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MEASURED PERFORMANCE *case study*

# Classroom and Office Building, UC Merced

*UC Merced*

The University of California at Merced (UC Merced) is the first new UC campus in 40 years. 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 served as a foundational aspect of directing 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. Several buildings, including the Classroom and Office Building (COB), have achieved LEED Gold certification and a rare 10 out of 10 Energy and Atmosphere points. As of March 2009, the campus requires all new buildings to meet a LEED Gold standard.

The Classroom and Office Building examined in this case study is one of five buildings in the initial phase of development at UC Merced. Others include a central plant, library, science laboratory building, and student housing. COB is three stories tall, with 103,006 gross square feet, and was completed in January 2006. The building provides multi-disciplinary instructional space and research office space for the Merced campus.

This case study examines the actual post-occupancy performance of COB 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
- 103,006 gross square feet
- Completed January 2006
- Located in Merced, California

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

**EFFICIENCY MEASURES**
- Efficient HVAC design
- Efficient lighting
- 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.*

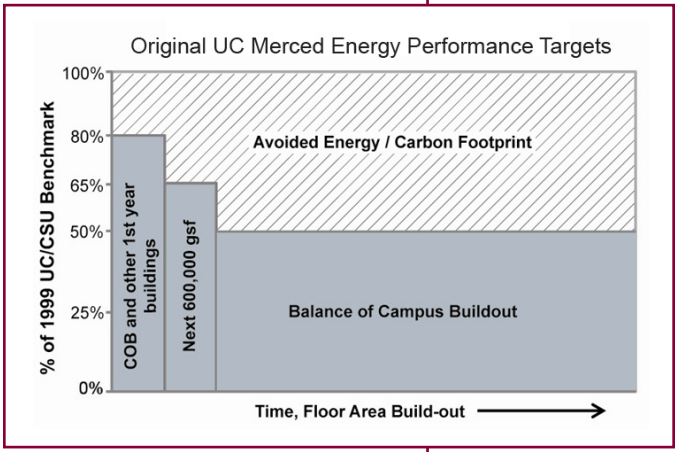
## THE PLANNING FOCUSED FIRST ON THE REQUIRED LOADS AT THE BUILDING, AND THEN ADDRESSED THE BEST WAYS OF MEETING THOSE LOADS

### KEY OBJECTIVES

To achieve the campus 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 COB 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 towards a **50% of benchmark** goal. UC Merced's energy performance targets are unique in that they account for the entire building performance, 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, UCM 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.

**FIGURE 1**




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.

### 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 describes the measures implemented in COB, followed by the measures included in the central plant that supplies heating and cooling for the campus.

#### CLASSROOM & OFFICE BUILDING

At COB, the primary features contributing to low energy use are high performance HVAC and lighting designs and an energy management control system.

The **HVAC design** incorporates a low pressure drop and avoids simultaneous heating and cooling. The building uses a variable air volume, dual-fan, dual-duct HVAC system with hot and chilled

[3] 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.

water provided from the central plant. If the cold or hot deck is active, the other is neutral, carrying outside or return air as appropriate to temper the active deck. Carbon dioxide sensors in densely occupied spaces allow ventilation levels to be greatly reduced during periods of low occupancy.

**Lighting** at COB was designed to surpass Title 24 requirements while meeting generally accepted guidelines for lighting quality. The lighting design avoids superfluous electric light. Low power density systems using T8 and T5 lamps, compact fluorescent lamps, and high efficacy fixtures were used throughout the building. Occupancy sensors are located in offices and programmable dimming controls are provided in the large classrooms and auditorium.

An **energy management and control system** (EMCS) allows for full scheduling of mechanical and lighting systems. Direct digital controls (DDC) are used at the plant, system and zone level. Facility operators can use the EMCS to monitor temperatures, flows, and damper positions to verify system performance and identify any equipment failures. This system allows facility managers to monitor results to ensure that energy systems perform as designed and that performance is maintained over time. Currently, UC Merced also uses the EMCS data to aggregate actual building performance relative to the energy performance targets on an annual basis. They are working towards operationalizing the performance benchmarking process on a real-time basis.

## CENTRAL PLANT

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.

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.

## ENERGY EFFICIENCY TECHNOLOGIES AND STRATEGIES

- Low pressure drop design for air systems
- Variable air volume, dual-fan, dual-duct HVAC
- No reheat for HVAC
- CO2 sensors to minimize airflow during low occupancy
- Low power density lighting with occupancy sensors
- Double pane low-E, low solar gain windows
- Controls to disable space conditioning when windows are open
- 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

Central Plant and TES Tank

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## MEASUREMENT AND EVALUATION

### MEASUREMENT METHOD

Comparing actual performance to the campus and building benchmark-based energy performance 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.

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.

### ENERGY PERFORMANCE RESULTS

On an as-operated basis, COB not only achieved, but surpassed its target performance (80% of benchmark) for all annual energy consumption metrics. COB's source energy use, gas and electricity combined, was only 62% of the benchmark, already better than the 65% target for the next phase of campus build-out. (The measured usage determining these ratios is shown in the table at the end of this section.)

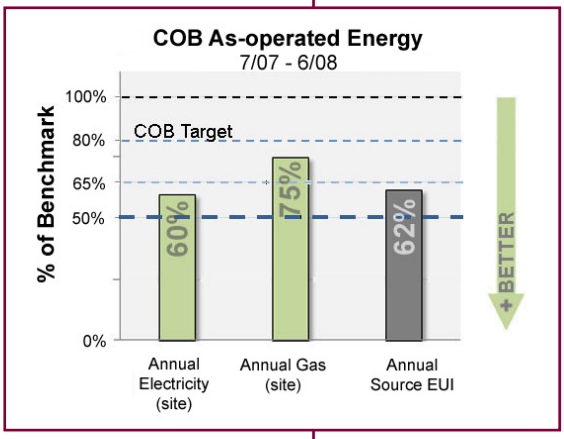


FIGURE 2

The peak power benchmark assumes that all chiller loads have been shifted off -peak and therefore reflects typical peak electricity demand for non-chiller uses, such as lighting, plug loads, fans etc. The as-operated peak power, at just 48% of benchmark, primarily shows the effectiveness of reduced lighting, fan and plug loads in the building.

The peak chilled water use at the building (85% of benchmark) reflects the effectiveness of design, shading, and insulation to reduce solar gain.

The analysis method used 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.

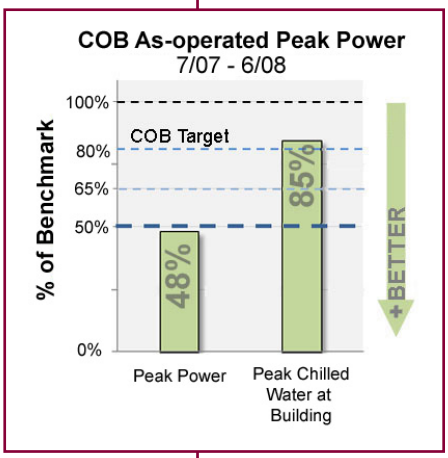


FIGURE 3

**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] | 15.1 | kWh/gsf | 12.1 | 9.03 | 60% | 8.49 | 56% |
| ANNUAL SITE GAS[4] | 0.20 | therms/gsf | 0.16 | 0.15 | 75% | 0.13 | 67% |
| ANNUAL SITE EUI | 71.1 | kBtu/gsf | 56.9 | 45.5 | 64% | 42.2 | 59% |
| ANNUAL SOURCE EUI[5] | 159 | kBtu/gsf | 127 | 97.8 | 62% | 91.4 | 58% |
| PEAK POWER | 3.65 | W/gsf | 2.92 | 1.75 | 48% | n/a | |
| PEAK CHILLED WATER AT BUILDING | 2.03 | tons/ 1000 gsf | 1.62 | 1.72 [6] | 85% | 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 efficiency and loop distribution losses.
(5) Site to Source conversion factors from CalArch: 2.7 for electricity, 1.0 for natural gas
(6) Excluding two raw observation spikes, one associated with recovery from a chilled water plant failure and one sampling anomaly

The table above shows that COB has exceeded the 80% of benchmark energy performance target with some metrics, almost nearing the 50% of benchmark goal that is assigned to future phases. The observed central plant efficiency was lower than expected, primarily because of some identified problems with chiller operation, including an apparent short circuit in the chilled water distribution loop. Additional central plant inefficiencies during the measurement period were due to plant equipment designed to serve the needs of additional campus build-out. The "best practice" plant efficiency levels are consistent with initial design expectations and should be achievable through a number of measures under review. Thus, COB has the potential of performing even better in the future, as 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 submeters is being considered to allow for more direct measurement of results.

## LESSONS LEARNED

UC Merced's energy performance achievements at COB can be credited to the skills of the project team, energy efficient design, measurement and verification, 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 COB ensured that energy efficiency was pursued through each phase of development and as a result, UC Merced's energy management goals have a high likelihood for success.

Integrating commissioning in COB's delivery process was a challenge for 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 HVAC and lighting control 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. The energy management and control system used to monitor performance at COB was set up strictly as a control and data acquisition system, not an energy information system. As a result, it does not present data in a way that is easy to monitor. Learning from this experience, UC Merced is developing a monitoring system specification so that metering and energy management and control systems for future buildings will provide data in a more readily usable format for monitoring building performance on an ongoing, real-time basis.

Based on the encouraging results from the first phase of construction, UC Merced expects to achieve their 50% of benchmark performance target. With confidence grounded in this initial success, 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 aggressive conservation efforts and development of on-site renewable power.

## ACKNOWLEDGEMENTS

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