Advanced Metering Implementations-A Perspective from Federal Sector

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ABSTRACT

Federal mandate (EPACT 2005) requires that federal buildings install advanced electrical meters-meters capable of providing data at least daily and measuring the consumption of electricity at least hourly. This work presents selected advanced metering implementations to understand some of the existing practices related to data capture and to understand how the data is being translated into information and knowledge that can be used to improve building energy and operational performance to meet federal energy reduction mandates. This study highlights case studies to represent some of the various actions that are being taken based on the data that are being collected to improve overall energy performance of these buildings. Some of these actions include- individualized tenant billing and energy forecasting, benchmarking, identifying energy conservation measures, measurement and verification.

Introduction

Federal mandates for energy and environment can be broadly classified into outcome-based and prescriptive-based (Figure 1). The outcome-based mandates include the following:

- E.O. 13423/EISA: Reduce energy intensity (Btu/gross square foot [GSF]) by 3% each year, leading to 30% by the end of fiscal year (FY) 2015 compared to an FY 2003 baseline. This goal was given the weight of law when ratified by EISA 2007.
- EPACT/E.O. 13423: Use renewable electric energy equivalent to at least 5% of total electricity use; at least half of which must come from sources developed after January 1, 1999.
- E.O. 13423/13514: Reduce water consumption intensity (Gal/GSF) by 2% each relative to 2007 baseline; 16% by the end of FY 2015; increased to 26% by FY 2020.
- E.O. 13514: Reduce government-wide scope 1 and 2 greenhouse gas emissions from targeted sources by 28% in FY 2020 compared to FY 2008.

One of the prescriptive-based approaches outlined for reducing energy consumption and improving the sustainability of DOE and other federal sites is to deploy advanced metering. Table 1 provides a summary of various federal metering requirements (FEMP 2011). The U.S. Department of Energy (DOE) Strategic Sustainability Performance Plan (SSPP) (DOE 2012) identifies measures to achieve statutory and Executive Order goals while safeguarding its mission, applying the best sustainability practices, and adopting emerging, promising technologies. The SSPP identifies metering as a key strategy for managing energy use in DOE facilities, to meet both energy-use and greenhouse gas (GHG)-reduction goals. Specifically, the SSPP advocates DOE "[utilization of advanced building metering for real time control and display, and to encourage energy efficient practices among employees through awards and incentives" (DOE 2012).

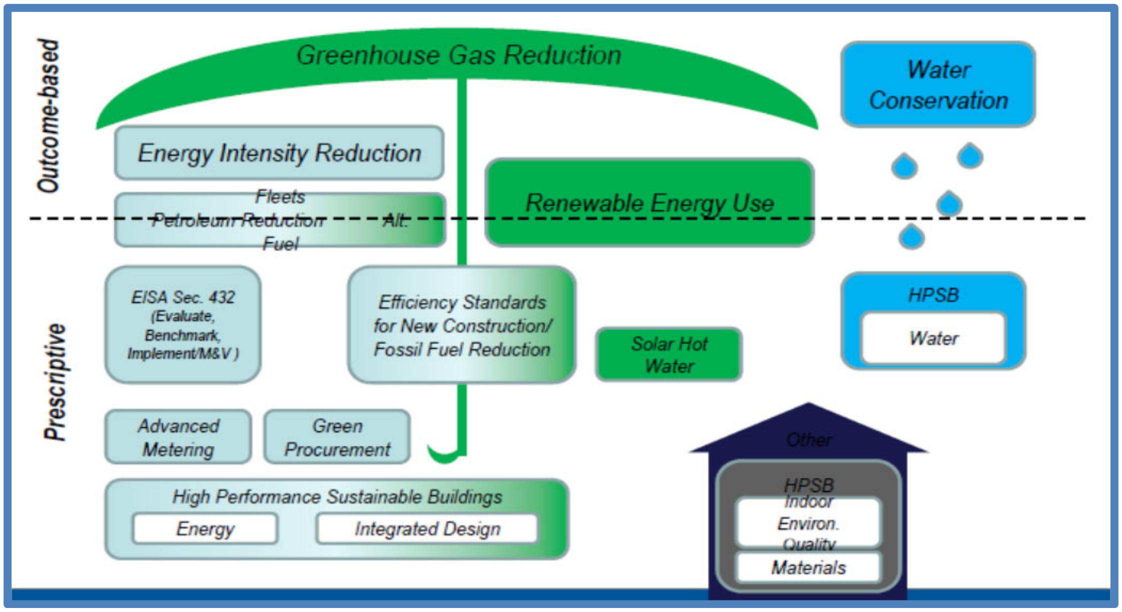

Figure 1. Prescriptive and Outcome-based Mandates (Greengov, Tremper 2011).

	Establishing Authority			
	Energy Policy Act of 2005	DoD Instruction 4170.11	Executive Order 13423	Energy Independence and Security Act of 2007
Metering Requirements Section	Section 103: Energy Use Management and Accountability	Paragraph 3.d(2): Metering	Not required in Executive Order.	Section 434 (b)
Applicability	All agencies	DoD facilities	All agencies	All agencies
Key Requirements	- All buildings - Where practicable - By October 1, 2012 - Meter electricity - Hourly interval data (minimum) collected at least daily	- Meter electricity, natural gas, and water in "appropriate facilities" by 2012. - Electricity, natural gas, and water meters with interval and remote reading capabilities on all new construction and renovation projects exceeding $200,000. - Steam will be metered at plants	The Instructions for Implementation encourage that meters be applied to "measure consumption of potable water, electricity, and thermal energy in Federal buildings and other facilities and grounds." The Instructions also recommend considering the inclusion of meters in alternatively financed projects.	- Not later than October 1, 2016 - Each agency shall provide for equivalent (as to Section 103 EPAct 2005) metering of natural gas and steam - Metering of water is encouraged to obtain data to support water intensity reduction goals
Supporting Documents	*Guidance for Electric Metering in Federal Buildings* (DOE/EE-0312)	*Department of Defense Energy Managers Handbook*, Chapter 10	Implementing Executive Order 13423, paragraph VI.A. (3) Metering.	EPAct 2005 and the *National Energy Conservation Policy Act*

Table 1. Summary of Federal Metering Requirements (FEMP 2011)

The term advanced metering applies to those that have the capability to measure and record interval data at least hourly for electricity. An advanced metering system (also referred to as energy information system) is a system that collects time-differentiated energy data from the advanced meters and other devices via a communication network, either on request or on a defined schedule. These data are collected, analyzed, and presented to the user in a format that is useful to operate and manage the building equipment's energy consumption and associated costs.

The Energy Policy Act of 2005 (EPACT 2005) requires federal sites to consider the application of meters for their buildings. Section 103 of EPACT 2005 includes the following requirements surrounding energy use measurement and accounting:

- All federal buildings must be metered "...for the purposes of efficient energy use and reduction in the cost of electricity used in such buildings..." by October 1, 2012.
- Advanced meters or metering devices must provide data at least daily and measure consumption at least hourly.

Advanced Metering System: Architecture

An advanced metering system is an integrated system that collects data from each of the individual meters, sub-meters, or individual sensors. These systems may also clean, archive, analyze, and translate those data into actionable activities that will help building operators to manage building operations effectively and efficiently. An advanced metering system has the following components (Figure 2) that process raw data into actionable items (AEC 2003):

Meters

Traditional meters, ones installed by utility company in most buildings, are used to measure and bill the customers for their energy consumption. Monthly bills display kilowatt-hours (kWh) and unit rate, and associated costs, based on manual or semi-manual reading of utility meters by utility personnel at the customer's site. Sometimes this information can be based on historical consumption estimates when the actual reading cannot be obtained. Most utilities have installed advanced meters, which go beyond monthly invoicing and can provide information to the user at a much higher granularity and frequency. An important drawback of the owner-installed meter, however, the utility cannot communicate directly with this meter to monitor the time periods so the facility can respond to price signals as a way to optimize its utility costs.

One of the key issues related to advanced meter installation is commissioning to ensure that the meter is installed correctly and reads accurately. This can be done through initial validation and checking periodically by comparing the meter data with billing data. Based on the input from various sites, most errors can be attributed to assigning an incorrect multiplier to calculate the totalized output, or due to incorrect CT size assumption or by assigning an incorrect pulse value.

A whole-building meter that represents the energy consumption at the most aggregate level is considered a first-tier level (FEMP 2011). Sub-meters are meters that are installed at lower levels of the building hierarchy to monitor the energy consumption of a particular system or sub-system. The second tier of metering can occur at the panel or sub-panel level and can monitor energy consumption at an aggregated level of specific loads (e.g., lighting or motor panels). The next level in the hierarchy is circuit-level metering that monitors energy consumption of specific loads or peripherals. The final level is end-use monitoring, which provides the ability to monitor and isolate the energy consumption of a particular system or piece of equipment. This level of metering is used to monitor and baseline the equipment performance, and also to measure and verify the performance to validate the savings (e.g., chillers, cooling towers, pumps, motors). The level of sub-metering needed for a commercial building depends on several factors, such as building age, end uses, electric panel configuration, and the presence of energy management and control systems (EMCS). The typical highest end-use loads are HVAC and lighting, which account for more than half of typical buildings' energy use may need to be metered first before some of the other end uses.

Data Collection System

The data collection system is used to store data that has been collected from the meters, so that it can be used for further processing and analysis. This data collection and storage system should be able to read and collect data from meters manufactured by different manufacturers and that use different protocols to communicate and each protocol has its own advantages and disadvantages (AEC 2003). The communication signal can be as simple as a pulse output that generates a simple voltage pulse that indicates that a certain quantity of commodity has passed through the meter, or it can be more sophisticated like a Transmission Control Protocol/Internet Protocol (TCP/IP) or Modbus communication protocol. Wireless mesh technology, where each node communicates with its neighbors to transmit the data, provides redundant ways to relay the data thereby improving the reliability of the network. In some cases, the existing building automation system that controls equipment to maintain comfort and schedule building operations can be used as a meter data collection system to collect, store, and output data from the meters.

Data Storage

Data that is collected in the data collection system needs to be stored in a database that can be retrieved for further analysis and reporting. Data can either be stored locally using local database software applications or remotely that can be accessed for further analysis. Database vendors help companies house the data on site if data security is of high importance. The other option is to allow a third party to store the data through cloud based software for a subscription fee. This software collects and archives the data and provides reports, through a web browser. In addition to storing the data, the software vendor can provide additional services, including analysis and reporting. Pulse Energy, is one such cloud based energy intelligence software deployed at LBNL, to manage energy use through benchmarking building's performance and improve operational efficiency.

Data Analysis, Presentation, and Reporting

The data that's collected and stored needs to be cleansed- to ensure that it's devoid of any missing or erroneous values- to be further analyzed and presented in a form that is easy to comprehend and actionable. This can be accomplished either manually or through automation, depending upon the amount of data being analyzed. Manual methods are expensive, time consuming, and often prone to error. To automate the data analysis procedures, companies can either develop the software in-house or purchase it off the shelf. Software packages are available from the meter manufacturers and other software vendors. The packages from the meter manufacturers are designed to work seamlessly with their own meters, often because the communication protocols are compatible. If all the meters that are installed are from the same manufacturer, this might be a suitable solution, and it can save a great deal of time and resources that would otherwise be spent integrating multiple disparate protocols and data formats. However, some third-party vendors might provide additional analysis features and functionality that are not available in the meter manufacturer's software data. To ensure communication compatibility with a variety of meters, most of these applications can communicate though many existing standard protocols. Another approach for data analysis and presentation is through an application service provider (ASP) or cloud based model, where a third-party vendor analyzes the data for a subscription fee. This vendor can be the same one that manages the data collection or storage software.

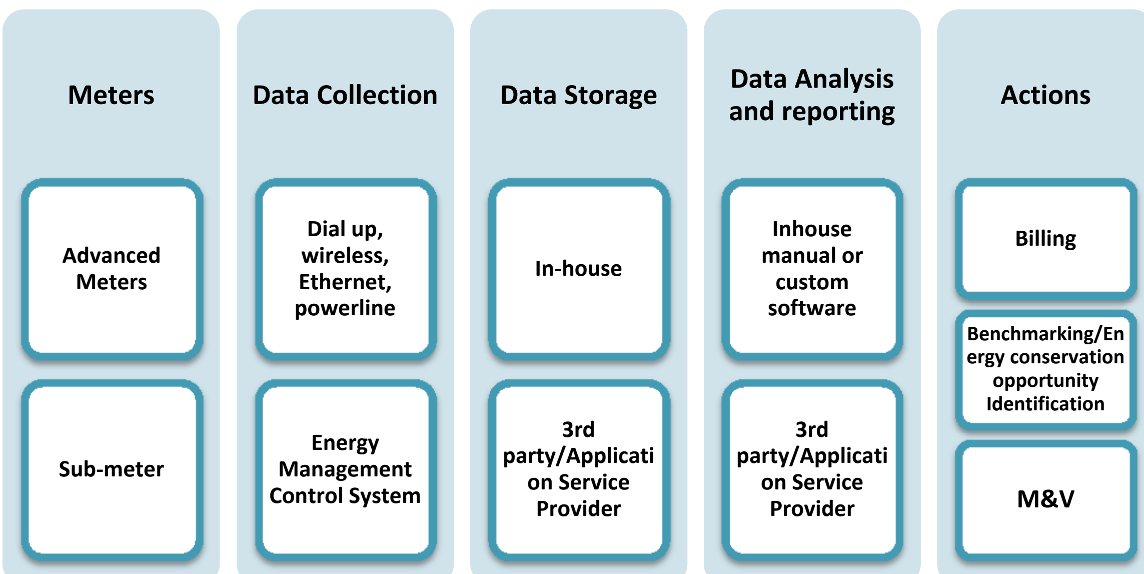

Figure 2. Schematic Showing an Advanced Metering System.

Data Actions

There are many potential applications (DOE 2006) for metered data, depending on the type of data and systems that are deployed at the site. One of the most common applications is to accurately bill tenants for their actual consumption instead of relying on historical averages. This actual consumption data can help building occupants clearly understand their energy consumption and act accordingly to reduce energy consumption and gather feedback about their actions almost in real time. This can in turn help to promote energy use awareness for building managers and occupants. Metered data can also provide a mechanism to verify energy consumption from the utility bills to reduce the possibilities of billing errors. By closely analyzing the advanced meter data, the building and facility operators can analyze their operations and possibly identify the best utility rate tariffs. This data could also be used to benchmark the building performance and compare its year over year performance. The building performance can also be compared with other similar buildings, to gauge its relative performance. By benchmarking the buildings within a portfolio, facility personnel can identify which buildings are underperforming and optimize their resources effectively.

The data from advanced meters can also be used, when combined with energy management and control systems (EMCS) and other data sources, to identify energy conservation opportunities through ongoing commissioning activities. This strategy will not only help reduce the building's energy consumption and costs, but can also help to prolong equipment life. Another important application of advanced meter data is to develop an accurate energy baseline. One of the important aspects of an alternate financed project (such as an energy savings performance contract, or ESPC) is to accurately formulate the baseline energy consumption for the project before installing the measures. Most ESPCs are projects implemented on a relatively small set of buildings across a large site; establishing the baseline energy consumption for a project with only a few meters across an entire site can be very difficult and potentially lead to more erroneous models. With the availability of building-level utility data, establishing baseline energy consumption for a project is relatively easy, and it can be modeled with less uncertainty. Subsequently, this model and data can also be used to measure and verify the savings associated with the project with greater confidence.

Study of Advanced Metering Projects

In the previous sections, some of the background information pertaining to advanced metering systems are presented. As part of this work, advanced meter installations at several DOE sites were studied to gain an understanding of the approaches used for implementation in terms of hardware, software, and data analysis procedures being adopted to utilize the metered data. In order to help with this study a detailed questionnaire was developed for collecting information regarding various advanced metering implementations across several DOE sites. The following section presents some of the data actions at a few of the sites that were studied.

Energy Billing

One of the most common applications witnessed across most of the labs studied is the use of advanced meter data for billing tenants for their actual consumption. Historically, tenants have been billed for their energy consumption based on average historical consumption data normalized for occupancy and or area. With the advent of the advanced metering, the tenants can be billed for their actual energy consumption and adjust their operations to optimize some of the costs. To better control electricity costs, most of the labs initiated metering programs for their buildings so that each of the resident programs can be billed based on their actual consumption. The idea is that if the occupants are billed for their actual consumption, they will be prompted to find ways to reduce some of these costs by adjusting their schedule and or operations appropriately.

Benchmarking

EISA requires metered buildings that are part of a federal agency's covered facilities be benchmarked for building energy performance. At Pacific Northwest National Laboratory (PNNL), sustainability program personnel use advanced meter data for longitudinal benchmarking, where the current energy consumption is compared with historical data that is trended and archived in FMCS system. These comparisons are made between the use observed at an earlier period such as the previous month or the same month from a previous year to evaluate a building's performance. Cross-sectional benchmarking is conducted at the whole-building level using metrics like kilowatt per square foot, or at a system level making use of the sub-meter data to evaluate the relative performance of a refrigeration system (using coefficient of performance, COP), boiler efficiency, or power utilization efficiency (PUE) of a data center.

Efficiency Opportunity Identification/Auditing/Retro-commissioning (RCx)

The benchmarking information can be augmented with interval meter data analyses to look for anomalies or events that might be attributable to the deterioration in building performance or system performance. Metered data at a PNNL building was analyzed and an unreasonably high use of gas rate was discovered. Field verification resulted in a steam leak being detected on a preheat heat exchanger and a unit heater. The estimated savings as a result of this action are 20 therms per hour. The PNNL team also found dampers that were not operating correctly, possible billing errors, controls that were not automatically turning lights off, steam leaks, overridden equipment setbacks and a host of other opportunities to improve efficiency across the campus.

Lawrence Livermore National Laboratory (LLNL) analyzes energy data and generates reports and alarms based on a building's energy consumption anomalies. These alarms/alerts are sent via e-mail to LLNL facilities managers when their buildings experience electric power use anomalies, such as sudden increases and drops in power consumption (Figure 3). Such notices allow facility staff to investigate and correct and/or explain causes of power use fluctuations.

Facility	Expected Daily Use (kWh)	Actual Daily Use (kWh)	Over Expected Use (kWh)	% Over Use
B166	548	859	311	56.89
T1631	62	97	35	56.89
T1601	92	145	52	56.89
Total	701	1,100	399	56.89

Figure 3. Screenshot of an Alert from Advanced Metering System.

At Oak Ridge National Laboratory (ORNL), the Building Management System (BMS) and advanced metering system are used in conjunction with an ongoing commissioning tool to provide real-time, continuous commissioning by comparing controlled variables against desired outcomes. The system quantifiably measures performance, measures the effectiveness of system changes with immediate feedback, and is capable of evaluating a great deal of equipment and systems effectively. This commissioning tool optimizes the building control system by collecting real-time HVAC operating data, running the collected data through control algorithms, and updating the pertinent setpoints to reduce energy consumption, increase comfort levels, track the performance of equipment and control strategies, and provide real-time tuning of control strategies.

Analysis and Visualization

PNNL uses Decision Support for Operations and Maintenance (DSOM-2009) tool to aid in data analysis, graphical presentation, and data storage. Designed and developed by PNNL, the DSOM system is an advanced supervision and diagnostic tool to reduce plant operation and maintenance costs and thereby helps extend plant life. A network of sensors constantly feed information regarding the performance of the facility's components into a computer. Using advanced communication techniques—adapted from industrial process controls—DSOM talks to most monitoring and control systems, mitigating the need for expensive upgrades of instrumentation for compatibility. DSOM software collects and verifies operations data, analyzes them in a customized database, and lets operators know, in real-time, if a system is malfunctioning or running below expectations. Beyond looking for early warning signs of problems, DSOM identifies conditions that could potentially lead to a problem, identifies the root cause, and prioritizes recommended solutions.

LLNL uses a monthly reporting tool to compare the before-and-after energy use of the metered facilities. This tool has a three-dimensional chart tool that graphically compares a facility's use for different time periods. Figure 4 shows the peaks and valleys attributed to nights and weekends that were not apparent in Figure 5. In Figure 5, the load was not being shed on nights and weekends due to lack of efficient HVAC controls.

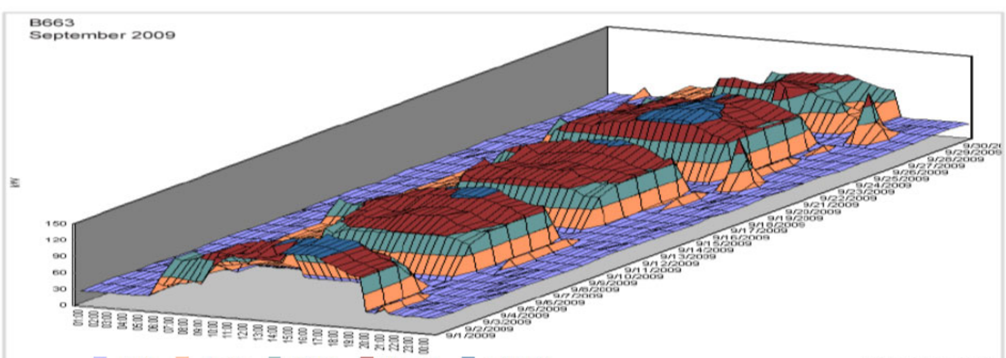

Figure 4. Energy Use Profile in September 2009 at a DOE building.

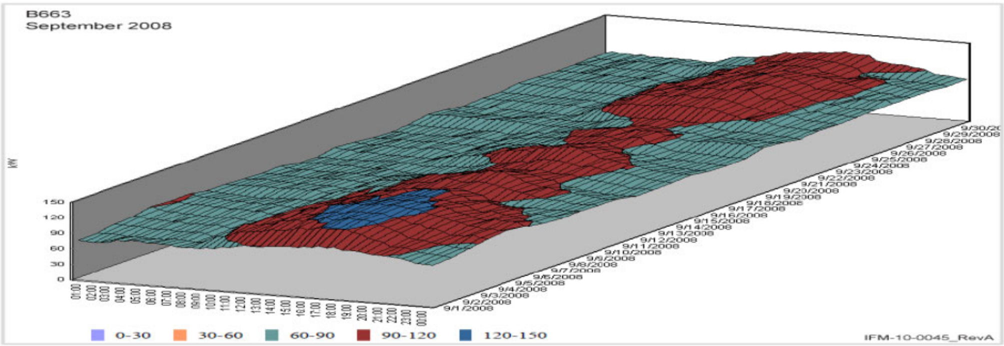

Figure 5. Energy Use Profile in September 2008 at a DOE building.

Measurement and Verification

Measurement and verification (M&V) establishes a systematic process to evaluate the performance of energy projects through a set of guidelines (International Performance Measurement and Verification Protocol [IPMVP] [EVO 2012] and Federal Energy Management Program M&V Guidelines [DOE 2008]). The federal ESPC authority requires the contractor (ESCO) to undertake M&V activities and provide documentation to demonstrate that the installed projects meet the savings guarantee established by the ESCO.

The Y-12 National Security Complex has developed and implemented an ESPC with four different energy conservation measures (ECMs): Chiller Plant Improvement, Condensate Return System Modification, Steam Trap Improvement, and De-mineralized Water Production Facility Replacement. Almost all the ECMs in this project employ IPMVP Option B[1] for evaluating performance and making use of advanced meter data.

For Chiller Plant Improvement measure, the baseline chiller plant performance was validated through the use of advanced meters (kW and kWh) and chilled water meters (Btu) installed and connected to the site-wide Utility Monitoring System. Data was collected and summarized on an hourly basis for over six weeks per chiller plant. Hourly dry bulb temperature was trended by the on-site weather station. A weather-based regression analysis was created using the metered data and the weather data corresponding to the baseline-metering period. That data were extrapolated to provide annual plant operating models and normalized using 30-year average weather data. Baseline validation was provided through the use of instantaneous measurement of pump and cooling tower fan electricity demand (kW) and comparison of the regression model with historical plant operating logs. The advanced electricity and chilled water meters installed for the development of this ECM were utilized throughout Year 1 of the performance period to validate system performance. The metered chilled water plant electricity input and chilled water output was used along with the recorded dry bulb temperature to create the performance year regression model. The data were normalized using the 30-year average weather data for comparison with the baseline regression model. The consumption between the two normalized models was used to compute the savings for the measure.

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[1] With option B, retrofit isolation with all parameter measurement is based on periodic or continuous measurements of energy use taken at the component or system level.

Dashboards

Dashboards are designed to present energy information in a way that is easy to understand and gather information about the building operation. BNL has experimented with dashboard programs provided by meter manufacturers, energy management control companies and other niche dashboard application software with varying degrees of satisfaction. At PNNL, the existing dashboards are provided by EMCS and the goal is to build dashboards and meter data interface systems for all of the buildings using DSOM. PNNL is also exploring the possibility of supplementing DSOM's analysis tools with a commercial dashboard application. Their goal is to improve the usability and functionality within DSOM to ensure that the metered data gets into the hands of practitioners across the Laboratory to make more informed engineering decisions. For the metered data to have the greatest effect, it must be available to and used by a greater number of staff than the small data analysis team within the Sustainability Program. The LBNL energy analysis software application, developed by Pulse Energy, provides three pre-configured main screens—dashboard, management charts, and reporting—to view energy consumption data. This software can be customized to develop dashboards and analytics for different user groups (Marini et al. 2011).

Behavior Modification

At LBNL, the lab Directorate initiated the Building Energy Savings Challenge in February 2010, with the incentive of a barbecue to the building that saved the most energy. The winner achieved a 17.6 percent reduction in energy usage ending July 2010 compared to a baseline period of FY 2008. The building placed second and third achieved 7.4 percent and 5.7 in energy reduction respectively. Overall energy use during this period at the Lab was down: total energy use by all buildings that were part of the challenge has declined 7.6 percent since FY 2003.

At BNL, most of the advanced meter data are analyzed monthly and sent to individual account holders where they can track monthly energy use and costs. Data has also been compiled into competition formats where individual account holders can see and compare their energy use to other buildings where individuals showing the largest decrease in energy use over a set period of time would win a free lunch and mention of their energy conservation measures. At PNNL, energy costs are broken down to increase awareness of where energy is being used across the Lab and to show what programs and areas are the highest consumers. In addition to being a valuable analysis tool, energy use and cost graphics are used to increase understanding and awareness among Laboratory employees.

Electric Costs Optimization

Electric utilities are offering a variety of creative rate-based products targeting a higher reliability of the electrical grid. The availability of 15-minute interval data for a site will not only help users understand the site's energy consumption but also allow a site to best understand its particular load characteristics when negotiating with prospective electric utilities and their offerings. The time-of-use pricing programs are designed to incentivize the “off-peak” use of electricity by offering reduced kilowatt (kW)/kilowatt-hour (kWh) charges during pre-defined and fixed off-peak time periods. Electric meters with interval capability can allow users to understand the value of these programs to the site’s specific electricity use characteristics. In addition, the data from these meters allow users to engage in scenario planning activities where they can estimate the value of shifting loads to off-peak periods.

BNL consumes a significant amount of electricity and draws a significant amount of demand. The annual electricity bill for FY 06 was $16 million, with consumption exceeding 241gigawatt-hours (GWh). Even though that averages to $0.065/kWh, the peak prices can go as high as $1/kWh, not including the demand charges that can add as much as $100,000 per megawatt per year (FEMP 2011). The lab facility personnel work very closely with the local utilities to ease city’s power demand during periods of high electricity usage; typically during the summer.

BNL historically has participated in at least two demand-response programs each year to keep electricity demand at a minimum. BNL currently has over 200 electric meters on site, meeting building loads, substations, individual transformers, and process loads. Pulse data from the electric meters are stored in digital data recorders. The data recorders are interrogated on a daily basis by a meter data retrieval program and this data is stored on a server and is used for monthly bill calculations, load analysis, and database input. The BNL uses a details model that analyzes the monthly data to develop a planned electric load for the subsequent months. Electrical load planning and management are critical and important activities in planning the site’s energy consumption, as most of the site’s electricity is purchased from the day-ahead market. Deviations from the scheduled usage are either sold or purchased on the spot market and can have huge financial implications. The actual consumption data are also presented on an hourly basis, and this information along with costs are made available to the tenants.

In response to a demand event, BNL employees are notified through e-mail when these critical days are called, and departments can participate by reducing lighting and cooling and shutting down non-essential equipment. The Laboratory is paid for participation in tests and events through bill credits to the electricity bill and receives payments based on planned curtailment per contracted megawatt (MW) per month during the program. Each year BNL’s payment profile is modified based on actual performance during the prior year/period. The presence of a high-frequency advanced meter in each building enables all of the payments received by BNL to be credited to all the participating departments or divisions, based on their actual reduction in electricity demand during those events. The BNL facility personnel found this practice of using real-time feedback from advanced metering data to adjust their energy use to be an excellent transparent means of encouraging participation and attaining the greatest reductions. BNL’s programmatic loads are on the order of 25 to 30 MW above the site baseload of 20 MW. As a result of monitoring consumption and adjusting its operations and schedule, BNL avoided approximately $2 million/year in demand charges and related costs as a result of these actions.

Conclusion

The work studied selected advanced metering implementations, to understand the existing practices related to capturing building data and how they are being translated into information and knowledge that can be used to improve the energy and operational performance of buildings to help meet federal mandates. It also presented some studies that highlight some of the innovative actions that can be taken based on the data that is being collected. Based on the study, almost all of the sites that were studied use advanced metering data to separately bill their tenants based on their actual consumption rather than based on consumption averages, as was the case before the advent of individual meters. A few sites were using the data to optimize and respond to the electricity price signals from the utility to reduce their electricity costs. Most of the sites that were studied are using the advanced meter data to conduct benchmarking to understand how these buildings are performing in comparison. A few of these sites were also using this data to not only identify potential energy conservation measures but also to ensure that the implemented measures are performing and realizing the savings as expected. Some of the ongoing work that's being conducted is to investigate how advanced meter data, along with some of the other data sources, can be used to develop robust and cost-effective M&V strategies, to ensure that the savings from energy conservation projects are being realized with a higher degree of confidence in a sustainable manner.

Acknowledgements

This work is funded by the U.S. Department of Energy's Sustainability Performance Office (SPO). The authors acknowledge the support offered by various DOE site personnel in providing information and data regarding their advanced metering implementations.

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