Energy Performance Platform: Revealing and Maintaining Efficiency With a Customized Energy Information System

Andrea Mercado, Lawrence Berkeley National Laboratory,
John Elliott, University of California, Merced

ABSTRACT

The University of California opened the Merced campus in 2005 with a goal that its buildings consume half of the energy and peak demand of other university buildings in California. The campus also committed, in early 2009, to achieving zero net energy by 2020. To realize these goals, an extensive metering infrastructure was developed, generating a large amount of building performance data. Recently, these metered data were made actionable by developing a customized energy information system, the Energy Performance Platform, which enables monitoring-based commissioning (MBCx) for the campus.

Continued MBCx will be essential in maintaining designed efficiency and allowing the campus to cost-effectively achieve zero net energy. In this paper, the development of a prototype version of the Energy Performance Platform (EPP) is described, followed by a presentation of the scope and structure of the EPP. Three example use cases are presented to provide insight into the content and value of the system. Lastly, future development plans for the next version of the EPP are presented, as well as how the EPP could be implemented beyond the UC Merced campus.

Introduction

This paper presents the Energy Performance Platform (EPP), a customized energy information system developed by UC Merced and Lawrence Berkeley National Laboratory and deployed at UC Merced. This system is intended as the primary tool to be used by the campus to improve and maintain energy efficiency as it works to achieve zero net energy by 2020. The EPP relies on an extensive metering infrastructure that has been established in campus buildings to support building operations and performance monitoring. The development of a prototype version of the EPP is described, followed by a presentation of the scope and structure of the EPP. Three example use cases are presented to provide insight into the content and value of the system. Lastly, future development plans for the next version of the EPP are presented, as well as how the EPP could be implemented beyond the UC Merced campus.

Overview of Past Work

An operational building performance visualization tool was developed as part of a research project conducted by Lawrence Berkeley National Laboratory, United Technologies Research Center, and UC Merced in 2009 (Narayanan et al. 2010). While this tool differed in scope and emphasis from the EPP, it provided the basic infrastructure of a software application that was able to, on an operational basis, extract all available building performance data from the UC Merced energy management and control system (EMCS), calculate and store a series of building performance metrics, and present them against benchmarks in a web browser-based environment. This tool became the first operational prototype for the EPP and included four basic functions:

- **Data access.** The visualization tool allowed for plotting and downloading thousands of trending data points from all buildings at UC Merced. This was intended to provide analysts and researchers access to performance data without needing access to the secure campus energy management and control system. The overall functionality of this feature was retained and refined for the EPP.
- **Performance metric calculation.** The visualization tool calculated metrics for one approximately 100,000 square-foot building at UC Merced, the Classroom and Office Building (COB), and for the central plant, which serves COB. Metrics included energy consumption and peak demand values, individual end use energy consumption values, and various operational metrics such as chilling plant efficiency. The overall functionality of this feature was retained, but substantially restructured, for the EPP.
- **Energy simulation modeling.** The visualization tool included a real-time EnergyPlus simulation model for COB, intended to provide a comparison to actual metric results at various levels within the building. This feature was not retained for the EPP. In the EPP, results are compared to static benchmarks, previous actual data, or across similar components rather than to simulated results.
- **Performance visualization.** The visualization tool included an integrated environment and interface to display the metric and comparison values at yearly, monthly, weekly as well as daily intervals. The tool included extensive functionality to indicate underlying data quality such as the ability to view plots of trend data for all points used to calculate a metric. These features were retained and refined for the EPP.

Energy Performance Platform

Motivation

UC Merced has deployed an aggressive new building energy efficiency program with a goal that that its buildings consume half of the energy and peak demand of other university buildings in California (Brown 2002). The campus also committed, in early 2009, to achieving zero net energy by 2020 (Elliott and Brown 2010), even as the campus grows significantly to accommodate a five-fold increase in student enrollment. Figure 1 shows an example path to zero net energy over campus build-out through a series of efficiency goals and renewable energy projects. The black trend line reflects business as usual loads included in the zero net energy commitment, while the colored wedges represent opportunities to reduce grid-supplied energy through energy efficiency or renewable energy generation. The first two wedges represent established and “stretch” energy efficiency targets that grow to account for over 60% of UC Merced approach to achieving zero net energy. The EPP was conceived as the primary tool to maintain energy efficiency over time.

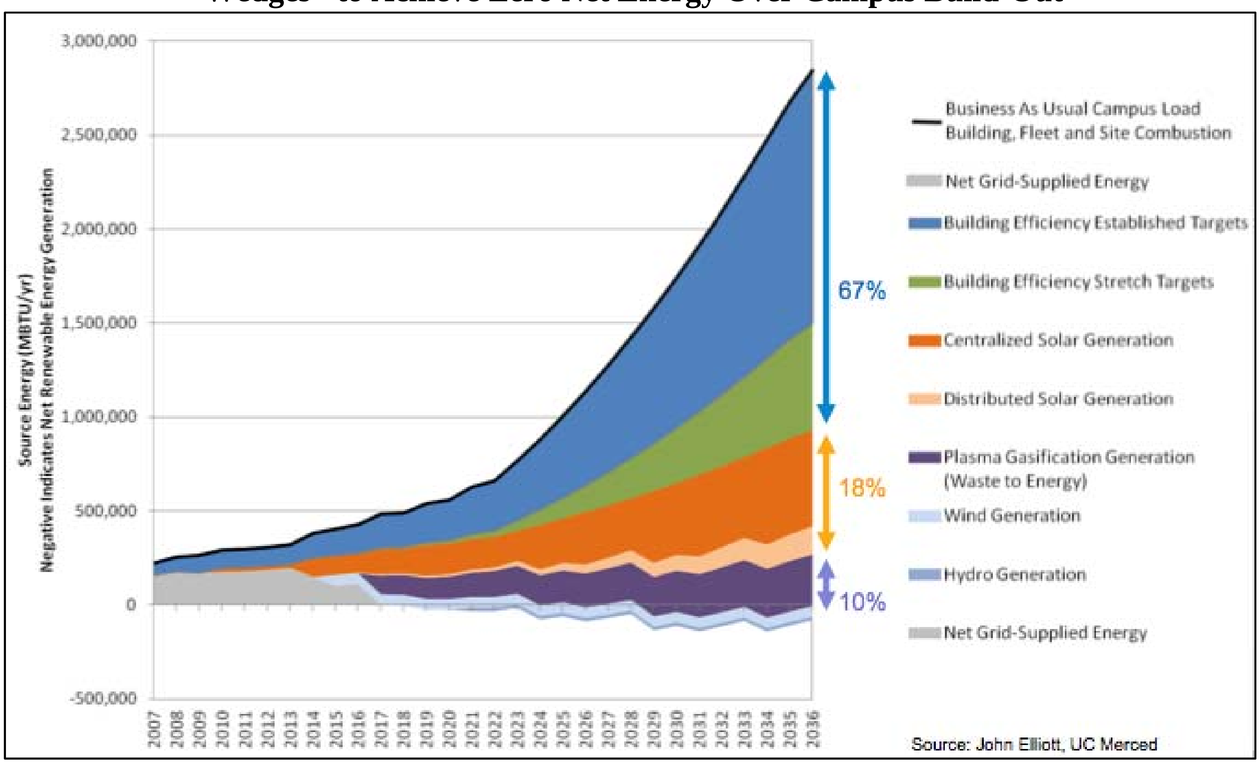
Design and Structure

While the original visualization tool code base was used, the EPP was significantly restructured to make it easier to navigate and scalable across multiple buildings. A much broader range of performance metrics were added to the prototype tool and the full set of metrics were developed for COB and added for an approximately 200,000 square-foot laboratory building, Science and Engineering 1 (SE1). The EPP now tracks approximately 70 percent of campus energy use in detail. Finally, the EPP also tracks total campus energy performance benchmarks by comparing campus-level data to composite benchmarks representing every building on campus. Documentation of how benchmarks for UC Merced were established based on 1999 UC/CSU energy use are described in an earlier paper (Brown 2002).

In general, the Energy Performance Platform was designed to decrease the time necessary to analyze operational data and guide actions that maintain and improve energy performance. Specifically, the EPP is intended to:

- Target both analysts and facilities technicians
- View data easily at different timescales
- Track at multiple levels, across all commodities (campus, building, end-use, and system level)
- Provide context by comparing results to benchmarks, similar equipment, and previous years
- Provide access to underlying data
- Identify the highest priority work items

Figure 1. UC Merced Example Analysis Showing Business As Usual Loads and "Wedges" to Achieve Zero Net Energy Over Campus Build-Out

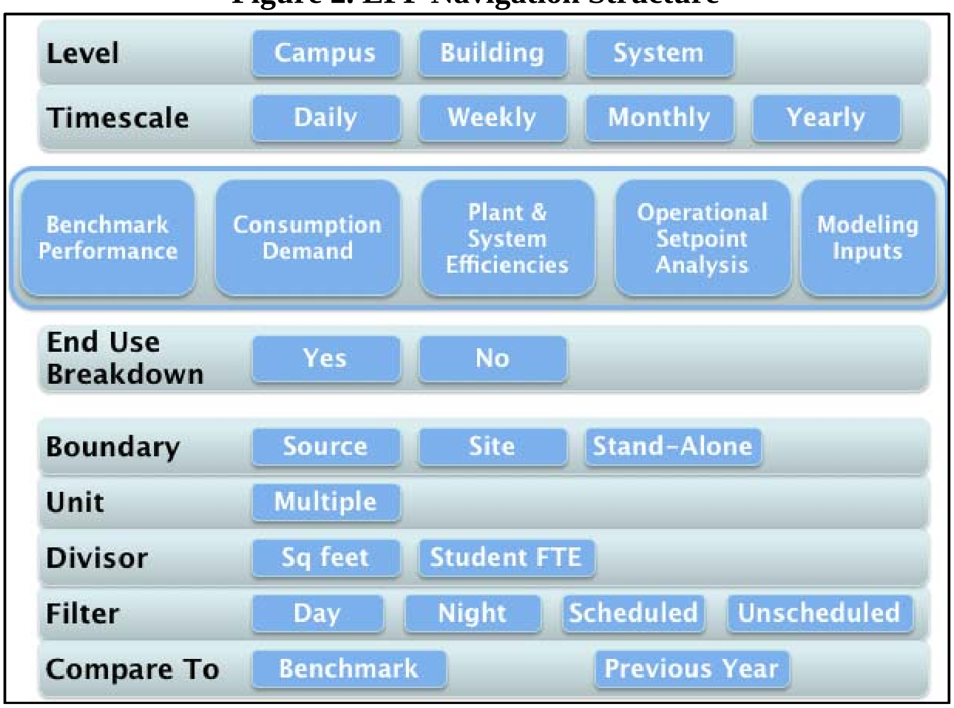


Notes: The data for 2007-2011 are measured values; "Wedges" concept originated by Pacala & Socolow.

The EPP is organized around five different content areas (see area outlined in blue in Figure 2). This interface allows the user to explore data at multiple levels starting from campus, to building, to a particular building system. The user is also able to easily move between timescales ranging from days to years (often as rolling twelve-month averages), facilitating review of both short-term operational changes and long-term performance trends. Automatic reporting of faults is not currently a feature of the EPP, rather, the interface is designed to facilitate review of data to indicate trends in performance and identify areas (either buildings or systems) in which energy performance may be degrading. The user is able to break out results by end use (typically HVAC, lighting, plug, and other)[1] and choose between multiple variants of results using different calculation boundaries or divisors. Finally, the user is able to filter out certain data from the result allowing, for example, independent review of metrics calculated during occupied and unoccupied hours. In general, results may be compared to benchmarks that were set by the campus as building design targets or to previous year data. The five content areas include:

- **Benchmark Performance.** These screens provide the highest overview of the campus performance and trend the performance of the campus or individual buildings as a percentage with respect to benchmark. At a quick glance, the user can see if and when benchmarking goals are reached and whether performance is improving or declining. These screens are intended to provide useful summary statistics and graphics as well as to prompt the user towards further investigation.

Figure 2. EPP Navigation Structure



[1] At UC Merced, electrical designers are directed to segregate lighting circuits by end use, allowing independent trending of energy use at that level.

- **Consumption & Demand.** These screens present building energy consumption and peak demand with the wide selection of customizable drop-down selections described above. Buildings and end use performance can be trended and compared, making it possible to identify when a building or end use begins to show a degradation of performance. These screens allow identification of significant uses - broken down by building, end use, or system – and targeting of those uses that show changes over time.
- **Plant Efficiencies.** These screens present the efficiencies of the chilled and hot water central plants that supply campus buildings including COB and SE1. Within the chilled water plant, the EPP can display efficiencies of the cooling tower, the chilling plant, and the entire chilling system including distribution over any selected time period.
- **System Efficiencies.** Air handler ventilation and hydronic pump efficiencies are summarized in these screens. Users may be led here if they find that fan or pump consumption is increasing at the building level to determine whether the degradation of performance is occurring at the building or plant level.
- **Operational Setpoint Analysis.** These screens present summaries of operational performance inspired by previous work on building commissioning (Seidl 2006). Setpoint analysis is available for hydronic loop temperature and differential pressure, air handling unit supply air temperature and static pressure, air handling unit outside air economizer operation, and zone temperature.
- **Modeling Inputs.** This screen provides a quick summary, with no graphics, of common inputs required to prepare simulation models of future buildings. At UC Merced, the new building energy efficiency program is enforced through the setting of energy budgets for design teams and a requirement to develop energy models that estimate expected performance and confirm that the building is within its energy performance budget. With EPP data, new building models may be informed by the actual performance of similar buildings already on campus. Modeling inputs include values such as peak lighting or plug demands and peak hydronic energy demands. The EPP does not run any simulations; instead this screen provides actual measured inputs required for simulations.

Most screens also have extensive functionality to allow the user to understand underlying data quality. The following links can be seen in Figure 3:

- **Data Missing Indicators.** Plots include indicators of the percentage of underlying data within a calculation that is missing or out of acceptable ranges. Indicators are displayed as small diamonds, as seen in Figures 4, 5, and 6.
- **Equation.** Plots include the equations used to calculate values for all displayed metrics.
- **SQL Statement**. Plots include the database SQL script used by the application to calculate the metric. This allows transparency for the user to troubleshoot and confirm the implementation of a calculation.
- **Data Table**. Plots include a table that summarizes the values presented in the graphic. Then for each metric used in the overall calculation, the equation is repeated, followed by a table of the parameters, or individual trend points, used by the equation. Each parameter has information about its physical location, minimum and maximum values, and number of records. These tables are valuable for identifying underlying data quality problems that may affect results.

Figure 3. Data Table for SE1 Electricity Use

Equation SQL Statement Data Table Plot Metric Data

Date	Electric Use
May 11	480,702.22
June 11	546,678.43
July 11	606,759.33
August 11	580,986.96
September 11	552,449.97

September 11

Electric Use

SUM{case when ((ta19 - ta18) * ta20) != 0.0 then (ba1 +ba9 + ba10 + ba11 + ba12 + ba13 +ba14 + ba15 + ba16) * 0.25 + (-ba2 - ba3 - ba4 - ba5 - ba6 + ba7 + ba8) * 0.25 * (((bc1 - bc2) * bc3) / ((ta19 - ta18) * ta20)) else null end} * (1 + 0.05)

Var	ALC Data Point	Description	Equipment	Unit	Min Value	Max Value	Min Date	Max Date	Rows
ta19	#chiller_control_0208/cmmn_chwr /trend_log	Chilled Water Return	Chiller Control	F	50.8	71.5	09/01/11	09/28/11	2222
ta18	#chiller_control_0208/cmmn_chws /trend_log	Chilled Water Supply	Chiller Control	F	38.1	57.2	09/01/11	09/28/11	2222
ta20	#all_bridge_valve_positions/m390	CHW Total Sec GPM	All Bridge Valve Position	gpm	0	1291.05	09/01/11	09/30/11	2769
ba1	#breaker_main_0200/kwtr	KW	Breaker Main	kW	0	705.45	09/01/11	09/30/11	2545
ba2	#msa_main_breaker_0208/kwtr	KW	MSA Main Breaker	kW	-1113.34	0	09/01/11	09/30/11	2690
ba3	#msb_main_breaker_0208/kwtr	KW	MSB Main Breaker	kW	-738.75	0	09/01/11	09/30/11	2499
ba4	#ats_s1_0208/kwtr	KW	ATS-S1-SH	kW	0	69.17	09/01/11	09/30/11	2514
ba5	#msb_ast_s2_0208/kwtr	KW	ATS-S2-CH	kW	-0.04	73.17	09/01/11	09/30/11	2509
ba6	#panel_ph_0208/kwtr	KW	Panel PH	kW	0	24.58	09/01/11	09/30/11	2514
ba7	#p-3_vfd_0208/m544	Power, kW	P-3 VFD Interface	kW	0	196.1	09/01/11	09/30/11	2452
ba8	#p-4_vfd_0208/m544	Power, kW	P-4 VFD Interface	kW	0	184	09/01/11	09/30/11	2452
bc1	#chw_bridge_0200/bldg_chwr/trend_log	Bldg CHWR Temp	CHW Bridge	F	48.6	69.1	09/01/11	09/30/11	2529
bc2	#chw_bridge_0200/prim_chws /trend_log	Primary CHWS Temp	CHW Bridge	F	37.5	55.9	09/01/11	09/30/11	2591
bc3	#chw_bridge_0200/chw_flow/trend_log	CHW Flow (gpm)	CHW Bridge	gpm	-225	467.8	09/01/11	09/30/11	2591

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- **Plot Metric Data.** Graphical plots are also available for all the parameter trends in individual plots in a separate screen. Again, this is useful in scanning for data quality problems or in understanding underlying data.

Initial Deployment

The EPP was deployed at UC Merced in fall of 2011, and has been in use by the campus energy manager and a student analyst. The initial focus in using the tool has been to review and improve data quality. UC Merced has successfully collected large amounts of performance data from its buildings, about 3,000 points per building every 15 minutes. But, it is only with the development of the EPP that the campus has defined which data points are critical to campus energy performance monitoring and narrowed it down to about 200 to 300 points per building. This provides an opportunity to target efforts to make sure that data points critical to EPP calculations are regularly monitored and maintained in order to avoid data gaps. Using a procedure that involves running a series of plots and reviewing statistics provided in the "Data Table" for each plot, it is possible to proactively identify data gaps. This process has been documented in order to develop an automated data gap alert feature that would identify data gaps in real time. The campus has modified the way in which data are stored within field devices that are part of the EMCS data collection system to provide a buffer against data loss. The campus is running data review plots weekly to monthly and have an additional two to three months in which to fix any data problems without any data loss. With attention to ensuring very limited data loss, EPP reports, especially those based on rolling twelve-month averages, will be more accurate and valuable.

Examples of Use

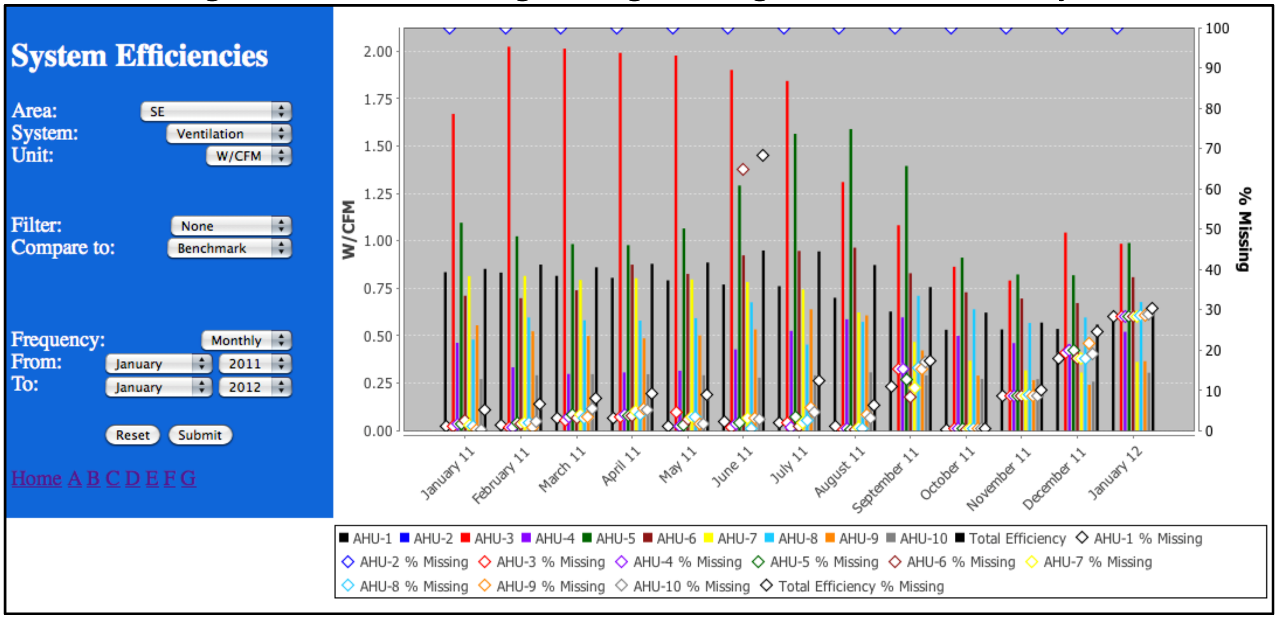
Below are some examples of how UC Merced has used the EPP to increase the campus energy performance.

Example 1: Proactive Retro-Commissioning

Triggered by an initial review of a ventilation system efficiency plot (Figure 4) that calculates aggregate individual ventilation efficiency across all building air handlers in SE1, it was clear that there was significant variability in fan efficiency. The campus determined that this was caused primarily by incorrect control of air handler fan speeds. Differential pressure sensors were found to be inconsistently placed, sometimes near the start and sometimes near the end of a duct run. Also, the differential pressure sensors were incorrectly mapped to air handler supply fan variable frequency drives. For example, in a common duct run supplied by two air handler units (AHU), the supply fan for one AHU (AHU-3, red bar in Figure 4) was running at full speed (and lower efficiency) while the supply fan for the other AHU (AHU-4, purple bar in Figure 4) was running at very low speed (and higher efficiency).

During August and September 2011, the campus reinstalled and recalibrated all differential pressure sensors controlling fan speeds and repaired the sequence of controls associated with the air handler supply fans. The plots indicate that average fan efficiency of 0.8-0.9 Watts/CFM dropped closer to 0.6 Watts/CFM. This retro-commissioning opportunity could have been found by investigating the logic within the campus EMCS. However, it had never become a priority to review the relatively detailed logic within the EMCS that was generally presumed to have been properly commissioned when the building was constructed. The EPP was instrumental in identifying the problem and provided an estimate of the magnitude of the problems, since flow values were easily accessible from the “Data Table” and “Plot Metric Data” areas that support the plot shown in Figure 4.

Figure 4. Science and Engineering Building Ventilation Efficiency

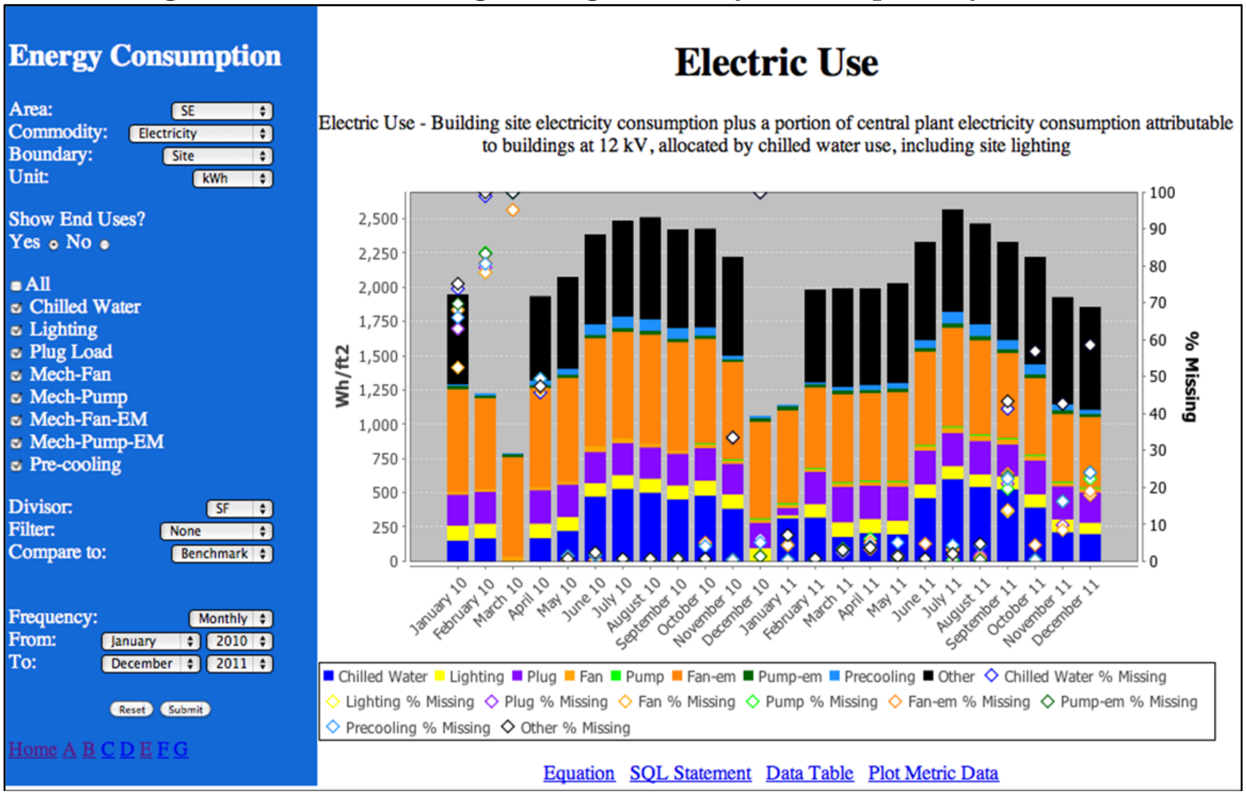


Example 2: Tracking Energy Performance by End Use

The campus is using plots of electricity consumption broken out by end use to monitor and estimate savings from a broad set of energy reduction projects in SE1. The orange portion of the bar indicates fan energy used in the building. During August and September 2011, the campus completed the differential pressure and controls changes described above. Over fall 2011, the campus also developed a complete reprogramming of laboratory controls in the building that will allow night airflow and temperature setback in laboratory spaces. These changes are being implemented in consultation with each lab in the first and second quarters of 2012.

Monthly values compared to the previous year provide an indication (uncorrected for weather) of the savings. In this case, October, November, and December 2011 averaged 27 percent lower than the previous year due to the differential pressure and control changes. Once all changes that should affect fan power in the building are complete, the same report could be run as a rolling twelve month average to provide a long-term indication of how performance is trending over time.

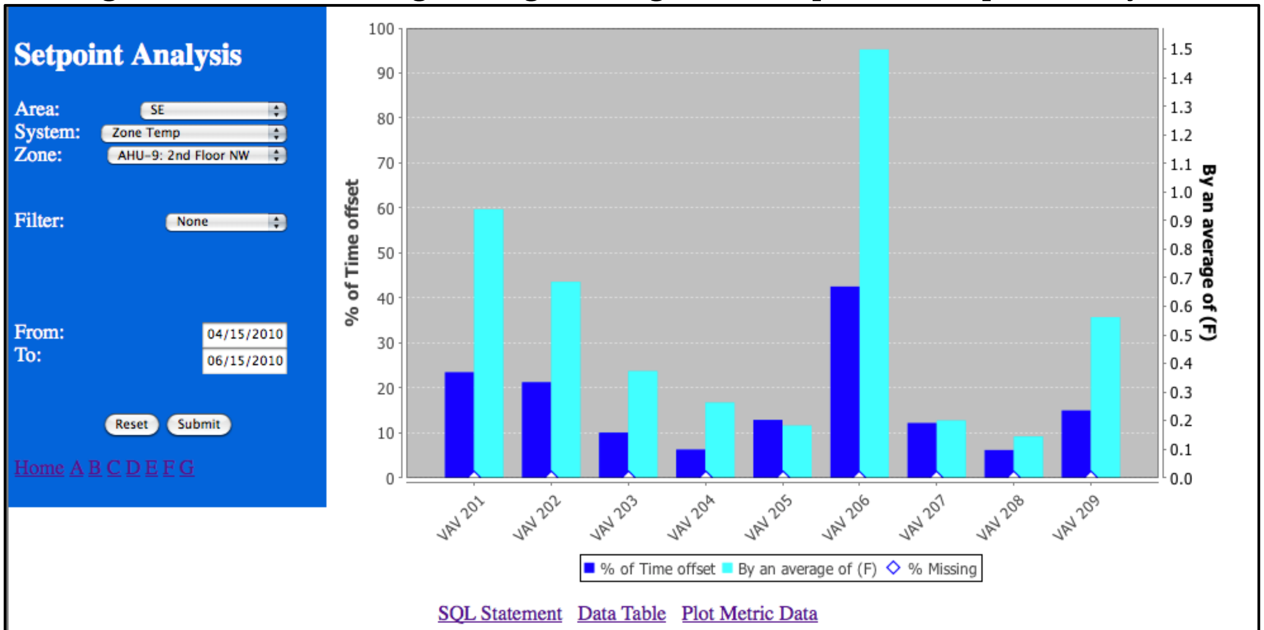
Figure 5. Science and Engineering Electricity Consumption by End Use



Example 3: Finding Operational Inefficiencies

Review of a Setpoint Analysis plot within EPP indicates the amount of time a trend is not meeting setpoint and by how much it is not meeting setpoint. Figure 6 below shows the percentage of time that a particular zone is not meeting its temperature setpoint and the average of the magnitude of the deviation (either above or below) of zone temperature from setpoint. The individual variable air volume (VAV) boxes are shown in the order they are located along the duct run, to support technicians' ability to diagnose anomalies caused by problems such as a closed fire smoke damper or not enough static pressure at the end of a duct run. The zone served by VAV 206 was not within the cooling and heating setpoints 43% of the time, it was over or under setpoint by an average of 1.5° F, clearly an outlier among the other VAVs on the same duct run.

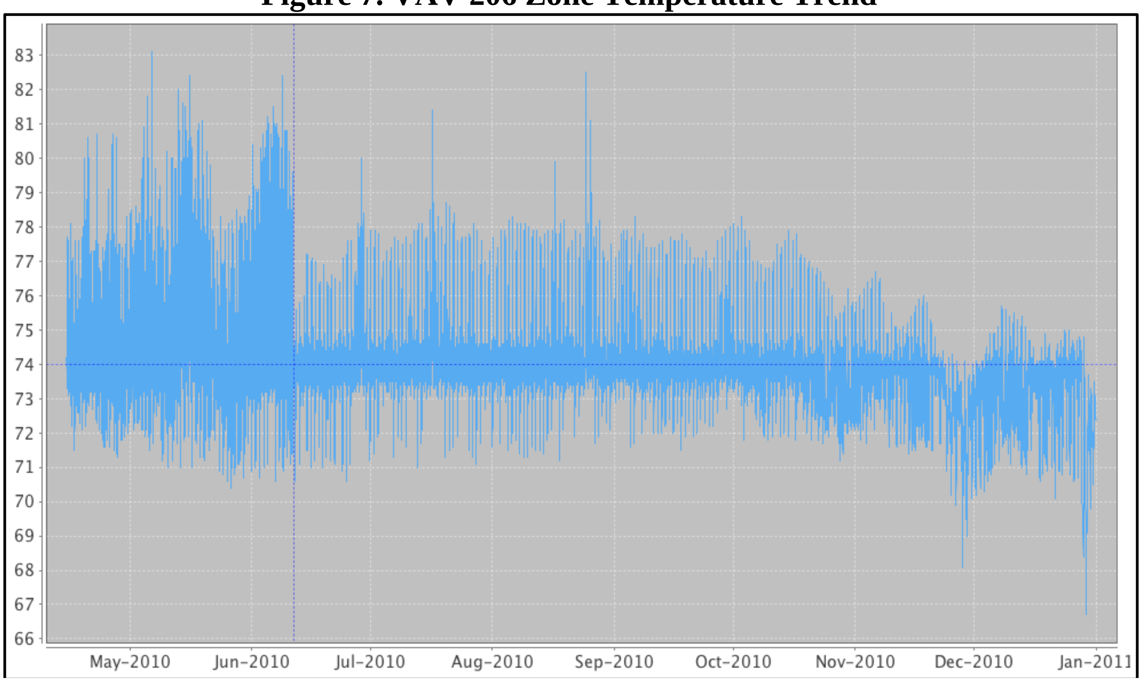
Figure 6. Science and Engineering Building Zone Temperature Setpoint Analysis



	VAV 201	VAV 202	VAV 203	VAV 204	VAV 205	VAV 206	VAV 207	VAV 208	VAV 209
% of Time Offset	23.48	21.26	10.03	6.28	12.85	42.53	12.18	6.17	14.97
Magnitude of Offset	0.94	0.69	0.37	0.26	0.18	1.50	0.20	0.14	0.56

An HVAC technician was dispatched in June to assess the VAV equipment; as a result, zone temperature was stabilized for optimal occupant comfort. By looking at a plot of the underlying data to the setpoint analysis for VAV 206 (Figure 7), the widely varying temperatures confirm poor control with sequential overheating and cooling. This same plot shows improved operation after the HVAC technician completed a repair, marked by the dotted vertical line.

Figure 7. VAV 206 Zone Temperature Trend



Future Development and Potential for Broader Implementation

The campus plans future development of the EPP, as it is an effective means to maintain energy performance, keep utility bills low, and effectively target and retrofit expenditures. Within the campus context of a zero net energy goal, the alternative to energy efficiency is relatively expensive generation of renewable power. The campus has not performed a full analysis of the cost-effectiveness of the system. The following enhancements to the EPP have been identified subject to the availability of additional funding:

- **Addition of all buildings on campus**. The metric equations used by the EPP were designed to be standard across all buildings on campus so the planned addition of new buildings to campus and the EPP is relatively straightforward and does not involve any database changes to the EPP.
- **Handling of missing or bad data.** Most plots within the current version of the EPP indicate missing data and in some cases, compensate for data gaps with extrapolations from existing data. Functionality to more accurately identify bad data (such as zeros for points that should never be zero) would improve accuracy. Finally, automating the procedure the campus has recently developed to identify missing or bad data and to generate a report of data quality would allow the campus to most efficiently and proactively address data quality problems.
- **Upload feature.** A manual upload from a flat file would allow replacing bad data or supplying data that cannot be trended directly from the EMCS, such as total campus built square footage.
- **Laboratory Energy Efficiency Profiler (LEEP) and Labs21 variables sheet.** LEEP and Labs21 (Mathew et al. 2004) are online tools for laboratory-specific buildings that offer benchmarking and energy efficiency suggestions through a self-reported online survey. Some variables required by the tools have to be calculated *from raw data.* To facilitate the process of utilizing these online tools, there could be a screen that calculates and summarizes these variables for a specified time frame.

UC Merced and the Berkeley Lab expect that the EPP will become more valuable as it is expanded and deployed across additional sites, for example at the Berkeley Lab campus or other UC campuses. While the EPP derives significant value from access to energy use data by end use, which is easier to gather if made a priority in new construction, the EPP can also provide value in cases where only whole-building data is currently available. Application in a retrofit environment would help illuminate the business case and verify what data monitoring would be worth installing and monitoring through the EPP. For either new construction or retrofit, the EPP delineates a minimum metering specification needed to operationalize monitoring-based commissioning.

Conclusions

The Energy Performance Platform has successfully made a significant database of trended building performance data actionable at UC Merced. From the authors' perspective, the EPP provides a unique balance of high-level results necessary to monitoring and direct efforts to improve building energy performance, along with access to very detailed underlying data that allows users to confirm what factors may be leading to unexpected results. Further, the application environment is expected to drastically reduce the time required to review large amounts of building performance data. UC Merced looks forward to broader implementation of the EPP to further validate the set of monitoring data deployed in the EPP. Development of a new zero net energy campus is most cost-effective if energy efficiency is prioritized in new construction and special attention is given to maintaining the installed energy efficiency over time. The EPP provides one example of an energy information system specifically targeted to this maintenance task.

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