Setting Enhanced Performance Targets for a New University Campus: Benchmarks vs. Energy Standards as a Reference?

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ABSTRACT

Most efforts to improve energy performance use efficiency standards as the reference point. Programs often specify energy use at 50% to 80% of the ASHRAE 90.1 or California Title 24 levels. Planning for the new University of California (UC) campus at Merced takes a different approach. Campus goals include not only reduced energy use, but also appropriate design of infrastructure and minimizing peak load on the electricity grid. UC Merced's environmental stewardship principles emphasize monitoring of energy use toward continuous improvement in campus operation and design.

Energy codes and standards do not generally address peak demand. Though otherwise very successful, efficiency standards are often not effective in guiding the sizing of cooling equipment. Codes and standards typically control design, with limited mechanisms for correlation with measured use. Building standards are hard to apply to laboratories, which are a hybrid of building HVAC and process systems.

While being careful to meet California Title 24, our efforts to do more have been focused not on the code itself as a reference point, but rather on benchmarking measured use of existing UC and State University campuses. We developed models for campus energy use and demand, correlated to climate and laboratory density. This approach has been successful in coordinating building and infrastructure design toward an integrated system, as well as motivating efficient design to meet campus goals. Benchmark-based targets have also been useful in fostering positive change in the design process.

Introduction

Codes and standards are one of the big success stories among programs and policies fostering an energy-efficient economy. In addition to their role as a backstop for minimum levels of efficiency, many energy efficiency programs use codes or standards as the reference point for efforts to achieve improved efficiency. The U. S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED™) rating system provides points for improving efficiency over standards by stepped percentage levels (USGBC 2001). Leading edge energy efficiency programs like the Canadian C-2000 program mark their progress by reference to the ASHRAE/IES Standard 90.1 (Todesco 1996). In California, the utilities' statewide commercial building energy efficiency program, "Savings By Design," bases incentives on a percentage improvement over the California Title 24 (Savings By Design 2001). Some University of California (UC) campuses nominally use Title 24 as a reference for more stringent design standards, specifying that new building designs must have annual energy use at only 80-90% of the maximum allowed by the code.

Prior to the beginning of energy planning for the new UC campus at Merced, most of the efficiency initiatives that used codes or standards as references limited their direct goals to control of total annual energy use. One of the few exceptions was the PG&E Advanced

Customer Technology Test (ACTT) program, which has marked its success in lowering both annual energy use and peak demand (Hernandez, Kolderup, and Syphers 1997). Only recently have more programs begun to focus on peak demand reduction.

The ACTT program and more recent emphasis on peak electricity demand is indicative of the importance of the relationship between energy efficiency, peak demand reduction, time valuation of, and the overall health and economy of the electricity infrastructure. This relationship has been rediscovered and newly illuminated by the recent "energy crisis" in California. The crisis has bolstered efforts to add time weighting or time valuation to California Title 24 (Fernstrom et al. 2000).

Goals of a New Campus

UC Merced has ambitious goals for environmental stewardship including energy efficiency. The efficiency goals have some unique characteristics specific to a new campus, regional concerns, a research university, and long-term energy planning efforts:

- Efforts toward energy–efficiency are focused on peak demand reduction.
- Starting from scratch as a new campus, UC Merced's efficiency goals are closely tied to the development of the campus and local energy infrastructure.
- As a research university, laboratory-type facilities are expected to be prominent in over one third of UC Merced's buildings.
- A cornerstone of the planning for the new campus is continuous monitoring of energy use and other environmental metrics—to ensure that energy systems perform as designed and otherwise assist commissioning efforts, to mark progress in energy management, and to foster continuous improvement in environmental stewardship (UCM 2002).

These four aspects of energy efficiency planning at UC Merced—peak demand reduction, infrastructure development, laboratory facility energy efficiency, and energy performance monitoring—all challenge the ability of the local energy code to act as a reference point for targeting improved efficiency.

Peak demand reduction. The bulk of UC facilities are on large service time-of-use rate schedules, with substantial premiums for both the electricity used and the levels of demand reached during summer peak periods. Emphasis on peak-period efficiency measures and the development of substantial chilled water thermal storage installations has been motivated by these local rate structures, not the energy code. A system-wide total of over 10 MW of demand is kept off peak by shifting cooling load to nighttime (with an equivalent amount of load kept off-peak by fuel-switching to gas-driven cooling). The growing set of chilled water thermal energy facilities operating on UC campuses is a remarkable and under-appreciated resource to the state's energy infrastructure.

Campus utility infrastructure design. The UC Merced campus infrastructure is being developed simultaneously with the first buildings, compelling unprecedented integrated energy planning for the campus. Integrated planning means that a systems approach can be taken to optimize the size of the infrastructure. A whole campus approach to efficiency includes efforts to examine trade-off between design of buildings, the distribution system, and the plant.

Codes and standards often treat buildings as distinct from a central plant infrastructure, drawing the "control volume" for analysis around the building and excluding the plant. For a new campus, the control volume is around the entire facility including the infrastructure.

Laboratory facilities. Benchmarking confirms that UC laboratory-type buildings average roughly three times the energy intensity of non-laboratory buildings. Observation of facility operation reveals that laboratory air systems and the associated heating and cooling loads are the primary end-use of energy in laboratory buildings (Huizenga, Van Liere and Bauman 1998). Given the anticipated high laboratory density of the Merced campus, laboratory air systems will dominate energy use. Building energy codes or standards are not generally designed to handle laboratory facilities with their large air-system and other process loads. Nor do they address non-laboratory process systems or appliances. Equipment loads can easily be overestimated though the misuse of name plate specifications and lack of accounting for diversity (Wilkins 1998, Wilkins and Hosni 2000).

A research university operates much of its facility around the clock. This provides another challenge to building energy codes or standards that may depend on a "business day" operating schedule for calculation of energy use through a performance compliance method.

Monitoring. Performance monitoring is at the core of UCM's environmental stewardship planning. Monitoring of energy use and other environmental parameters will facilitate several objectives:

- assurance that energy systems perform as designed and that performance is maintained over time,
- tracking of energy use in comparison with targets (energy management),
- use of the facility itself as a "living laboratory" for the study of engineering and resource conservation, and
- continuous improvement in design of future phases of the campus.

Compliance with codes and standards is generally determined by a plan check, and is an intervention only in the design stage of the building process. Energy performance monitoring can provide feedback on the actual operating levels of energy use for the campus, going beyond the design process. Actual measured use includes many end-uses not regulated by codes and standards, as well as operating schedules potentially different from standard compliance assumptions. Use of codes and standards as a reference for the targets would require much normalization and estimation to correlate with actual measured levels of use. It is important to note that there is no intent to use the monitoring system for energy cost recharge purposes, nor is the system being specifically designed to facilitate this.

Benchmarking as an Alternative to Standard-Based Targets

UC Merced's energy efficiency and overall success in energy management will be documented by monitoring; looking for substantially reduced use as compared to the historic levels of other campuses. Monitoring is synergistic with other planning needs for a campus. Expansion of infrastructure can be better planned with detailed information about measured levels of energy use from the earlier facilities. Also, the operating budget is something that follows the principle "you cannot manage what you cannot measure". The UC system has resources available to provide a reference point for monitored levels of use. Whole-campus energy use and other physical plant data are available from established campuses, for use in a benchmarking system.

Such a benchmarking exercise was started as a part of the energy load projections for the new campus. Early in the planning process, it was recognized that these projections would be needed long before there was a detailed design available for load estimation The author has also observed that conventional engineering methods chronically over-estimate load for new facilities. In one example, the measured maximum chilled water load is less than half of the building plant capacity, with the chiller loading at an inefficient 25% or less most of the time. (Piette et al. 1997). In another example, facility engineers were successful in halving the size of the plant proposed by design engineers, with the as-installed plant still having twice the capacity needed to meet the actual loads of the fully occupied building (Dunn 2002). Such inaccuracy is not acceptable for a campus intended as a showcase for energy efficiency and other forms of environmental stewardship.

Load projections need to be based on improved efficiency targets for the new campus as well as observed energy use of existing campuses. In this way, the process of integrated energy planning naturally results in a benchmark system for setting efficiency targets.

Our benchmarking is similar to some previous efforts (Sharp 1998, Noren and Pyrko 1998), but works with rougher whole campus data and is focused on energy load projection rather than detailed diagnosis of the cause of energy waste. Other benchmarking methods for laboratory-type facilities take model-based approaches or look at energy sub-systems (Federspiel, Zhang, and Arens 2002, Sartor et al. 2000).

The Benchmark Reference

Data quality. The benchmark system needs to be accurate enough to produce a significant improvement over engineering estimates. We believe that normalization of loads for different plant configurations and mapping of utility data onto floor area are the major potential sources of error. The existing UC and CSU campuses have a wide variety of plant configurations including thermal energy storage, both gas and electricity driven cooling, and cogeneration. Previous efforts to compare energy use indices across the campuses have been thwarted by the plant-driven differences in utility consumption—differences that mask the true loads.

We observe that the amount of floor space on campuses and plant operations change significantly from year to year. The influence of these factors appears to be larger than year-to-year variations in weather, loading of floor space, or building operations prior to the California "energy crisis" (or other potential sources of error such as choice of degree-day base, proximity of weather stations, etc.). We therefore make careful effort to process campus utility data in a consistent manner, accurately map it onto floor space, and normalize loads based on campus operation for one year in which operational and floor area information is well known (pre-crisis 1999).

Boiling the numbers down to load. Our benchmark system is effective in processing utility meter data to give a true indication of the loads from facilities, as served by the plant. We use additional information about the operation of campus plants to normalize campus load data to a standard case. Maximum demand and annual energy use is adjusted to account for output of cogeneration plants or operation of thermal energy storage systems and gas or cogeneration-driven cooling. In the standard case:

- all cooling loads are served by electricity (i.e. no gas-driven cooling),
- there is no thermal energy storage, and
- there is no cogeneration.

This standard case applies to either a campus where buildings have individual plants or to a campus where there is a simple central plant with chillers and boilers. If large differences in efficiency exist between distribution system configurations, this method has the potential to reveal them.

Site or source? Either! As with codes and standards, the success of a benchmark system depends on a rational framework for describing the relationship between the electricity and natural gas (or other fuel). UC Merced needs to make projections for both electric and natural gas loads to size the respective utility infrastructure. Our benchmark system treats electricity and natural gas (or fuel) use separately, including indices for both maximum demand and annual use per gross square foot of floor area. These indices can be combined to obtain either a site or source energy index for the campus.

Regression models. The electricity benchmarks are currently based on a set of eight UC and California State University (CSU) campuses, chosen for relevance to the UC Merced planning context. The natural gas benchmarks are based on a set of four campuses. Useful correlation exists between campus energy intensity per square foot of floor area, laboratory density, and sometimes climate parameters. We believe that these benchmarks are the best available basis for Merced campus energy planning. However, there has not yet been opportunity to obtain more quality controlled data for replication of the results, or for testing limitations of the models for other applications.

Annual energy use correlates with laboratory density and traditional degree-day totals. However, on the West Coast, maximum electric demand is relatively independent of annual electricity use and degree-days do not provide a good correlation. Reconciling maximum demand required an innovative method of analysis with respect to climate data. We use the cooling design temperature normalized to the same base temperature as the most common degree-day base (65 degrees F). Multi-variable regression analysis creates models of the general form:

$$\text{Energy Intensity} = a + b * \%\text{lab} + c * \text{climate variable}$$

An example of the resulting regression model for maximum electric demand is,

$$W/gsf = 0.85\ W/gsf + 4.0\ w/gsf * \%lab + 0.067\ W/gsf/degF * CD65$$

where, W/gsf is watts of peak demand per gross square foot of floor area, %lab is the fraction (by floor area) of buildings that are considered complex (i.e. with laboratory or other high energy use systems), and CD65 is the 0.4% cooling design temperature - 65 degrees F. For example, the 0.4% cooling design temperature for Castle Air Force Base near Merced is 102 degrees F and the CD65 is 37 degrees F.

Augmentations to the model. Using the whole-campus load projections for plant design requires further analysis of plant operation by the benchmark campuses. The fraction of the electric load identified as chilled water production is determined from the chiller size and loading.

Several custom augmentations are also necessary for the case of the Merced campus. The model was extended to account for a year-round operations scenario, alternative fuel transportation scenarios, and the potential for future on-site water/wastewater facilities.

The Planning Scenarios

Several efficiency and load management scenarios were examined based on the augmented models. The three scenarios with the most significance are:

- Base Case—the campus with no thermal energy storage or other load management and no special efficiency efforts,
- Conventional Load Management—the campus with conventional load management through chilled water thermal energy storage (not gas cooling), and
- Efficient Design—the campus with progressively improving energy-efficient design utilizing commonly available technology (plus conventional load management).

Conventional load management. The goal for conventional load management was set at the highest level achieved in the UC system—virtually all on-peak use of electric chillers is eliminated. In the California Central Valley, this is equivalent to approximately 25% of the peak base case maximum electric demand.

Efficient design targets over the long timeframe for campus development. Goals for efficiency need to allow the campus to "spin-up" its efficiency levels over time, learning as it goes and adopting new technology as it becomes commonly available on the market. The target for the development of the first plant and buildings to open in 2004 is based on the highest level of aspiration of the other UC campuses—the UC Irvine new construction design standard at 80% of the maximum energy use allowed by Title 24. This goal was adapted to be 80% of the 1999 UC/CSU average campus benchmark, including peak demand. Both demand and annual energy use by all facilities (not just code-regulated parts of the campus buildings) is to be reduced by an average of 20%.

For buildings completed in 2005 though 2007, the efficiency goal is raised, lowering the target energy intensity to 65% of the 1999 UC/CSU campus average. This intermediate goal is partially based on the adoption of new technology expected to soon become commonly available, including duct sealing for commercial buildings. It is also anticipated that data from monitoring of the new Bren Hall laboratory facility at UC Santa Barbara will become available to inform the design of facilities at Merced (Bren Hall 2002).

For buildings completed in 2008 and beyond the efficiency goal is again raised, lowering the target energy intensity to 50% of the 1999 UC/CSU campus average. This goal is based on the potential identified by the PG&E ACTT Project for commercial buildings (Hernandez, Kolderup and Syphers 1997) and by Lawrence Berkeley National Laboratory for laboratory facilities (Mills 1999). The long-term goal accounts for additional new technologies like advanced fume hoods currently undergoing field tests.

The efficient design scenario (with conventional load management) is the campus planning target. Summary projections for the scenarios are presented in Table 1:

Table 1. UC Merced Energy Load Projections

		Fiscal Year 2004-2005	Fiscal Year 2007-2008	Full Campus
Programming Assumptions				
Floor Area (Gross)*	kSqFt	680	1,200	8,600
Laboratory-type (complex) Buildings		35%	35%	35%
Total Students	FTE	1,000	3,400	25,000
Load Scenario				
Base Case				
Maximum Electric Demand	MW	3.6	6.3	46
Maximum Chilled Water Demand	Tons	1,500	2,600	19,000
Annual Electric Usage	MWh	16,000	28,000	205,000
Maximum Gas Demand	Th/hr	150	270	1,900
Annual Gas Usage	kTh/yr	550	980	7,100
Conventional Load Management**				
Maximum Electric Demand	MW	2.7	4.8	34
Efficient Design (with conventional load management)				
Maximum Electric Demand	MW	2.1	3.5	18
Maximum Chilled Water Demand	Tons	1,200	1,900	9,900
Annual Electric Usage	MWh	12,400	20,000	107,000
Maximum Gas Demand	Th/hr	120	200	1,020
Annual Gas Usage	kTh/yr	440	720	3,900

* Estimate for Energy Planning Only
** Thermal Energy Storage

Efficiency Targets for Building Types

Because of the good correlation between measured energy use and laboratory space, the efficient design targets for UC Merced could be broken down further to budgets for laboratory and non-laboratory buildings. Measurements are not yet available to inform the delineation between academic buildings and housing or student service buildings, so we used conventional engineering estimates based on accumulated design experience to make a split between these two classes of buildings. The conversion from whole-campus targets to building budgets requires the application of a diversity factor on maximum load targets. The resulting structure of the building design budgets is shown in Table 2.

Table 2. UC Merced Building Energy Budgets

	Maximum Power *	Maximum Chilled Water **	Annual Electricity ***	Maximum Thermal ***	Annual Thermal ***
	W/gsf	tons/kgsf	kWh/gsf/yr	Th/hr/kgsf	Th/gsf/yr
Laboratory Buildings					
Opening in 2004	5.4	3.0	33	0.34	1.5
2005-2007	4.4	2.4	26	0.28	1.2
2008+	3.4	1.9	20	0.21	0.9
Classroom, Office, Library					
Opening in 2004	2.9	1.6	12	0.10	0.16
2005-2007	2.4	1.3	10	0.08	0.13
2008+	1.8	1.0	7.6	0.06	0.10
Housing, Services, and Recreational					
Opening in 2004	2.0	1.1	8.5	0.14	0.22
2005-2007	1.7	0.9	6.9	0.12	0.18
2008+	1.3	0.7	5.3	0.09	0.14

* Including Prorated Part of Small Peak (Pumping) Load at Plant
** Load on Plant
*** Including Prorated Part of Plant Use

Experience in Using the Benchmark-Based Targets

The resulting designs. Going into the construction drawing phase, the building and infrastructure design includes an unprecedented number of efficiency features within a normal project budget:

- high performance glazing
- sun shading for the exterior of buildings
- high quality lighting with low power density (using T5HO systems)
- low pressure-drop design of laboratory air systems
- indirect evaporative pre-cooling of outside air for laboratory systems
- laboratory process and refrigeration load rejection to the indirect evaporative system
- some HVAC systems without reheat
- individual HVAC control zones for some personal offices
- high chiller plant efficiency
- chilled water thermal energy storage
- enhanced energy performance monitoring

Changes in design methods. Part of the efficiency of the chiller plant results from the accurate sizing made possible by the benchmark system. The plant is sized with a healthy margin of safety over the total expected diversified building loads, even with the largest chiller unit out for maintenance. However, the plant is significantly smaller and less expensive than the plant that would have been designed using less accurate conventional load estimation methods.

The benchmark-based targets were difficult for some engineers to reconcile with traditional design methods. Incredulity was often expressed at how low measured campus loads are relative to traditional "design" values. Traditional design values appear to be based on an across-the-board worst case estimate of equipment (plug) loads, with little consideration of diversity, plus large margins of safety.

The benchmark based targets for maximum demand and chilled water load resulted in evolution of an alternate analysis that can be called "Most Likely Maximum" (MLM) load or "peak credible demand". The MLM estimates and design should correspond to the actual measured maximum loads for the building. The monitoring provides the potential for a direct check on this design parameter. Because of the accuracy of this method, design for efficient operation at both the MLM load and part load can be effectively mandated, compelling designers to consider the potential range of operation for the energy systems. The difference between the MLM and the design loads can be "value-engineered" to reach a reasonable margin of safety for each subsystem.

As a testimonial to the promise of the approach, architects and engineers working on the project have reported that the benchmark-based performance targets are effective in fostering high-efficiency design (Daly 2002, Davis 2002).

Compliance with LEED ™. UC Merced also has the goal of a Silver LEED ™ rating for the initial facilities. LEED ™ points for energy efficiency are based on exceeding the local energy code (California Title 24) by a stepped scale of percentages. Credit for these points could conceivably be obtained in various ways. An equivalence between the benchmarks and standards could be demonstrated, allowing direct use of the target compliance calculations (i.e., 80% of the benchmark) to determine the points available. In this case there might be an "innovation" credit available for also documenting the reduction of peak demand. Alternatively, Title 24 calculations could be adapted to determine the points available. This is the approach taken to obtain a Platinum LEED™ rating for Bren Hall at UC Santa Barbara (Bren Hall 2002). Innovation credit might then be pursued based on all the measures and systems that are not captured in the Title 24 calculation. At this writing it remains to be seen which path will be pursued.

Conclusions

The advantages of standard-based targets are:

- no special study of similar buildings is necessary,
- an industry "infrastructure" is available to document compliance,
- a more rigorously vetted set of analysis procedures exists,
- compliance with targets is closely related to actual code or standard compliance, and
- there is close linking to rating systems like LEED ™.

The advantages of benchmark-based targets are:

- all facility systems are counted, including appliances and laboratory systems,
- all potential efficiency approaches can be employed to meet the targets,
- compliance with the targets is measurable in actual operation,
- targets are linkable to infrastructure development, and
- design can be more easily based on measured loads.

Benchmark-based targets have worked well for UC Merced. Good architects and engineers can design to ambitious energy goals, even as capital budget always forces trade-offs with other priorities. It was helpful that the goals were set early, during programming. It was also made clear to design teams that energy efficiency and other aspects of environmental stewardship were to have a high priority during design and value engineering exercises.

The design of the next UC Merced buildings to a lower and more challenging energy budget will provide a further test of the benchmark-based approach. The first objective feedback will come from the monitoring of the first buildings after 2004.

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