Hitting the Whole Target: Setting and Achieving Goals for Deep Efficiency Buildings

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ABSTRACT

Deep efficiency and zero net energy goals require two profound shifts in thinking about evaluation of building performance. First, performance targets must expand from a limited set of building systems addressed by traditional codes and standards, to an all-systems accounting of energy use. Second, there must be intent to assess performance relative to targets as-operated (measured) in addition to as-designed (modeled). These two shifts need to be accompanied by availability of more measured performance data to support goal setting and modeling.

The University of California, Merced has established a benchmark-based process that successfully achieves these shifts. This paper describes target setting, modeling, and performance validation approaches adopted from the outset by the new campus, including detailed results for one building. Successes and lessons learned in implementing this process can support other building projects on the trajectory toward zero net energy, as well as provide insights for program design, implementation, and evaluation.

The campus implemented comprehensive targets along side traditional standard-based targets. Designers were challenged to do analysis that would not only provide the basis for LEED® ratings and public purpose incentives, but also stand the test of validation by post-occupancy performance monitoring. Some of the first buildings exceeded initial expectations for deep efficiency. A large classroom and office building and a large laboratory use less than 65% total energy and have around 50% of the peak demand of benchmark buildings. This success contributed to the establishment of a whole-campus goal of zero net energy by 2020.

Background

Zero net energy or carbon neutrality goals have emerged as a defining theme for building energy efficiency. This has been accompanied by interest in greenhouse gas emission accounting in anticipation of either carbon trading schemes or regulation of such emissions. These trends have spurred an increased interest in the actual measured energy performance of buildings. Yet, due to the need for early analysis relative to code and rating system requirements, energy modeling during design has become decoupled from actual measured performance of new buildings (Diamond et al. 2006, NBI 2008).

Limitations of Traditional Goal-Setting for New Buildings

Traditional goal setting for new buildings will typically focus on using a certain percentage less energy than the prevailing code (e.g., California Title 24 for this project) or a recognized national standard (e.g., American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1). The U.S. Green Building Council's increasingly popular Leadership in Energy and Environmental Design (LEED®) rating system bases its energy efficiency credits on the ASHRAE Standard or acceptable local codes.

This traditional approach has two fundamental limitations. First, these codes and standards only address a fraction of the energy-using systems in the building. Second, the models are only as good as the assumptions about operating conditions and building management practices.

Building sub-systems left out of planning. Building energy-efficiency codes and standards avoid regulating process loads, including "plug" loads (ASHRAE 2007, CEC 2008, CEC 2009, CPUC 2009). Also, there are areas where real-world energy savings cannot be taken as a credit in code-compliance modeling due to complex implementation rules. For example, designing systems to work properly at very low fan pressures is not an allowable credit in the California Title 24 Energy Standard (CEC 2008, CEC 2009). Codes and standards are trying to be more inclusive, with Title 24 recently extending itself to include exterior lighting in a recent update. But gaps still exist, particularly for plug-loads.

Operating assumptions and equipment not customized to building. Traditional modeling may include assumptions about operating hours or equipment loads that are not representative of the conditions the building will eventually encounter. For example, inaccurate load estimation can be due to a lack of feedback from existing buildings to the design process (Brown 2002). Or code compliance rules may require use of standard assumptions for operating hours (CEC 2009).

Modeling not intended for as-operated predictions. In addition to specific gaps in new building modeling, the intent of analysts also limits what the models can accomplish. Analysts are simply not expecting their models to be tested against actual building performance. As authors of a recent study intended to assess the relationship between LEED® ratings and measured energy performance observe: "The accuracy of modeling is limited not only by the inherent complexity of buildings, but also by variation in operational factors such as building schedule and occupancy, internal plug-loads and weather. Therefore, most professionals in the energy modeling industry are careful to adopt caveats in their predictions or emphasize that modeling is a tool to identify relative energy performance, not to predict actual energy use. Despite these caveats, modeling is widely used to estimate actual future energy use." (NBI 2008).

Modeling and market needs. There is a great deal of controversy over the current value of building modeling in applications such as LEED® New Construction (NC) Ratings (Diamond et al. 2006, NBI 2008). The current approach is useful to assess the design relative to codes or standards, establish building asset value, or assess relative impact of changes to design. But with new zero net energy policy goals as well new disclosure requirements in locations such as Washington D.C., Seattle, New York City, City of Austin, and California, there is an increasing expectation that building energy modeling results should also more accurately align with actual measured building energy use (CPUC 2009, IMT 2010).

Needed Enhancements in Prediction of New Building Performance

Two basic enhancements are needed for prediction of new building performance. First the analysis must give full consideration to all energy using systems, not just those currently regulated by codes and standards. Increased attention to plug loads is the key step for an all-systems or "all-in" analysis.

Second, modeling should attempt to accurately predict actual measured performance. This requires universally establishing this expectation, and an assessment of anticipated operating conditions by the design team working in conjunction with the owner. Use of actual anticipated operating schedules is the key difference from many applications of modeling for code or rating system compliance. Best available information often must suffice. This may range from estimates made by the owner, to information from similar facilities, to published references. To support these enhancements, modelers need access to substantially more data on actual energy end use of a range of building types and building sub-systems.

As a case study for such a process—we present the goal setting, design, modeling, and performance measurement process for the University of California (UC), Merced Classroom and Office Building. With the presence of simple intent to predict actual energy performance, the UC Merced experience suggests a manageable effort to assess anticipated equipment loads and operating conditions combined with basic information on actual usage of similar buildings may be sufficient to substantially improve accuracy of models relative to measured performance.

Energy Goal Setting, Modeling, and Performance Verification for UC Merced

The new UC Merced campus began energy system planning in 1999, prior to most of the popular interest in benchmarking or measured energy performance. An early focus on measured energy performance was partly due to a vision of the campus as a "living laboratory" or test bed for innovation and feedback to later phases of campus design (Brown 2002). It was also driven by the need to integrate infrastructure design into campus planning on a limited budget.

Energy Performance Goal Setting

The key differences in the UC Merced energy goal-setting process include integrated infrastructure and building design, a progressive sequence of deep efficiency goals creating a trajectory toward zero net energy, and the use of the energy modeling approach described in this paper—concurrent with traditional modeling for participation in mainstream rating and incentive programs. More details of the evolution of campus planning toward a 2020 zero net energy goal can be found in a companion paper (Elliott and Brown 2010).

Integrated Infrastructure and Building Design. Planning of energy infrastructure requires assessment of peak loads to enable plant system sizing. Typical practice is to use rules of thumb or repeat past practice, without feedback from measured performance of the past projects. This can result in excessive margins of safety and misallocation of project resources toward larger plant systems. The lack of measured performance data for buildings perpetuates this cycle.

However, UC Merced planners and designers had the advantage of a clear vision for environmental stewardship and the campus as a "living laboratory". This was accompanied by access to operational data for existing campuses, as well as academic staff expertise in building energy performance. These advantages, along with the constraint of a limited development budget, led the campus to seek an integrated approach to building and infrastructure planning. The integrated approach to campus energy planning compelled the use of firm targets for building loads, along with explicit and carefully considered margins of safety in plant sizing.

A trajectory toward deep efficiency. At the time of the initial campus planning, the body of experience suggested that building energy use and peak loads could be reduced from business-as-usual cases by as much as 50% (Brown 2002). The campus wanted to capture this full potential, but lacked the confidence to immediately pursue what, at the time, was considered a radical goal. So, a progressive sequence of targets was established, starting with 80% of business-as-usual for the initial set of campus buildings, then ramping to 65%, and now set at 50%. The targets were introduced as firm design requirements for the first buildings and eventually became campus standards[1]. The business-as-usual (baseline) case was established through a load study of eight UC and California State University (CSU) campuses, normalizing for climate and mix of building types. Details of the targets can be found in an earlier paper describing the original campus planning (Brown 2002).

Concurrent traditional and comprehensive targets. The campus established a multi-faceted environmental stewardship and energy efficiency process that included not only the comprehensive benchmark-based energy targets, but also traditional goals including building labeling rating and utility efficiency program incentives. Thus, designers were given multiple concurrent goals for energy performance.

Description and Comparison of Five Modeling Scenarios

Energy modeling is typically applied to a project design in two well-established ways: as an evaluation tool in an iterative design process, or as a part of compliance or labeling processes. For typical projects there can be multiple compliance or rating scenarios for code-compliance, to establish design incentives, or for building labeling systems. At UC Merced, modeling scenarios were used to support comparison with California Title 24, calculation of incentives for the "Savings By Design" utility energy efficiency program, and a LEED® rating. UC Merced energy planning adds a fundamentally new modeling scenario associated with benchmark-based targets. The five different modeling scenarios for UC Merced are summarized in Table 1.

Conventional modeling scenarios. The first four scenarios rely on a "relative" comparison between a simulated baseline case and a simulated proposed case. In general, un-calibrated energy modeling can be adequate for this type of relative analysis because as long as the same calculation engine and assumptions are used on each side of the relative comparison, the impact of the changes under study can be reasonably evaluated separate from the effects of all the assumptions needed to make the models run. This allows designers to focus on getting the inputs right for the changes under consideration, with less time spent on most of the other assumptions needed to get the model to run.

An additional modeling scenario predicting actual performance. At the beginning of energy planning for the new campus, UC Merced introduced an "absolute" comparison with addition of

[1] UC Merced remains the only one of the ten UC campuses to standardize such a method (St. Clair 2010).

benchmark-based energy budget compliance analysis to the modeling effort. In this scenario the baseline case and proposed case results are generated by entirely different analytical methods.

The baseline energy use quantities for the "budget" calculations were determined as part of the UC Merced benchmarking and planning process. These numbers are derived from regressions of real-world performance data from California university campuses (Brown 2002).

The "proposed" case predictions are based on traditional energy modeling. However, the goal of comparing energy model predictions to the real world means that simplifying assumptions and "general" inputs are no longer adequate as they do not fall out of the relative analysis. The many inputs needed just to get the model to run now all have some important role in determining the final energy prediction.

Peak electricity demand and chilled water load predictions were also required for use in integrated planning of buildings and energy infrastructure.

Table 1. Modeling Scenarios

Energy Modeling Purpose	**Analysis**		**Key Inputs and Assumptions (1)**	
	Units (2)	**Metrics**	**Baseline Case**	**Proposed Case**
1. Design Decision-Making **(Relative)**	▪ Life-Cycle Costs [$]	▪ Return on Investment ▪ Payback Period	▪ Design team establishes a reasonable baseline	▪ Design team determines cases to be evaluated
2. Energy Code Compliance **(Relative)** California Title 24 Calif. LEED® v2.1	▪ Source Btus "TDV" (3)	▪ Yes/No	▪ Mandated inputs (schedules, window-to-wall ratios, etc) ▪ Automatically generated by a detailed "rule-set" ▪ "Standard" schedules ▪ "Process" loads exempt	▪ Automatically generated by a detailed "rule-set" ▪ "Process" loads exempt
3. Utility Incentive Program **(Relative)** Savings by Design	▪ kWh ▪ therms ▪ kW ▪ % better than code	▪ $ Incentive Payments to Owner and Designers ▪ Both demand and use	▪ Inputs governed by incentive program rules ▪ "Actual" schedules ▪ "Process" loads exempt	▪ Inputs governed by incentive program rules ▪ "Process" loads exempt
4. Voluntary Green Building Rating System **(Relative)** LEED® Typical	▪ Energy Cost [$] ▪ Energy	▪ LEED® Credits	▪ Inputs governed by rating system rules (ASHRAE 90.1 Appendix G method) ▪ "Process" loads included	▪ "Process" loads included
5. UC Merced Energy Budget Compliance **(Absolute)**	▪ kWh/gsf ▪ th/gsf ▪ W/gsf ▪ tons/kgsf	▪ Over/Under ▪ % of Benchmark	▪ Established by UC Merced Benchmarking and Planning process	▪ All energy uses fully accounted for including "process" loads

(1) All modeling was done using eQuest version 2.55 build 3730, employing DOE-B2.2D8g.
(2) gsf—gross square feet
(3) Time Dependent Valuation
Source: Allan Daly, Taylor Engineering

Modeling Results for the Classroom and Office Building

This section describes details of the modeling process and the modeling results for the UC Merced Classroom and Office Building (COB). This was the best-documented process among the original set of buildings designed circa 2001. The multiple modeling scenarios all describe the same building design, but with different analysis assumptions.

Predictive model inputs. For the UC Merced COB, the model was not calibrated to the benchmark base case. This was primarily because available benchmark data did not disaggregate end-use data in a way that allowed input to the model.

Designers instead relied on experience and judgment to identify and quantify the inputs thought to have the most significant impact on the energy prediction results. For example, great attention was given to schedules for occupancy and levels of diversity in the lighting, plug, and other equipment loads over the course of the day. ASHRAE research was used to estimate reasonable plug-loads (Wilkins and Hosni 2000). Standard California Climate Zone weather files mandated by the California Title 24 Energy Code were used for all model scenarios.

Utility incentive modeling allows actual schedules. Program rules allowed the proposed cases for the utility incentive and the UC Merced energy budget scenarios to use identical inputs and assumptions (e.g., actual schedules) so these results are the same. However, the utility incentive program rules resulted in a baseline case that is substantially different than the UC Merced, benchmark-based energy budget baseline (see Table 2 and Figures 1 & 2).

California Title 24 modeling requires "standard" schedules. California Title 24 protocols required the use of "standard" schedules that were substantially shorter than the actual anticipated schedules. So, both the Title 24 baseline case and the Title 24 proposed case gave smaller energy use number than the UC Merced energy budget predictive model.

Effect of other California Title 24 implementation rules. There were other idiosyncrasies of California Title 24 modeling rules that caused the Title 24 cases to be different from the other proposed scenarios. For instance, the Title 24 modeling rules at the time would not allow modeling of (or credit for) demand-controlled ventilation.

LEED® and California Title 24. Acceptable local codes are an option for the basis of analysis to determine eligibility for LEED® credits. The actual analysis was a hybrid of Title 24 and ASHRAE 90.1 rules. While the energy use calculations were developed using Title 24 for comparison purposes, the actual credit determination used the cost basis option (see Table 2).

Benefits to the design process. The modeling scenarios were developed concurrently, so the iterative design modeling benefited from the highly scrutinized assumptions developed for the UC Merced predictive scenario. As is common in the design of buildings with aggressive energy goals, the design team for the COB employed an integrated design approach starting in the early phases of design.

For this project, integrated design meant balancing building form, envelope elements, air-conditioning, lighting design, and building controls to optimize energy performance. As the design progressed, the design team used energy modeling rep eatedly to test the performance of the individual systems and components as well as integrate the performance of those elements into total building performance predictions. The increased attention to load assumptions and other model inputs increased effectiveness of the design process and optimization of the design. More optimal equipment sizing was one key factor leading to increased efficiency.

Measured Performance of the UC Merced Campus and Buildings

A performance snapshot of the entire campus and two of the first buildings has been completed for the period of July 2007 through June 2008. The two buildings are the COB described in the previous sections and the first campus lab building, Science and Engineering Building I (S&E I). The timeframe for this snapshot was the first opportunity to capture performance numbers for fully occupied buildings, nine years after the first energy planning work in 1999—a long feedback loop typical for new building construction. This paper presents modeling and measured performance results for COB only (see Table 2 and Figures 1 & 2).[2]

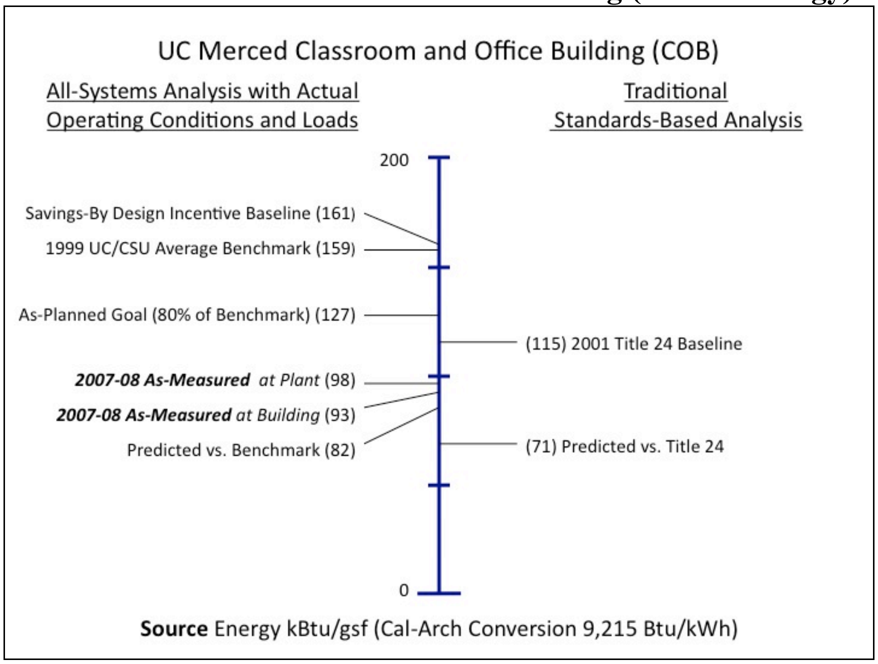
Table 2. UC Merced Classroom and Office Building Performance Metrics

	Annual Electric Use (kWh/gsf)	Annual Gas Use (therms /gsf)	Annual Source Energy Use (1) (kBtu/gsf)	Annual Site Energy Use (kBtu/gsf)	Building Peak Power (W/gsf)	Peak Chilled Water at Building (tons/kgsf)
Baseline (2): UC/CSU 1999 Average Benchmark Classroom & Office	15.1	0.196	159	71	3.65	2.03
Baseline: Title 24/LEED®	*9.3*	*0.295*	*115*	*61*		
Baseline: Savings-By-Design (SBD)	11.3	0.574	161	96		
As-Planned: 80% of Benchmark	12.1	0.157	127	57	2.92	1.62
As-Designed: vs. Benchmark and for SBD Incentive	**7.7** (51%)(5)	**0.11** (56%)	**82** (52%)	**37** (52%)	1.9 (52%)	1.5 (74%)
As-Designed: for T24/LEED	6.9 (74%)	0.074 (25%)	71 (61%)	31 (50%)		
As-Designed: for T24/LEED (Cost)	47%	25%	Aggregate 44% incl. effect of TES			
As-Operated/<u>Measured</u> (3): vs. Benchmark	9.0 (60%)	0.147 (75%)	98 (62%)	46 (64%)	1.75 (48%)	1.72 (85%)
As-Operated/<u>Measured</u> (4): Equivalent Stand-Alone (at Building)	8.5	0.147	93	44	1.67	1.72

(1) 9,215 Btu/kWh Cal-Arch source energy conversion (11,377 Btu/kWh used in original modeling)
(2) Corrected for UC Merced climate and early semester-based academic year start, adjusted for building type
(3) Uncertainty estimates (95% confidence): Electricity/Power ±5% of value, Chilled Water/Gas ±10% of value
(4) "Equivalent Stand-Alone" performance proxy for building performance if not connected to a central plant
(5) Percent of Benchmark – A lower number is better
Source: Taylor Engineering 2001 and CIEE 2010

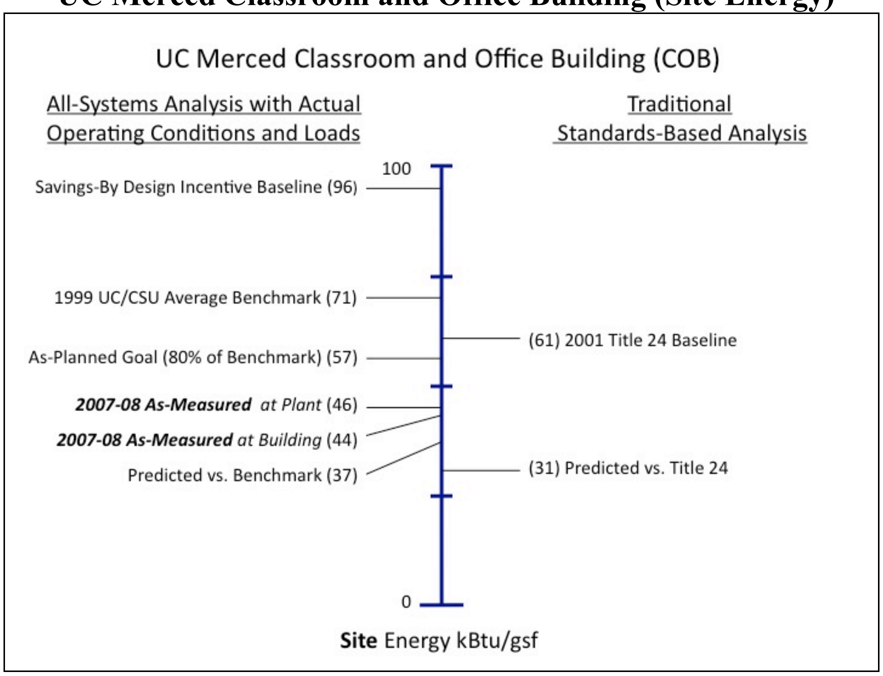
[2] Shorter timescale energy data is just beginning to be mined and organized into accessible form at the time of this writing, and so is not yet suitable for meaningful analysis in the context of this paper.

Figure 1. Predicted and Measured Performance of UC Merced Classroom and Office Building (Source Energy)



Source: Taylor Engineering 2001 and CIEE 2009

Figure 2. Predicted and Measured Performance of UC Merced Classroom and Office Building (Site Energy)



Source: Taylor Engineering 2001 and CIEE 2009

Measured performance results for S&E I and details of COB and S&E I design can be found in Measured Performance Case Studies (NBI 2009a, 2009b). The predictive ability of the benchmark-based modeling and the deep efficiency performance for S&E I are similar to COB. However, full understanding of the complex S&E I building is pending in-progress shorter time scale data and performance trending that tracks ongoing commissioning and changes of use.

Measured whole campus performance during the snapshot period in consistent with COB and S&E I results. More information about campus planning, measured performance trends, and the 2020 zero net energy goal is presented in a companion paper (Elliott and Brown 2010).

Classroom and Office Building performance. Measured performance of COB is presented in Table 2, along with all of the modeling results and predictions.[3] We note that the performance of the building has generally far surpassed the original goal of 80% of benchmark for the first campus buildings, with energy use below the next stage goal of 65% of benchmark and peak electric demand at the long-term goal of 50% of benchmark. This deep efficiency is surpassed by only a small fraction of new building stock nationwide.[4] Performance validated by actual measurement or including all building systems is even less common (NBI 2007, St. Clair 2010).

Accuracy of model predictions. Predictions for building peak loads were slightly better than for annual energy use. Predicted peak electric load was just 9% high and predicted peak cooling load was 13% low. Predicted annual electricity use was 14% low and predicted annual gas use was 27% low, with the total source energy 16% low. Predictions compared favorably with a large study of LEED-NC® rated buildings where half of the model predictions varied by more than 25% from the actual energy use (NBI 2008). Predictions by the all-systems analysis better matched as-operated performance compared to the traditional standards-based analysis, which generally under-predicted energy use by even more. The predicted and measured values for total energy use are illustrated on an absolute scale in Figures 1 and 2.

The pre-construction modeling correctly predicted that the building would generally surpass performance goals. However, the predictions may have been too optimistic based on the initial performance snapshot. The performance of the building is expected to improve with additional commissioning. The campus energy manager notes that he is not yet satisfied with the rigor with which systems are turned down or shut-off during occupied periods. In addition, the district chilled water and heating systems are not yet operating at the overall efficiency anticipated by the design or as achieved by plants at other UC and CSU campuses. Part of this is due to the light loading of the plant designed to serve five times the floor area that existed at the time of the snapshot. Additional commissioning items are being identified through the ongoing monitoring process. As a result, the predictions of annual energy use may eventually turn out to better match as-operated performance.

However, it is notable that both the traditional standards-based analysis and the all-systems analysis under-predicted the actual measured energy use of the building in the first performance snapshot. This did not pose a problem for this campus as the project designs significantly surpassed the goals. But it could present problems for projects with designs just

[3] Chilled water and hot water supply was measured at the building and overall central plant efficiency used to convert to electricity and natural gas usage attributable to the building.

[4] UC Merced has achieved all available (ten) LEED® EA1 Energy Efficiency Credits for more buildings (three including COB) than any other UC campus (Coghlan 2010)

meeting goals or projects closer to zero net energy. Improvements in all-systems predictions should be sought.

The Future of Predictive Modeling

Some subsequent UC Merced projects have benefitted from the modeling experience developed with the COB project, as well as access to detailed measured load data from the first buildings. Predictions for these buildings are anticipated to be even better than for the original COB project.

Establishing the simple intent for modeling to project actual performance may be the most important step. However, the degree of success in extending the methodology to other sites will depend on the skill of designers in applying the limited disaggregated load data currently available, or on development of improved "prototype" data sets. Ongoing building benchmarking efforts have the potential to provide the needed data, but may not be oriented to that goal. More disaggregated interval data would be helpful in determining air-conditioning loads. Sub-system benchmarking and model-calibration protocols could also be useful. Research that identifies which parameters have the most impact could also help energy modelers focus their efforts.

UC Merced COB designers note that since this groundbreaking project, they have been asked to do predictive modeling only on subsequent UC Merced projects or on zero net energy building projects. The recent attention to the limitations of conventional modeling may spark increased interest in predictive modeling and more demand for its use.

Conclusions and Recommendations

UC Merced energy planning has created a valuable new approach to building modeling, as well as advances in the goal-setting process for new building energy performance. The following conclusions and recommendations are made based on this experience:

All-inclusive energy performance targets for buildings are feasible. UC Merced projects have been successful in setting, reaching, and even surpassing all-systems building performance goals. Actual monitoring has validated individual building performance and whole-campus progress toward its zero net energy goal.

Conventional building modeling processes can be enhanced to predict actual building performance. With careful attention to load estimates and anticipated occupancy schedules, and establishing this intended role for the model with the design team, conventional building modeling can become a tool for predicting actual energy performance of new buildings. Rule sets imposed by code are often not conducive to predicting actual performance. Reliance on traditional modeling approaches would have inhibited UC Merced in reaching its goals.

More load data and model calibration will help. The potential for building modeling to predict the actual energy performance in new buildings is limited by existing actual load data. Projects with access to measured data from similar existing buildings are currently at an advantage with respect to predicting actual use for new buildings. The development of more extensive data sets and virtual building prototypes based an actual building performance will enable more projects to effectively predict new building performance.

Acknowledgements and Disclaimer

The authors wish to recognize the first Chancellor of UC Merced, the late Carol Tomlinison-Keasey, for her vision of campus environmental stewardship. Her leadership was the key-enabling factor allowing the campus to embark on a path toward sustainability.

Other early campus leaders who made major contributions included Campus Planner Trudis Heinecke, Vice Chancellors Cliff Graves and Lindsay Desrochers, and COB Project Manager Cynthia Hughes-Doyle. Current campus staff that are continuing the effort include Chancellor Steve Kang, Campus Architect Tom Lollini, Energy Manager John Elliott, James Genes, Catherine Kniazewycz, Michael Chow, Mark Maxwell, Steve Rabedeaux, and Min Jiang.

Bettina Gill of HMH Resources did the computational heavy lifting for the original campus load study. The more recent monitoring analysis team included Mary Ann Piette of Berkeley Lab, as well as Cathy Tuner and Howdy Reichmuth of the New Buildings Institute.

This report was prepared as a result of work sponsored by the California Energy Commission (Energy Commission) and the University of California (UC). It does not necessarily represent the views of the Energy Commission, UC, their employees, or the State of California. The Energy Commission, the State of California, its employees, and UC make no warranty express or implied, and assume no legal liability for the information in this report; nor does any party represent that the use of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the Energy Commission or UC, nor has the Energy Commission or UC passed upon the accuracy or adequacy of the information in this report. Reference therein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute endorsement, recommendation, or favoring by the Regents or any CIEE sponsor.

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