PNNL-23494

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Metering Plan

Informed Decision Making Through Measuring and Monitoring of Utility Resource Consumption

July 2014

Jason E. Pope

U.S. DEPARTMENT OF
ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

The Sustainability Program at Pacific Northwest National Laboratory (PNNL) has adopted a "triple-bottom-line" approach of environmental stewardship, social responsibility, and economic prosperity to its operations. Metering at PNNL works in support of all three, specifically to measure and inform building energy use and greenhouse gas emissions and minimize water use. The foundation for metering at PNNL is a core goal set, which consists of four objectives: providing accurate data without interruption; analyzing data while it is still new; providing actionable recommendations to operations management; and ensuring PNNL's compliance with contract metering requirements. These core objectives guide the decisions that we make during annual planning and as we operate throughout the year.

This 2014 edition of the Metering Plan conveys the metering practices for and vision of the Sustainability Program. It presents our progress toward the metering goals shared by all federal agencies and highlights our successful completion of metering requirements. PNNL's approach to the installation of new meters will be discussed. Perhaps most importantly, this Plan details the analysis techniques utilized at PNNL that rely on the endless streams of data newly available as a result of increased meter deployment over the last several years. Previous Metering Plans have documented specific meter connection schemes as PNNL focused on deploying meters in a first step toward managing energy and water use. This Plan serves not only to highlight PNNL's successful completion of agency metering goals but also as a guideline for meter installation and data analysis.

Acronyms and Abbreviations

AEE	Association of Energy Engineers
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BOCC	Building Operations and Control Center
BTU	British thermal unit
CEDR	Consolidated Energy Data Report
CEM	Certified Energy Manager
CO_2	carbon dioxide
COP	coefficient of performance
CRAC	computer room air conditioner
CSF	Computational Sciences Facility
DOE	U.S. Department of Energy
DSOM	Decision Support for Operations and Maintenance
ECM	energy conservation measures
EISA	Energy Independence and Security Act of 2007
EMSL	Environmental Molecular Sciences Laboratory
EO	Executive Order
EPAct 2005	Energy Policy Act of 2005
FEMP	Federal Energy Management Program
FIMS	Facilities Information Management System
F&O	Facilities and Operations
FMCS	Facilities Management Control System
ft^2	square foot/feet
FUA	Facility User Agreement
HPSB	high performance and sustainable building
HVAC	heating, ventilation, and air conditioning
ILA	industrial, landscaping, and agriculture
ISB	Informational Sciences Building (1 and 2)
LSB	Laboratory Support Building
M&O	Maintenance and Operations
MOU	Memorandum of Understanding
PNNL	Pacific Northwest National Laboratory
PUE	power utilization effectiveness
RCL	Radiological Calibrations Laboratory
R&D	research & development
RDHx	rear door heat exchanger
SME	subject matter expert
SPO	(PNNL's) Sustainability Performance Office
SSP	Site Sustainability Plan
VOC	volatile organic compounds
WCM	water conservation measures

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1.0 Introduction

Pacific Northwest National Laboratory (PNNL) has an established Sustainability Maintenance and Operations (M&O) Program with an annual submittal of a Metering Plan as one of its three program deliverables. The other deliverables are:

- The contractually required Site Sustainability Plan (SSP) and associated Consolidated Energy Data Report (CEDR)
- The annual report on progress toward comprehensive energy and water assessments as required in the Energy Independence and Security Act (EISA) of 2007.

Metering at PNNL is managed within the Sustainability Program. All three program deliverables rely on data collection, analysis, and professional recommendations resulting from metering efforts performed within the Sustainability Program.

This 2014 edition of the Metering Plan conveys the metering practices for and vision of the Sustainability Program. It presents our progress toward the metering goals shared by all federal agencies and highlights our successful completion of metering requirements. PNNL's approach to the installation of new meters will be discussed. Perhaps most importantly, this Plan details the analysis techniques utilized at PNNL that rely on the endless streams of data newly available as a result of increased meter deployment over the last several years. Previous Metering Plans have documented specific meter connection schemes as PNNL focused on deploying meters in a first step toward managing energy and water use. This Plan serves not only to highlight PNNL's successful completion of agency metering goals but also as a guideline for meter installation and data analysis.

2.0 Advanced Metering Plan

2.1 Vision

The PNNL Sustainability Program has adopted the “triple-bottom-line” approach of environmental stewardship, social responsibility, and economic prosperity to its operations. Metering at PNNL works in support of all three, specifically to measure and inform building energy use and greenhouse gas emissions and minimize water use. The foundation for metering at PNNL is a core goal set, which consists of four objectives:

- Provide accurate data without interruption. Data should be of sufficient quality, quantity, and timeliness to enable effective analysis and support real-time commissioning.
- Analyze data while it is still “fresh.” Data analyses and the resulting recommendations are most relevant when real-time data is used.
- Provide actionable recommendations to operations management.
- Ensure PNNL’s compliance with contractual metering requirements.

These core objectives guide the decisions that we make during annual planning and as we operate throughout the year. Additionally, metering works to enable the SMART^3 initiative, PNNL’s Facility and Operations Directorate’s vision to integrate the *smartest* facilities, connected to the *smartest* people, by the *smartest* systems (PNNL 2014a). The SMART^3 initiative near-term objectives are to deploy sensors in 100% of our managed facilities; use the Building Operations and Control Center (BOCC) to monitor and control building performance; leverage existing research & development (R&D) technical capabilities; and ensure optimal control, response, and efficiency across all Facilities and Operations (F&O) managed facilities using interconnected hardware and software tools.

Sensors deployed as part of the SMART^3 initiative are termed *smart sensors*, which reduce operational costs by quickly allowing staff to troubleshoot equipment and correct system operation, allowing for energy saving strategies, enabling condition-based preventative maintenance, and generating diagnostics to enhance reliability. Its specific values are to:

- increase occupant comfort (temperature and environmental control)
- improve operations (troubleshooting and monitoring)
- allow for energy saving strategies (advanced programming techniques)
- enable condition-based maintenance (perform maintenance as needed)
- perform diagnostics (detect system abnormal conditions).

The SMART^3 initiative begins by defining sensors through a graded approach based on added value and cost effectiveness. In working with the Plant Operations, Sustainability and Energy Group, and Engineering several smart sensors were identified as providing the most impact in the five value areas.

The top value smart sensors are space temperature sensors, demand-based ventilation sensors (carbon dioxide [CO_2] or volatile organic compounds [VOC]), air filter differential pressure sensors, discharge temperature sensors, British thermal unit [BTU] meters, and status sensor on fans/pumps (current transducer). Sensor installation is combined with programmed functions and control routines to enable the *smart sensor* capability. An example of installed *smart sensors* in action is detailed in the Case Study section of this report.

2.2 Goal Progress

A key metric used to gauge meter installation progress at PNNL is our progress toward the fourth Metering Plan objective: *ensure PNNL's compliance with contractual metering requirements*. Our Program has made this goal a priority and has taken a leadership stance by completing the goal ahead of the requirement schedule for three services: electricity, natural gas, and potable water.

- The Energy Policy Act of 2005 (EPAct 2005) Section 103 requires that all federal buildings install advanced electric metering systems where practicable by October 1, 2012. ***PNNL has met this requirement, installing whole building advanced electric meters in 23 buildings***.
- EISA 2007 and the National Energy Conservation Policy Act require that all federal buildings be metered for natural gas by October 1, 2016. ***PNNL has met this requirement, installing whole building advanced natural gas meters at 12 buildings***.
- EISA 2007 encourages metering water to validate savings made as part of water intensity reduction goals in the Act. ***PNNL has placed a high priority on metering water down to the building level and completed the water meter installation portfolio with advanced or standard meters on 23 buildings***.

As shown in Table 2.1, meters were installed in all Facilities Information Management System (FIMS) buildings where practicable. Decisions to install advanced metering were made using the cost justification methodology introduced in the Federal Energy Management Program (FEMP) Metering Best Practices Guide, as discussed below.

Table 2.1. Advanced Meter Technologies for PNNL Buildings

Building	Building ID	Building Square Footage (ft^2)	Electrical Meter	Gas Meter	Water Meter Schedule
Environmental Molecular Science Laboratory	3020	224,463	Advanced	Advanced	Advanced
Radiological Calibrations Laboratory	318	37,025	Advanced	Advanced	Advanced
Radiochemical Processing Laboratory	325	144,820	Advanced	Advanced	Advanced
Life Sciences Laboratory	331	115,127	Advanced	Advanced	Advanced
Plant Operations & Maintenance Facility	350	22,048	Advanced	N/A	Advanced
Material Sciences & Technology Laboratory	3410	79,878	Advanced	Advanced	Advanced
Radiation Detection Laboratory	3420	81,369	Advanced	Advanced	Advanced
Ultra Low Background Counting Laboratory	3425	7,418	Advanced	Advanced	Advanced
Ultratrace Laboratory	3430	70,298	Advanced	Advanced	Advanced
Large Detector Laboratory	3440	5,488	Advanced	N/A	Advanced
Laboratory Support Warehouse	LSW	20,092	Advanced	Advanced	Standard
2400 Stevens Office/Laboratory Building	2400 Stevens	99,626	Advanced	N/A	Standard
Environmental Technology Building	ETB	100,358	Advanced	N/A	Standard
Information Sciences Building – 1	ISB1	50,200	Advanced	N/A	Standard
Information Sciences Building – 2	ISB2	60,080	Advanced	N/A	Standard
Laboratory Support Building	LSB	83,921	Advanced	N/A	Standard
National Security Building	NSB	100,358	Advanced	N/A	Standard
Sigma 1 Office Building	Sigma I	20,000	Advanced	N/A	Standard
Sigma 2 Office Building	Sigma II	20,100	Advanced	N/A	Standard
Sigma 4 Office Building	Sigma IV	20,530	Advanced	N/A	Standard
Biological Sciences Facility	BSF	78,218	Advanced	Advanced	Advanced
Computational Sciences Facility	CSF	65,861	Advanced	Advanced	Advanced
Systems Engineering Facility	SEF	47,676	Advanced	Advanced	Standard
Total Square Footage Suitable for Advanced Meters		1,554,954			
Percent Square Footage with Advanced Meters Where Practicable		100.0%			

2.3 Implementation

PNNL's Metering Plan uses four generic approaches to metering across campus. From our commitment to metering as a key component of the Sustainability Program, we typically focus on long-term metering. We evaluate installations on a case-by-case basis and consider costs and returned benefits from metering. As a result, we are equipped to deploy any of the four basic approaches for metering based on specific need.

- **One time/spot measurement**: Achieved through measurement by an electrically trained and qualified craftsman. Used to meter equipment where the current draw does not typically modulate and a single measurement is needed, typically as a consideration for a design project.
- **Run-time measurement**: Achieved exclusively through our facility management and control system. Run-time measurement is used as a diagnostic tool and also to alternate between motors on equipment where lead/lag settings are used in the control sequence to facilitating even wear.
- **Short-term monitoring**: Used to quantify savings from a specific project when a permanent meter installation is not warranted. Most short-term monitoring is for the purpose of measuring electrical consumption. We typically use battery-powered HOBO meters by Onset to meet this need. Examples include installing a temporary meter to baseline air compressor power for 30 days before a project to repair leaks in the distributed compressed air system throughout a building. At the conclusion of the project, the system is again monitored for 30 days to estimate savings as a result of the repairs. Likewise, we install a temporary meter on a lighting circuit before implementing advanced lighting control. This enables us to quantify savings and assists in commissioning the system because we can monitor how often the lights are off in the night when the building is unoccupied. This monitoring has alerted us to occupancy sensors installed in less than desirable locations, such as near air discharge registers, where false occupancy is detected.
- **Long-term monitoring**: Our standard approach. Long-term monitoring provides valuable information in the short run but also allows trending over time, a primary input to our data analysis approach. PNNL collects data from long-term electric meters at the service for each building. Likewise, natural gas and water meters installed at the building entry are also long-term installations.

2.4 Design and Installation

The Metering Plan at PNNL employs a variety of meter types and technologies. Along with a cursory review of existing metering, new projects should begin design by working through three questions detailed below.

► ***Do I need any additional meters to manage energy use?***

Proposed meter installation projects are evaluated against cost justification for simple payback detailed in the FEMP Metering Best Practices guide. The following formula is taken from the guidance:

$$\frac{\left[\left(\frac{\textbf{Installed Cost}}{\textbf{Desired Simple Payback}}\right) + \textbf{Annual Cost}\right]}{\textbf{\% Annual Savings}} = \textbf{Minimum Annual Electric Bill}$$

This simple payback formula is used to determine if the return on investment of the meter installation is acceptable. While the formula provides an informative decision-making tool, because each meter installation is evaluated separately, there are cases where a meter does not meet the threshold of practicality by the simple payback calculation but is still installed. This occurs if investigation reveals an opportunity for optimizing building or equipment operations where savings beyond costs for the service being metered can be realized.

Once it is determined that metering will be installed, the first tier is at the whole building level for electricity, natural gas, and water. Requirements behind whole building metering are detailed in the Goal Progress section. After ensuring that requirements for metering at the whole building level are met, consideration should be given to installing the sub-metering necessary to divide electrical consumption into four load categories: heating, ventilation, and air conditioning (HVAC); IT; lighting; and miscellaneous plug load (discussed in the Data Analysis section). PNNL buildings should consider metering necessary to show the load for each lab, usually at the lab panel. Further metering necessary for process optimization should be considered based on the scope of the project.

► ***What meters should I use?***

Existing **electric meters** installed across the campus take on different characteristics due to the time period in which they were installed, design preferences, and project design constraints. Electric meter types installed include Veris, E-Mon, PQube, Square D, Cutler Hammer, Utility provider pulse, and others. New installations must be evaluated on a case-by-case basis given the design constraints.

On new switchboard installations, metering can be included as part of the manufactured package. The Veris product line has proven robust and affordable 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, no local display, and communicates directly with the Facilities Management Control System (FMCS). Recently, the new Veris E50 meter has been selected for several installations and is functioning well.

The E50 communicates using the Building Automation and Control network (BACnet) protocol with a compact local display and data logging capability. Separate meter power on the E50 has made it an attractive option for installations at equipment fed from two sources of power via a three-position transfer switch. PNNL is following an industry-wide trend to move toward control equipment that communicates using the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)-developed communications protocol standard. The primary benefit of selecting equipment that uses BACnet is its open protocol, allowing freedom from proprietary systems that limit future options.

In some applications, electric usage data for a specific piece of equipment can be obtained from a variable frequency drive or other installed component. When possible, we prefer to take advantage of existing metering or specify metering integral to a system being installed.

The most widely used **natural gas meter** at PNNL is the Dattus by Itron. This solid-state meter uses fluidic oscillation technology and has data logging capabilities. Other meters in use include the Roots by GE (formerly Dresser), also installed as a flanged or threaded meter in the gas line, and the Sage Prime, a thermal mass flow insertion meter that can be installed in an existing line. Meters for natural gas tend to be the most costly to purchase and install.

PNNL employs several technologies of **water meters** across campus. The most accurate (and most costly) to purchase and install is the compound meter, which combines disc and turbo meters in a single body. The Badger Compound Series is installed at several buildings and has proven to work well. Because of the ease of installation and low cost, the insertion turbine meter is an attractive, effective option. An additional benefit of the insertion meters is the ability to "hot tap" an in-service line, eliminating the need for a system outage. The Onicon 1100 and 1200 series meters offer an alternative to a full bore meter like the Badger Compound. Care must be taken during the design phase to ensure that minimum flows are met. Considerations can be taken, such as reducing the pipe diameter for a short section to increase fluid velocity across the meter. The Onicon F-3500 is an electromagnetic insertion meter used most recently at PNNL that allows accurate readings at lower flow levels than the insertion turbine meters. To meter water used for irrigating outdoor landscaping, a McCrometer propeller meter is installed in the non-potable water line. This type of meter is especially suited to dirty water flows and handles solids suspended in water without clogging. It also requires no external power or batteries, so is suited for installation in irrigation lines far from buildings where power is not readily available.

Guidance on meter installation is included in the F&O Administrative Procedure ADM-CM-057, PG-01, *Engineering Design Standards* (PNNL 2013).

► ***How do I link these meters to the appropriate data collection systems?***

Most of the electric meters installed communicate to the Johnson Controls Metasys FMCS. The preferred method of communication for electric meters is BACnet standard communication protocol. Communication can also be accomplished using the JCI N2 communication protocol or a meter pulse output collected on an accumulator point within the Metasys system, with translators that take proprietary communication protocols and translate them to an option compatible with the JCI system. Metered data is stored and trended and can be accessed using the Metasys interface. PNNL also employs stand-alone advanced electric meters that store data that can be accessed directly either through a phone line or network connection. Data from meters not connected to the FMCS are retrieved by the Decision Support for Operations and Maintenance (DSOM) program, which also has the ability to gather FMCS data.

Most gas meters, including all those employed at PNNL, use a pulse output from the meter collected on an accumulator point within the FMCS. This is a reliable, relatively simple way to collect data from the meter. The Dattus meters also log information that can be retrieved locally with a laptop and feature a local display.

PNNL has worked with the City of Richland, which is the main water purveyor on the campus, to retrofit some existing Badger water meter recorders with a pulse output module allowing data to be accumulated by the FMCS for real-time data without installing a separate meter in some locations. Most of the insertion turbine meters also offer a pulse output, with each pulse accounting for a stated number of gallons measured at the meter. Insertion turbine meters are also available with an analog output of 4−20 mA or 1−10 VDC and measure water velocity or flow rate.

As previously noted, the above guidelines are used to select meters on a case-by-case basis. Additional considerations for new installations include the availability of existing infrastructure, space constraints, and consistency with other meters within a building.

2.5 Data Analysis

The importance of data analysis within the PNNL Sustainability Program cannot be overstated. In performing data analysis, we seek to achieve the following four objectives (Hooke, Landry, and Hart 2009):

- **Determine energy use and cost** – Determining energy costs provides an increased awareness of where energy is being used and what utilities and areas are the highest consumers. Targeting heavy users offers an opportunity for larger savings with the same percentage reduction than a smaller user. Graphics are the best way to illustrate the division of use and cost. In addition to being a valuable analysis tool, energy use and cost graphics are used to increase understanding and awareness among laboratory employees.

  Currently, the total energy and water use at PNNL is broken down by building for electricity, gas, and water. Sub-meters are used heavily to monitor specific systems or pieces of equipment. The preferred sub-metering strategy for new installations is to create a load profile for each building that will divide electricity use into four subsystems: HVAC, IT, lighting, and plug load. Metering laboratory panel boards also allows us to identify labs with high electrical intensity that may be a candidate for focused energy reduction efforts.

- **Calculate performance levels** – To compare our buildings and processes against other buildings and processes, industry standards, or the same buildings and processes from an earlier period, we calculate performance levels. These can be simple such as kW per square foot for an entire building or more detailed such as coefficient of performance (COP) for a refrigeration system, boiler efficiency, or power utilization effectiveness (PUE) of a data center. Examples of how performance levels are used at PNNL are detailed in the Benchmarking and Data Centers areas below.

- **Understand the reasons for variable energy use and performance** – Energy use and performance levels can vary based on factors outside of our control, such as weather. The goal of our analysis is to understand the reasons for the variability and to identify parameters within our control that can improve performance and reduce energy use. Understanding the load profile for a building as a division of base load, weather load, and variable load can assist in this analysis. Using metered data and analysis techniques, we are working to establish optimum settings for HVAC equipment in various weather conditions. An example of high variability in performance levels is the COP in chiller plants at different loads. An example of the process that PNNL uses to understand varied energy use is discussed in the Benchmarking portion of this report.

- **Track progress toward energy use targets and identify poor performance** – As a national laboratory within the U.S. Department of Energy (DOE), our energy and water use target is clearly defined. PNNL contract clause H-43 requires reducing energy intensity by at least 30% by 2015 compared to a 2003 baseline. It also requires reducing potable water use by at least 16% by 2015 compared to a 2007 baseline and reducing industrial, landscaping, and agricultural (ILA) water 20% by 2020 compared to a 2010 baseline. PNNL is working aggressively toward these energy and water reduction goals. In addition to comparing current energy and water use to our mandated reduction goal, we also compare with historical data trended and archived within our EnergyCap Utility Payment software system. Most commonly, we will compare observed use with an earlier period such as the previous month or the same month from a previous year as discussed below.

2.6 Benchmarking

Monthly meetings with building management teams (known as Core Teams) are an important part of the benchmarking strategy at PNNL. Metered electricity, natural gas, and water data are consolidated in a "Campus Energy Consumption" spreadsheet. Data are maintained through a partnership with the Energy and Environmental Directorate, a research organization within PNNL. Monthly core team meetings are held to discuss benchmarking goals, perform trend analysis, and identify opportunities for energy savings. Meetings are conducted in the BOCC, a state-of-the-art asset capable of displaying multiple trends simultaneously on oversize wall monitors and accessing real-time data. Attendees at these meetings typically include the building manager, one or more building engineers, the PNNL campus utility manager, and the sustainability engineer. Graphics are frequently used to illustrate benchmarking results and track progress toward energy goals. An example of a trend used in the December 2013 benchmarking meeting for the 318 Building, Radiological Calibrations Laboratory (RCL), is shown in Figure 2.1. This trend displays the BTU/day/square foot vs. the monthly average temperature over several years.

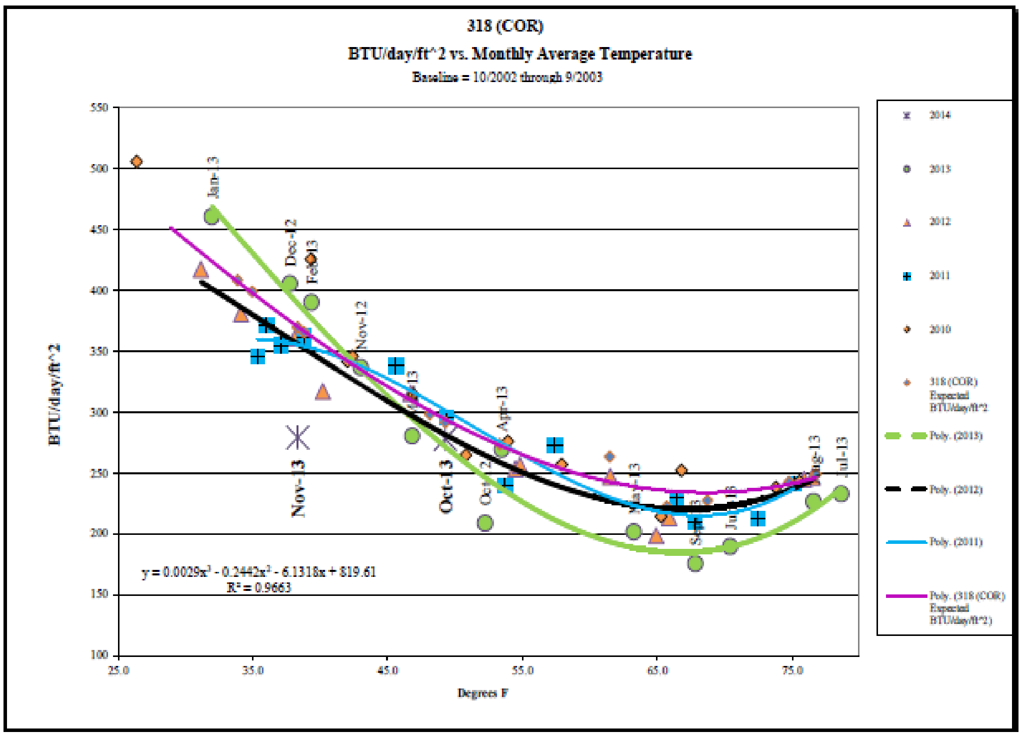

Figure 2.1. Example Trend – December 2013 318 Building Benchmarking Meeting

2.7 Portfolio Manager

PNNL makes use of the U.S. Environmental Protection Agency's Portfolio Manager tool to track and assess energy and water consumption across the campus, as well as track progress toward High Performance and Sustainable Building (HPSB) goals. Data collected from electricity, natural gas, and water provider meters is entered into EnergyCap, the commercial energy management software used at PNNL, and is automatically uploaded monthly to Portfolio Manager's database. DOE's Sustainability Performance Office (SPO) now uses Portfolio Manager (Figure 2.2) to pull site energy and water data from all sites and consolidate it to monitor progress on agency energy and water reduction goals. Portfolio

Manager has benchmarking tools and the ability to compare building energy performance with similar buildings off of the campus. Additional information on Portfolio Manager is available at http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager.

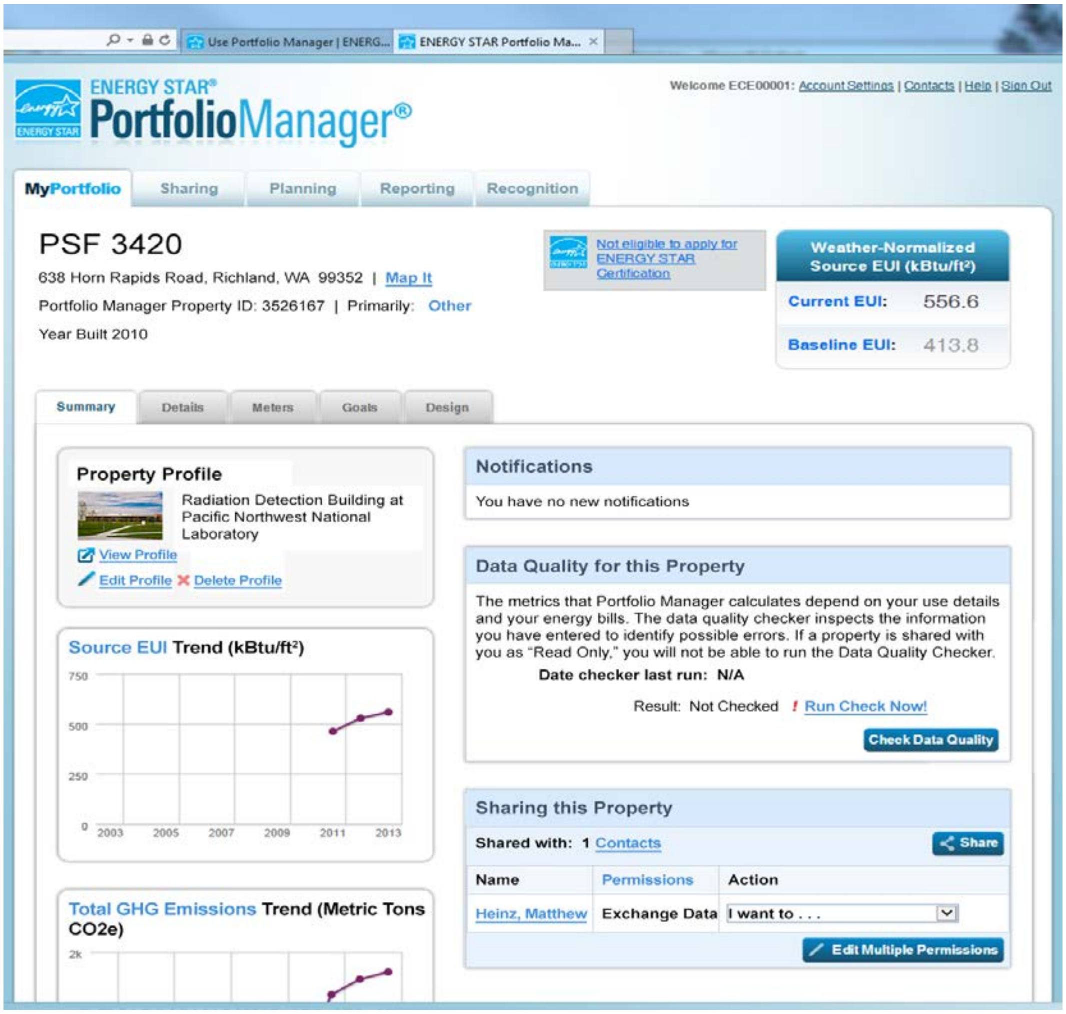

Figure 2.2. Portfolio Manager

2.8 DSOM

To aid in data analysis, graphical presentation, and data storage, PNNL utilizes the DSOM tool. Developed by PNNL, the DSOM system is an advanced supervision and diagnostic tool to reduce plant operating and maintenance costs and extend plant life.

Linking plant operators, maintenance staff, engineers, and administrators in one enterprise-wide system, DSOM combines online condition monitoring and control of equipment with unique diagnostic routines. Originally created for efficient operation of nuclear power plants, the science at the core of DSOM has been adapted cost effectively to meet the needs of industrial processes, including power plants, continuous industrial processes, facility plants, HVAC systems, and today's metering.

DSOM software collects and verifies operations data, analyzes them in a customized facility database and lets operators know in real-time if a system is malfunctioning or running below expectations. Beyond early warning signs, DSOM identifies conditions that could potentially lead to a problem.

DSOM is built around the concept of condition-based management. DSOM's diagnostic capabilities prompt operators to make changes to keep systems operating at peak performance and avoid degradation and failures. It has been successfully integrated with standard sensor technology plus advanced systems like vibration monitoring, laser systems, ultrasonic monitoring, and utility meter plus sub-metering.

Field experience has validated that cost reductions of 20 to 40% can be realized through improved process efficiency, reduced operations and maintenance workload, reduced maintenance parts and labor, reduced energy consumption, and equipment life extension.

DSOM is integrated into the PNNL daily operations and tracking of energy and water goals.

2.9 BOCC

PNNL remains aggressive about reducing its water use 16% and energy intensity 30% by 2015. To meet this reduction goal, the BOCC monitors and reports using benchmarking, energy and water meetings, and energy and water conservation measures. As a hub for the FMCS and DSOM systems to connect with building managers, building engineers, design engineers, and soon even the building occupants, the BOCC is the driving force for ensuring that energy and water goals are met through continuous monitoring and reporting. Specifically, the BOCC links historic, real-time monitoring and diagnostics with analytics to optimize energy and water, extend asset life, and enhance the reliability and efficiency of the PNNL campus. The BOCC leverages data from the FMCS and in-house developed R&D software—DSOM—to perform diagnostics, trending, and analytics. These two systems are the backbone of the BOCC.

The goal of the BOCC is to create an intelligent infrastructure that uses real-time data to make informed decisions resulting in reduced building operational cost (PNNL 2014b). Costs are reduced by using information from sensored buildings to creating condition-based maintenance service requests, preventing equipment failures using real-time commissioning, and reducing energy cost by monitoring and reporting building operations and implementing energy and water conservation measures (ECMs and WCMs, respectively), which are used to reduce building energy consumption by identifying projects with life-cycle cost effectiveness and return on investment. ECMs can be used to substantiate upgrades on existing out-of-date equipment and systems to improve the overall operation of the building. ECMs can range from no cost/low-cost sequence modifications to complete equipment replacements. The BOCC collaborates with Projects and Engineering, building management and building engineers, and R&D to identify, prioritize, and plan ECMs and WCMs. The BOCC through the real-time commissioning and energy meetings maintains the Master ECM List for each core team.

2.10 Data Centers

PNNL has three data centers located in the Computational Sciences Facility (CSF), the Information Sciences Building (ISB) 2, and the Environmental Molecular Sciences Laboratory (EMSL). Each center has meters installed to measure the IT equipment load and the facility support load such as lighting and cooling. Metered data are used to calculate PUE for each center. As the primary measure of efficiency, PUE is used to benchmark one data center against another and as a means of verifying energy savings inside a single data center. Executive Order (EO) 13514 requires agencies to meter data centers and reduce their PUE to 1.4. To reduce the weighted average of the three centers at PNNL to a PUE of 1.4, innovative energy conservations measures have been implemented and installed metering has verified the results. The newest data center at PNNL in the CSF space uses well water and a plate and frame heat exchanger to supply cool water to rear door heat exchangers (RDHx) on server racks (Figure 2.3). The water is also supplied to a chiller that serves a computer room air conditioner (CRAC) when needed. The diagram below shows the flow for this ground source system and shows the location of meters measuring electric power, water temperature entering and leaving the RDHx and CRAC, and water flow rate in these two systems. These meters validate the excellent efficiency of this system, which yields a PUE of 1.1 with only the RDHx in operation and 1.2 when the CRAC is running.

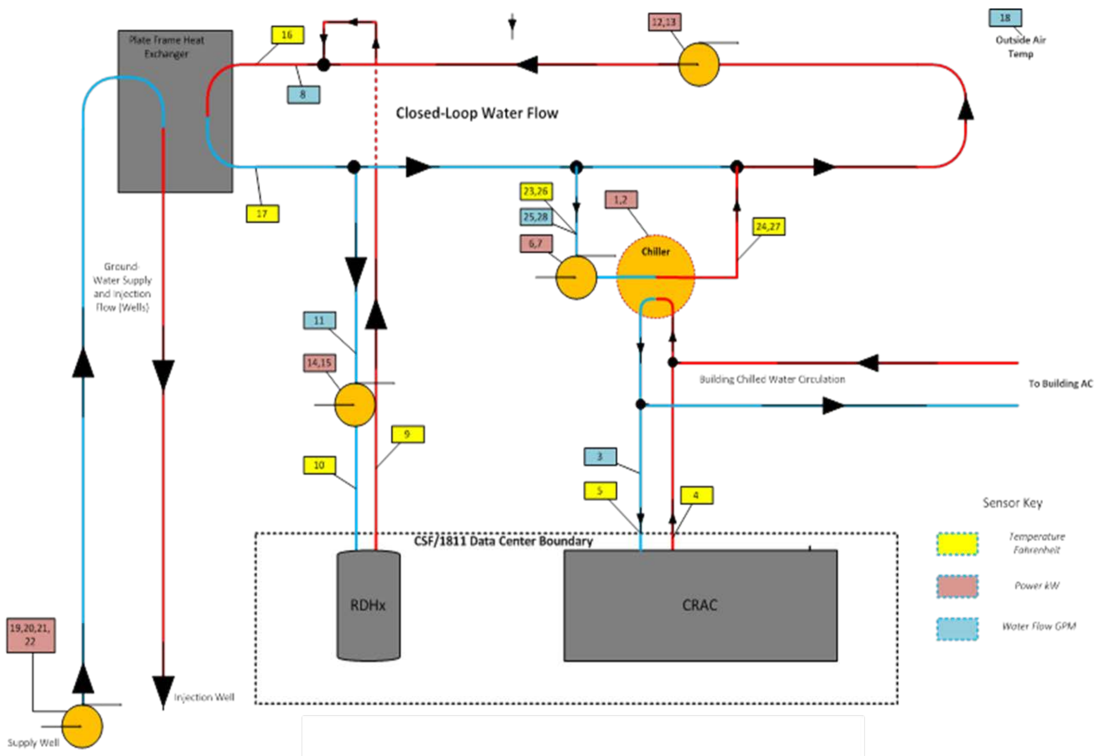

Figure 2.3. CSF/1811 Groundwater Cooling System

In ISB2, the meters measuring IT load and facilities load are connected to APC’s StructureWare Central and SynapSenss software packages. The program plots the various loads and displays PUE components graphically. Temperature sensors throughout the data center are displayed on a heat map to assist in locating hot spots. The data center manager uses the metered data to analyze the system and provide customers with a graphical representation of the efforts to reduce energy and cost (Figure 2.4). Using virtual machine software, the total number of servers in the data center has been reduced. The dip in the kW (upper) trace below during the month of April 2014 was a result of taking several single-purpose servers out of service and transferring that capability to virtual machine servers serving multiple users. The reduction of power toward the end of the month was a result of shutting down a 3Par storage array and transferring the capability to existing machines yielding an annual savings of 126,144 kWh and $6,937.92.

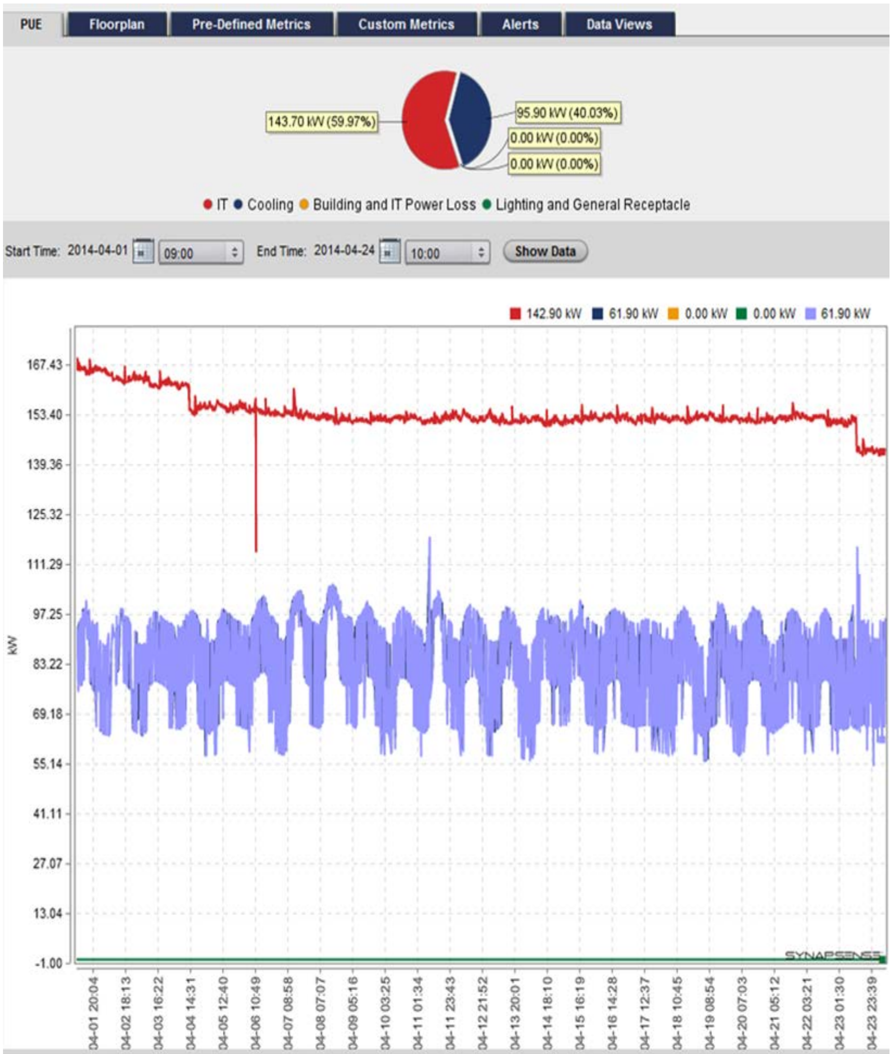

Figure 2.4. CSF/1811 Groundwater Cooling System

2.11 Case Study

An example of analytics developed using metered data and the FMCS system is new diagnostics summary page shown below (Belew 2014). Using this technique, it was discovered that one of the heat pump compressors at the 350 Building had failed and was using the more costly auxiliary strip heat. Mixed air and discharge air temperature sensors, part of the "smart sensor" suite, were utilized to diagnose this failure that would have otherwise gone unnoticed. Figure 2.5 shows a screen-shot summary page developed to diagnose problems with the roof-top conditioning units at the 350 Building.

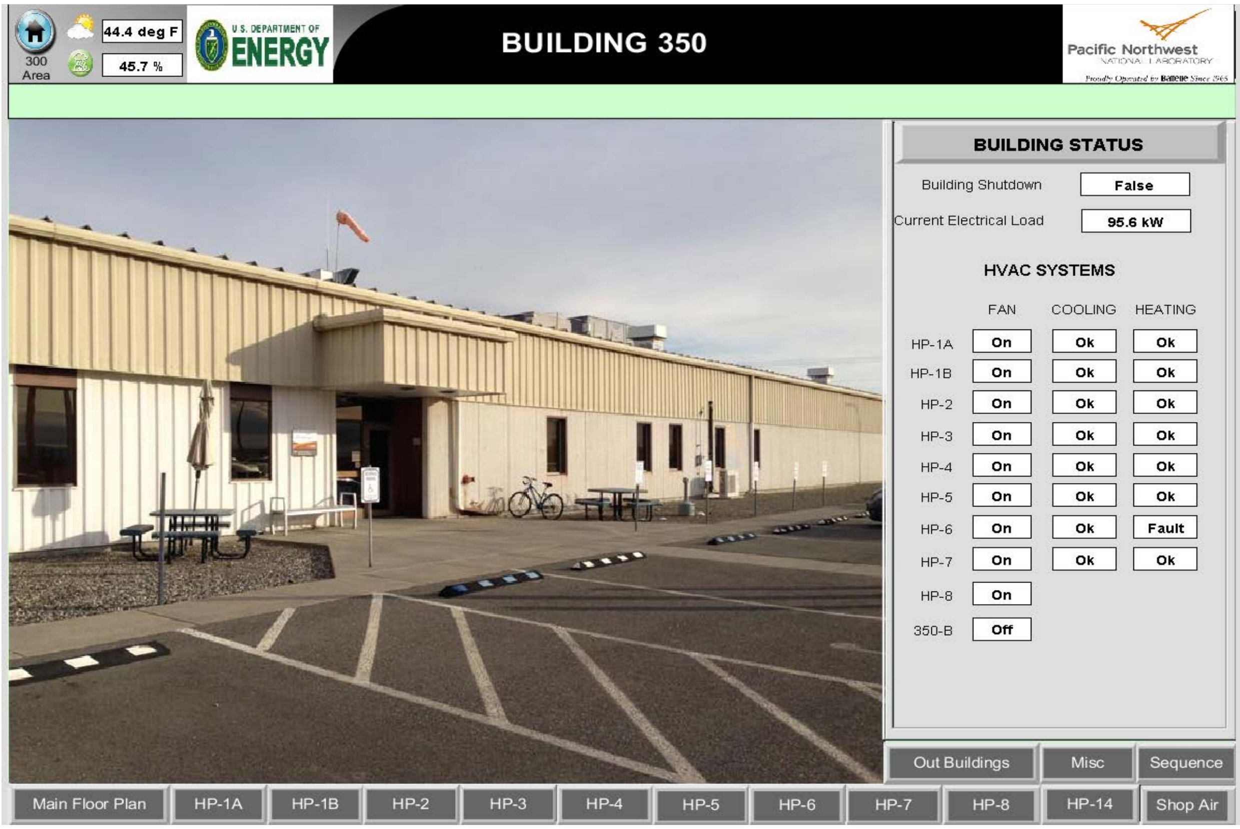

Figure 2.5. Building 350 Diagnostic

Using sensor inputs and logic programmed into the FMCS system, the temperature difference across the unit compressors is compared to the normal operating range in the heating mode, around 20 degrees Fahrenheit. For this example, we see that temperature delta on March 21, 2103 was less than 12 degrees, triggering a fault on the diagnostic screen. The trace in Figure 2.6, which compares discharge air temperature and mixed air temperature, illustrates what the fault looks like and when it occurs.

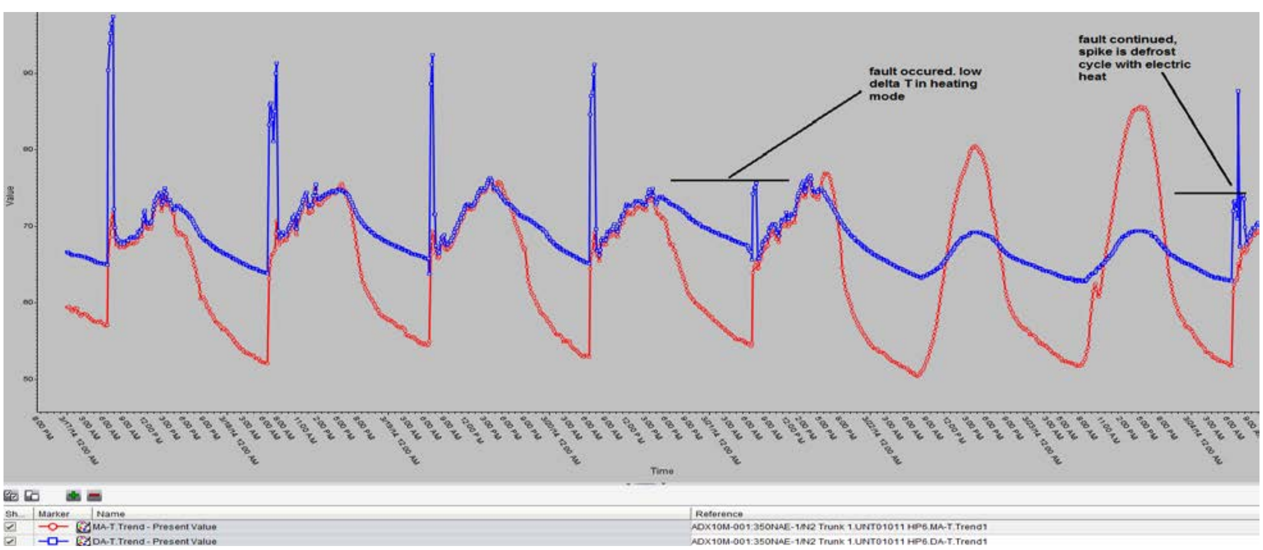

Figure 2.6. Trace Illustration for Building 350

The heating fault programming compares the two temperatures during the heating stage and generates a fault warning if the temperature difference is less than 15 degrees (Belew 2014). This diagnostic is used to identify operational issues before impacting occupant comfort, reliability of the equipment, and before excessive energy and water costs are consumed.

2.12 Personnel Training

Metering technologies, the systems that aggregate the data, and the software that assists in data analysis are all rapidly advancing. As the nation steps up to face energy and water challenges, PNNL practitioners must stay current and relevant. To maintain that edge, the Sustainability Program promotes the following for its staff:

- taking an active role in working groups within the industry
- continuing education for FMCS technicians and engineers to maintain current working knowledge of the rapidly changing options and solutions for connecting new meter technologies to the existing and updating FMCS infrastructure
- encouraging engineers to certify with industry professional peer groups such as the Certified Energy Manager (CEM) certification through the Association of Energy Engineers (AEE)
- attending trade shows and vendor trainings.

Much of the training, development, and mentoring of staff at PNNL will utilize the resources of the BOCC. Access to real-time data and control on the multiple large display screens provides a rich learning environment. The diversity of specialization working through the BOCC such as FMCS specialists, Air Balance Operators, Commissioning Engineer, Sustainability Engineer, Controls Engineer, and research and development staff creates an incubator for cross-training and collaboration.

2.13 Funding

Funding is necessary to maintain the Metering Plan equipment and staff, data collection, analysis, and reporting activities. Funding for the Metering Plan is established in the annual Sustainability Program budget. Key implementations are outlined in the Sustainability M&O Program description and are divided into three categories – people, systems, and processes – from which the Metering Plan draws from two. In the *people* category, the Metering Plan uses four key implementations: sustainability subject matter experts (SMEs), sustainability engineer, facility energy manager, and utility data management specialist. Likewise, in the *systems* category, the Metering Plan feeds data into the FMCS in two ways: installation of strategic metering in support of goals and objectives; and maintenance, corrective actions, and upgrades for existing metering and data collection systems.

While priorities are established and funding is set on a fiscal year basis, PNNL’s Sustainability Program maintains a nimble, agile approach. If unexpected opportunities arise during the year, the Program remains poised to act and can adjust based on emerging needs.

2.14 Data

2.14.1 Meter Data Validation

Once meters are installed, it is important to validate the resulting data. Meter data should go through an initial validation and then be checked periodically as part of an ongoing validation effort.

- **Initial**: The initial performance validation of the meter involves comparing the meter data with billed data. Because billed data lags, the real-time metered data the validation of a new whole-building meter can take several months.
  - The absence of specific billed data for sub-meters (less than the whole building level) makes validation more difficult. Expected totals as a result of engineering calculations designed to allocate a whole building load to a more specific level are often used to compare with values yielded by sub-meters. Our experience with meter validation is that usually meters come correctly calibrated from the factory. Errors are almost exclusively attributed to an incorrect multiplier in the totalization phase, either by assuming an incorrect electric CT size, gas delivery pressure, or assigning an incorrect pulse value.
- **Ongoing**: Ongoing validation is performed in a similar manner as the initial check. Our experience has shown installed and validated meters rarely drift from calibration, rather that meters occasionally fail and stop sending information. When one of the collection systems stops receiving data from a meter in the field, troubleshooting and repair are initiated. Our experience has also shown that gas meters require more maintenance and calibration than electric meters. Gas meter repair and calibration is performed by qualified, manufacturer approved, offsite service providers. Spot-checks of meters to validate field readings are consistent with billed data are also performed.

2.14.2 Support of HPSB

In 2006, DOE signed the Federal Leadership in High Performance and Sustainable Buildings (HPSB) Memorandum of Understanding (MOU), along with 21 other agencies. The MOU originally committed DOE to follow the Guiding Principles for new construction and major renovations and was revised in 2008 to include transforming existing buildings into HPSBs. The Guiding Principles for sustainable existing buildings focuses on five topic areas:

- employ integrated assessment, operation, and management principles
- protect and conserve water
- enhance indoor environmental quality
- optimize energy performance
- reduce environmental impact of materials.

EO 13423 “Strengthening Federal Environmental, Energy, and Transportation Management” and EO 13514 “Federal Leadership in Environmental, Energy, and Economic Performance” require that 15% of an agency’s existing buildings and leases meet the Guiding Principles by 2015. Additionally, EO 13514 requires agencies to make annual progress toward 100% of buildings meeting the Guiding Principles.

Metering at PNNL directly supports the effort to reach these goals. PNNL is exceeding this requirement, and at the end of FY 2013 had 31% of the FIMS buildings certified as HPSBs. Three of the five topic areas in the Guiding Principles require the use of meters and sensors. Requirements include meters to quantify the reduction of electricity, natural gas, and water; using meters to benchmark building performance; measuring and verifying building utility usage; and measuring the amount of renewable energy generated on-site and fed back into the campus distribution system.

2.14.3 Support of ASHRAE Analysis

Metering at PNNL supports ASHRAE Standard 55-2004 *Thermal Environmental Conditions for Human Occupancy* analyses performed on campus buildings as part of the HPSB effort. Compliance with ASHRAE Standard 55-2004 is a requirement to meet the *Enhance Indoor Environmental Quality* Guiding Principle. To perform the analysis, permanently mounted temperature sensors located throughout the building are used. Typically ten sensors in varying locations, on the perimeter and interior, and on each floor, are chosen for examination. One year's worth of data at each sensor measured every 15 minutes during operating hours is analyzed, about 115,000 measurements. The data points are plotted and compared to the minimum and maximum acceptable temperatures of 68 and 81 degrees. As shown in Figure 2.7, 1 year of data is plotted from a sensor in the Laboratory Support Building (LSB). Data points from all 10 sensors examined in this building were in the acceptable range 99.70% of the time, with no individual sensor being in the acceptable range less than 98.26% of the time. Using this method, we determined that all of the spaces analyzed in the LSB exhibited acceptable thermal environmental conditions.

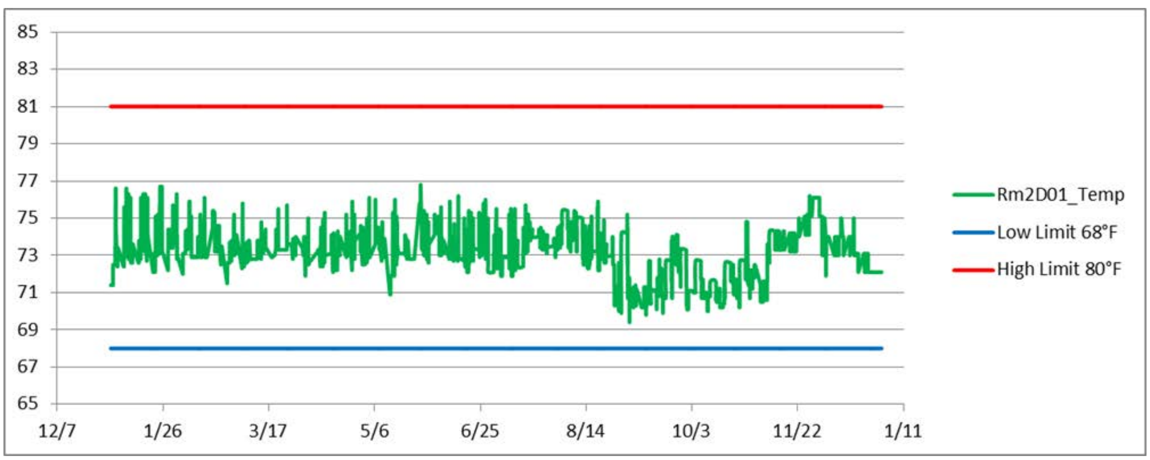

Figure 2.7. Sample Trace Showing 1 Year of Temperature Data in LSB Room 2D01

2.14.4 Support of FUA for Temperature Compliance

Metering at PNNL also supports the effort to verify temperature conditions are consistent with those outlined in the Facility User Agreement (FUA), an agreement that formally captures the physical attributes of the facility and operational boundaries, among other things. This agreement is between the F&O Directorate and the directorates performing research in each building. Permanently mounted temperature sensors are used to create temperature maps that are monitored in the BOCC. As shown in Figure 2.8, temperatures in the Sigma II office building are displayed and spaces are color-coded to indicate temperatures in relation to the set point. Temperature maps indicate which conditioning zone each space is in to aid in troubleshooting hot or cold spots.

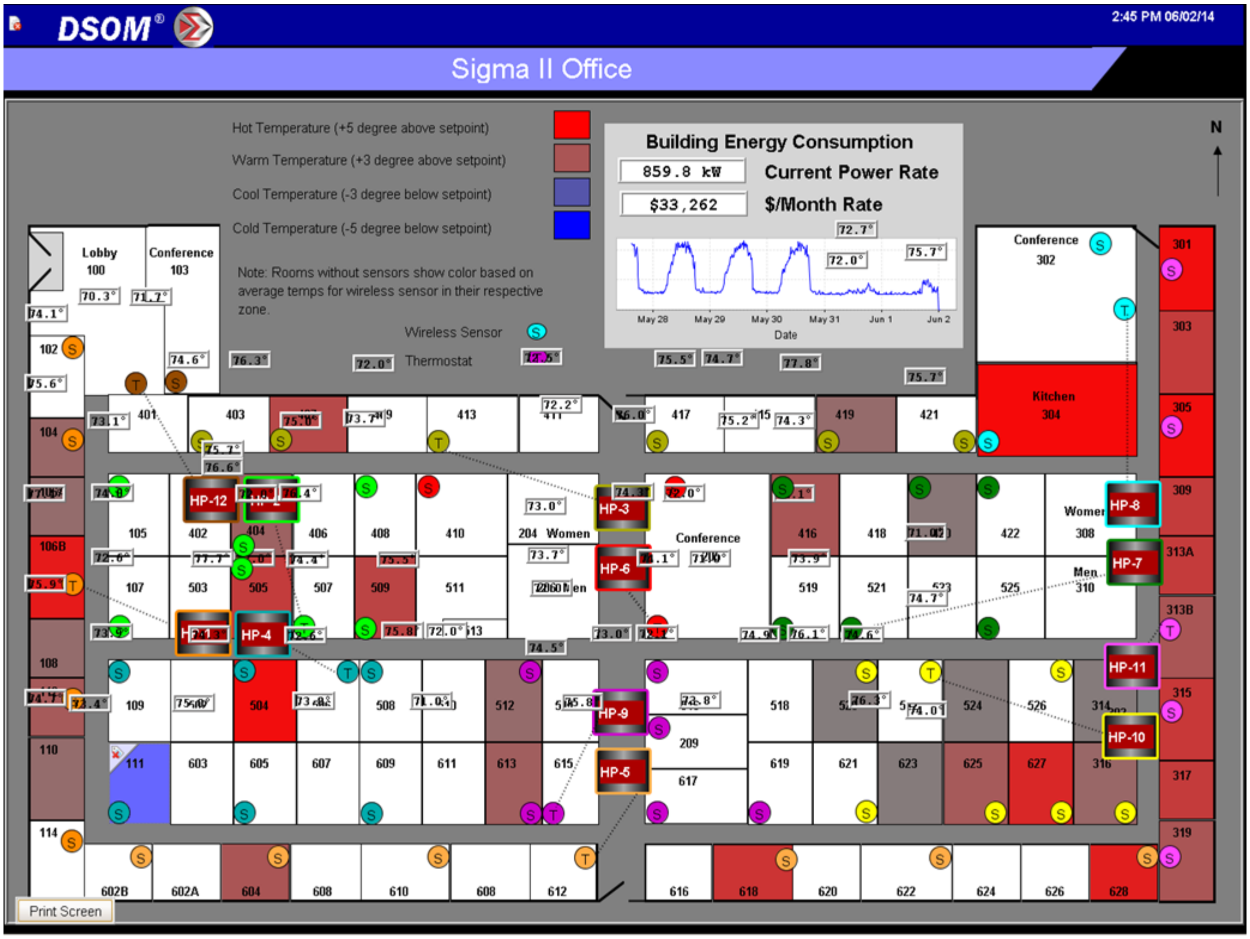

Figure 2.8. Sigma II Office Temperature Map

2.14.5 Support of ILA Management

Metering at PNNL supports the contractual goal of a 20% reduction of ILA water usage by 2020 from the 2010 baseline. Installation of water sub-meters measuring ILA water use at PNNL began in 2013. Prior to the installation of ILA meters, irrigation water use was estimated by prorating based on area for facilities fed from the only existing master meter and by using standard assumptions to estimate use for facilities with no meter installed. ILA sub-meters have been installed at the PSF complex, which includes buildings 3410, 3420, 3425, 3430, and 3440; the combined grounds for ISB1 and ISB2; the combined grounds for NSB and ETB; at the User Housing Facility; and at BSF and CSF, where two meters are summed to provide the total for these facilities. The meter chosen for these applications is the McCroMeter propeller with local display. Two additional meters are planned for installation at EMSL that will provide accurate usage information, allowing energy managers to implement and measure the effectiveness of water reduction strategies. One strategy is to benchmark irrigation intensity at different facilities across the campus to identify areas that may be over-irrigated. Another strategy is trending irrigation use over several years to identify higher than normal consumption.

2.14.6 Support of Dashboards

Meter data collected at PNNL is used to support an effort to post dashboards at building entrances, providing an energy and water summary to occupants. Dashboards such as that shown in Figure 2.9 and posted at the entrance to the 350 Building display the year-to-date use of electricity, natural gas, and water for a particular building, as well as the running 7-day electricity usage. Dial indicators compare the current year to previous year for a quick visual gauge on whether use is trending up or down. Dashboards are also used by Sustainability Program staff for a quick assessment. More detailed information can be attained from the dashboards by clicking on the icons.

Figure 2.9. Building 350 Energy Dashboard

2.14.7 Support of EISA Audit and Commissioning

Section 432 of EISA (2007) requires comprehensive energy and water evaluations performed for all designated Covered Facilities at each federal agency. Covered Facilities are identified as all buildings comprising at least 75% of the each federal sites total energy usage. Covered Facilities at PNNL from 2013 are EMSL, 331, 325, CSF, PSF 3430, PSF 3420, PSF 3410, and ISB-2. Together, these eight facilities used 79.22% of the total PNNL site energy.

EISA evaluations consist of performing energy/water audits and commissioning assessments on a 4-year cycle for each Covered Facility. The energy/water audits and commissioning assessments can be performed separately using qualified in-house staff and/or contracted with private sector auditors and commissioning agencies. The PNNL Sustainability/Energy Program Office is responsible for the implementation, completion, and reporting for all EISA requirements.

EISA requires an energy/water audit similar to a Level 1 ASHRAE energy audit, which consists of an initial building walkthrough and identification of ECMs. Targeted systems audited include:

- Building Envelope
- Water Usage
- Electrical Usage
- Interior/Exterior Lighting

Test procedures resulting from EISA and HPSB commissioning assessments provide the foundation for an optimized commissioning strategy using portable technology coupled with the metering capabilities monitored in the BOCC along with in-house staff to maintain efficient building performance as a real-time commissioning strategy to ensure optimized building performance (Lechelt 2014). Metering at PNNL supports the EISA audit process specifically by supplying data for the electrical and water usage analyses.

2.15 Data Recovery

The backbone of our recovery plan is early detection when a data loss problem arises. Often, data loss can be attributed to a disruption in communication from meter to data collection system, usually Metasys or DSOM. Data recovery after a communication failure is made much simpler when advanced meters are installed with data logging capability. In the FEMP-sponsored *Metering Best Practices, A Guide to Achieving Utility Resource Efficiency, August 2011* (Sullivan, Pugh, and Hunt 2011), advanced meters are defined as having the capability to measure and record interval data (at least hourly for electricity) and communicating the data to a remote location in a format that can be easily integrated into an advanced metering system, which includes data acquisition and analyses.

When a communication failure is discovered, efforts to restore the line should begin immediately. As some meters can be read locally with a laptop computer, this feature can be used to restore lost data sets manually, although it is time consuming. Meters that will cache data for a month or more and report after a failed communication line has been restored are preferred. It is also possible to use trend and historic data to fill in gaps on buildings where reporting is required, but our goal is accurate, timely information.

3.0 Conclusion

The Sustainability Program has been successful in meeting contractual energy and water metering goals as well as submitting one of the three Program deliverables. As meter installations continue, data analysis and data organization move to the forefront in our effort to reduce energy and water consumption. PNNL will continue to strive to meet the energy and water reduction challenges. The Metering Plan will be updated as needed as the PNNL building portfolio changes.

With the program established, metering at PNNL is on solid ground, consistently delivering reliable data for benchmarking, analysis in the BOCC, and advanced analytics like DSOM. As efforts lean toward new challenges, our goal of environmental stewardship will never cease or go out of focus. The tenets of our program – to provide accurate data, analyze that data, and provide actionable recommendations – are the mileposts along the road to reductions in building energy and water use and greenhouse gas emissions.

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