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A New Campus Built on Efficiency

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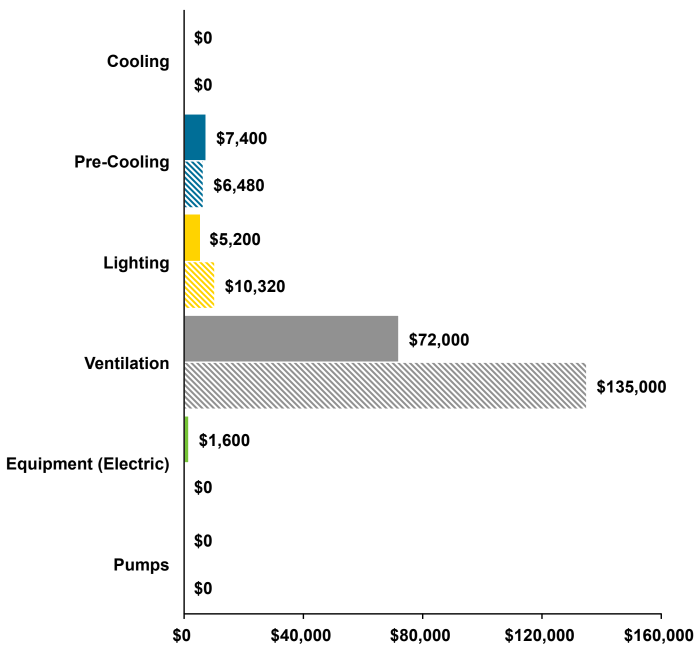
A New Campus Built on Efficiency

The University of California (UC), Merced partnered with the U.S. Department of Energy (DOE) to develop and implement solutions to reduce energy consumption by as part of DOE's Commercial Buildings Partnerships (CBP) Program. Lawrence Berkeley National Laboratory (LBNL) provided technical expertise in support of this DOE program. This case study reports on the process and outcome of this project including the achieved savings from design improvements for the campus.

The intent of the project was to retrofit the Science & Engineering (S&E) building and the central plant at UC Merced to achieve up to 30% energy reduction. The anticipated savings from these retrofits represented about 17% of whole-campus energy use. If achieved, the savings contribution from the CBP project would have brought overall campus performance to 56% of the 1999 UC/CSU benchmark performance for their portfolio of buildings. However, the final design that moved forward as part of the CBP program only included the retrofit measures for the S&E building.

Expected Whole-Campus Energy Cost Reductions



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

Courtesy of UC Merced

Project Type	Academic Laboratory, Retrofit
Climate Zone	ASHRAE Zone 3C, Warm Marine
Ownership	Public
Barriers Addressed	• Lack of funding • Limiting campus policies • Staffing changes • Data quality issues
Square Footage of Project	• 237,000
Expected Energy Savings	~704,000 kWh/year electricity
Actual Energy Savings	1,266,000 kWh/year electricity
Actual Cost Reductions[2]	~$152,000
Project Simple Payback	~0.9 years
Expected Carbon Dioxide Emissions Avoided	~350 Metric Tons per Year[3]
Construction Completion Date	September 2011

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 kilowatthour of electricity (Energy Information Administration, 2002).

Energy savings for the S&E building amounted to ~1.3 million kilowatt-hours, a 28 percent reduction in the energy use of the electricity end uses, equivalent to 13% reduction in the total site energy for the building, and, at UC Merced's typical utility rates, an annual cost savings of $152,000.

In addition, the energy saved by the CBP retrofits supports the broader goal of 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 this CBP project demonstrates.

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 features a relatively dense metering network with data available at the campus and building levels by system, such as ventilation fans or hydronic pumps, and by end use including HVAC, lighting, plug, and other loads. UC Merced defines energy performance targets for building projects 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 which included the S&E building, UC Merced aimed for buildings that performed at 20% better than average benchmark. This target was raised to 50% as new buildings were added to the campus (Brown, 2002).

The S&E Building was targeted for retrofits to fix original construction defects and further 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.

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

In addition to the S&E Building, 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. 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. 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. Available gas meter data provided incomplete information regarding system efficiencies, which made it difficult to fully confirm savings opportunities.

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.

Decision Criteria

The energy efficiency measures (EEMs) for the UC Merced S&E building and central plant went through several approval stages before being selected for implementation.

EEMs for the S&E Building were generated using the Labs21 Benchmarking tool and the Laboratory Energy Efficiency Profiler (LEEP) Tool (Mathew et al., 2004), the inputs for these tools were derived from UC Merced's energy information system, the Energy Performance Platform (EPP). EPP tracks metered energy use and sensor data, 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 and 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. eis.lbl.gov). 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.

EEMs for the central plant were developed by a technical expert team led by The Weidt Group. The technical team studied central plant loads and operation over a variety of use conditions to identify EEMs with energy savings potential, which were modeled based on available data and relevance to the project.

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 floor area 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 had been sized for future growth but could not operate efficiently at the low loads of the campus' initial build out. Additionally, when the campus was designed, the need for a small amount of steam year round had not been specified, but meeting this need resulted in a constant off-season load. 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 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 completed in this project. Measures that were part of the initial plan but not completed and measures that were proposed but not included in the project plan are not included in the table, but are discussed below. These measures are considerations for future projects on the UC Merced campus.

- 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.
- Because of UC Merced's emphasis on planning for energy efficiency, the S&E Building already incorporated a number of efficiency measures, including variable-air-volume fume hoods, evaporative pre-cooling, and a four-pipe design that eliminates reheating in laboratory spaces. As a result, the S&E EEMs needed to target less typical energy savings opportunities.
- The EEMs are presented ranked by expected annual savings within each end use.
- The EEMs are presented ranked by expected annual savings within each end use.

Energy Efficiency Measures

EEM	Implemented in This Project	Will Consider for Future Projects	Annual Savings kWh/yr		Annual Savings[4] kWh/yr		Actual Improvement Cost	Actual Simple Payback yr	Cost of Conserved Energy (CCE) $/kWh[5]
			Expected	Actual	Expected	Actual			
Science & Engineering Building									
Lighting (1.9% 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	87,000	$5,200	$10,400	$5,400	0.5	0.01
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	1,124,000	$71,000	$135,000	$130,000	1	0.01
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	54,000	$7,400	$6,500	$1,200	0.2	0.00

4. Cost savings are 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.

EEMs Not Incorporated into the Final Design

There were several EEMs proposed by the technical team but not included in the final executed plan:

- Further reducing the reheat energy use in the S&E Building, was projected to save 179,000[7] kWh/year with a cost savings of $21,000/year. Eliminating reheat energy use would have resulted in completely shutting down the heating plant during summertime. This would be ideal, except that cutting all summer reheat load would require complete re-piping of the HVAC system and zones at a substantially high cost investment, making this option overall not cost effective.
- Installing low-pressure-drop bag-type filters in the S&E Building. This EEM was not pursued because replacement of air handling equipment would have been necessary to support bag-type filter installations, and the replacement equipment would not fit in available space.
- Aerosol seal air distribution ducts in the S&E Building. This EEM was not pursued because the ductwork is only six years old, and the initial installation appears to be in good condition.
- Improving steam generation efficiency by replacing the oversized existing steam boiler with a new right-sized 70% efficient unit. This was projected to save 2.1 million kWh7 equivalent in energy, and $47,000 annually at an improvement cost of $140,000.
- Improving heating efficiency by adding a new smaller hot water boiler to replace the exiting oversized unit. Several variations of the hot water boiler measure were proposed with the version with the lowest first cost and 80% efficiency being selected. This was projected to save 2.1 million kWh7 equivalent in energy, and $51,000 annually at an improvement cost of $100,000.
- Improve steam plant efficacy of the central plant through a series of measures that included installing a heat exchanger between the steam systems and the hot water loop to load the system; unload the hot water boilers to reduce cycling of both systems;lower the steam operating pressure to reduce boiler system distribution losses; and eliminate steam plant use for autoclaves and replace with electricity-driven units. UC Merced maintenance staff judged that these measures would increase staffing needs and therefore were not pursued.
- Reset the supply temperature set point on the boiler in the central system from 210°F to 160°F with a 130°F return water temperature.

The three S&E Building EEMs mentioned above will be considered for future projects. Two issues that were difficult to predict caused some of the central plant EEMs to not be completed. The major issue was that the cost of the boiler system changes. They were intended to be paid for by on-bill financing, which was contingent upon approval of the utility. The considerable savings estimated by the technical team were based on effective efficiencies different enough from the nameplate efficiencies that the utility company required that a further confirmatory review be completed before moving forward, and that study could not be done within the timeframe of the project.

Energy Use Intensities By End Use

Several models were used to analyze the impacts of EEMs identified for the S&E building. 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.

Model 3: Pre-Retrofit, S & E Building

The first S&E model is the S&E Building's pre-retrofit design baseline; it represents the building's calendar year 2010 performance, 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 including steam and heating hot water provided by the central plant. The electrical only annual EUI for the building which includes all other building services was ~59.3 kBtu/ft^2. All EUI figures as listed are site EUIs.

Model 5: Final Design, S & E Building

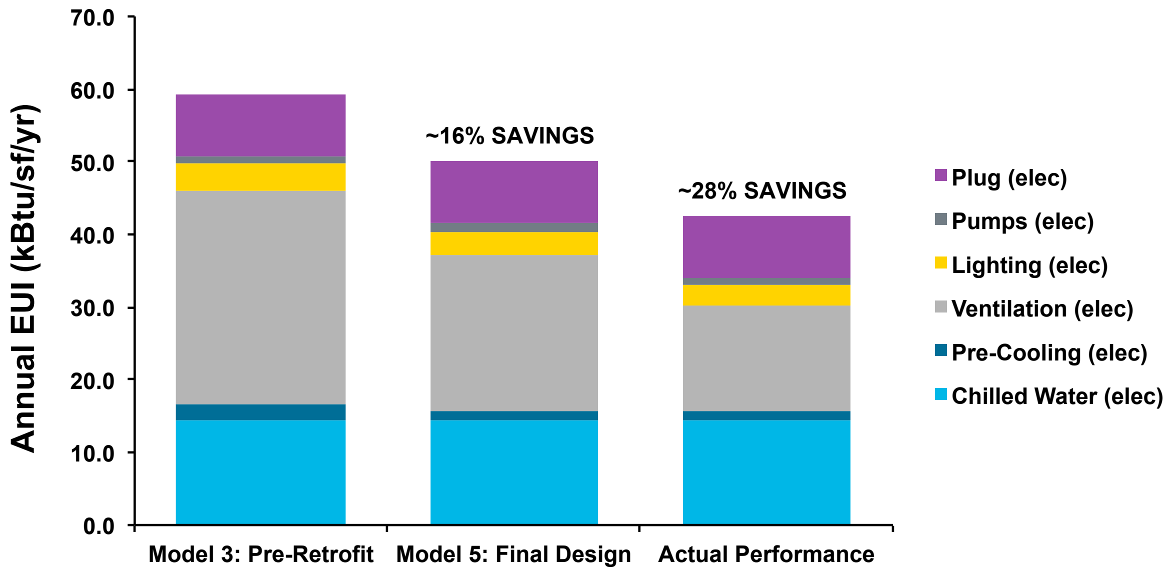
The second S&E model applied the EEMs selected for the S&E Building to represent the proposed S&E condition after retrofit. This model includes the following S&E EEMs: re-commissioned lights, modified pre-cooling system controls, and ventilation system EEMs. This model has an annual EUI of approximately 127.4 kBtu/ft^2 for the overall building and an electrical only annual EUI of ~50.0 kBtu/sf which is ~16% below the original pre-retrofit baseline.

Actual Performance, S & E Building

A total of five EEMs had been planned at UC Merced as retrofits to the S&E Building and the Central Plant, with an expected whole campus saving of approximately 17%. Timing issues lead to the Central Plant EEMs being dropped from the plan. The three S&E Building EEMs were completed with measured energy savings of 1.3 million kWh with a cost equivalent of $152,000. Two of the three completed EEM's achieved greater than expected savings and the aggregate savings for the project were greater than expected. The figure below compares the S&E Building energy intensities for the Baseline Pre-Retrofit model with the measured savings of the retrofitted S&E Building for the implemented EEMs. In aggregate the S&E Buildings achieved ~28% improvement in energy use compared to the pre-retrofit baseline.

7. These are kWh equivalent of natural gas use.

Comparing Energy Use Intensity (EUI) for S&E Building



S&E Building Annual Energy Use and Percent Savings by End Use

End Use Category	Model 3: Pre-Retrofit	Model 5: Final Design		Actual Performance	
	Annual EUI (kBtu/ft²)	Annual EUI (kBtu/ft²)	Percent Savings Over Model 3	Annual EUI (kBtu/ft²)	Percent Savings Over Model 3
Chilled Water	14.5	14.5	0%	14.5	0%
Pre-Cooling	1.9	1.1	42%	1.2	37%
Ventilation	29.5	21.5	27%	14.6	51%
Lighting	3.8	3.2	15%	2.7	30%
Pumps	1.0	1.0	0%	1.0	0%
Plug	8.5	8.5	0%	8.5	0%
Electricity Total	**59.3**	**50.0**	**16%**	**42.5**	**28%**

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

Electricity End Use Category	Expected Savings	Actual Savings
Cooling	0 kWh	0 kWh
Pre-Cooling	62,000 kWh	54,000 kWh
Interior Lighting	43,000 kWh	87,000 kWh
Ventilation	599,200 kWh	1,125,000 kWh
Equipment	0 kWh	0 kWh
Pumps	0 kWh	0 kWh
Electricity Total	**704,200 kWh**	**1,266,000 kWh**

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 over supply air. This problem was costing UC Merced more than $70,000 a year in wasted energy. The problem was eliminated when the sensor position was 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.

Make best use of existing data

The Energy Performance Platform (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 their 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 as 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.

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

Stakeholder involvement and leadership can be critical

A substantial portion of the energy savings expected in the original CBP plan were not realized due to failure to obtain funding which necessitated dropping the EEMs for the central plant. The main issue in the funding was uncertainty on the part of the participating utility about the reliability of the efficiency estimates and of the savings estimates based on them, and lack of time to do a confirmatory study. The estimates of the operating efficiencies of existing equipment were substantially below nameplate rating and anticipating that those could be questioned and getting buy-in from the funding source early might have avoided the necessity of altering the plan.

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

Courtesy of CITRIS

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