1999, EWEB partnered with Energy Interactive, Inc. to provide customers information access with either a web-based interface or more powerful desktop software. For web access, verified data is uploaded nightly to a host web site. Currently, EWEB has 109 meters subscribed to the PowerLine™ web service and three customers have leased desktop software.

Cost. Commercial meter installations require a solid-state meter with a pulse output that costs approximately $300. Commercial and industrial sites take an average of 90 minutes to prepare, costing approximately $80-$100 in labor. Adding the meter shop technician labor and database setup brings the total cost of remote metering at typical commercial/industrial sites to approximately $550-$600 per meter. EWEB offers web access for $29 per meter per month, with desktop software available at $1,500 per workstation or leased for $180 per month.

Viewing the Interval Data

Many software applications can translate interval data into a meaningful graphic profile. For example, spreadsheet programs can be used to provide data visualization; however, utilizing spreadsheets is considerably more time consuming than using specialized applications. Profiling software includes Energy Interactive, EnerLink, Silicon Energy, and others. These applications allow the user to quickly zoom to the desired time interval (day, week, or month) and do statistical analysis. Statistics can be generated from daily or cumulative ranges and include information such as average kW, peak kW, time of peak

[3] Teldata's units come with four channels, so a single unit can handle two non-KVAR electric meters, one water meter, and one gas meter. Communication can be either via inbound phone (using either a non-dedicated phone line or a cell phone), dial-up phone (requiring a dedicated phone line), radio broadcast, or internet. EWEB uses in-bound phone for most meters. All current transformer meters used at large commercial and industrial facilities can have AMR equipment installed without a service interruption.

occurrence, and total kWh. Statistical overlays of the peak day vs. the average weekday can be generated similar to the one shown in Figure 8. They are designed to quickly import interval data and other data streams such as hourly dry-bulb, cloud cover, relative humidity, chiller kW, etc. Weather data in many standard formats can be imported from either a local DDC system point or on-line weather service. Energy professionals typically view interval data in one of three modes: monthly, weekly, and daily. What to look for in each view will be discussed below.

Monthly data. Visually scanning a year's worth of data by month is a quick way to see how loads change seasonally. Typically, a cooling load will be present in summer months and a quick observation of how the magnitude of kW changes can give valuable information. The monthly view is just a starting point to get a high level view of how the building operates.

Additionally, overall weekday and weekend operation patterns are easily detected as seen in Figure 1. Typically, weekdays are identifiable by a series of five repeating daily profiles of nearly equal magnitude (kW). Weekend profiles are typically seen as two repeating daily profiles somewhat lower in magnitude (kW) than weekdays.

Figure 1. Typical Monthly Profile

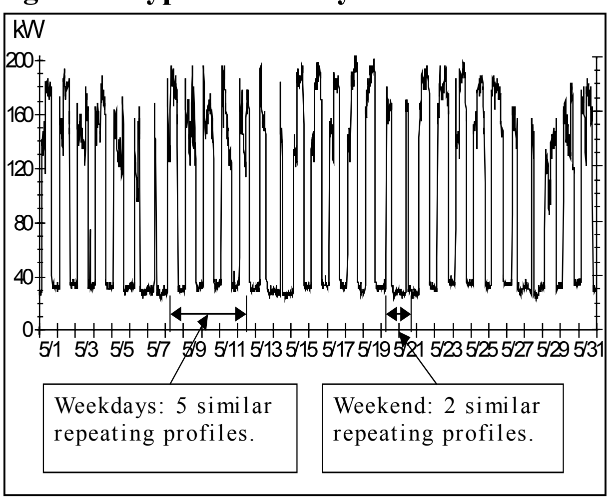
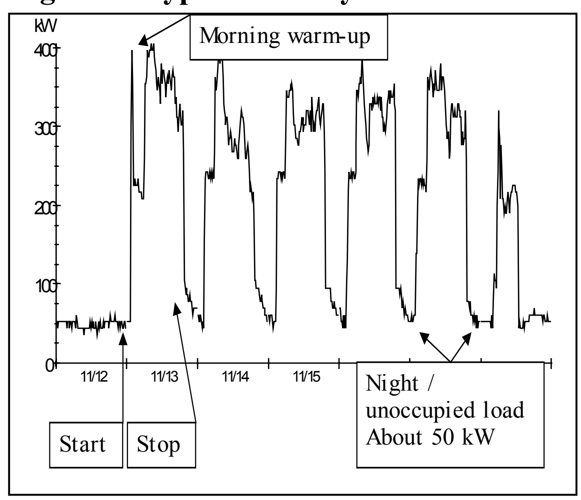


Figure 2. Typical Weekly Profile



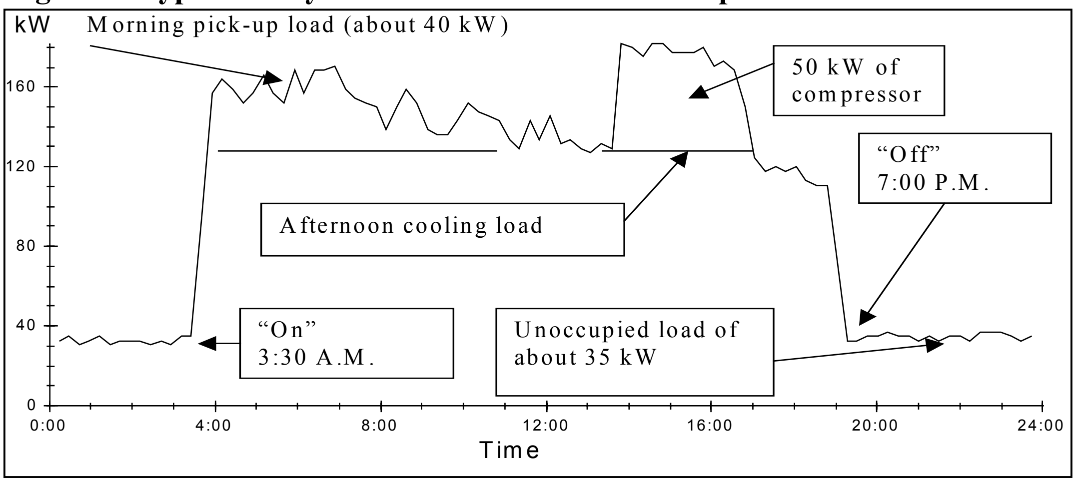
Weekly data. Viewing interval data in a weekly mode provides additional detail on systemic patterns. Figure 2 shows daily load shapes side by side. Detail starts to emerge, such as morning warm-up spikes, nighttime loads, and scheduled start and stop times; allowing the analyst to see weekday and weekend differences in finer detail.

Daily data. Viewing daily profiles provides the greatest level of detail as seen in Figure 3. At first glance, the graphical data indicates basic on/off building operation, unoccupied load, and peak loads. 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. There is an unoccupied load of about 35 kW. With this information, some questions may 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 fan system be turned off at 5:00 or 5:30 P.M.?

Adding Comparative Information

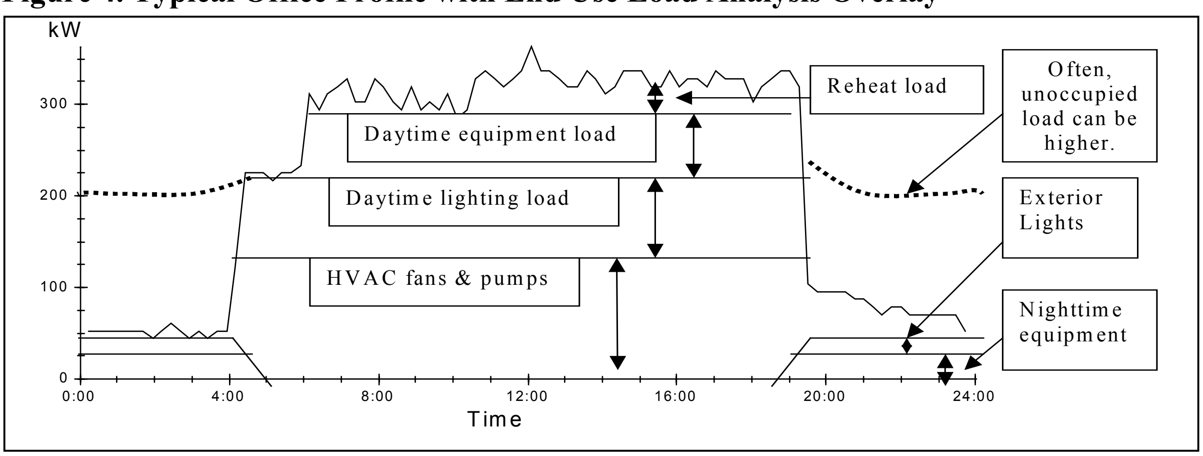
As described earlier, the graphical representation of AMR interval data provides the necessary backdrop for system analysis. Comparative data can be added from an end-use analysis or estimate. Concurrent weather data, or other trend data points from data logging or a DDC system are also useful for comparison.

Figure 3. Typical Daily Profile with Excess Warm-Up



End-use load comparison. To complete an End-Use Load Analysis (EULA), start with a facility survey of system loads (kW). Information gathered should include 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, sampled surveys and end-load estimates may be appropriate here. Lighting Watts per square foot from a sampled area or expected fan hp per square foot for a similar system can be used in place of surveyed data.

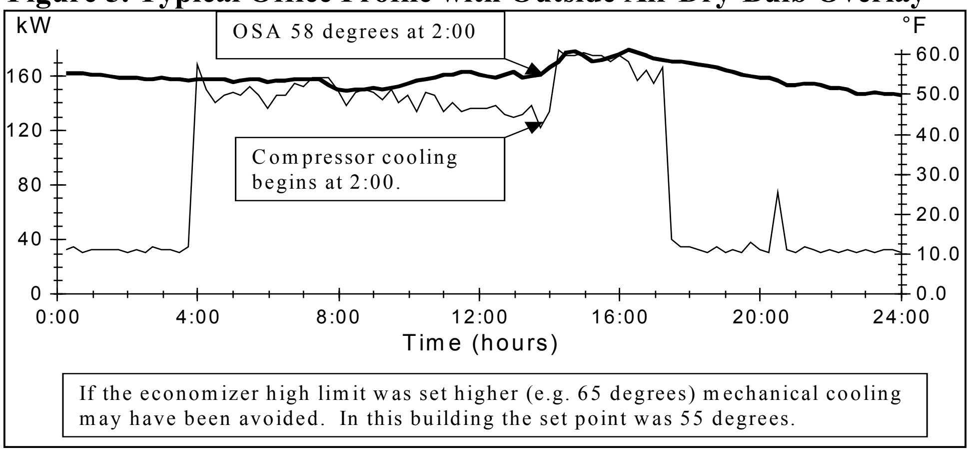
Figure 4. Typical Office Profile with End Use Load Analysis Overlay



The analyst can overlay expected end-use information on the measured daily load profile. With it, the analyst can compare actual operation with an expected profile. Figure 4 shows a building that has reasonable operating loads and expected schedules; however, the daily profile will often look different. The overlay stimulates questions such as: "Why is there 200 kW of load on at night when only 50 kW is expected?" The expectation might be based on 8 kW in exterior lighting, 15 kW in emergency-circuited interior lighting, and 27 kW of equipment load.

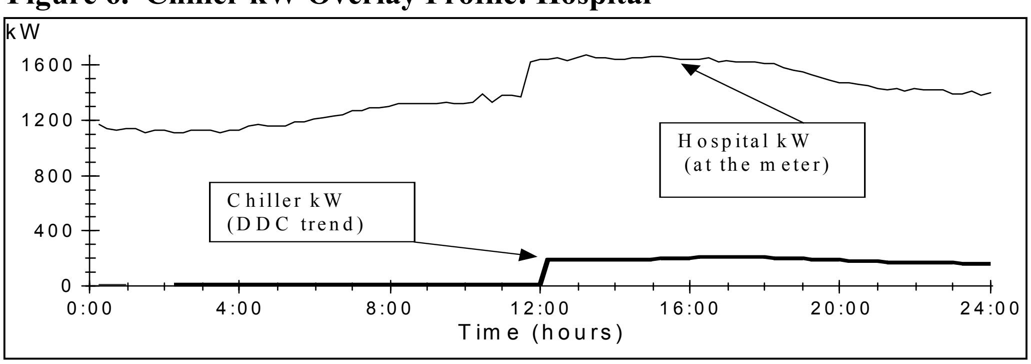
Weather data comparison. An additional level of information can be obtained by adding hourly weather data. The overlay in Figure 5 lets the analyst see how the building responds to weather in a dynamic way. For example, with an overlay of hourly dry-bulb temperature, it may be possible to see if the HVAC economizer cycle is working properly. For longer-term analysis, profiling daily highs and lows on a month-long profile may help spot unusual HVAC operation.

Figure 5. Typical Office Profile with Outside Air Dry-Bulb Overlay



Comparison to DDC or data logger trends. The third level of added information is obtained by overlaying data streams from existing DDC trends (where available) or data loggers. Many data streams may be of interest, such as chiller kW (see Figure 6), discharge-air temperature, cooling tower 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.

Figure 6. Chiller kW Overlay Profile: Hospital



Case Studies

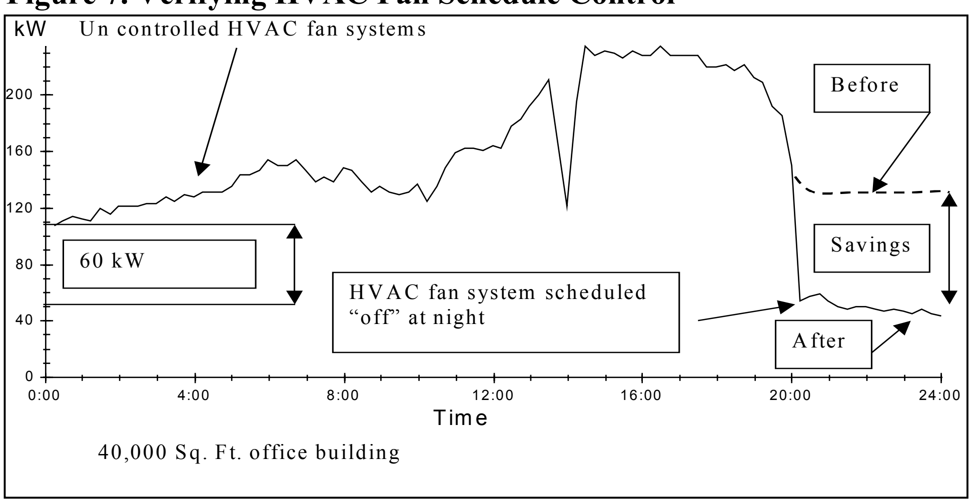
Over the past two years, more than a dozen EWEB customers have benefited from bulls-eye commissioning. Several representative examples of utilizing AMR interval data are discussed below. Table 1 summarizes the four case studies.

Table 1. Case Study Summary

Case	Facility	Commissioning	O & M	M & V	Other
1	40,000 sq. ft. office building	Identify OSA economizer & schedule control problem	Simple control change	Major efficiency project (lights, HVAC, controls)	
2	Airport Terminal	Identify demand spikes	Demand reduction	Single ECM	
3	50,000 sq. ft. office building				Quick ECM analysis or elimination
4	Convention Center: 116,000 sq. ft.			Major efficiency project (lights, HVAC, controls)	DOE2 calibration

Case study 1: re-commissioning, O&M, and M&V of an office building. In a 40,000 square foot, four-story office building, the HVAC system consists of two roof-mounted 40-ton packaged VAV units with perimeter electric-resistance fan-powered VAV boxes. After the building received a major HVAC, control, and lighting retrofit, the energy use was found to be higher than expected. The DOE2 model indicated the project would save about 23% in annual electricity use, while the interval data showed only 10% savings. While monthly utility bills would show the same thing, the interval data gave the feedback within a few days, as compared to a thirty-day wait for a normal electric meter read.

Figure 7. Verifying HVAC Fan Schedule Control



A component of the retrofit was to upgrade the pneumatic controls to a DDC system. After project completion, the electrical profiles of the building were reviewed. The profile seen in Figure 7 quickly demonstrated that the unoccupied loads were very high. After a quick end-use load analysis (similar to the one shown in Figure 4), it seemed likely that the HVAC fan system was operating 24 hours per day. Phone calls to the property manager and HVAC controls contractor were placed. 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 7. The analysis also uncovered economizer control problems using the method of overlaying dry-bulb weather data shown in Figure 5. The economizer lockout setpoint was adjusted, adding to the savings.

Case study 2: O&M analysis for airport terminal. On completion of a major lighting upgrade at a municipal airport, analysts used bulls-eye commissioning to verify ECM energy savings (M&V). During review, profiles revealed an unexpected pattern of periodic demand spikes. Figure 8 uses a peak day vs. average weekday comparison to find demand peaks. Weekly and monthly graphs were also used to see the repeating pattern. The anomaly was discussed with the airport electrician, who immediately recognized the issue and indicated that he tested the concourse lighting system periodically. The lighting system is master switched (i.e., individual lighting circuits are ganged in large groups) so a large demand spike occurred with each test. Two options became apparent: change the switching arrangement (to switch fewer relays at one time) or test during the next shift when the background demand is lower. This correction will reduce peak demand by about 150 kW saving the airport $500 per month.

Figure 8. Demand Spike Anomaly

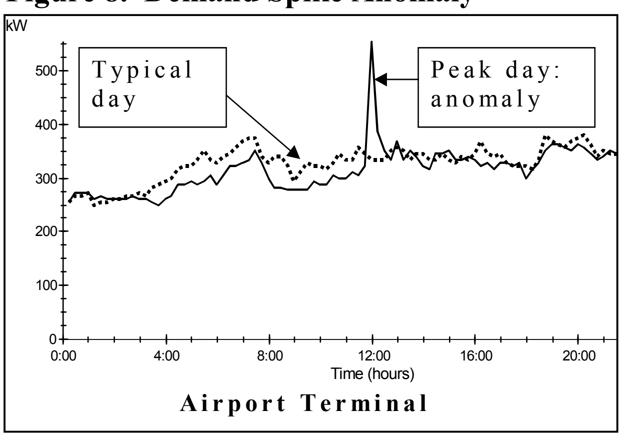
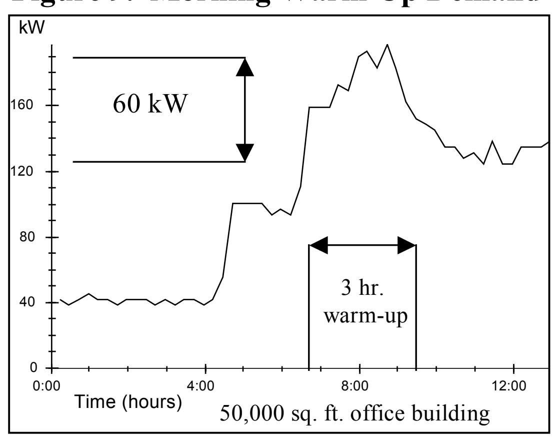


Figure 9. Morning Warm-Up Demand

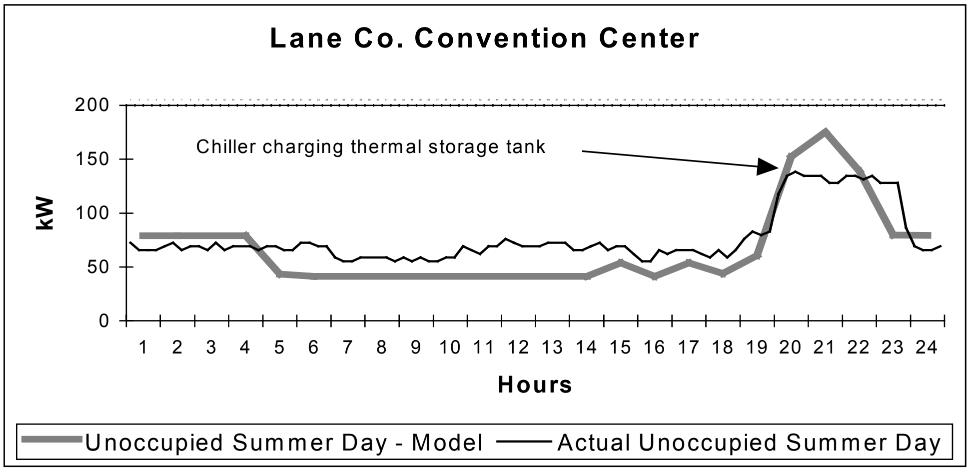


Case study 3: ECM evaluation. A major capital-cost energy conservation project was proposed for a 50,000 square foot office building. Part of the proposal included an expensive retrofit of the VAV boxes so that plenum air could be utilized when heating. Currently electric resistance coils in the perimeter VAV boxes heat cooled primary air for zone heating. Analysts viewed the AMR interval data in Figure 9 to determine the magnitude of the re-heat and found that the typical winter morning warm-up period is about two to three hours with about a 60 kW re-heat load.

Even if half of the warm-up demand and energy were saved three hours per day for the entire heating season, the simple payback would have been 30 years for the measure.

This quick analysis saved time and money. Without bulls-eye commissioning, a relatively expensive DOE2 model would typically be used to find the potential savings.

Figure 10. Using AMR Data to Tune a DOE2 Model



Case study 4: DOE2 calibration of chilled water storage. DOE2 modeling is often used in initial energy analysis and M&V activities for identifying ECM savings. AMR data can be used to calibrate DOE2 models, especially for unusual systems. A 116,000 square foot convention center uses chilled water storage. Chillers charge the storage system at night when chillers are more efficient. The stored chilled water is used during the day when background demand is higher. AMR data clearly showed how the system operates. This data can be effectively used to tune DOE2 models as demonstrated in Figure 10. The usefulness of a DOE2 model is dependant upon how well it models reality. The various engineering inputs and assumptions that go into a DOE2 model can be tested. By comparing DOE2 hourly reports against the real interval data, the model can be adjusted to more closely match building operation. This iterative process of modifying the DOE2 model is referred to as calibrating or tuning a model. For an existing system, bulls-eye commissioning makes the tuning process more efficient and accurate.

Advantages, Disadvantages, 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. Major advantages of bulls-eye commissioning using whole-building interval data include:

- There is only one point to check: total building electrical usage. Reviewing a single point takes less time than reviewing many.
- Data directly represents total electric energy use the customer pays for.
- The data is often available from utility billing meters.

- The data visualization pinpoints events by time of day. This type of information is easy to comprehend, allowing further sleuthing into scheduling and controls.
- The process provides a quick feedback loop to see how equipment or operational changes impact building loads. Typically, the actual load profile resulting from changes in operation can be reviewed the next day.
- Using a common data set allows a utility analyst or consultant to work with several customers who may have different control system manufacturers. Campus facility managers with control systems from multiple vendors can use AMR data from main building meters as a common reference point.
- The software provides quick access to average and peak profiles and summary use.
- Baseline profiles can be quickly compared to another period of interest.
- Pictures make the point. Graphic profiles can be powerful evidence that motivates change. For example, at the University of Oregon, graphic AMR profiles showed that unoccupied and weekend energy use was almost half of occupied period use. This (along with a significant rate increase) was used to motivate several developments: (1) Information Technology changed their policy to recommend that computers be turned off after hours, (2) HVAC technicians focused on turning off lights and fans, and (3) a campus-wide "lights-out" campaign was started.

Disadvantages of main meter interval data analysis include:

- System problems may get lost in the "noise" of the total building profile.
- It requires an experienced analyst to properly interpret the profiles.
- It will not find problems with one small system among many systems.

Bulls-eye commissioning limitations are:

- **Complicated systems.** Facilities that have heavy process loads tend to blur the end-use analysis. A hospital is an example of a complicated process-load-driven facility that is much harder to analyze with only AMR data. Even so, AMR data on even the most complicated facilities can reveal useful information (see Hospital: Figure 6).
- **Campus Aggregation.** Another factor in a hospital, office, or educational campus is that several buildings may share one meter. Individual building sub-metering is recommended on any campus to better track building energy use.
- **Multiple systems.** Facilities that have many individual HVAC units with differing occupancy periods will show the aggregate usage patterns, but the individual patterns for individual HVAC units may be blurred.
- **The human factor.** Many other examples similar to the case studies were not included in the paper. Often the building owner, operator, or manager chose not to act on the information presented (Yoder & Kaplan 1994). When given evidence in the form of graphical interval data along with suggested operational solutions (e.g., adjust start/stop schedules), responses vary and include thinking errors like:

- “That’s okay, this building is on DDC controls, we have an ‘optimal start’ routine.” This expresses the belief that if the building is operated by a computer it must be operating correctly.
- “We can’t start up the building later; it takes hours to warm up.” Operators provided this excuse even when space temperature trends indicated that zone temperature set points are satisfied within a half-hour of start up.
- “We can’t turn the computers off at night, it will wear them out.”

- **Subtle or short term variations.** Bulls-eye commissioning will not find subtle issues such as compressor short cycling or a chilled water PID control loop that needs tuning. To deal effectively with these issues, shorter time intervals (one-minute or less) and more specific data are needed.

Possible Next Steps in Bulls-Eye Commissioning

Bulls-eye commissioning is a work in progress. There are opportunities to expand its usefulness. A brief discussion follows of how different options might be developed.

O&M saving alarms. Once ECM installation and commissioning is complete and a building has been tuned, the building operator needs to know when systems go out of tune. A daily diagnostic system could use trending of energy use adjusted to weather. Stored indicators or profiles from proper operation could create a unique healthy building signature. The system could notify the building operator automatically by e-mail or other means whenever the building operates outside of user-selected tolerances. These limits would require trial and error to avoid nuisance calls. Such diagnostic indicators (Brambley & Pratt 2000) could be embedded into existing software applications by profile monitoring developers.

Communication improvement. As AMR meters, recorders, and network protocols continue to evolve so lone devices can be easily accessed over the internet without a supervisory server, complex firewall, or router, we expect that networking will replace inbound telephone and radio broadcast as the preferred communication method. With internet access, real-time data will be available and more immediate alarming can be provided.

AMR data analysis acceptance. As AMR becomes more widespread and analysts and consultants become more familiar with how to access and interpret it, it will become more useful. At present, some consultants reject using whole-building data because it does not provide the narrow information they are seeking.

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. Typically, the easiest and most cost-effective ways to save energy with bulls-eye commissioning are:

- Reducing unoccupied energy use from unneeded HVAC, lights, and equipment.
- Reducing peak loads, especially testing or short cycling that can be adjusted.
- Reducing unnecessary mechanical cooling through economizer optimization.
- Reducing unnecessary re-heat, especially during prolonged warm-up periods.

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