LBNL-XXXX

Ernest Orlando Lawrence Berkeley National Laboratory

Advanced Metering Installations – A Perspective from Federal Sites

Shankar Earni

Energy Technologies Area

May 2, 2016

DISCLAIMER

Acknowledgements

This work is sponsored by The U.S. Department of Energy (DOE) Sustainability Performance Office (SPO) under Contract No. DE-AC02-05CH11231. The authors acknowledge the support provided by the following DOE site personnel in providing information and data regarding their advanced metering implementations.

Contact	**Affiliation**
Karin King	Lawrence Livermore National Laboratory
Greg Palko	Oak Ridge National Laboratory
Chris Evans	Sandia National Laboratory
Mark Toscano	Brookhaven National Laboratory
Jason Pope	Pacific Northwest National Laboratory
Blair Horst	Lawrence Berkeley National Laboratory
Chris Gaul	National Renewable Energy Laboratory
Maura Miller	Los Alamos National Laboratory

About this Document

Purpose

This report is intended to provide guidance to the United States Department of Energy (DOE) and other federal agencies to highlight some of the existing practices related to advanced building metering systems. This study identified some of the existing actions related to advanced meter data and proposes how advanced metered data can be employed to develop robust cost effective measurement and verification (M&V) strategies. This report proposes an integrated framework on how advanced meter data can be used to identify energy conservation opportunities and to develop proactive M&V strategies to ensure that the savings for energy projects are being realized.

This information will help improve metering, feedback, and dashboard implementations for reducing energy use at DOE facilities, based on lessons learned from various advanced metering implementations.

This work supports DOE Strategic Sustainability Performance Plan (SSPP) Goal 1 (Scope 1 & 2 Greenhouse Gas Reduction) and Goal 3 (High-Performance Sustainable Design/Green Buildings & Regional and Local Planning).

Audience

Primary

- Facility managers
- Facility engineers
- Building operators
- Sustainability managers

Secondary

- Building occupants
- Control providers

Table of Contents

1 Summary

The U.S. Department of Energy (DOE) Strategic Sustainability Performance Plan (SSPP) (DOE 2012a) 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 "*[u]tilization of advanced building metering for real time control and display, and to encourage energy efficient practices among employees through awards and incentives*" (DOE 2012a, p. 29).

This project studied selected advanced metering implementations to understand some of the existing practices related to capturing these data, and to understand how the data are being translated into information and knowledge that can be used to improve building energy and operational performance to meet federal mandates. This study tried to draw commonalities among different sites in terms of hardware, software, and data analytics. It also presented case studies to represent some of the various actions that are being taken based on the data that are being collected.

This work also presents analysis on how advanced meter data can be used to develop robust and cost-effective measurement and verification (M&V) strategies, to ensure that the savings from energy conservation projects are being realized with a higher degree of confidence and in a sustainable manner. Analysis is also presented on how advanced metering data can be used to identify energy conservation opportunities to improve overall building performance.

To advance the overall performance of a building toward a path of continuous improvement, this report proposes a framework to integrate M&V and commissioning activities by utilizing existing data sources, including advanced meters. This framework can provide the foundation to automate activities that are proposed in the Energy Independence and Security Act (EISA) Section 432 toward achieving Scope 1 and Scope 2 greenhouse gas (GHG) reduction targets[1].

[1] DOE established Scope 1 and 2 GHG reductions of 28% by FY2020 compared to a FY2008 baseline. For more information on what constitutes a Scope 1 or Scope 2 emissions source, see www.epa.gov/oaintrnt/ghg/strategies.htm.

2 Introduction and Background

Federal mandates for energy and environment can be broadly classified into outcome-based and prescriptive (Figure 2.1). 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 a 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.

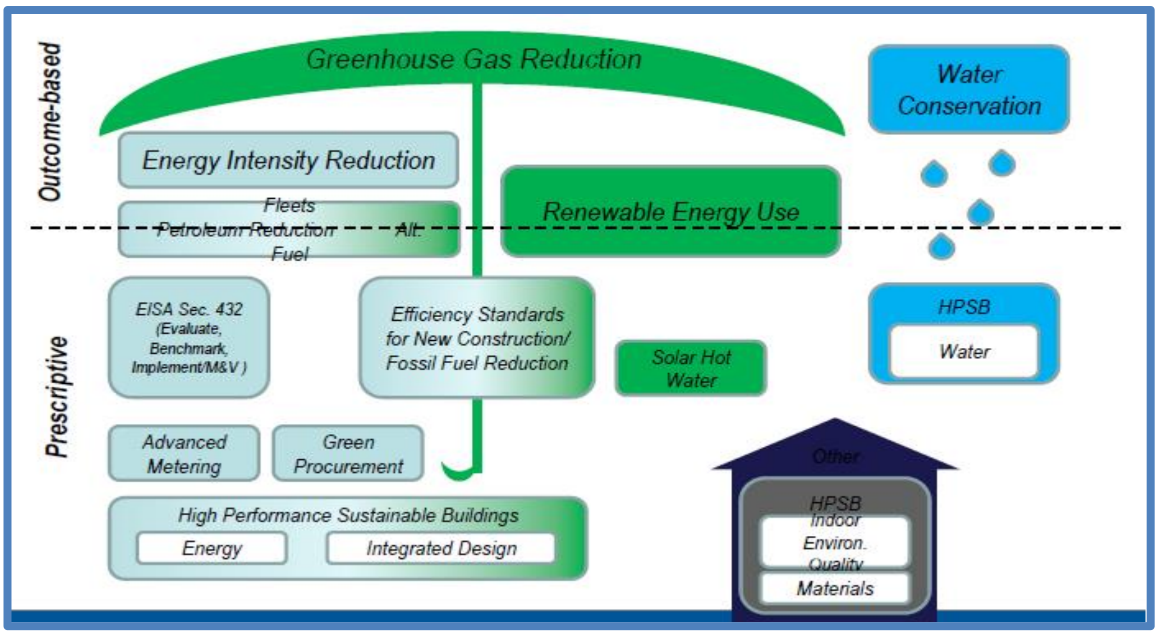


Figure 2.1: Prescriptive and Outcome-based Mandates (Greengov, Tremper 2011)

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 2.1 provides a summary of various 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.

Table 2.1: Summary of Federal Metering Requirements (FEMP 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*

The Energy Policy Act of 2005 also states that the metering system must be used to the maximum extent practicable. There are many potential applications that can result in reduced Scope 1 and Scope 2 GHG reductions while improving the operational effectiveness of buildings. Data from these meters will help occupants and facility personnel effectively manage energy consumption and its associated costs. In addition to helping customers reduce their energy consumption, energy data from advanced meters can also help utilities effectively manage energy supply and its associated assets by deploying them effectively and efficiently, thereby improving electrical grid stability. Other common applications of the data include benchmarking buildings to compare a building's year-to-year performance with its relative performance compared to other similar buildings. When combined with other data sources, these data can be used to identify energy-conservation opportunities through ongoing commissioning activities. The data can also be used subsequently to evaluate the performance of various energy-conservation measures through robust M&V strategies, to ensure that the savings from the measures are being realized sustainably with increased confidence.

In addition to increasing some of the outcome-based mandates of energy-reduction requirements (e.g., increased EPACT 2005 energy reduction requirements from 20% to 30% by 2015), EISA 2007 extended the metering requirements for federal buildings to natural gas and steam by October 1, 2015.

In order to meet various outcome based federal mandates outlined above, a systematic methodology for facility energy and water project management and benchmarking, (DOE 2012b) is proposed. This approach includes a four-step continuous improvement process that starts with (1) identifying covered facilities, (2) assigning energy managers, (3) conducting comprehensive energy and water evaluations, and (4) project development, project implementation, and project follow up/M&V. It also requires that metered buildings that are, or are part of, covered facilities be benchmarked annually.

The objectives of this present work are to study selected instances of the implementation of the advanced metering requirements of EPACT 2005, to understand some of the existing practices related to capturing data from those meters, and to understand how the data are being translated into information and knowledge that can be used to improve building energy and operational performance to meet federal mandates. This study attempts to draw commonalities among different sites in terms of hardware, software, and data analytics. It also presents case studies that represent some innovative actions that can be taken based on the collected data. This report also presents a framework on how advanced meter data can be used to not only identify energy conservation opportunities but also monitor building performance to ensure that the savings from the various measures are being sustained with a greater degree of confidence. This framework can provide the foundation to automate some of the activities proposed by EISA Section 432. As per the most recent statistics from the compliance tracking system (CTS), there are 47 active DOE covered facilities, with total facility gross area of 78 million square feet—of which 1,755 separate buildings are metered for electricity and 17 million square feet has been benchmarked.

This work will help DOE sites reduce their Scope 1 and 2 greenhouse gases by:

- reducing the energy intensity of their buildings by harnessing the metered building data through benchmarking performance, and

- identifying energy-conservation measures, through re-commissioning and ongoing commissioning of buildings (Table 2.2).

Table 2.2: Summary of the SSPP Goals this Work Addresses

Goal	Reduction Target	This work addresses
Scope 1&2 GHG Emission Reduction	Target of 28% by 2020 (2008)	Yes
Scope 3 GHG Emission Reduction	Target of 13% by 2020 (2008)	
Reduction in Energy Intensity	Target of 30% by 2015 (2003)	Yes
Use of Renewable Energy	Increase renewable energy by 7.5% by 2013	
Reduction in Potable Water Intensity	Reduce intensity (gal/ft2) 26% from 2007 through 2020	
Reduction in Fleet Petroleum Use	Target of 30% by 2020 (2005)	
Green Buildings	15% of building stock meet HPSB by 2015, net-zero energy use by 2030	

3 Advanced Metering System: Architecture

An advanced metering system, also referred to as an *energy information system* (EIS) is an integrated system that collects data from individual meters, sub-meters, or individual sensors and cleans, archives, analyzes, and translates those data into actionable activities that will help building operators to manage building operations effectively and efficiently. This integrated EIS has the following components (Figure 3.1) that process raw data into actionable items (Granderson et. al 2009):

1. **Meters:** Traditionally, the meters prevalent in most buildings have been installed by the utility company to measure and bill the customers for their energy consumption. This monthly bill displays monthly 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.

   However, it is futile to use the basic information from this monthly bill to understand consumption information in more detail, and it lacks the immediate feedback needed to alter building operations to optimize its energy consumption. By installing advanced meters, most utilities have moved beyond this monthly invoicing and now provide information to the user at a much higher granularity and frequency. Still, there may be different accounts associated with a single facility, and there may be more than one utility providing service, so the data are captured in different databases. Therefore, it may be difficult for a user to retrieve the data readily or synchronize the time stamps across these multiple utilities and accounts.

   Owner-installed advanced meters can help mitigate some of these problems because they enable users to gain flexible and consistent access to the meter data and the meters can be installed at any level of the facility without the restrictions that a regular utility meter stipulates. This flexibility lets users collect data in one common database so that they can use sophisticated techniques to analyze it and take actions to improve the overall energy efficiency of the building and facilities as a whole. An important drawback of the owner-installed meter, however, is that even though it can "shadow" the utility meter and present the actual consumption at the facility, 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.

   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 specifically 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).

2. **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 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. 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 complicated like a Transmission Control Protocol/Internet Protocol (TCP/IP) or Modbus communication protocol.

   There are many ways to communicate the meter information to the storage servers. Each has advantages and disadvantages (AEC 2003). The most common method is to use the Internet, which can provide nearly real-time access to the meter information over public networks using a standard browser. Some of the security issues inherent in this method may be mitigated using an intranet as a form of communication. Modbus is another commonly used open communication protocol between the meter and data-collection device. Modbus TCP/IP uses the Ethernet for communications. Some meters can act as web servers, providing data in HTML or XML.

   Wireless communication is also commonly used, especially for applications where there are a large number of meters or sensor locations and an Ethernet drop is not in the vicinity of the meter or sensor. In applications where it would otherwise be necessary to install long, costly cable runs, wireless communication can be attractive from an economical standpoint. However the quality of the wireless signal can impact the data transfer reliability. This issue is somewhat mitigated with the advent of wireless mesh technology, where each node communicates with its neighbors to transmit the data, thereby providing redundant ways to relay the data. 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.

3. **Data Storage:** Data that is collected in the data collection system has to be stored in a database so that is can be used for analysis and reporting. Database vendors help companies house their data on site if that option is desired. The other option is to allow a third party to perform this function through an application service provider (ASP) business model for a subscription fee. An ASP collects and archives the data and provides reports, most likely through web browser. In addition to storing the data, the ASP can provide additional services, including analysis and reporting.

4. **Data Analysis, Presentation, and Reporting:** This function retrieves the data that are stored in the database and cleans, analyzes, and presents the data in a form that is easy to comprehend and actionable. This can be done manually or it can be automated, depending upon the amount of data being analyzed. Manual methods are expensive, time consuming, and often error prone. 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 in Modbus or by using other standard protocols.

Another approach for data analysis and presentation is through an ASP 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 software.

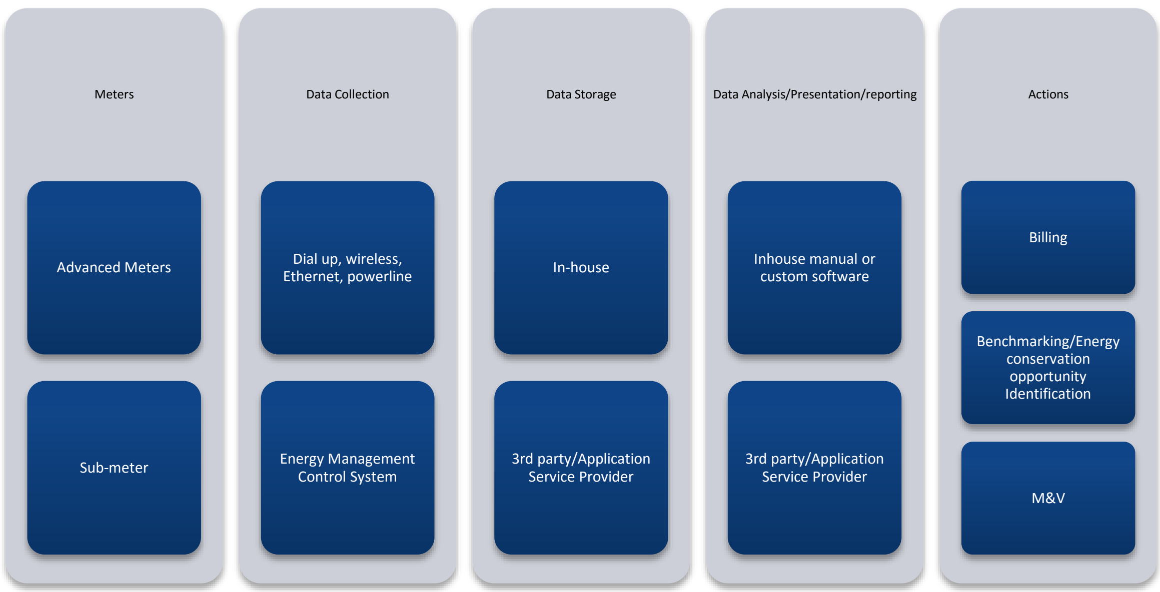


Figure 3.1: Schematic Showing an Advanced Metering System

5. **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 also 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. These metered data will 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. Since almost all federal buildings will be equipped with these

advanced meters, the data could be used to benchmark the buildings and to compare each building's year-to-year performance to other similar buildings, to gauge its relative performance. By benchmarking the buildings, the facility personnel can identify which buildings are underperforming and optimize their resources.

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 potential use of advanced metered data is to facilitate using third-party financing to achieve energy savings. 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 erroneous conclusions. 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.

4 Study of Advanced Metering Projects

In the previous sections, some of the background information pertaining to advanced metering systems is 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 (Appendix A) was developed for collecting information regarding various advanced metering implementations across several DOE sites.

4.1 Meter Hardware

Most of the facilities studied use a wide variety of electric meters (e.g., Veris, E-Mon, PQube, Square D, Cutler Hammer) based on the time when they were installed, their design preferences, and project design constraints. Appendix A contains the form used in the study. All meters used to measure electrical consumption are industry-standard utility-grade meters/recorders that are standardized to record at 15-minute intervals. Brookhaven National Laboratory (BNL) has electric meters originating at the main transformer level followed by transformer cubicle meters, and terminating with building-level meters, as well as smaller load metering used for billing and load research.

Based on experience at Pacific Northwest National Laboratory (PNNL), the Veris product line has proven to be robust and cost effective for applications requiring retrofitting of existing equipment with metering. PNNL has installed hundreds of Veris Enercept meters to date. This meter has a compact design with no local display, and it communicates directly with the facilities management control system (FMCS). At PNNL, additional sub-meters are installed in many buildings. These mostly electrical sub-meters are installed at specific systems or panels for specific programs like electric car charging stations. As additional sub-meters are installed, a load profile for each building that characterizes electricity consumption by each of the sub-systems—HVAC, IT, lighting, and plug load—will be developed.

4.2 Meter Data Collection and Analysis Software

Brookhaven National Laboratory and Lawrence Livermore National Laboratory (LLNL) use the utility industry standard MV-90 xi from Itron to interrogate, store, and analyze all metering data.

Itron's MV-90 xi is the industry's leading software system for collecting and processing interval data from complex metering devices. In addition to its data-collection capabilities from multiple disparate devices, MV-90 xi also provides tools for analyzing and applying those data through easy integration with other applications. This software has the ability to collect data from several different metering devices and supports a variety of communications including public switched telephone network (PSTN), cellular, radio frequency (RF), handheld file (HHF) import, Itron's C&I Network, and TCP/IP. It also offers several procedures for data validation, editing, and estimation—including analysis tools including graphs and reports, data aggregations, time of use, loss calculations, and billing determinant calculations.

Currently BNL captures kilowatt/kilowatt-hour readings with the ability to measure real-time power quality with the newer power quality meters. These meters communicate via IP and have the capability to collect other parameters such as power factor, volts, amps, and more. BNL is also utilizing Itron's Energy

Management Suite to predict power purchase costs for different load profiles in a real-time power-purchase environment. This information is also used to generate the lab's electrical bill based upon projected load profiles. Data from MV-90 xi can also be migrated into the Energy Management Suite for tracking building consumption trends and building power costs.

At LLNL, the MV-90 xi platform is used as a meter data collection/data repository software, currently used to collect metering information from the existing 151 dial-up meters. To augment and supplement data analysis techniques, the data collected from the MV-90 xi will be analyzed using the McKinstry Enterprise Energy Management Suite (EEM Suite). The EEM Suite software package includes the Meter Data Analyst and Bill Analyst modules. The Bill Analyst provides a way to manage billing data and forecast and budget energy costs. This provides energy or accounting managers at LLNL with tools to process utility information more efficiently and accurately and improves the ability to accurately allocate costs to the appropriate departments. It enables users to automate cost allocation and utility bill expenses reporting to individual departments, cost centers or tenants, or programs. It also provides the site the ability to view consumption and costs with extensive reporting and analysis tools for energy managers and facility management staff to control energy usage for their buildings and directorates.

Additional features of the EEM Suite include usage analyses for performance monitoring, benchmarking, load aggregation, demand management, and Measurement and Verification (M&V). It also enables LLNL to model its utility rates and predict energy usage and costs. It provides tools for effective rebilling and helps develop accountability for energy consumption among users, along with GHG emissions tracking and reporting. This EEM analysis software enables the site Energy Manager and energy service company's (ESCO's) engineers involved with LLNL's ESPC to analyze utility data, track energy use at specific facilities, target buildings for further energy savings initiatives, be alerted to sudden changes in energy use, and provide a standard to promote energy-efficiency behavior of the building occupants.

Lawrence Berkeley National Laboratory uses Schneider Electric's ION enterprise energy management software, which acquires data from power monitoring and control systems, building and process automation systems, utility information systems, weather services, spot-market energy pricing feeds, and enterprise business applications, then cleanses it, and warehouses it. This information is analyzed and presented through personalized, browser-based dashboards, along with visualization and modeling tools. This information can be used to monitor, validate, predict, and control energy-related expenses. Some of the other features include personalized dashboards, key performance indicators, charts, trends, real-time condition, regression analysis, normalization, correlation, integration of all relevant drivers, and contextual data. The tool also provides a built-in rate engine and rate wizard to optimize energy-related costs. The data from this application can also be integrated with other enterprise applications.

Lawrence Berkeley National Laboratory is also evaluating various commercial dashboard offerings, including one that is available with the current licensing agreement associated with the ION enterprise energy management system –Enterprise Energy Management Suite (EEM Suite) that includes the Meter Data Analyst and Bill Analyst modules. 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).

4.3 Case Studies: Data Analysis Techniques

Table 4.1 presents a summary of advanced metered data actions at various national laboratories. Some of the features related to the software platforms are as follows:

1. **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, BNL has initiated an aggressive metering program for most of the 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.

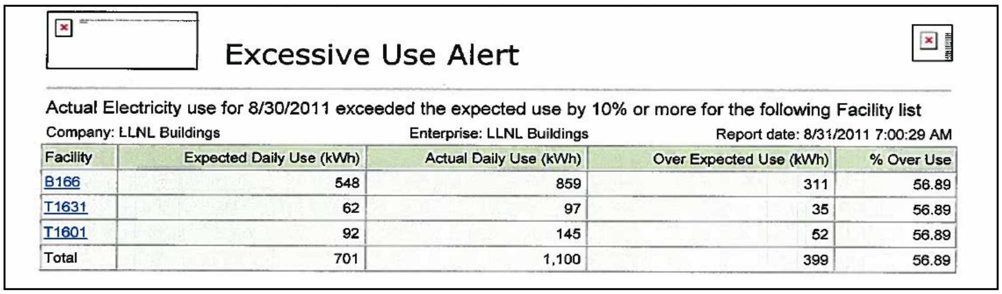
2. **Benchmarking:** EISA requires metered buildings that are (or are a part of) a federal agency's covered facilities to be benchmarked for building energy performance *Benchmarking* is a process of collecting and trending building-level utility data for the purpose of assessing the building's relative performance. It can be *longitudinal*, where a given building's performance is compared to its performance in previous years (adjusting for weather) or *cross-sectional*, where the building's utility data are compared to that of other similar buildings. Often, building benchmarking is accomplished using some kind of normalized metric, such as kilowatt-hours or Btu per square foot. At PNNL, sustainability program personnel use advanced meter data for longitudinal benchmarking. In this benchmarking, 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 building performance. Cross-sectional benchmarking will be done 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 performance for a refrigeration system (using coefficient of performance, COP), boiler efficiency, or power utilization efficiency (PUE) of a data center. PNNL makes use of the United States Environmental Protection Agency's (EPA's) Portfolio Manager tool to track and assess energy and water consumption across the campus.

3. **Efficiency Opportunity Identification/Auditing/Retro-commissioning (RCx):** The benchmarking information can be combined with the meter interval data analyses to look for anomalies or explained events that might be attributable to deterioration in building performance. Once identified, systems or sub-systems can be further analyzed by employing more detailed metering or sub-metering to identify potential energy conservation measures. Based on advanced metering analysis, the PNNL team discovered systems that are operating outside of their optimal efficiency and prescribed measures to improve them.

Table 4.1: Summary of Advanced Metered Data Actions at Various Sites

Uses of Metered Data	BNL	NREL	LBNL	LLNL	ORNL	PNNL	LANL
Energy Billing & Procurement- measuring tenant energy use, verifying utility bills,	Yes	Yes	Yes	Yes			Yes
identifying best utility rate tariffs and partcipating in demand response programs	Yes			Yes., off-peak use is always considered with non-critical programs when feasible.			
Auditing/RCx	Yes		Yes	Anomolies in the usage/day (kWh/day) is detected, and investigated to identify the root cause, and may result in an facility energy audit. Energy audits to meet EISA Section 432 and efforts to increase efficiency (e.g. combining energy audits with condition assessment surveys) along with re-commissioning/retro-commissioning are constantly being evaluated and metering data will be used to monitor and fine tune building HVAC systems.	Program alarms and warnings based on typical building electrical demand and consumption profiles will alert appropriate personnel when a building is deviating from pre-defined power parameters. This information provides an indicator that something has changed in a building's power consumption profile to initiates a response from facility personnel and/or building occupants. Real time continuous Commissioning is employed by comparing controlled variables against desired outcomes on an easy–to-use dashboard configured to display equipment performance.	Yes, measures like identifying steam leaks, Optimizing chiller system performance by effectively meeting the demand with the supply	Started using metering data for building recommissioning/efficiency concerns. Increase this activity in FY13 as data becomes more robust so as to better evaluate locations for corrections.
Baseline Development/M&V (ESPC, UESC, other internal projects)	Yes			ESPC project involves installation and upgrading of building automation controls in 23 of the largest LLNL Main Site buildings currently being implemented and advanced meter may be used for M&V			Yes., Established a M&V process for implemented ECMs by analyzing brief periods of meter data immediately before and after implementing the measure to verify the savings. If this detailed analysis does not provide expected and comparable meter data, further investigation into the validity of the meter data is required.
Budgeting and forecasting	Yes						
Promoting energy use awareness/behavioral modifications	Yes		Yes		The use of an advanced metering system will provide real-time data to both the tenants and the support staff in a facility. This will make it possible to provide incentives to the building occupants to conserve energy. Metering also aims to improve energy and sustainable awareness throughout the ORNL workforce using a unique initiative called Sustainable Energy Education and Communication, or SEEC. SEEC is a management program focused on improving behavior and reducing waste.		

The team found dampers that were not operating correctly, possible billing errors, lighting controls that were not automatically turning lights off after hours as intended, steam leaks, equipment setbacks that were overridden for a specific task and not restored, and a host of other opportunities to improve efficiency across the campus. Lawrence Livermore National Laboratory uses the EEM Suite, which provides a data analyst feature that generates reports and alarms based on a building's energy consumption anomalies. This EEM suite automatically transmits notices via e-mail to LLNL facilities managers when their buildings experience electric power use anomalies, such as sudden increases and drops in power consumption (see Figure 4.1 below) or a Zero Alert where no anomalies have been detected. Such notices allow facility staff to investigate and correct and/or explain causes of power use fluctuations. The Energy Management Program will oversee this program to assure that notices are properly provided and that appropriate responses are made.



Excessive Use Alert

Actual Electricity use for 8/30/2011 exceeded the expected use by 10% or more for the following Facility list

Company: LLNL Buildings　Enterprise: LLNL Buildings　Report date: 8/31/2011 7:00:29 AM

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 4.1: 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 the Facility Performance Index (FPI) 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. The FPI optimizes the building control system by collecting real-time HVAC operating data, running the collected data through control algorithms, and updating the pertinent setpoints. The FPI optimization algorithms are designed to reduce energy consumption, increase comfort levels, track the performance of equipment and control strategies, and provide real-time fine-tuning of the control strategies. The following operational issues can be identified rapidly through review and analysis of advanced meter data:

- Air-Handling Units (AHU) or chiller running when it should be off (nights and weekends)
- Heating hot water pump running when it should be shut down for the summer
- Chiller, cooling tower, chilled water pump, or condenser water pump running when it should be shut down for the winter
- Operation of more chillers than required to meet the cooling load
- Running more pumps than required to meet flow requirements
- Operation of a chiller when airside economizers should be operating
- Continuous operation of equipment that should be cycling on and off or modulating
- Disconnected or bypassed control component (e.g., sensor, controller, actuator)
- Outside air intake that is greater than required
- Outside air economizer that is not operating when it should be
- Simultaneous heating and cooling occurring within a building or area

- Lights left on overnight, over weekends, or over holidays
- HVAC systems requiring cleaning or maintenance
- Large instantaneous load start-up that affects peak demand charges
- Electric heaters operating when not required

4. **Analysis and Visualization:** BNL uses MV-90 xi software that provides a large reporting platform for end users. It can generate reports and graphs for energy use on any meter that supplies data to it. Pacific Northwest National Laboratory uses the Decision Support for Operations and Maintenance (DSOM) 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 extend plant life.

   At ORNL, an intuitive graphic illustrating the campus is presented through the BMS. This graphic is an illustration of all buildings being monitored and may have, as a quick first glance, the real-time kilowatts for each building. By clicking on the building of choice, the BMS penetrates down to the individual building level where another graphic depicts the building's power feeds and any or all of the 26 parameters measured by the power meters. From this point, links on this graphic penetrate further into previously constructed trend studies. Additionally, automatic trend studies can be generated for a desired time interval (e.g., weekly, monthly, annually) to assist in billing and overall metering system management.

   Lawrence Livermore National Laboratory uses EEM suite's monthly reporting tool to compare the before-and-after energy use of the metered facilities. The EEM Suite has a three-dimensional chart tool (see Figure 4.2 and Figure 4.3 below) that graphically compares a facility's use for different time periods. Figure 4.2 shows the peaks and valleys attributed to nights and weekends that were not apparent in Figure 4.3. In Figure 4.3, the load was not being shed on nights and weekends due to lack of efficient HVAC controls.

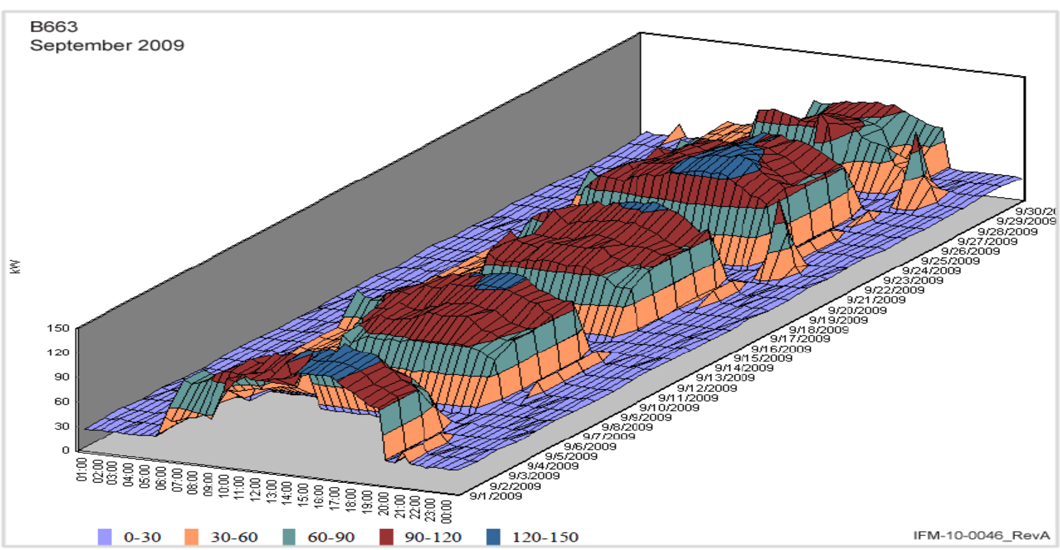


Figure 4.2: Energy Use Profile in September 2009 at a DOE building

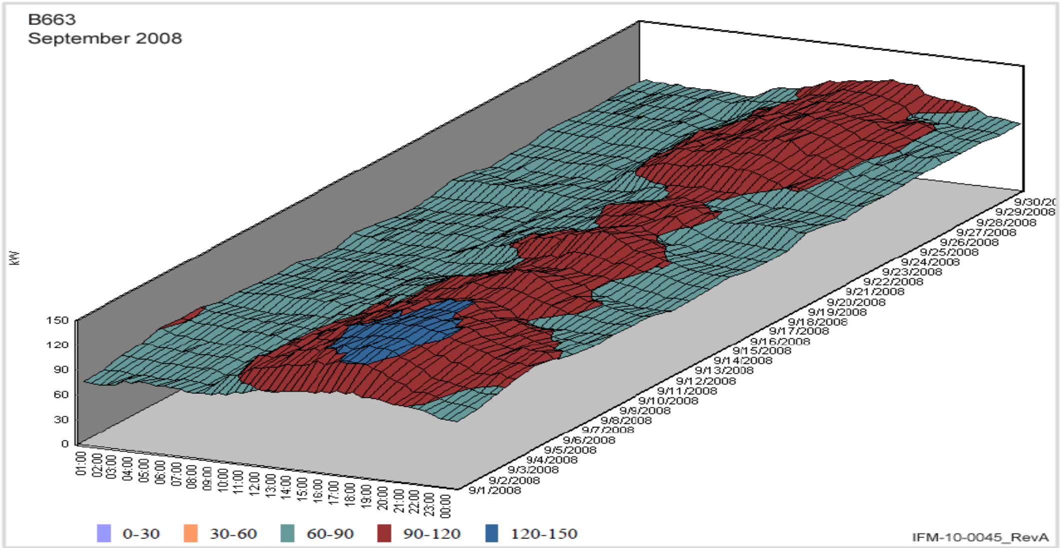


Figure 4.3: Energy Use Profile in September 2008 at a DOE building

5. **Measurement and Verification:** Measurement and verification establishes a systematic process to evaluate the performance of energy projects through a set of guidelines (International Performance Measurement and Verification Protocol [IPMVP] [EVO 2007] and Federal Energy Management Program [FEMP] 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.

This case study illustrates an ESPC project where advanced meter data are used not only to develop the baseline energy performance of the building but also to evaluate the performance of the project on a continuous basis. 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 Demineralized Water Production Facility Replacement. Almost all the ECMs in this project employ IPMVP Option B[2] for evaluating performance and make use of advanced meters

Baseline chiller plant performance was validated through the use of advanced meters (kW and kWh) and chilled water meters (Btu) installed and tied into the site-wide Utility Monitoring System (UMS). 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. Those 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

[2] 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.

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.

6. **Dashboards:** Dashboards are designed to present the energy information in a way that is easy to understand and gather information about the building operation. Even though BNL's MV-90 xi does not have built-in dashboard function, BNL has experimented with other dashboard programs, utilizing MV-90 xi data with varying degree of successes, including WebCTRL from Automated Logic (Figure 4.4).

Figure 4.4: WEBCTRL's dashboard shows an Environmental Index, to compare comfort versus energy consumption, revealing areas for improvement.

At Pacific Northwest National Laboratory, there are some existing dashboards provided by the EMCS and the goal is to build dashboards and meter data interface systems for all of the buildings in the DSOM.

Pacific Northwest National Laboratory is also exploring the possibility of supplementing DSOM's analysis tools with a commercial dashboard application. Improving the usability and functionality within DSOM will be the biggest step in getting metered data into the hands of practitioners across the Laboratory that so that they can use the technology to make 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).

7. **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 buildings that 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 utilities 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.

8. **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 power suppliers 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. Similar to time-of-use pricing, real-time pricing encourages decreased energy use during peak utility periods. However, rather than having predetermined fixed periods and associated energy costs, real-time pricing allows the utility to vary both—and does so giving the customer a nominal notification period. Sometimes these notifications are "day-ahead" or as short as an hour ahead. To take advantage of these offerings, facility managers need to have real-time metering and the flexibility to curtail loads commensurate with the utility needs and curtailment periods.

Brookhaven National Laboratory 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. The electricity is purchased on the real-time market by the hour using the New York Power Authority (NYPA) as its purchasing agent and transmitted to the laboratory by the Long Island Power Authority (LIPA). The lab facility personnel work very closely with the local utilities to ease Long Island's power demand during periods of high electricity usage; typically during the summer. BNL purchases its electricity from NYPA, and LIPA delivers it on its electric distribution system.

Brookhaven historically has participated in at least two demand-response programs each year to keep electricity demand at a minimum. Brookhaven 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 via an analog phone line connection. These data are 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

Brookhaven National Laboratory participates in one of the demand-response programs offered by the New York Independent System Operator (NYISO) special cases resource (SCR) program, which can be deployed in energy-shortage situations to maintain the reliability of the bulk power grid. As a participant, BNL is required to reduce power usage, and as part of their agreement they are paid in advance for agreeing to cut electric demand during "events" or "tests" for a specified duration, with a minimum duration of one hour.

In response to this event, BNL employees are notified through e-mail when these critical days are called, and they 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. It 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 the 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.

5 Advanced Meter Data Analysis for M&V

5.1 Background

Measurement and verification helps establish a systematic methodology to ensure that the savings from energy efficiency projects are being realized with a certain degree of confidence. Energy savings cannot be directly measured, since they represent the absence of energy consumption. Instead, savings are determined by comparing the energy usage before and after the installation of energy conservation measures and making appropriate adjustments to account for any changes in the conditions. M&V does not directly contribute to the savings of the project, but it adds certainty that the savings from the energy projects are being realized. Since developing and implementing project M&V activities costs money, tailoring the program for the energy project is very important. The higher the desired level of certainty in proposed savings, the more extensive the M&V activities can get, and thereby more expensive.

Designing M&V activities for a project is striking a balance between the savings risk and the associated costs. IPMVP (EVO 2012) presents guidelines to measure, compute, and report savings achieved by energy and water efficiency projects. M&V plans and related M&V activities for federal ESPC projects are developed in accordance with FEMP M&V Guidelines 3.0 (U.S. DOE 2008). These guidelines are based on IPMVP and, like them, are not intended to be prescriptive: they do not specify which M&V strategy be used for an ECM, what parameters be measured, or at what frequencies. These guidelines define various options and provide a general framework for M&V for energy-efficiency projects and measures. They are intended to help develop a project-specific M&V strategy that balances costs and savings uncertainty, to ensure that the project is performing and demonstrating the proposed performance. However, since these guidelines do not provide any specific M&V strategy for given ECMs, they are interpreted and applied differently by different users.

The IPMVP and FEMP M&V Guidelines offer different options, with different implementation costs and levels of rigor. Option A (retrofit isolation with key parameter isolation)has the lowest M&V cost but generally provides the least certainty of claimed savings. Option B (retrofit isolation with all parameter measurement) is considerably more accurate but has higher M&V costs. Option C (whole building analysis) can be implemented with higher degrees of certainty and cost but performance of individual ECMs cannot be isolated. Computer simulation (Option D) is labor and cost-intensive, but it can be used for new construction or other projects where real baseline data do not exist.

5.2 M&V Issues

Based on the M&V plans from recent federal ESPC projects (which have mandatory M&V requirements), there is a heavy reliance on M&V Option A; 80% of all savings from all ESPC projects (1998–2007) (Earni et al. 2010) completed under the government's major umbrella contract for ESPCs is being verified using Option A. While Option A is appropriate for the simplest, least-interactive ECMs, such as standard lighting and plumbing fixture replacements, much more complex ECMs like chiller replacements, EMCS upgrades, and HVAC upgrades might need more robust M&V options (Option B or C) to ensure that the savings risks are adequately mitigated. One of the primary reason that options B and C are not used is that they rely on permanently installed meters, which were rare in federal buildings prior to the EPACT 2005 advanced metering requirement. The associated data collection and analysis can also be expensive without proper infrastructure. Energy projects (like ESPC) often involve the installation of several measures in a small number of buildings on a large campus-type facility that used to contain a single revenue meter. The savings generated can be a small fraction of the facility's total energy use, and it can be difficult to estimate these savings from analysis of monthly utility bills. For this reason, indirect methods such as modeling and engineering calculation are often used for retrofit isolation. Option A is commonly used to evaluate the performance of the project, which often results in more savings uncertainty. With the advent of advanced meters that enable buildings to be individually metered at a higher frequency, consumption data before and after the project can be used to establish the energy-use baseline and to report energy savings with a much higher degree of confidence.

5.3 Advanced Meter Data Analysis for M&V

IPMVP Option C involves using whole-facility utility data (typically monthly) to verify the performance of the energy projects in which whole-facility baseline and performance period data are available. Option C usually involves collecting historical whole-building baseline energy use and related data and continuously measuring the whole-building energy use after the ECM installation. The baseline energy consumption is used to develop a statistical regression model as a function of independent variables (like weather), and this model is used to compute the baseline energy consumption. The predicted baseline energy consumption is compared with the actual energy consumption to compute the project's actual savings. This option may only be used to evaluate the performance of the entire project; the savings from individual measures is difficult to isolate.

To develop a regression model that is adequate, several goodness of fit characteristics have to be met. The coefficient of determination (R^2) is the measure of how well the independent variables explain variation in the energy. The rule-of-thumb for an acceptable model using monthly billing data is an $R^2 > 0.75$. Energy use in buildings has a degree of randomness that can vary greatly over the year. To accurately verify energy savings, the savings must be significantly greater than this degree of uncertainty (Jump 2008). A statistic that captures this uncertainty is the coefficient of variation of the root mean squared error—CV_{RMSE}—which describes how well the model fits the data. The IPMVP states that measured savings should be at least double the CV_{RMSE}, and ASHRAE Guideline 14 (ASHRAE 2002) states that the baseline model shall have a maximum CV_{RMSE} of 20% for the monthly data. The IPMVP and FEMP M&V guidelines imply that the predicted savings (using monthly data) from the energy projects have to be as high as 20% of the overall baseline energy consumption to be distinguishable. Some research studies imply this ratio of savings to overall building consumption can be as low as 5% using interval data (Katipamula 1995). This means that some of the issues that have plagued Option C analysis can be mitigated if high frequency interval data can be used to develop the model instead of monthly data.

The following data analysis was conducted to compare the model formulated using high-frequency data from different buildings (figures 5.1 and 5.2) with the traditional modeling approach.

1. **Traditional modeling approach:** Traditional modeling approaches use monthly electricity data to develop a correlation with heating and cooling degree-days (HDD and CDD) for each month during the baseline period, along with other key independent variables.
2. **LBNL modeling approach:** Lawrence Berkeley National Laboratory has developed a regression-based approach (Mathieu et al. 2011) that predicts energy use at the same frequency that data are recorded. This model uses outdoor air temperature and time of the week as independent variables to predict the electricity consumption. The analysis used the advanced meter data from the same DOE building as that above.

The characteristics for both these models for two different buildings are summarized in Table 5.1. The advanced meter electricity data from two BNL buildings were collected and analyzed and the results are provided in Appendix B. The coefficient of determination (R^2), error, and root-mean-squared error (CV_{RMSE}) are all considerably better for the LBNL model. The characteristic that is of great importance is CV_{RMSE}, which is an order of magnitude lower than the one obtained from the monthly model. This means that the proposed savings as a percent of baseline can be significantly lower with the LBNL model and still be distinguishable from the random variation in the data.

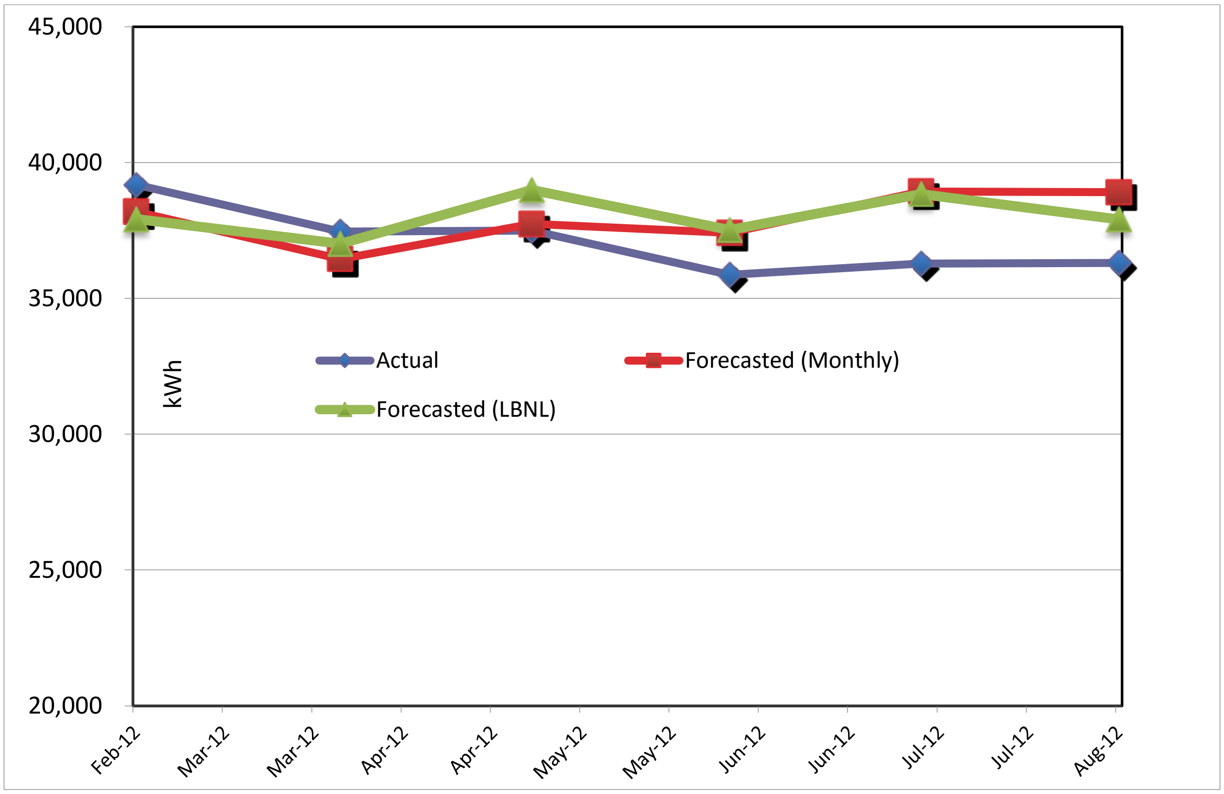


Figure 5.1: Comparison of actual energy use measurements (blue) to predictions by the monthly regression model (red). Energy use was measured and predicted at monthly intervals (LBNL Building 50). The data from June 2011 to November 2011 (six months) was used to tune the model, and the model was used to predict the energy consumption for the rest of the period.

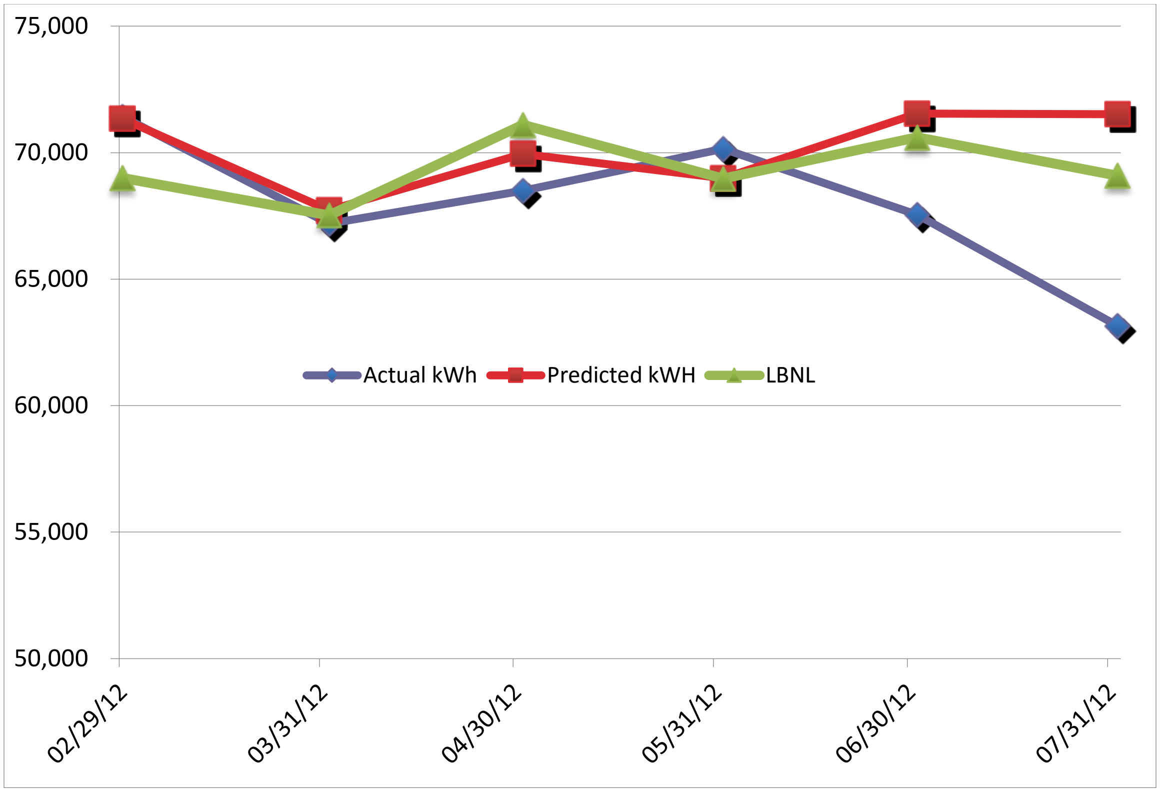


Figure 5.2: Comparison of actual energy use measurements (blue) to predictions by the monthly regression model (red). Energy use was measured and predicted at monthly intervals (LBNL Building 46). The data from June 2011 to November 2011 (six months) was used to tune the model, and the model was used to predict the energy consumption for the rest of the period.

Table 5.1: Summary of Model Characteristics

Building	Statistic	Monthly Model	LBNL Model
LBNL 50	R^2	0.75	0.89
	CV_{RMSE}	8.94%	0.1%
	Error	6.6%	3.1%
LBNL 46	R^2	0.88	0.88
	CV_{RMSE}	8.52%	0.07%
	Error	3.2%	1.4%

5.4 Benefits of the Approach

Some of the benefits of LBNL approach are as follows:

- The traditional approach requires a significant amount (typically 12 months) of training data to obtain an adequate model. The LBNL regression model requires less metered data to develop the baseline and determine the savings from an energy retrofit project. It can provide good results with as little as three months of training period data, provided the temperature in those three months spans the temperature range of the forecasting period. This reduces the time and resources needed to evaluate the impact of an energy-efficiency project and reduces the need for making any adjustments due to factors that are outside the scope of the project (referred to as *non-routine adjustments due to static factors*).

- The LBNL model is found to have better goodness of fit and less error compared to the monthly model (see Table 5.1). Comparing the predicted energy use against the actual data, the monthly average model (for Building 46) resulted in an error of 3.2% in total energy, while the LBNL model predicted the energy consumption with an error of about 1.4%. The CV_{RMSE} is less than 0.1% for the LBNL model, compared to 8.52% from the monthly model. This means that the proposed savings as a percent of baseline can be less than 1% and the savings can still be distinguishable from the noise. This number is lower than some of the previous studies in this area (Katipamula 1995 indicates this ratio of savings to overall building consumption can be as low 5% using interval data). This number is close to 18% with the monthly model and aligns with the IPMVP and FEMP M&V Guidelines number of 20% to be distinguishable.

- The LBNL model predictions can occur at higher granular time periods (e.g., weekly, as shown in figures 5.3a and 5.3b), and this feature can help to quickly identify any anomalies in the performance of the project and help devise any corrective actions. The traditional monthly model computes the overall monthly energy consumption and does not account for fluctuations in outdoor air temperature throughout the day or the month. For example, if temperature fluctuates significantly throughout a day, the average temperature may be mild (indicating low energy use), while in actuality, both heating and cooling were necessary (indicating higher energy use), which typically is not captured in the monthly model.

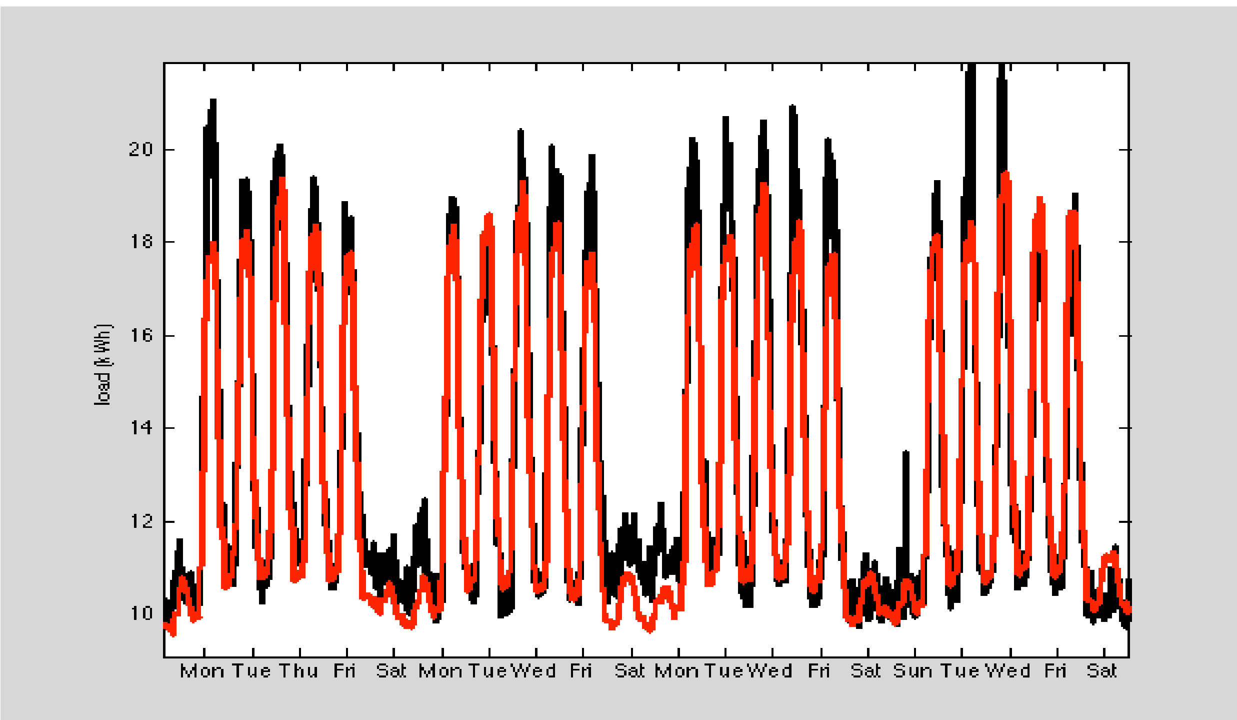


Figure 5.3a: Comparison of energy use measurements (black) to predictions by LBNL's regression model (red) for a period from March 25, 2012 to August 31, 2012. For clarity, the plot only shows the data for a four-week period starting from March 25, 2012. Energy use was measured and predicted at 15-minute intervals (for LBNL Building 50).

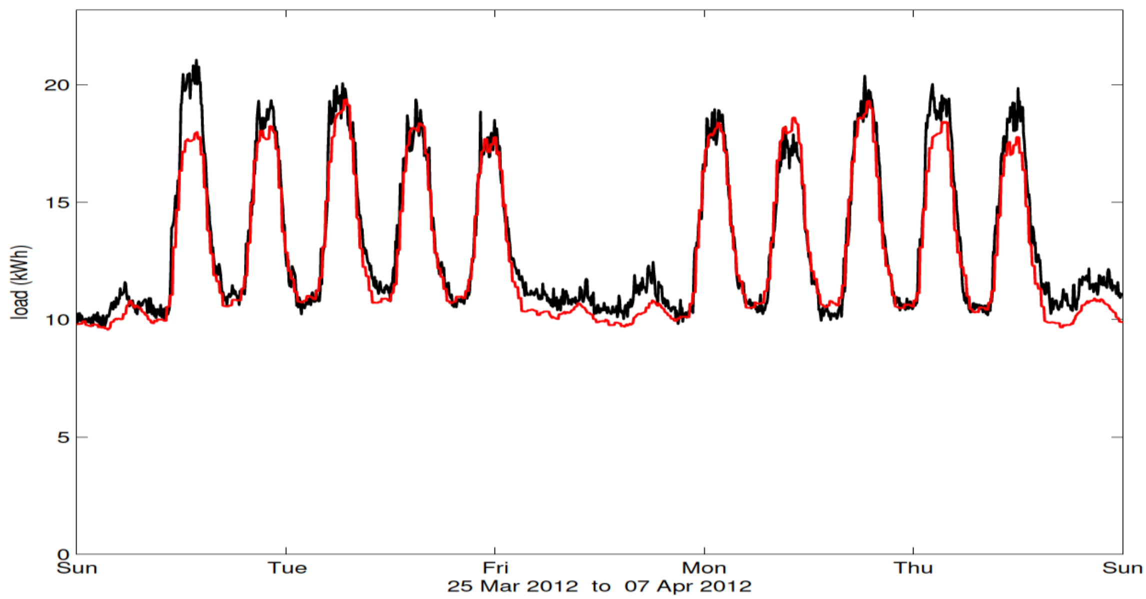


Figure 5.3b: Comparison of energy use measurements (black) to predictions by LBNL's regression model (red) for a period from March 25, 2012 to April 7, 2012 (for LBNL Building 50).

- One of the drawbacks of the Option C utility bill analysis has been that the impact of individual measures cannot be evaluated separately. The LBNL model can help mitigate this by separating the energy consumption for occupied and unoccupied periods, including weekdays and weekends. Therefore, this feature can help users separately identify the impact of suitable measures; for example, evaluating the impact of a night setback measure by comparing pre- and post-energy consumption during an unoccupied period.

- The LBNL model can not only ensure that the installed measures are performing as intended and generating the savings, but this model can also help to identify additional energy-saving opportunities as a cursory auditing and re-commissioning tool. Figure 5.4 shows three-month metered data from a building. The data in the month of June are considered to be baseline and devoid of any issues. As evidenced in the months of July and August, this building fails to shut down at night (shaded periods). The facility personnel, armed with this information, can act to identify the root cause and address this issue, which can not only save energy but also help to prolong the life of the equipment.

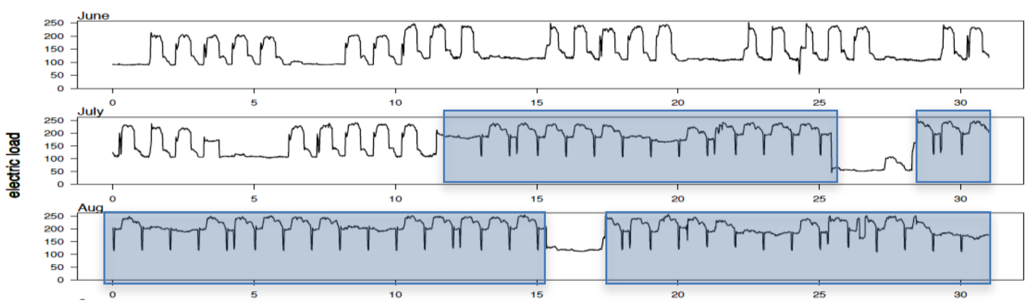


Figure 5.4: Whole-building Load for Building with a Scheduling Problem

6 Conclusions and Recommendations

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. This study tried to draw commonalities among different sites in terms of hardware, software, and data analytics. It also presented case studies that highlight some of the innovative actions that can be taken based on the data that is being collected.

This work also conducted analysis on how advanced meter data 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. Analysis is also presented on how advanced metering data can be used to identify energy conservation opportunities to improve overall building performance.

To improve overall building performance and lead toward continuous improvement, we propose a framework to integrate M&V and commissioning activities by harnessing some of the existing data, including advanced meter data. This framework utilizes advanced meter and other data sources through a cost-effective monitoring-based commissioning (MBCx) approach to reduce energy consumption and to monitor system performance. This monitoring can be used to ensure the persistence of energy savings by identifying anomalies that will lead to degradation in performance. *Monitoring-based commissioning* is defined as the "adjustment, maintenance or repair of existing equipment as opposed to upgrade of equipment."

The proposed framework has the following components:

- **Data collection and analysis:** This function can be accomplished with an advanced metering system. This system retrieves whole-building electric data, sub-metered data, and other related parameters from sub-systems, or from components collected by an EMCS (Figure 6.1). These data are analyzed to calculate the key performance indicators (KPIs) at each level: building, system, or sub-system of the hierarchy that specifies the energy performance.

- **Benchmarking:** There are several benchmarking tools in the market that can readily be used to compare the performance of the building to that of other similar buildings. Hierarchical and end-use benchmarking (Sartor et al. 2000) is probably the most suitable and appropriate in the proposed framework. It shows the overall potential for reductions in energy intensity within each end use and its priority relative to other end uses. The Carbon Trust (Action Energy 2003) has demonstrated the application of end-use benchmarking to identify efficiency opportunities in office buildings in the United Kingdom. Another related technique, action-oriented benchmarking (Mathew and Mills 2008), extends generalized whole-building energy benchmarking to include analysis of system and component energy use metrics and features. This benchmarking, coupled with the appropriate decision-tree logic, allows users to identify, screen, and prioritize potential ECMs, and can in turn be used to inform and optimize a full-scale audit or commissioning process.

- **Tuning.** The process of "tuning" involves comparing the actual KPI information obtained from the EIS with established benchmarks such as the Commercial End-Use Survey (CEUS) to generate corrective action based on the difference initiated by the EMCS. The MBCx mechanism can be used to combine ongoing building energy system monitoring with standard re- or retro-commissioning (RCx) practices with the aim of providing substantial, persistent, energy savings (Brown and Anderson 2006).

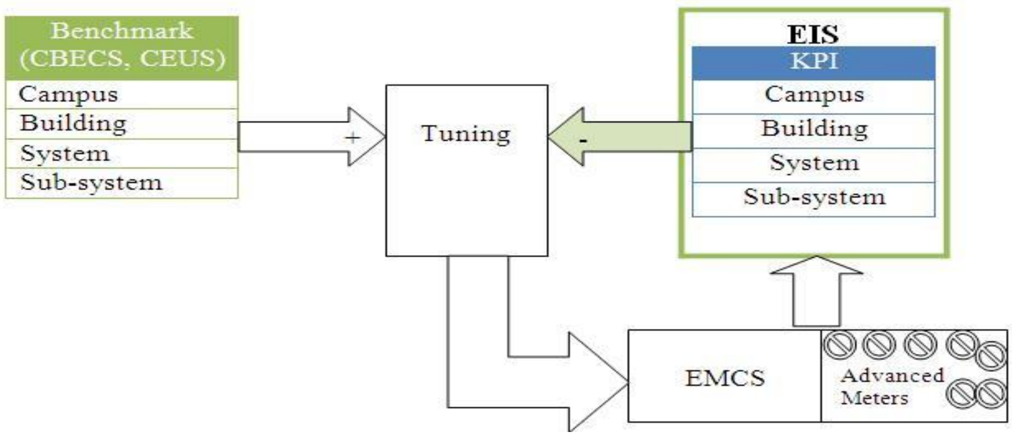


Figure 6.1: Integrated Framework for Proactive M&V

This framework can provide the foundation to automate some of the activities required by EISA Section 432, toward meeting the emission-reduction goals for Scope 1 and 2 GHG (E.O. 13514) in buildings. This aligns well with proposed implementation methods outlined in DOE's Strategic Sustainability Performance Plan (Goal 1.a.iv, page 27) (DOE 2012a)—conducting process assessments and energy and re-commissioning audits, metering processes and individual buildings for performance diagnostics, benchmarking building performance, and M&V of installed measures.

According to the Compliance Tracking System (CTS) for EISA Section 432, there are 47 active covered DOE facilities, with total facility gross area of 78 million square feet, of which 1,755 separate buildings are metered for electricity, among which 17 million square feet has been benchmarked. Potentially, all these DOE buildings/facilities can employ this framework to automate auditing, re-commissioning, and M&V activities related to EISA Section 432.

7 References

AEC. 2003. *Advanced Utility Metering.* Under contract NREL/SR-710-33539, Architectural Energy Corporation. Boulder, Colorado.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers. 2002. Guideline 14 on Measurement of Demand and Energy Savings.

Brown, K., and M. K. J. Anderson. 2006. Monitoring-Based Commissioning: Early Results from a Portfolio of University Campus Projects. San Francisco, Calif. The National Conference on Building Commissioning: April 19–21, 2006.

Earni, S., Coleman, P., Sanders, M.: "Integrated Framework toward a Closed Loop Measurement and Verification Approach," ACEEE Summer Study, August 2011.

EVO (Efficiency Valuation Organization). 2012. International Performance Measurement and Verification Protocol (IPMVP).

Federal Energy Management Program (FEMP). 2011. *Metering Best Practices: A Guide to Achieving Utility Resource Efficiency, Release 2.0.* Prepared by Pacific Northwest National Laboratory for the Federal Energy Management Program, U.S. Department of Energy, Washington, D.C. Available at: http://www1.eere.energy.gov/femp/pdfs/mbpg.pdf.

Granderson, J., M. A. Piette, G. Ghatikar, and P. Price. 2009. *Building Energy Information Systems: State of the Technology and User Case Studies.* Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division, Berkeley, California.

Jump, David (Quantum Consulting, Inc.). 2008. *Guidelines for Verifying Existing Building Commissioning Project Savings: Using Interval Data Energy Models, IPMVP Options B and C.* California Commissioning Collaborative.

Katipamula, S., T. A. Reddy, and D. E. Claridge. 1995. "Effect of Time Resolution on Statistical Modeling of Cooling Energy Use in Large Commercial Buildings." *ASHRAE Transactions* 101, Part 2, 172–185.

Marini, K., G. Ghatikar, and R. Diamond. 2011. *Using Dashboards to Improve Energy and Comfort in Federal Buildings.* Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division Berkeley. LBNL-4283E.

Mathieu, J. L., P.N. Price, S. Kiliccote, and M. A. Piette. 2011 "Quantifying Changes in Building Electricity Use, with Applications to Demand Response." *IEEE Transactions on Smart Grid* 2(3): 507–518. doi: 10.1109/TSG.2011.2145010.

Sartor, D., M. A. Piette, W. Tschudi, and S. Fok. 2000. “Strategies for Energy Benchmarking in Cleanrooms and Laboratory-Type Facilities.” *Proceedings of the ACEEE 2000 Summer Study on Energy Efficiency in Buildings* (10): 191–203.

Tremper, C. “Government Progress Toward Facility Sustainability Goals,” GreenGov Symposium, Oct. 31 - Nov. 2, 2011, Washington, DC.

U.S. Department of Energy. 2006. *Guidance for Electric Metering in Federal Buildings.* February 3.

U.S. Department of Energy. 2008. *M&V Guidelines: Measurement and Verification for Federal Energy Projects.* Version 3.0.

U.S. Department of Energy. 2012a. *2012 Strategic Sustainability Performance Plan.* Report to the White House Council on Environmental Quality.

U.S. Department of Energy. 2012b. Guidance for the Implementation and Follow-up of Identified Energy and Water Efficiency Measures in Covered Facilities (per 42 U.S.C. 8253(f), Use of Energy &Water Efficiency Measures in Federal Buildings).

Appendix A: Study Form

Activity: Integrated framework for combining advanced metering, retro commissioning and measurement & verification (M&V)

Performer: Lawrence Berkeley National Laboratory

The proposed scope of work, supported by DOE's SPO, is to study successful advanced meter installations at several DOE sites 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. This work will produce a brief report, documenting some of the current practices for implementing advanced metering, along with data management and analysis techniques.

The study seeks to obtain the following information:

- Advanced metering system and major components
    - hardware manufacturer
    - software analysis platform
- How advanced metering (AM) was proposed vs. how it was actually installed?
- Was the AM installation commissioned?
- Who uses the AM system? What does it help them do?
- Can the metered data be used to improve building operations?
- AIs the AM system used to help commission the retrofits installed by the ESCO or others?
- Is the AM system used for verifying the project savings (M&V)?
- Is the AM system used for on-going performance monitoring and benchmarking?

Part 1: AM in your facility

1. Advanced metering (AM) system details
    a. Details of various components
        i. Capability to measure and record interval data. At least hourly for electricity.
            1. What types of meters are used?
            2. Do you have any sub-meters?
        ii. Communicates the data to a remote location/common database.
            1. What type of system or database is used?
            2. How many and what points (variables) are collected?
            3. What time interval is monitored for each point (sampling rate)?
        iii. What features and functionality related to energy use management, procurement, and operations are supported by the AM system?
            1. Who uses the system?
            2. Does the system include an analysis or visualization platform?
                a. May we have samples?
            3. What types of data analysis methods are used? What are the key performance metrics that are tracked to assess a building's energy consumption (EUI etc.)?
            4. Does the system include a dashboard? If so how easy is to understand and gather information about the building operation?
    b. What issues or problems have been encountered either during installation or operation?
    c. What actions have been taken based on AM analysis? (Measures, Behavior modification, billing)

Part 2: AM for Existing Building Cx

1. How is commissioning applied in the facility?
    a. Commissioning installed systems to make sure they operate correctly
    b. One-time EBCx process to identify problems preventing optimum operational / energy performance
    c. On-going commissioning, where problems are continuously identified and addressed
2. How is AM system used for these commissioning activities?
3. Is AM data used for benchmarking?
4. What measures or practices were identified based on the AM?
5. How were the measures discovered?
6. What are the benefits /results of EBCx with AM?

Part 3: AM for M&V

1. Do you have any M&V requirements for energy projects (ESPCs or others) to make sure that the energy savings are being realized from various retrofit projects?
2. Is the AM system used for M&V?
3. How was the AM system used for M&V?
    a. Whole-building approach
    b. Retrofit Isolation approach

4. What kinds of baseline techniques are used?
    a. Regression method
    b. Non-regression method
    c. Other method (describe)
5. Was the AM system data used as a check on overall savings?
6. Is the AM system used to help assure savings persist?
7. What were the advantages of using AM for M&V?
8. What were the disadvantages of using AM for M&V?
9. Is AM used for any other purposes?
10. On a scale of 1-10:
    a. How effective is the system?
    b. How reliable is the system?

Part 4: Return on AM System

1. How is the AM system financed?
    a. ESPC
    b. UESC
    c. Internal funds
    d. Other-Specify?
2. Did AM improve the cost effectiveness of the project?
3. Did AM improve the cost effectiveness of M&V?
4. What savings resulted from the installation of the AM system?

Part 5: AM Management and Planning Framework (from Chapter 3 Best Practices Guide[3])

1. Did you develop a metering plan?
    a. What are the main elements of your plan?
    b. Who was involved? What was their role?
    c. Do you believe that this planning process was effective?
    d. Does it have performance validation and persistence criteria to ensure the effectiveness of metering program?
    e. Are the metering system equipment maintained annually and source of funding to accomplish this?
    f. Is there annual training for system operators?
    g. Are there any performance goals or incentives to motivate staff?

[3] *Metering Best Practices: A Guide to Achieving Utility Resource Efficiency*. A Pacific Northwest National Laboratory document prepared for FEMP, provides a detailed guide to understanding the use of metering to help optimize the savings and benefits from energy projects.

Appendix B: Data Analysis

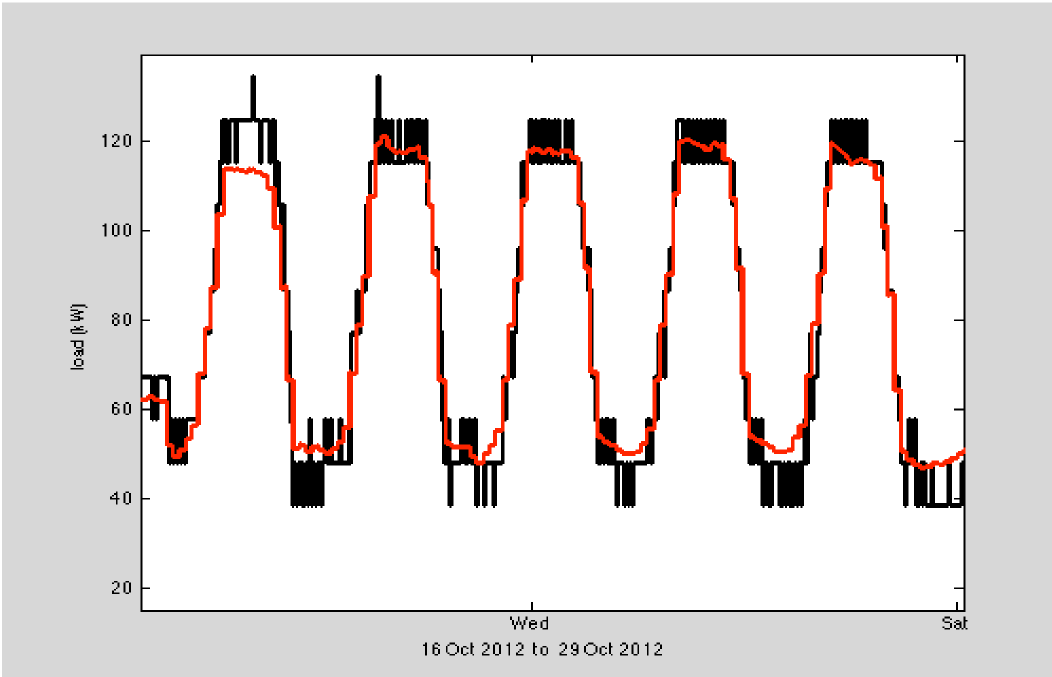


Figure B.1a: Comparison of energy use measurements (black) to predictions by LBNL's regression model (red) for a period from October 16, 2012 to October 20, 2012 (for BNL Building 400R1).

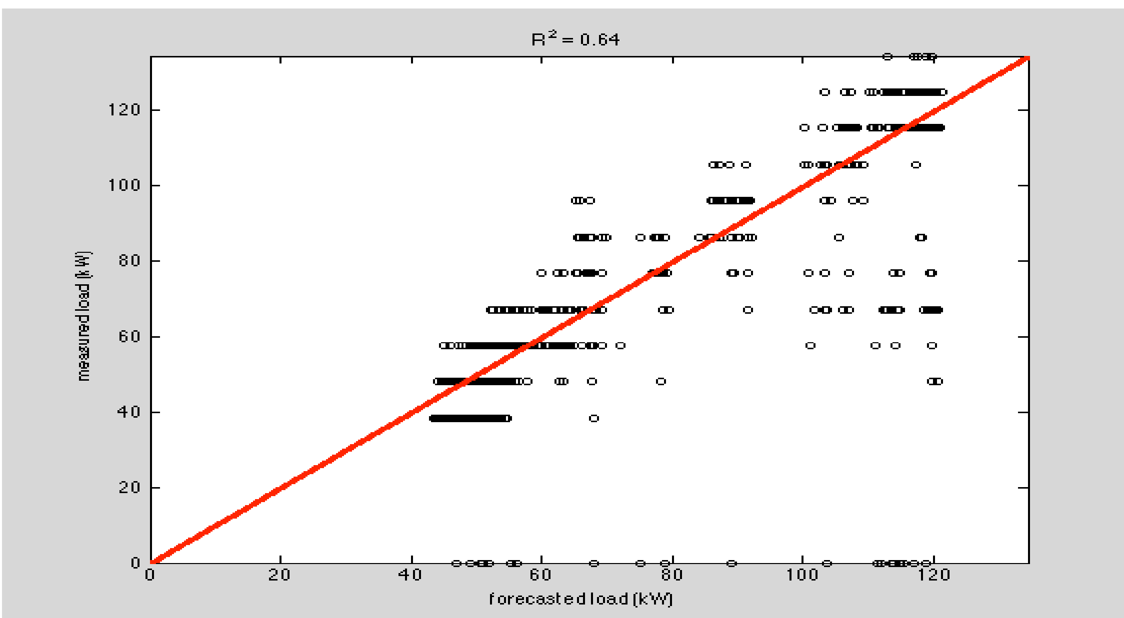


Figure B.1b: Comparison of measured energy use vs predictions by LBNL's regression model (for BNL Building 400R1).

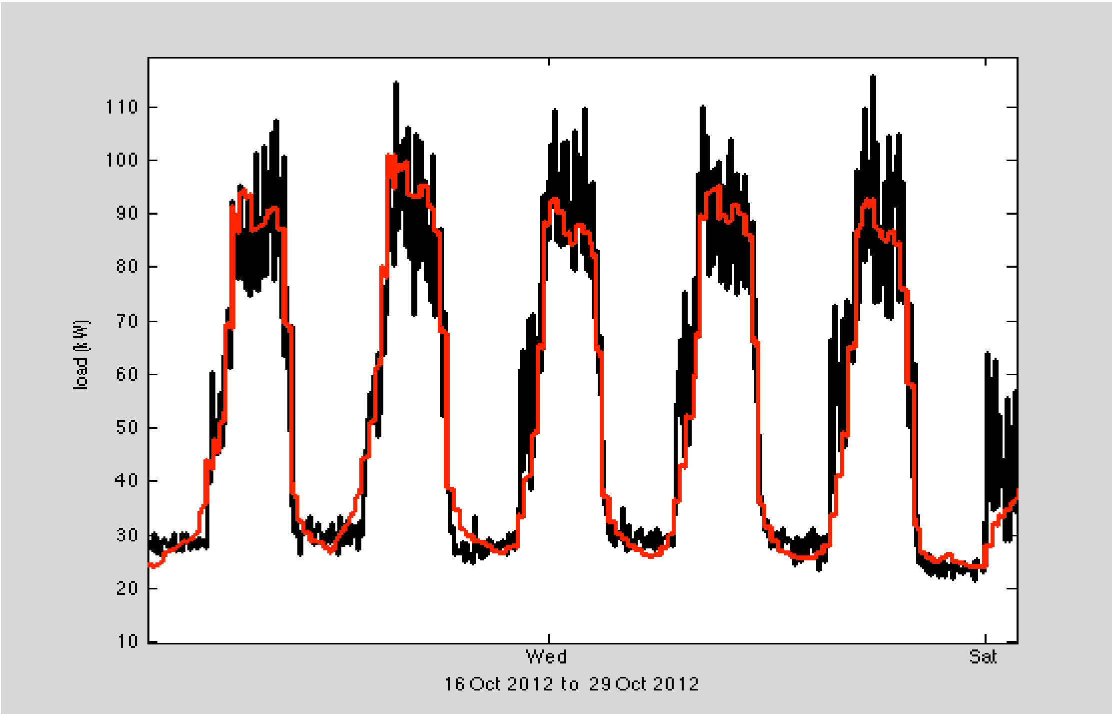


Figure B.2a: Comparison of energy use measurements (black) to predictions by LBNL's regression model (red) for a period from October 16, 2012 to October 20, 2012 (for BNL Building 134R1).

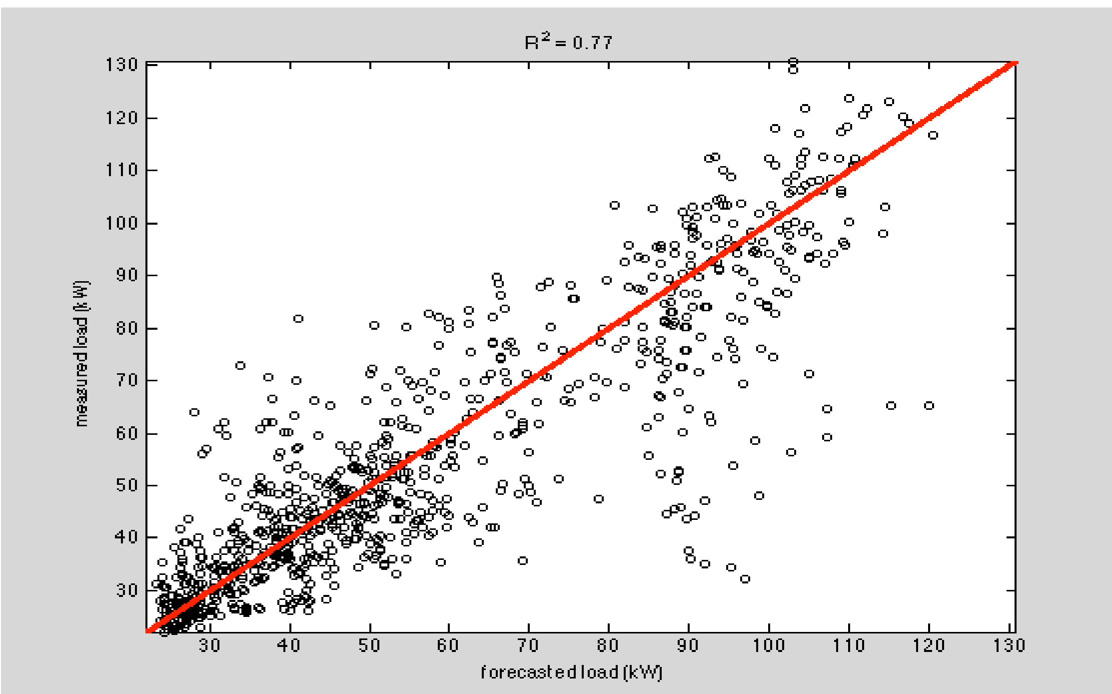


Figure B.2b: Comparison of measured energy use vs predictions by LBNL's regression model (for BNL Building 134R1).