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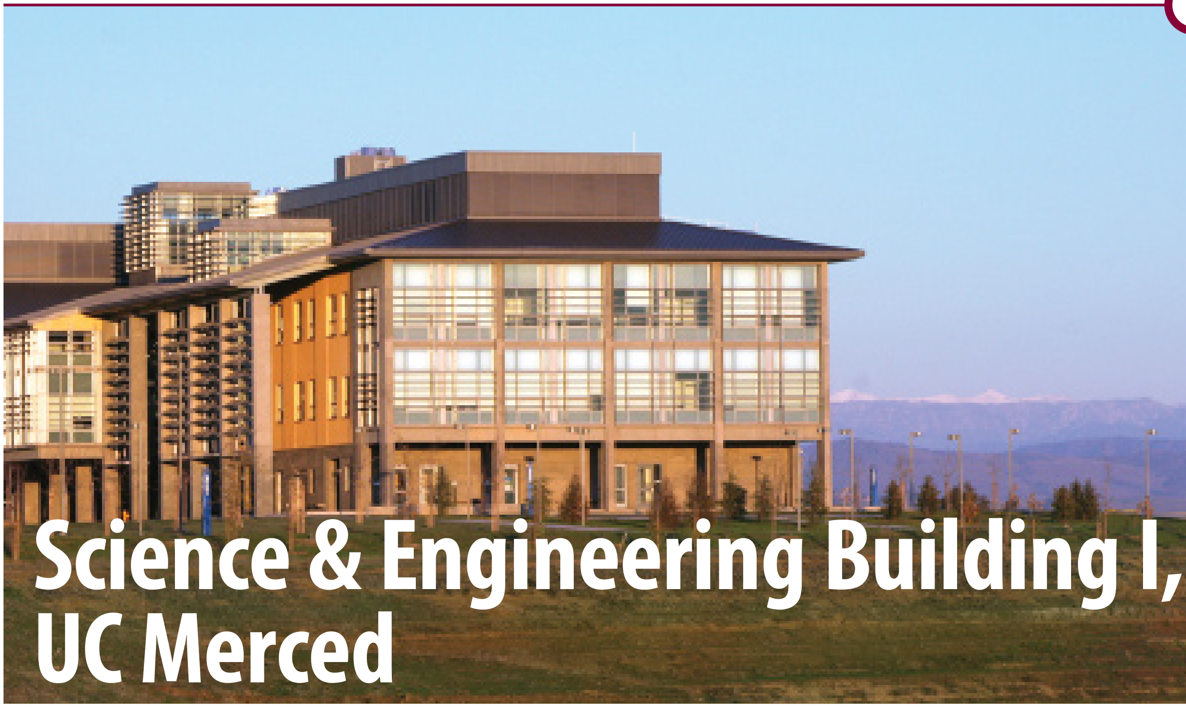
MEASURED PERFORMANCE *case study*



UC Merced

Science & Engineering Building I, UC Merced

The University of California at Merced (UC Merced) is one of the first new research universities to be developed in the 21st Century. UC Merced aims to be a model for environmental stewardship and sustainable design, with its facilities serving as a living laboratory for the interdisciplinary study of resource conservation and engineering. As the tenth campus of the UC system, UC Merced will be one of the most laboratory-intensive campuses, with up to 35% of the buildings used for laboratories and other scientific services. Opened in 2005 with just 1,000 students, the campus is planned for growth of up to 25,000 students over the next few decades. This 21st century campus responded to the pressing environmental concerns of climate change by setting a goal of using 50% less energy than other California state campuses. This ambitious aim has driven many aspects of the design, construction and operation of all buildings on the Merced campus. The campus pursued LEED[1] silver for all buildings in the initial phase of development. Most buildings, including the Science & Engineering Building I (S&E), have achieved LEED Gold certification. As of March 2009, the campus requires all new buildings to meet a LEED Gold standard.

Science & Engineering Building I is one of five buildings in the initial phase of development at UC Merced. Others include a central plant, library, classroom and office building, and student housing. Completed in January 2006, S&E is three stories tall, with 236,989 gross square feet. Approximately half the building space contains wet and dry laboratories for research and instruction, with the remainder used as academic and administrative office space.

This case study examines the actual post-occupancy energy performance of S&E in relation to design elements and objectives. The measurements cover July 2007 through June 2008. Some initial commissioning tasks were still being completed during this measurement period.

[1] US Green Building Council's Leadership in Energy and Environmental Design (LEED) program

OVERVIEW

SITE DETAILS
- New construction
- 236,989 gross square feet
- Completed January 2006
- Located in Merced, California

ACTIVITY TYPE(S)
- University laboratory
- University classroom
- Office

EFFICIENCY MEASURES
- Eliminate reheat in labs
- Evaporative pre-cooling
- Energy Management Control System
- Performance monitoring
- Thermal energy storage

COVERED METRICS
- Whole building EUI
- Annual electricity use
- Annual fuel use
- Peak electric demand
- Chilled water demand

CERTIFICATIONS
- LEED Gold

This case study was prepared by New Buildings Institute in partnership with the California Institute for Energy and the Environment (CIEE). It is part of NBI's efforts to collect and disseminate information on the actual energy performance of new buildings.

THE TYPICAL LABORATORY BUILDING CAN USE UP TO FIVE TIMES AS MUCH ENERGY PER SQUARE FOOT AS AN OFFICE BUILDING

KEY OBJECTIVES

To achieve the goal of using 50% less energy, the project team developed energy-use benchmarks for the campus and each building based on data, adjusted for building type and climate, from eight other UC and California State University campuses[2]. Benchmark metrics address both peak demand and annual consumption.

Performance targets were set as a percentage of the benchmark metrics. The target for S&E and other buildings in the first 600,000 gross square feet developed is to operate at or below 80% of benchmark (a 20% reduction in energy consumption). Incremental targets for future phases moved toward 50%of benchmark. UC Merced's energy performance targets are unique in that they account for performance of the entire building, not just selected systems, as is the case with building code-based targets (such as California's Title 24 and the earlier versions of LEED).

In addition to the benchmark-based performance targets, UC Merced set a goal of performing a minimum of 30% better than Title 24 for all buildings in order to qualify for LEED ratings and utility incentives. The project team incorporated the energy performance targets into the design specifications for each building. This ensured that the design and construction team would make decisions within this constraint and reduced the risk of having energy efficiency measures compromised through value engineering.

UC Merced's aggressive energy management goals for laboratory buildings made them eligible for a Pilot Partnership with the Laboratories for the 21st Century Program (Labs21®), a U.S. Department of Energy and Environmental Protection Agency effort that works to improve energy and water efficiency in U.S. laboratories. Labs21® provided technical assistance with energy efficient designs and strategies for the laboratory spaces.

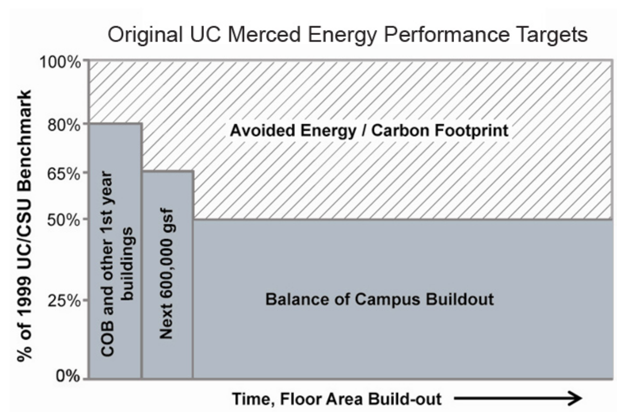


FIGURE 1

TECHNOLOGIES AND DESIGN STRATEGIES

Consistent with sound engineering practice for energy efficiency, the planning focused first on the required loads at the building, and then addressed the best ways of meeting those loads. This section first describes the measures implemented in S&E, followed by the measures included in the central plant that supplies heating and cooling for the campus.

[2] Brown, K. 2002. "Setting Enhanced Performance Targets for a New University Campus: Benchmarks vs. Energy Standards as a Reference?" *Proceedings of the 2002 ACEEE Summer Study of Energy Efficiency in Buildings.* 4:29-40. Washington, D.C.: American Council for an Energy-Efficient Economy.

SCIENCE & ENGINEERING BUILDING I

The typical laboratory building can use up to five times as much energy per square foot as an office building due to high ventilation requirements and extensive equipment loads including test and refrigeration equipment. To address these requirements, UC Merced incorporated numerous energy efficiency strategies at the building level. At S&E, the primary features contributing to low energy use are high-performance HVAC, an energy management control system and variable air volume (VAV) fume hoods with sash management. Attention is also being paid to use of efficient refrigeration equipment when available.

The **HVAC system** incorporates a low pressure drop design. To mitigate the energy impact of the 100% outside air requirement for laboratory areas, an evaporative pre-cooling system using closed-circuit cooling towers tempers outside air for all lab space. A complete terminal heating and cooling (4-pipe) system is used at the zone level to eliminate simultaneous heating and cooling. Carbon dioxide sensors in densely occupied spaces such as conference rooms allow ventilation levels to be greatly reduced during periods of low occupancy.

An **energy management and control system** (EMCS) allows for full scheduling of mechanical and lighting systems that are not controlled by occupancy sensors. Direct digital controls (DDC) are used at the plant, system and zone level. Facility operators can use the EMCS to monitor temperatures, flows, pump and fan speeds, and valve and damper positions to verify system performance and identify operational problems. This monitoring can ensure that energy systems perform as designed and that performance is maintained over time. A separate system is used to control laboratory areas because of the complexity of the VAV fume hood systems and the need for pressurization control. Currently, UC Merced uses the EMCS data to aggregate actual building performance relative to the energy performance targets on a snapshot basis. They are working toward operationalizing the performance benchmarking process on a real-time basis.

ENERGY EFFICIENCY TECHNOLOGIES AND STRATEGIES

- Low pressure drop design for air systems
- Evaporative pre-cooling
- No reheat for lab areas
- VAV fume hoods
- CO2 sensors to minimize airflow during low occupancy
- Low power density lighting with occupancy sensors
- Double pane low-E, low solar gain windows
- Solar shading on all non-north facades
- Direct digital controls at the plant, system and zone level
- Meters for all energy types, including hot/chilled water

Ninety-eight **VAV fume hoods** are employed in research and teaching laboratories. The campus's good sash management practices make the most of the VAV hood capability to reduce energy use while providing good capture and containment of hazardous substances. The EMCS measures sash height for every fume hood, and a program is being developed to educate laboratory users on proper use of sashes in cases where the system shows them left open for long periods. Active management and user education have been key to achieving S&E's energy performance targets in this area.

CENTRAL PLANT

UC Merced

The cooling needs for campus buildings are met by a central plant that uses centrifugal chillers and a two-million gallon thermal energy storage (TES) tank for cooling. Chillers operate only at night when off-peak pricing is lowest to charge the tank. Water stored in the tank overnight is cycled through the chilled water loop the following day to cool buildings without requiring activation of the plant's chillers. Shifting the campus's electrical cooling load to off-peak hours significantly flattens the building electric demand profile and results in large cost savings due to daytime demand reduction. Hot water boilers at the central plant provide district heating for a portion of campus use. Steam for laboratory autoclaves and other lab use is supplied by a steam boiler in the central plant. At this time, S&E is the only building on campus that uses steam.

To achieve UC Merced's energy management targets, the design team developed a sophisticated energy model for the central plant using a "most likely maximum" parameter to size the mechanical systems to meet heating and cooling needs with an explicit margin of safety agreed upon by the owner and design team. This approach helped avoid the typical gross oversizing of equipment, which often occurs when using conventional "rule of thumb" load estimation methods.

MEASUREMENT AND EVALUATION

MEASUREMENT METHOD

Comparing actual performance to the campus and building benchmark-based energy targets is integral to UC Merced's energy efficiency strategy. Hot water and chilled water from the central plant are sub-metered at each building, as is direct electricity use. Total building energy consumption is derived from building meter data and an allocation of central plant energy used for providing the hot and chilled water service. Whole campus energy consumption, from the campus utility electric and gas bills, is used to cross check building energy use calculations within an energy balance framework. Reconciled total building energy use is compared to the corresponding benchmark targets to assess building performance.[3]

Initial data review and crosschecking revealed some cases of missing data, unreasonable readings, or implausible trends arising from problems with the meters and the data accumulation process, particularly with respect to hot water. It was found that many primary campus meters needed calibration, repair or reinstallation to support operational and performance monitoring needs. Some data correction and assumptions were necessary to generate results for this first measurement period. The measured results and methods used were evaluated by analysts from each of the partners in this study and found to be reasonable and consistent with all available data, including energy balances with master utility meters. The uncertainty in these initial results is highest for the measurement of hot and chilled water and steam supply to the building. For these parameters, this initial performance snapshot is thought to have an uncertainty of +/-15% of value.

[3] Primary energy performance evaluation performed by Lawrence Berkeley National Laboratory, with assistance provided by UC Merced staff and CIEE.

S&E HAS EXCEEDED THE INITIAL STAGE TARGETS (80% OF BENCHMARK) IN ALL AREAS, WITH SEVERAL NEARING THE 50% OF BENCHMARK GOAL THAT IS ASSIGNED TO FUTURE PHASES.

ENERGY PERFORMANCE RESULTS

On an as-operated basis, S&E not only achieved, but surpassed its target performance (80% of benchmark) for all annual energy consumption metrics. S&E's source energy use, gas and electricity combined, was only 61% of the benchmark, already better than the 65% target for the next phase of campus build-out. (The measured usage on which these ratios are based is shown in the table at the end of this section.)

While each of the energy ratios is better than the S&E target, the gas ratio is higher than the others. Steam accounts for 39% of total gas use, equivalent to an annual 51 kBtu/gsf over the entire building. Commissioning opportunities identified during the course of this study are expected to substantially reduce future gas use attributed to steam.

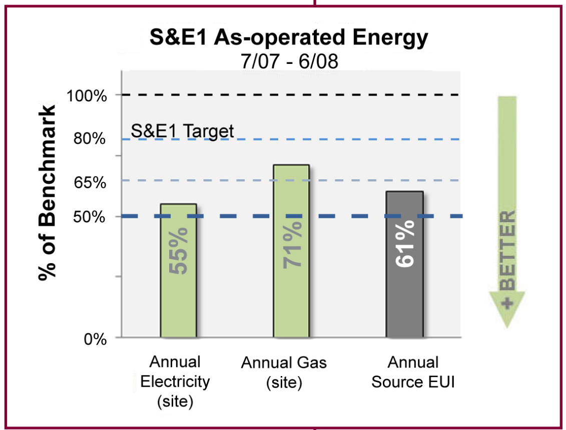


FIGURE 2

The peak power benchmark assumes that all chiller loads have been shifted off -peak. It therefore reflects typical peak electricity demand for non-chiller uses, such as lighting, lab equipment, plug loads, pumps and fans. The peak power as operated, at just 46% of benchmark, shows the potential for high-efficiency design and equipment selections, as well as the effectiveness of giving the design team a clear mandate to reduce demand. The peak chilled water use at the building at just 49% of benchmark also reflects the effectiveness of the evaporative pre-cooling to meet the lab's hot weather ventilation needs and elimination of the potential for simultaneous heating and cooling, as well as design, shading and insulation to reduce solar gain.

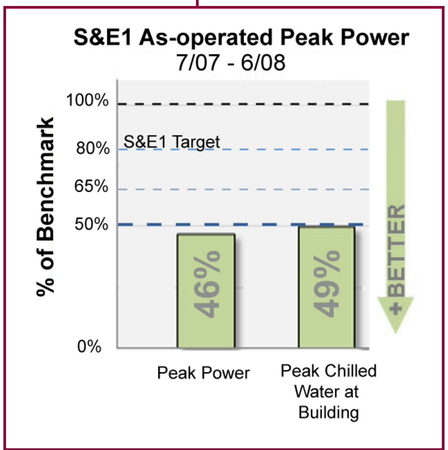


FIGURE 3

The performance analysis method includes both a direct accounting of actual plant load associated with service to the buildings and a "best practice" plant that estimates the as-operated case improved with optimized central plant efficiencies. The "best practice" plant represents a reasonable upper level of performance potential. This dual actual and "best practice" plant analysis isolates building energy use so that initial central plant performance issues do not misrepresent individual building performance. The table below shows the as-operated results used in the above graphs as well as the projected "best practice" plant scenario. As noted, S&E has exceeded the initial stage targets (80% of benchmark) in all areas, with several nearing the 50% of benchmark goal that is assigned to future phases. The building is fully occupied, and the campus is working to actively manage loads that could grow in the future if laboratory spaces are used with greater intensity.

TABLE 1: RESULTS COMPARED TO BENCHMARK

	BENCHMARKS		TARGET	AS-OPERATED[1]		BEST PRACTICE PLANT[2]	
METRIC	VALUE	UNITS	80% OF BENCHMARK	VALUE	% OF BENCHMARK	VALUE	% OF BENCHMARK
ANNUAL SITE ELECTRICITY[3]	40.7	kWh/gsf	32.6	22.5	55%	21.4	53%
ANNUAL SITE GAS[4]	1.82	therms/gsf	1.45	1.30	71%	1.22	67%
ANNUAL SITE EUI	321	kBtu/gsf	257	207	64%	195	61%
ANNUAL SOURCE EUI[5]	557	kBtu/gsf	446	338	61%	320	57%
PEAK POWER	6.73	W/gsf	5.38	3.13	46%	n/a	
PEAK CHILLED WATER AT BUILDING	3.74	tons/ 1000 gsf	2.99	1.85 [6]	49%	n/a	

(1) Measurement period; July 2007 - June 2008
(2) Best Practice Plant efficiency assumptions compared to As-Operated:
Chiller 0.6 kW/ton vs 1.0 kW/ton as-operated
Hot water 85% boiler efficiency vs 76% as-operated
(3) Including pro-rated central plant chiller energy use and distribution losses. These figures include approximately 5% transformation / distribution losses and exterior site lighting not typically a part of metered usage for stand-alone buildings.
(4) Including pro-rated central plant heating and steam generation efficiency and loop distribution losses
(5) Site to Source conversion factors from CalArch: 2.7 for electricity, 1.0 for natural gas
(6) Excluding one raw observation spike associated with recovery from a chilled water plant failure

The observed central plant efficiency was lower than expected, primarily because of some identified problems with chiller operation, including chiller tube scaling and equipment failures that resulted in some short circuiting within the chilled water distribution loop. Additional central plant inefficiencies during the measurement period were also due to the sizing of boiler plant equipment designed to serve the needs of additional campus build-out. As noted above, steam for the autoclaves and related lab uses accounts for 39% of the building's annual gas consumption. The high gas usage for a relatively small end use suggests significant distribution and stand-by losses, although problems with the steam system metering have delayed pinpointing the exact location of the inefficiencies.
To improve future performance, UC Merced is considering either a reconfiguration of the central steam plant or use of local steam generation at S&E. Note that the "best practice" plant projections did not assume any improvement in steam delivery, so S&E has the potential of performing even better than those projections as all central plant issues are addressed. The UC Merced team plans to continue monitoring, comparing actual results to the "best practice" estimates. Calibration, repair or replacement of several primary sub-meters is being considered to allow for more direct measurement of results.

LESSONS LEARNED

UC Merced's energy performance achievements at S&E can be credited to the skills of the project team, energy efficient design, measurement and verification, and follow-through by facility staff. UC Merced's bold energy performance goals were responsible for providing direction for the project team. Incorporating energy performance targets into the design specification for S&E ensured that energy efficiency was pursued through each phase of development. As a result, UC Merced is on track to meet its long-term aggressive energy management goals.


UC Merced

Due to tight construction schedules, the building commissioning performed was just enough to satisfy the LEED requirement, no more. During the first few years of operation, UC Merced found several issues that could have been caught prior to occupancy with a more thorough commissioning process that included a commissioning of the EMCS and monitoring systems. Data integration issues between the EMCS and the separate control system used for S&E's laboratory spaces have limited the level of monitoring available at the zone level; as a result. Energy managers cannot trend operational data to closely monitor laboratory performance. In addition to the data integration issues, the EMCS was set up strictly as a control and data acquisition system, not an energy information system, and does not present data in a way that is easily monitored. Learning from this experience, UC Merced is developing a monitoring system specification so that metering and energy management and control systems for future laboratory buildings will provide data in a more integrated and readily usable format for monitoring building performance on an ongoing, real-time basis.

Based on the encouraging energy performance results at S&E, UC Merced expects their second science and engineering building, planned to open in 2014, to achieve the 50% of benchmark performance target. UC Merced is already looking to the future and is developing a plan to move beyond their current energy performance goals to achieve zero net energy by 2020 through even more aggressive conservation efforts and development of on-site renewable power.

ACKNOWLEDGEMENTS

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