A New Campus Built on Efficiency

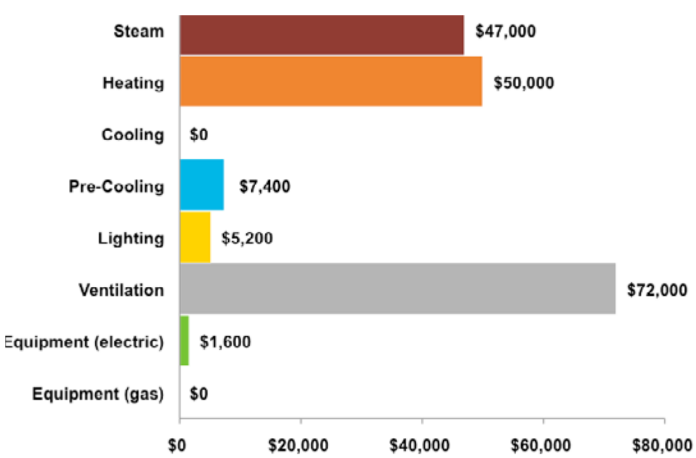
The University of California (UC), Merced partnered with the U.S. Department of Energy (DOE) to develop and implement solutions to retrofit two existing buildings to reduce energy consumption by at least 30% as part of DOE's Commercial Buildings Partnerships (CBP) Program.[1] Lawrence Berkeley National Laboratory (LBNL) provided technical expertise in support of this DOE program. This case study reports expected savings from proposed design recommendations for the campus, which are subject to change in final construction. It is estimated that UC Merced will achieve the 30% reduction in the two participating buildings, the central plant and the Science & Engineering (S&E) building. The savings from retrofits of those buildings represent about 17% of whole-campus energy use. In addition, the energy saved by the CBP retrofits supports a broader goal, UC Merced's "Triple Zero" commitment to zero net energy, zero landfill waste, and zero net greenhouse gas emissions by 2020. Although the campus has already made progress toward that goal with its efficient building construction and operation, opportunities for deeper savings remain, as the CBP project demonstrates.

The Science & Engineering Building houses laboratories, classrooms, and office space.

Courtesy of UC Merced

Project Type	Central Plant & Academic Laboratory, Retrofit
Climate Zone	ASHRAE Zone 3C, Warm Marine
Ownership	Public
Barriers Addressed	• Lack of funding • Limiting campus policies • Data quality issues
Square Footage of Project	• 856,568 (campus) • 236,989 (Science & Engineering Building)
Expected Energy Savings (vs. historical operation)	~17% whole campus savings (includes ~15% central plant savings and ~2.4% S&E savings)
Expected Energy Savings (vs. average UC/CSU campus energy use in 1999)	~56% whole campus savings attributable to existing and new efficiency measures
Expected Energy Savings	• ~720,000 kWh/year electricity • ~140,000 therms/year natural gas
Expected Cost Reductions for Whole Campus[2]	~$180,000/year
Actual Cost Reductions	To be verified
Project Simple Payback	~2.1 years
Expected Carbon Dioxide Emissions Avoided	~930 Metric Tons per Year[3]
Construction Completion Date	To be determined

Expected Whole-Campus Energy Cost Reductions



1. The Commercial Building Partnerships (CBP) program is a public/private, cost-shared initiative that demonstrates cost-effective, replicable ways to achieve dramatic energy savings in commercial buildings. Through the program, companies and organizations, selected through a competitive process, team with U.S. Department of Energy (DOE) and national laboratory staff who provide technical expertise to explore energy-saving ideas and strategies that are applied to specific building project(s) and that can be replicated across the market.
2. Cost reductions based on 2010 utility rates for UC Merced of $0.12/kWh and $0.67/therm.
3. Using an emissions factor of 0.61 pounds of carbon dioxide per kilowatt hour of electricity (Energy Information Administration, 2002).

UC Merced's comprehensive approach to capturing and maintaining energy efficiency includes setting building energy performance targets and focusing on continuous monitoring-based commissioning. The campus's energy performance targets for building projects are defined against benchmarks representing the energy performance of the existing building stock across UC and California State University (CSU) campuses, differentiated by space type and normalized for climate. For the first campus buildings, which were completed in 2005 and included the S&E building, UC Merced aimed for buildings that performed at 20% better than average benchmark. This target ramped to 50% as new buildings were added to the campus (Brown, 2002). The ~17% whole-campus savings from the CBP project will bring overall campus performance to ~56% of the 1999 UC/CSU benchmark.

The central plant services most buildings on the nearly one-million-square-foot campus, including a library, a laboratory, two classroom buildings, a dining commons, a recreational center and clinic, and several dormitories. The campus features a relatively dense metering network with data available at the campus and building level by end use (generally, heating, ventilation, and air conditioning [HVAC], lighting, plug, and other loads) as well as the system level (for example, ventilation fans or hydronic pumps). As part of the CBP program, UC Merced worked with LBNL and consultants to analyze the central plant configuration and operations for opportunities to save energy. UC Merced suspected that the central plant heating and steam systems were not performing as efficiently as possible and were compromising whole-campus energy performance. These systems had been sized for future campus growth, and the plant had problems meeting lower loads of the current, partially built-out campus during many months of the year. Also, available gas meter data provided incomplete information regarding system efficiencies, which made it difficult to fully confirm savings opportunities.

In addition to the central plant, the S&E building was targeted for retrofits to fix original construction defects and reduce energy use. The S&E building is a laboratory building and has the highest energy use intensity on campus: although it represents only one- fifth of the campus square footage, it consumes more than half of the campus energy. Based on metered data and operational experience, it was clear that several sensor and control problems were preventing the building from shifting properly to energy-saving setbacks during unoccupied hours.

Decision Criteria

The energy efficiency measures (EEMs) for the two UC Merced buildings went through several approval stages before being selected for implementation. First, a technical expert team, led by The Weidt Group, studied central plant loads and operation to identify EEMs with energy savings potential. This team modeled the EEMs based on available data and relevance to the project. Concurrently, the energy performance platform (EPP), which is UC Merced's energy information system to track metered energy use and sensor data, was used to derive input values for the Labs21 Benchmarking tool and the Laboratory Energy Efficiency Profiler (LEEP) Tool (Mathew et al., 2004), to generate EEMs for the S&E Building. The EPP provides quantified energy use data and tracks performance of systems against benchmarks to maintain and improve energy performance, which are critical inputs to campus decision-making (Mercado, Elliott, 2012). Although the EPP was custom designed for UC Merced, commercially available energy information systems (EIS) could be used for similar purposes. References and resources on EIS tools are available online (Granderson et al., 2011). UC Merced considered retrofits derived from LEEP and the EPP to be operational improvements and generally evaluated them on a simple payback basis; however, other decision criteria were also considered, including which measures would have the greatest aggregate impact across the campus as a whole.

A rainbow touches down over the UC Merced campus. The Central Plant can be seen on the far right; the Science & Engineering building is directly to the left of the plant.

Courtesy of UC Merced

Economic

Public universities can find it difficult to fund energy efficiency projects because of variable annual funding cycles that are linked to state budgets. UC Merced faced these constraints but utilized several approaches that enabled adoption of the CBP EEMs:

- Measures with simple paybacks longer than three years were not considered.
- Efficiency measures that qualified for available utility rebate and financing programs were preferred, to optimize operational and capital savings.
- Measures that did not require purchasing new equipment, such as re-commissioning or reinstalling faulty sensors and controls and optimizing the existing system, were considered ideal.
- Efficiency measures targeting the central plant were prioritized because they would produce savings across the entire campus as well as for future buildings added to the system.

Operational

UC Merced emphasized EEMs that made best use of the existing campus control and monitoring system, thereby leveraging their previous investment in a robust energy management and control system (EMCS) and the EPP. For these EEMs, UC Merced relied on knowledgeable staff to cost-effectively implement modifications to the control systems. UC Merced's operational criteria emphasized:

- Re-commissioning controls that could be accomplished directly from the EMCS software and would be relatively inexpensive to implement; even measures with smaller energy savings would be worthwhile investments of time by on-site staff.
- Measures that improved the operational efficiency of the existing equipment were favored over measures that required buying and installing new equipment. Optimizing and extending the investment in existing equipment aimed to ensure the best return on previous capital investments.
- System and plant design had to be adaptable to campus growth, both in terms of building square footage and number of students and faculty, while at the same time being designed to provide efficient operation at part load and peak load for both current and future build-outs. This strategy maximized the return on capital investment while emphasizing energy efficiency. In practice, this strategy had not been executed effectively in all cases; for example, the original steam system design was sized for future growth but could not operate efficiently at the low loads of the campus's initial build out. Additionally, when the campus was designed, the need for a small amount of steam year round, which resulted in a constant off-season load, was not specified. As a result, the plant operated very inefficiently year round. A modular system that was sized to address the low constant loads as well as needs for future growth would have met both the growth and efficiency needs.

Policy

UC Merced has a strong focus on sustainable operations and growth. The campus's Triple Zero commitment fosters continuous energy efficiency improvements, including:

- A commitment to reduce energy performance from the designed 20% to approximately 60% savings over UC/CSU benchmarks in the S&E Building and to maintain it at that level (NBI 2009).
- A focus on using cost-effective new technologies to maximize potential energy savings.
- Continuous energy use monitoring and improvement to both maintain efficiency gains and improve upon them.

Energy Efficiency Measures Snapshot

The following table lists energy efficiency measures (EEMs) that were proposed for inclusion in this project. Measures that were not included in this project but are considerations for future projects on the UC Merced campus are also included in the table.

- For the central plant analysis, measures focused primarily on the steam and hot water systems and on identifying methods to increase the efficiency of part-load operation (which is the typical mode of operation). Steam on campus is used for laboratory operations and not for heating purposes, while the hot water system provides heating for the campus. Plant equipment and control sequences were prioritized for better turn-down and energy reduction. Existing plant controls included variable-speed pumping.
- For the S&E Building, EEMs were proposed using EPP to identify systems that were consuming more energy than benchmark targets, and through discussions with knowledgeable operations staff. Measures were selected to improve operations through minimal retrofits or controls modifications because the systems in this building were relatively new, and replacement retrofits would not have been cost-effective on previous investments. The S&E building existing EEMs include variable-air-volume fume hoods, evaporative pre-cooling, and a four-pipe design that eliminates reheating in laboratory spaces. The S&E EEMs therefore needed to target less typical energy savings opportunities. The S&E energy savings presented here include the selected steam/heating energy efficiency improvement at the central plant.
- The EEMs are presented ranked by expected annual savings within each end use.

Energy Efficiency Measures

The technical team recommended heating and steam EEMs for the central plant retrofits. For the S&E Building, ventilation, heating and cooling, lighting, and plug load EEMs were derived from the LEEP Tool and EPP analysis.

EEM	Implementing in this Project	Will Consider for Future Projects	Expected Annual Savings[4]		Expected Improvement Cost, $	Cost of Conserved Energy (CCE),[5] $/kWh	Simple Payback years
			kWh/year	$/year			
Central Plant – Affecting Whole Campus							
Heating (7.3% Whole-Campus Savings)							
Add new, smaller condensing hot water boiler to replace under-loaded, oversized boilers.	No	No	2,300,000	$55,000	$130,000	$0.004	2.4
Add new, smaller 85% efficient hot water boiler to replace under-loaded, oversized boilers.	No	No	2,300,000	$54,000	$100,000	$0.003	1.9
Add new, smaller 80% efficient hot water boiler to replace under-loaded, oversized boilers.	Yes	No	2,100,000	$51,000	$100,000	$0.003	2.0
Reset supply temperature set point on boiler system from 210°F to 160°F with a 130°F return water temperature.*	No	No	79,000	$990	$500	$0.0004	0.5
Steam (7.1% Whole Campus Savings)							
Install heat exchanger between steam boilers and hot water loop to load the system and unload the hot water boilers for many hours of the year and reduce cycling of both systems.	No	No	2,300,000	$53,000	$82,000	$0.003	1.5
Replace oversized steam boiler with new, right-sized, gas-fired 70% efficient steam boiler.	Yes	No	2,100,000	$47,000	$140,000	$0.005	3.0
Eliminate steam plant and use electricity-driven autoclaves.	No	No	2,100,000	$21,000	$280,000	$0.009	13
Lower steam operating pressure from 110 pounds per square inch (psi) to 60 psi, to reduce boiler system distribution losses.	No	No	96,000	$2,200	$500	$0.0004	0.2
Science & Engineering Building							
Lighting (0.1% Whole-Campus Savings, 0.5% S&E Building Savings)							
Re-commission lighting controls to allow greater occupant control and deploy a "manual on/auto off" strategy throughout lab spaces.	Yes	Yes	43,000	$5,200	$5,400[6]	$0.009	1.0
HVAC (2.3% Whole-Campus Savings, 6.9% S&E Building Savings)							
Re-commission ventilation controls and reinstall differential pressure sensors for controlling fan speeds; sensors are currently placed near corners in the air system resulting in inaccurate pressure readings and excessive airflow.	Yes	Yes	590,000	$71,000	$130,000	$0.015	1.8
After re-commissioning ventilation, change laboratory ventilation controls to reduce ventilation rates from 6 to 4 air changes per hour during unoccupied times (Brase, 2011).	Yes	Yes	9,200	$1,100			
Re-commission pre-cooling system controls to original designed performance.	Yes	Yes	62,000	$7,400	$1,200	0.001	0.2
Further reduce reheat energy use.	No	Yes	280,000	$650	N/A[7]	N/A	N/A
Install low-pressure-drop bag-type filters.[8]	No	Yes	N/A				
Aerosol seal air distribution ducts.[9]	No	Yes	N/A				

- Climate-dependent EEM.

4. Cost savings based on 2010 utility rates for UC Merced of $0.12/kWh and $0.67/therm.
5. CCE evaluated with 5% discount rate for 25 years (Meier, 1984).
6. Improvement cost is a labor cost only.
7. Insufficient reheat load was identified, so first cost was not modeled.
8. Replacement of air handling equipment would have been necessary to support bag-type filter installations; replacement equipment would not fit in available space, so this EEM was not pursued.
9. Ductwork is six years old, and initial installation appears to be in good condition, so EEM was not pursued.

Energy Use Intensities By End Use

Central plant EEMs were identified and analyzed by the technical team, which was comprised of The Weidt Group and KJWW Engineering Consultants. Central plant energy modeling was based on the plant's construction drawings and 15-minute energy usage trend data from sensors.

Several models were used to analyze the impacts of EEMs identified for the S&E building. To account for the impact of the central plant energy efficiency modifications on the heating and steam systems provided to the S&E building, a revised baseline for the S&E building was constructed, which incorporated the new higher-efficiency steam and heating systems. S&E EEMs were evaluated in relation to this baseline.

For S&E ventilation EEMs, packages of measures were modeled together to support UC Merced's decision-making needs. These measures included reinstalling and recalibrating differential pressure sensors and reducing ventilation rates to four air changes per hour in lab space during unoccupied hours. (Because S&E laboratory space is unscheduled only from 1 AM to 6 AM daily, the unoccupied hours are relatively short. If the unoccupied period were longer, savings from this measure would be greater.) All other measures were simulated individually for the S&E building, to allow for direct comparisons among them.

Models 1 and 2, described below, show savings from the central plant EEMs. Models 3 through 5 were created to assess whole-building savings at the S&E building. Model 3 is the S&E building pre-retrofit design baseline, representing the building's 2010 performance. Model 4 represents energy saved at the S&E building as a result of EEMs implemented at the central plant; this model creates a new baseline for the S&E building to account for the effect on the building of increased central plant efficiency resulting from EEMs at the central plant. Model 5 builds upon Model 4 to include the S&E building EEMs and shows their incremental impact on energy savings.

Model 1 – UC Merced Pre-Retrofit Campus Central Plant

This first model represents the campus baseline using measured pre-retrofit central plant data from 2010, construction documents, and notes from site visits for equipment efficiencies. Because of a sensor failure, hot water data were missing for January, most of February, most of November, and December 2010. These data were replaced with other near-date data. Steam data from 2010 were sparse and unreliable, so the steam consumption was modeled based on S&E building steam data that had been collected on magnetic tape drives[10] as well as on utility gas meter information. Data were collected for this equipment in May 2011 during the early stages of the CBP analysis. In the S&E building, steam is only used for autoclaves and cage or glass washing; therefore, consumption is relatively constant throughout the year.

The campus pre-retrofit baseline has an energy use intensity (EUI) of about 116 kBtu/ft^2.

Model 2 – UC Merced Campus Central Plant Proposed Design

The second model represents the effects of the central plant heating and steam system EEMs. The measures chosen were to temporarily (until the campus reaches full build-out) provide an alternative to using the oversized, inefficient hot water boilers at the plant by adding a new, smaller, hot water boiler that is correctly sized for the current low loads. As a worst-case scenario, the new hot water boiler was modeled as 80% efficient. The steam boilers at the plant would be idled and replaced by a modular steam boiler until the campus is fully built out so that the load is appropriate for the large boiler. The new, smaller steam boiler was modeled at 70% efficiency as a worst-case scenario. The resulting EUI is approximately 99 kBtu/ft^2 for services provided to the campus, which is ~15% lower energy consumption than the pre-retrofit baseline (Model 1).

Model 3 – UC Merced Pre-Retrofit Science & Engineering Building (2010)

The first S&E model represents the S&E building baseline for calendar year 2010, based on actual energy use data from the EPP. The S&E pre-retrofit baseline has an annual EUI of about 138 kBtu/ft^2.

View of Scholar's Lane, main campus thoroughfare in 2010, from the newest building on campus. (All buildings served by Central Plant)

Courtesy of Julian Ho 12/16/10

10. A tape drive is a data storage device that reads and writes data on a magnetic tape.

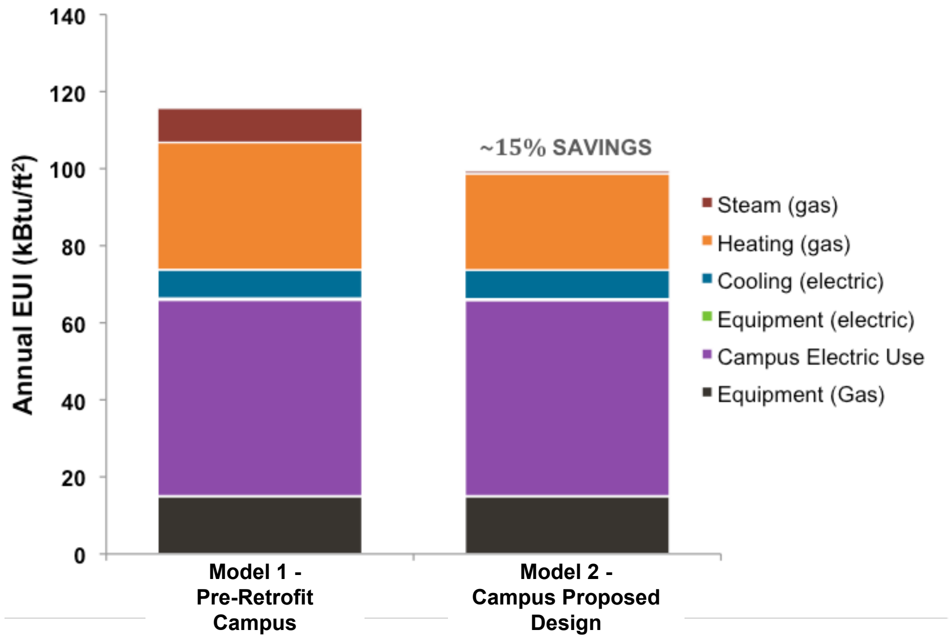
Model 4 – UC Merced Pre-Retrofit Science & Engineering Building (Revised)

The second S&E model represents S&E building energy use after implementation of central plant EEMs. This model has an annual EUI of approximately 99 kBtu/ft², which is ~28% lower energy consumption than the pre-retrofit baseline (Model 3).

Model 5 – UC Merced Science & Engineering Building Proposed Design

The third S&E model takes the revised baseline (Model 4) and applies the EEMs selected for the S&E building to represent the proposed S&E condition after retrofit. This model includes the following S&E EEMs: re-commissioned lights, modified pre-cooling system controls, and ventilation system EEMs. This model has an annual EUI of approximately 88 kBtu/ft², which is ~36% below the original pre-retrofit baseline (Model 3).

Comparing EUI of Pre-Retrofit and Proposed Design for the Campus



Expected Campus Annual Energy Use and Percent Savings by End Use

End Use Category	Model 1 - Pre-Retrofit Campus	Model 2 – Campus Proposed Design	
	Annual EUI (kBtu/ft²)	Annual EUI (kBtu/ft²)	Percent Savings Over Pre-Retrofit
Steam (gas)	8.9	0.7	92%
Heating (gas)	33	25	25%
Cooling (electric)	7.5	7.5	0%
Equipment (electric)	0.3	0.2	22%
Campus Electric Use[11]	51	51	0%
Equipment (gas)	15	15	0%
Total Savings	**116**	**~99**	**~15%**

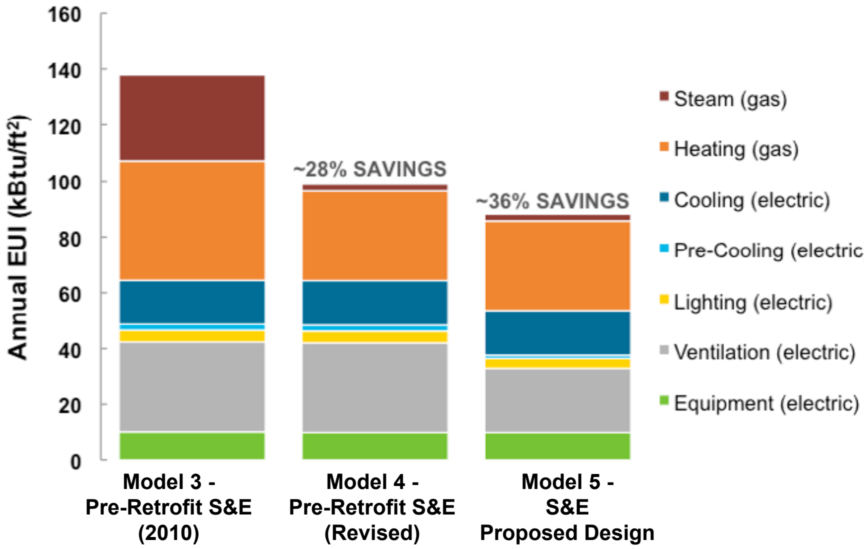
Expected Campus Energy Savings from Implemented EEMs by End Use

Electricity End Use Category	Energy Savings
Cooling	0 kWh
Equipment	15,000 kWh
Campus Electric Use	0 kWh
Electricity Total	**~15,000 kWh**

Gas End Use Category	Energy Savings
Steam	70,000 therms
Heating	73,000 therms
Equipment	0 therms
Gas Total	**~140,000 therms**

11. Electricity used by campus buildings for all electric end uses that is not attributable to Central Plant energy use.

Comparing EUI of Pre-Retrofit and Proposed Designs for S&E Building



Expected S&E Building Annual Energy Use and Percentage Savings by End Use

End Use Category	Model 3 – Pre-Retrofit S&E (2010)	Model 4 – Pre-Retrofit S&E (Revised)		Model 5 – S&E Proposed Design	
	Annual EUI (kBtu/ft^2)	Annual EUI (kBtu/ft^2)	Percent Savings Pre-Retrofit (2010)	Annual EUI (kBtu/ft^2)	Percent Savings over Pre-Retrofit (2010)
Steam (gas)	30.7	2.4	92%	2.4	92%
Heating (gas)	42.8	32	25%	32	25%
Cooling (electric)	15.8	16	0%	16	0%
Pre-Cooling (electric)	2.1	2.1	0%	1.2	42%
Lighting (electric)	4.2	4.2	0%	3.5	15%
Ventilation (electric)	32	32	0%	23	27%
Equipment (electric)	10	10	0%	10	0%
Total	**138**	**~99**	**~28%**	**~88**	**~36%**

Expected S&E Building Energy Savings from Implemented EEMs by End Use

Electricity End Use Category	Energy Savings
Cooling	0 kWh
Pre-Cooling	62,000 kWh
Lighting	43,000 kWh
Ventilation	600,000 kWh
Equipment	0 kWh
Electricity Total	**~710,000 kWh**

Gas End Use Category	Energy Savings
Steam	67,000 therms
Heating	26,000 therms
Gas Total	**~93,000 therms**

Note: Natural gas savings are the equivalent central plant savings for the S&E building.

Lessons Learned

As part of their CBP work on the UC Merced campus, UC Merced, LBNL, and The Weidt Group learned lessons that can help other campuses achieve similar results.

If a building is to achieve zero net energy, which is UC Merced's ultimate goal, efficiency has to be the top priority. UC Merced's 20-year growth plans target a level of building efficiency that will avoid 67% of the campus's expected energy (Mercado, 2012). Expected energy usage is based on calculated benchmarks that represent existing energy performance for similar building types across UC and CSU campuses (Brown, 2002). The remainder of the campus load will be met with on-site generated energy through solar arrays (18%), plasma gasification (10%), and wind and hydro (5%). When consultants, engineers, and designers are presented with the challenge of stretching building efficiency, as is the case at this campus, best practices are surpassed, and innovative solutions are encouraged.

"After you invest in efficient equipment, there are always opportunities for finding additional operational savings through continuous metering."

—John Elliott,

Director of Energy and Sustainability, UC Merced

Focus on efficiency of existing systems first

For the ultimate goal of achieving zero net energy, the primary focus should be continually striving for greater operational efficiency. Before investing in new equipment, building operators should refine and tune existing sensors and controls as the best first opportunity for energy savings. Retro-commissioning of systems and recalibrating of key sensors can cost-effectively save substantial energy with minimal effort. For example, one EEM proposed for the S&E lab ventilation system calls for re-commissioning and reinstallation of differential pressure sensors. Faulty positioning of the sensors had caused sensor errors, forcing the system to oversupply air. This problem is costing UC Merced more than $70,000 a year in wasted energy. The problem will be eliminated when the sensor position is corrected. Investing in control modifications can cost-effectively increase efficiency and avoid the need for investment in larger-scale retrofits. UC Merced endorses this philosophy whole-heartedly, applying it in their daily operational practices as well.

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Make best use of existing data

The EPP was designed to track UC Merced's energy performance and to support low-cost, continuous, monitoring-based commissioning. The EPP uses data collected at 15-minute intervals to display energy use metrics in a graphical form that allows users to quickly and effectively determine performance. However, a custom-designed system is not necessary; many buildings use energy management systems (EMSs) to control their HVAC systems, and operations personnel can use archived EMS data to continuously track and analyze building operations and performance. UC Merced takes its monitoring practices a step further by identifying key energy and performance metrics across all systems and installing meters and sensors in key areas to enable analysis of energy savings throughout buildings. A graphical interface is key for facilities staff to identify and compare efficiency opportunities and for analysts to determine where energy use can cost-effectively be reduced, for example by re-commissioning or tuning of control sequences.

Data analysis can be cost-effective

UC Merced's metering infrastructure provides a wealth of data that allow the facilities staff to understand how the campus uses energy; however, a robust and agile means of analyzing the data to identify energy savings opportunities is key to benefiting from these data. Free on-line tools are available that offer guidance on how to reduce energy use in buildings. These include: ENERGY STAR's Portfolio Manager, which offers free energy use tracking; EnergyIQ, which offers benchmarking and suggests efficiency actions for commercial buildings; and Labs21 and LEEP, which focus on laboratory benchmarking. These tools are most effective with rich data sets (such the data collected at UC Merced); if end-use-level data are input to the tools, the tools provide end-use-level recommendations. Taking advantage of these tools is a strategic way to focus budget dollars on investigating and implementing the most effective energy efficiency measures. A small investment in collecting and analyzing operational data can enable the identification of a wealth of energy saving opportunities.

UC Merced installed a 1-megawatt solar array to help meet zero net energy on campus.

Courtesy of CITRIS

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