Title

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Disclaimer

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Benchmark-based, Whole-Building Energy Performance Targets for UC Buildings

I. Introduction

The University of California (UC) is a leader in energy efficiency for buildings. The UC Sustainable Practices Policy mandates that all new building projects, other than hospitals, shall be designed, constructed, and commissioned to outperform the California Building Code (CBC) energy-efficiency standards (aka, Title 24) by at least 20%. An energy performance metric based on a percentage beyond code has a number of limitations, however, and UCOP is proposing a complementary method of designing for energy efficiency using benchmark-based, whole-building energy performance targets.

Benchmark-based, whole building energy performance targets are becoming the best practice method for designing energy efficient and zero net energy buildings. National leaders in energy research, such as the National Renewable Energy Laboratory (NREL), are embracing these targets as the most holistic method for designing high-performance buildings. There are several advantages to energy performance targets, including a static baseline (to allow for comparison of buildings over time), the ability to capture energy use and efficiency for all building energy loads (not just the loads regulated by code), and the ability to carry design targets through to operations. In addition, benchmarks available for UC campuses provide targets that address peak demand. For these reasons, the UC campuses are encouraged to adopt whole-building energy performance targets in their building design process, to help maintain UC's leadership in energy efficiency.

UC Merced has been using whole-building energy performance targets since its founding and has had great success in delivering buildings with very energy efficient designs that perform to those design targets in their ongoing operations. The targets are expressed as a percent of a baseline and cover all critical design parameters including annual and peak electric and natural gas use, as well as peak chilled water loads (Brown 2002, Brown et al. 2010). The baselines reflect the 1999 benchmark energy performance of existing building stock for similar buildings, corrected for local climate. They were derived using a regression analysis of actual energy data collected in 1999 at several UC and California State University (CSU) campuses.

In 2011, the system was introduced at UC San Francisco for use in UCSF's new design guidelines at the Mission Bay campus. The 1999 benchmarks were validated by being compared to metered data at existing UCSF buildings. This provided confirmation for using the same method to establish benchmark-based baselines and targets at all UC campuses, which have consequently been developed.

II. The need for benchmark-based whole building energy performance targets

Energy incentive programs, green building rating systems, and energy labeling programs are commonly based on a percentage of energy savings beyond the code maximum energy allowance. The UC Sustainable Practices Policy states that all new building projects are to outperform CBC energy efficiency standards by 20%. This approach has worked reasonably well, but percent savings can become confusing as energy codes become more stringent, especially if policy makers move to set goals for zero net-energy buildings—requiring both deep energy efficiency and renewable energy sources to "net out" the remaining energy use.

A percentage savings beyond code is relative to a moving baseline, as the code is regularly updated per statute and the more stringent standards are enabled by technological advances. California updates to energy efficiency standards in 2001, 2005, and 2008 reduced maximum energy use from between 5% to 8%. For the 2013 update the energy use reduction is predicted to be closer to 20%. Early green buildings claimed savings of 40% or more relative to the CBC at the time that they were built, but many of these buildings would fail to comply with the 2008 and 2013 CBC (Eley et al. 2011).

Whole-building energy performance targets can be based on a static baseline – in this case, the UC benchmarks developed from the 1999 UC/CSU building stock. As new energy efficiency technologies and approaches become available, the target for new buildings can be moved as appropriate to continue making progress toward zero-net energy buildings. The baseline will stay the same, however, allowing for easy evaluation of energy efficiency across buildings and over time.

Percent savings beyond code is also a limited measure because not all of the energy used in buildings is regulated by the CBC. In past code cycles, regulated energy only included heating, cooling, hot water, and interior lighting. Process energy, plug loads, commercial refrigeration, and other non-regulated energy uses were not included because the codes did not establish a baseline for these end uses. In the 2013 code cycle, fan and pump energy and some process loads are included in the energy efficiency standards for the first time. However, much of the building energy use remains unregulated, an estimated 30% averaged across all building types. This creates uncertainty as to whether percent savings includes all building loads or only those regulated, and does not incentivize taking energy efficiency measures on unregulated loads (Eley et al. 2011). Whole-building energy performance targets are based on total energy use and by definition include all building loads.

In addition, whole-building energy performance targets are easier to verify in operations because they are not dependent on the modeling assumptions of a baseline case. Measured verification enables campuses to gain a better understanding of which energy efficiency measures are most effective. It also provides measured evidence for the fact that energy efficiency in new construction projects is oftentimes more cost-effective then later retrofits. Furthermore, whole-building energy performance targets can be carried through to operations and they are much more integrated with UC's climate action policy, as they provide a method of predicting and verifying greenhouse gas emissions of new buildings.

For these reasons, national leaders in energy efficiency, such as NREL, are adopting benchmark-based whole-building energy performance targets as the method of designing for energy efficient buildings. Whole-building energy performance targets are a vital element in continuing UC leadership in building energy efficiency and reaching the University's and climate goals.

III. Development of Benchmarks

The 1999 UC/CSU building energy benchmarks were developed using whole-campus energy use and floor area data from eight UC and CSU campuses (UC Berkeley, UC Davis, UC Irvine, UC Riverside, UC San Diego, UC Santa Barbara, CSU Fresno, CSU Stanislaus), including both annual use/output and peak observed use/output. This utility and space data was combined with corresponding data on the wide range of combinations of district heating and cooling, heating and cooling plants, cogeneration, and thermal energy storage systems to create a consistent data set of energy loads per unit floor area from buildings, independent of campus energy infrastructure.

This building energy load data correlated reasonably well with climate parameters and with density of buildings containing complex space (e.g., labs). Therefore, it was possible to create regressions to project campus loads at UC Merced during the design of the first buildings and infrastructure. It was also possible to do a simple disaggregation of use based on building type (complex vs. non-complex). A further delineation was made between non-complex classroom/office and housing building types, with the former using a disproportionately high amount of electricity and the latter a disproportionately high amount of natural gas.

Though the building-level energy performance benchmarks are independent of the infrastructure serving the buildings, in a campus setting variability remains in the types of loads from the buildings (e.g., natural gas and/or district hot water/steam, chilled water and/or electricity) and the point of measurement (e.g., at the building or at the campus meter). The benchmarks presented here are for the most straightforward combinations of loads from campus buildings, with notes provided on how to adjust the benchmarks for other variations. The following notes apply to use of the benchmarks:

1) All heating loads are served by gas (e.g. there is no electric resistance or heat pump heating in the building). Heating loads are typically associated with natural gas use, with boilers in buildings considered equivalent to district hot water systems. For district steam systems, extra losses need to be considered for steam distribution and energy conversion to hot water within the buildings.
2) All cooling loads are served by electricity (e.g. there are no absorption or steam-turbine driven chillers in the building). Annual energy use for cooling is typically associated with electricity use, either with chillers in the building or with a district chilled water system. However, if the building is served by a district chilled water system, peak demand is separated out as a chilled water load.

IV. Experience at UC Merced

The regression-based projections have been validated by measurement of actual UC Merced energy use at both the campus and building levels, with one exception for which an update was implemented. The campus set progressive whole-energy performance targets, below the 1999 benchmarks developed by the regression. The first 600,000 gsf had a target of 80% of benchmark and the next 600,000 gsf had a target of 65% of benchmark. Buildings are currently being designed with a target of 50% of benchmark. (An exception is maximum thermal load, which has remained at 80% of benchmark.)

The actual measured campus use has tracked just below the level that would be predicted for buildings meeting the targets, on a floor area basis. This is currently around 70% of benchmark with a blend of occupied 80% and 65% target buildings. Actual peak electricity demand is tracking far below predictions. Maximum chilled water load is tracking predictions. The Classroom and Office Building and Science and Engineering I have both been studied in more detail and the as-operated measured performance has been substantially better than the design targets (61-62% of benchmarks reflecting total source energy use, NBI 2009a, NBI 2009b).

The first UC Merced campus buildings might now be considered in some ways better benchmarks than those derived from the existing UC/CSU campus load study. Use is measured at the building level and there is no need to adjust for climate. However, the "sample size" is bigger for the 1999 UC/CSU benchmarks and there is value in maintaining static baseline, as it allows buildings to be compared over time. Moreover, the 1999 UC/CSU benchmarks align in time with the national building energy benchmarks provided by the 2003 CBECS (Commercial Buildings Energy Consumption Survey) database. Therefore, UC Merced has chosen to maintain the original benchmarks as the primary reference for current building design.

V. Expanding whole-building energy performance targets to other UC campuses

The process of developing building energy benchmarks used by UC Merced was adapted for use by UC San Francisco in 2011, and climate-adjusted, benchmark-based performance targets were used in the design-build proposal process for the Mission Bay Faculty Office Building. San Francisco sites are an "extrapolation" in the sense that the climate is slightly milder than any of the campus sites from the original load study. Therefore, an extra validation step was taken, comparing the benchmarks with metered data from UCSF buildings. The analysis suggested that the existing system of benchmarks can be used for UCSF, with adjustments for buildings using steam (e.g., Parnassus campus and Mt. Zion facilities), along with adjustments for sub-metering of electricity use at low distribution voltages at the building (the original system of benchmarks is based on master-metering at the campus level). Please see Appendix I for further details.

Based on the success of developing appropriate building energy use benchmarks at UC Merced and UC San Francisco and designing to whole-building energy performance targets at UC Merced, UCOP has applied the same method to develop benchmark-based baselines and targets for all UC campuses. Further details on this method are provided in Appendix II. Table 1 presents the baselines and Table 2 presents the targets equivalent to those currently being used at UC Merced (50% of benchmark, except for maximum thermal load at 80% of benchmark).

Table 1: UC Building 1999 Energy Benchmarks by Campus – Baseline for Targets

	Annual Electricity **kWh/gsf/yr** Includes prorated part of plant use and site lighting	**Maximum Power** **W/gsf** Includes prorated part of small peak (pumping) load at plant	**Max. Chilled Water tons/kgsf** Load on plant	**Annual Thermal** **therms/gsf/yr** Includes prorated part of plant use	**Max. Thermal** **therms/hr/kgsf** Includes prorated part of plant use
Academic/Administrative Non-complex Space					
Berkeley	11.2	3.1	N/A	0.21	0.12
Davis	13.3	3.3	2.5	0.20	0.12
Irvine	13.0	2.6	1.93	0.16	0.12
Los Angeles	12.3	2.3	1.72	0.17	0.12
Merced	14.3	3.5	2.6	0.20	0.12
Riverside	13.9	3.3	2.5	0.18	0.12
San Diego	12.2	2.2	1.66	0.16	0.12
San Francisco Parnassus	11.1	2.0	1.51	0.21	0.12
San Francisco Mission Bay	11.4	3.1	N/A	0.21	0.12
Santa Barbara	11.5	2.2	1.66	0.19	0.12
Santa Cruz	11.1	3.2	N/A	0.23	0.12
Housing Non-complex					
Berkeley	7.8	2.1	N/A	0.30	0.18
Davis	9.3	2.3	1.75	0.29	0.18
Irvine	9.1	1.79	1.35	0.23	0.18
Los Angeles	8.6	1.60	1.20	0.24	0.18
Merced	10.0	2.4	1.82	0.28	0.18
Riverside	9.7	2.3	1.75	0.26	0.18
San Diego	8.6	1.55	1.17	0.23	0.18
San Francisco Parnassus	7.8	1.40	1.06	0.30	0.18
San Francisco Mission Bay	8.0	2.1	N/A	0.30	0.18
Santa Barbara	8.0	1.55	1.17	0.28	0.18
Santa Cruz	7.8	2.2	N/A	0.32	0.18
Lab/Complex Space					
Berkeley	36	7.6	N/A	1.83	0.43
Davis	38	6.3	4.7	1.83	0.43
Irvine	38	5.6	4.2	1.78	0.43
Los Angeles	37	5.4	4.1	1.79	0.43
Merced	39	6.4	4.8	1.82	0.43
Riverside	38	6.3	4.7	1.80	0.43
San Diego	37	5.3	4.0	1.78	0.43
San Francisco Parnassus	36	5.2	3.9	1.84	0.43
San Francisco Mission Bay	36	7.6	N/A	1.84	0.43
Santa Barbara	36	5.3	4.0	1.81	0.43
Santa Cruz	36	7.6	N/A	1.85	0.43
Building-Specific Adjustments					
Unique situations such as Santa Cruz's district condenser water system and Berkeley's interconnected building chillers and absorption chillers may require custom adjustments.	Annual chilled water use is typically associated with electricity use and is included in this value.	For campuses with district chilled water (e.g. Davis), if a specific building has a chiller instead, multiply value by (1/0.7) or 1.43 to account for the chiller's electric load.	Only applicable if building supplied by district chilled water system.	These values are directly applicable to buildings with boilers in the building or connected to (low-loss) district hot water systems (non-steam). They can be applicable to buildings connected to district steam systems if additional losses characteristic of steam systems is accounted for where appropriate. For example, 50% extra use from trap/exchanger losses within the building plus 50% extra use from trap/leakage losses in distribution systems has been commonly observed.	
	These values may be slightly lower than previously published values (i.e. for UC Merced) because they reflect load on the building meter (480 V) instead of at the campus meter (12 kV). To reflect load on campus meter, increase value by 1.05 (to account for distribution and transformation losses).				

Table 2: UC Building Energy-Performance Targets by Campus

	Annual Electricity kWh/gsf/yr Includes prorated part of plant use and site lighting	Maximum Power W/gsf Includes prorated part of small peak (pumping) load at plant	Max. Chilled Water tons/kgsf Load on plant	Annual Thermal therms/gsf/yr Includes prorated part of plant use	Max. Thermal therms/yr/kgsf Includes prorated part of plant use
Academic/Administrative Non-complex Space					
Berkeley	5.6	1.53	N/A	0.10	0.10
Davis	6.7	1.66	1.25	0.10	0.10
Irvine	6.5	1.28	0.96	0.081	0.10
Los Angeles	6.2	1.14	0.86	0.085	0.10
Merced	7.2	1.73	1.30	0.10	0.10
Riverside	6.9	1.66	1.25	0.090	0.10
San Diego	6.1	1.11	0.83	0.080	0.10
San Francisco Parnassus	5.6	1.00	0.75	0.11	0.10
San Francisco Mission Bay	5.7	1.53	N/A	0.11	0.10
Santa Barbara	5.7	1.11	0.83	0.10	0.10
Santa Cruz	5.6	1.58	N/A	0.11	0.10
Housing Non-complex					
Berkeley	3.9	1.07	N/A	0.15	0.14
Davis	4.7	1.16	0.88	0.15	0.14
Irvine	4.5	0.90	0.67	0.12	0.14
Los Angeles	4.3	0.80	0.60	0.12	0.14
Merced	5.0	1.21	0.91	0.14	0.14
Riverside	4.9	1.16	0.88	0.13	0.14
San Diego	4.3	0.77	0.58	0.11	0.14
San Francisco Parnassus	3.9	0.70	0.53	0.15	0.14
San Francisco Mission Bay	4.0	1.07	N/A	0.15	0.14
Santa Barbara	4.0	0.77	0.58	0.14	0.14
Santa Cruz	3.9	1.11	N/A	0.16	0.14
Lab/Complex Space					
Berkeley	18.0	3.8	N/A	0.92	0.34
Davis	18.9	3.1	2.4	0.91	0.34
Irvine	18.8	2.8	2.1	0.89	0.34
Los Angeles	18.5	2.7	2.0	0.89	0.34
Merced	19.3	3.2	2.4	0.91	0.34
Riverside	19.1	3.1	2.4	0.90	0.34
San Diego	18.4	2.7	2.0	0.90	0.34
San Francisco Parnassus	18.0	2.6	1.94	0.92	0.34
San Francisco Mission Bay	18.1	3.8	N/A	0.92	0.34
Santa Barbara	18.1	2.7	2.0	0.91	0.34
Santa Cruz	18.0	3.8	N/A	0.93	0.34
Building-Specific Adjustments					
Unique situations such as Santa Cruz's district condenser water system and Berkeley's interconnected building chillers and absorption chillers may require custom adjustments.	Annual chilled water use is typically associated with electricity use and is included in this value.	For campuses with district chilled water (e.g. Davis), if a specific building has a chiller instead, multiply value by (1/0.7) or 1.43 to account for the chiller's electric load.	Only applicable if building supplied by district chilled water system.	These values are directly applicable to buildings with boilers in the building or connected to (low-loss) district hot water systems (non-steam). They can be applicable to buildings connected to district steam systems if additional losses characteristic of steam systems is accounted for where appropriate. For example, 50% extra use from trap/exchanger losses within the building plus 50% extra use from trap/leakage losses in distribution systems has been commonly observed.	
	These values may be slightly lower than previously published values (i.e. for UC Merced) because they reflect load on the building meter (480 V) instead of at the campus meter (12 kV). To reflect load on campus meter, increase value by 1.05 (to account for distribution and transformation losses).				

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Appendix I: Analysis of application of 1999 UC/CSU Benchmarks to UC San Francisco

Accounting for steam system losses at some sites (Parnassus and Mt. Zion) and with one significant outlier (Byers Hall), UCSF energy use patterns are consistent with the 1999 UC/CSU benchmark-based regression data used to develop the energy use benchmarks and targets for UC Merced.

A. Buildings Served By Steam Systems

Significantly higher steam (equivalent natural gas) use on the Parnassus campus and for the Mt. Zion facility can be explained by typical in-building losses associated with the district steam system at those sites. Our study of other California campuses indicates that losses from district steam systems roughly double the equivalent natural gas use compared with any other type of infrastructure (e.g., in-building boilers or hot water distribution). One plausible explanation for the higher gas use at the Parnassus and Mt. Zion sites is that roughly half of the typical steam losses are between the plant and the building, with the other half being on the building side of the steam metering and observed in the data.

Benchmarks and targets for equivalent natural gas use should be adjusted upward by 50% to account for steam distribution losses inside buildings served by district steam systems at UCSF (e.g., Parnassus Campus buildings). However, this will have no net effect on the end-use system design goals as design teams should concurrently be instructed to add 50% to their design analysis to account for the potential losses. Of course, design teams should also be encouraged to design for minimum losses on the building side of the steam meter, targeting a level well below benchmark.

B. Accommodation of Large Process Systems

Byers Hall is a significant outlier for electricity use at roughly 160% of the climate-adjusted benchmark. This is explained by the presence of large Magnetic Resonance Imaging units and associated cooling systems. (It should also be noted that the adjacent Byers Hall, Genentech Hall and Community Center are partially conjoined with some HVAC services supplied by common systems.) In a situation where an unusually large process system will be included or added to a building (e.g., MRI, data center, clean room) it is recommended that energy use analysis of such a system be done separately, and the benchmark-based targets are applied to the balance of the building.

C. Adjustment for Electric Metering at the Building

UCSF electricity use data was obtained as metered at the building at distribution voltage (480V). The 1999 UC/CSU Benchmarks were developed to correspond to the portion of campus metered electricity use attributable to the building, inclusive of distribution and transformation losses between the campus meter and the building. This caused some minor confusion in the UC Merced design analysis and subsequent performance measurement process. In order to avoid that in the application of future benchmarks, a 5% decrease in the climate adjusted benchmarks can be applied for direct application to the design process. It should also be noted that the benchmarks are inclusive of all unattached site lighting allocated to the building targets. If a significant portion of unattached site is not associated with the building designs, then the benchmarks and targets will be slightly conservative on the high side.

D. Acute Care Facilities and Complex (Wet Lab) Building Benchmarks

The adjustments already implemented and mentioned above are necessary to adapt to UCSF conditions. UCSF acute care facilities have roughly the same energy footprint as the other complex (wet laboratory) buildings. If the above adjustment is made for buildings served by district steam systems, it appears the benchmarks and targets for buildings containing wet laboratory space might be useful for acute care facilities. However, because of the limited data set so far examined, medical centers are encouraged to supplement benchmarks with their own data.

Appendix 2: Method used to calculate whole-building energy use benchmarks at UC campuses

1. Climate Data
   Identify historic climate data for campus site using same references as were used for original derivation of benchmarks. See "University of California, Merced Campus Energy Planning Module I: Preliminary Load Projections. Working Draft. 2000" for the original references. The following independent climate variables are included
   - Cooling Design Temperature (deg F, 0.4% design temperature for 35 hours of exceedence)
   - Cooling Degree-Days base 65 deg F
   - Heating Degree Days base 65 deg F

2. Apply Regression Formula
   Set lab building fraction to 0% for non-lab (non-complex) building benchmarks.
   Set lab building fraction to 100% for lab (complex) building benchmarks.
   Obtain campus-level benchmarks for:
   - Maximum power (W/gsf, chillers in buildings)
   - Annual Electricity Use (kWh/gsf/yr)
   - Maximum Thermal (therms/hr/kgsf)
   - Annual Thermal (Therms/gsf/yr)

3. Apply Concurrence Fraction(s) to Account for Load Diversity at Building Level
   For electric and thermal maximum benchmarks, convert from campus level to building level by applying concurrence fraction(s) to account for load diversity. A 90% concurrence factor was originally assumed for maximum electric (including both electricity and chilled water for a district cooling campus) and thermal (natural gas) load. Based on measurements of chilled water diversity at UC Merced, the concurrence factor has been updated to 84% for all maximum loads at the building level.

4. Apply Adjustment for Increasing Summer Occupancy
   The benchmarks were developed primarily from quarter-term campuses (except Berkeley) with the typical partial summer occupancy. Early UC Merced planners insisted that UC Merced would almost immediately become the first (non-medical center) campus to operate a summer quarter with equivalent campus population to the other three quarters. Therefore, an adjustment was made to the benchmarks for this increase in summer use over the benchmark campuses. Ten percent is added to the maximum power benchmark and 2% is added to the annual electricity use benchmark.

   Soon thereafter, the 1st Chancellor took a decision to go to the semester system, starting in August and finishing the first semester before the winter holidays. This shift, along with the hot summer weather, decreased momentum toward full year-round operation.

   However, the adjustments to the benchmarks were maintained and are carried through to the present. Electric and chilled water loads for the August start are almost as high as the slightly hotter part of the summer. The 2% adjustment to the electricity benchmark is considered de minimis. Taking away these adjustments would have seemed like a take-back to the campuses designers challenged by the benchmark-derived targets.

   The next application of the benchmarks at UCSF was for a medical campus that has something approaching year-round operation. So the adjustment was maintained. The adjustment has been maintained for other campuses for simplicity.

5. Split Between Peak Electricity and Chilled Water for a District Cooling Campus
   For a campus with district cooling (and in some cases thermal energy storage (TES)) the peak electric benchmark must be split at the building level between the electricity peak and the maximum chilled water demand. This is the fraction of the electric peak that is shiftable off-peak with TES.

The split at the benchmark campuses with district cooling appeared to be ~25% chilled water maximum and 75% electricity peak from fans, pumps, lights, and plug load—based on a generic chiller performance metric of 0.6kW/ton. Based on a pattern of easily meeting electricity peak targets and relative difficulty meeting chilled water peak targets at UC Merced, the split has been adjusted to 30% chilled water maximum and 70% electric peak.

6. <u>Distinction between Academic Buildings and Housing</u>
   For non-laboratory buildings, to account for higher electricity usage in "commercial"-type classroom, office, and library buildings, as well as higher gas usage in "residential"- type buildings. Electricity benchmarks for housing are set at 70% of the level of non-residential" buildings by multiplying the basic non-laboratory benchmark by the square root of the 70% factor and electricity benchmarks for non-residential buildings dividing the basic non-laboratory benchmark by the square root of the 70%.

   The inverse process is used to account for higher gas usage in residential buildings than in "commercial" buildings.

7. <u>Adjusting for Building Metering</u>
   The benchmarks are derived from data collected at the campus meter at approximately 12 kV. There are distribution and transformation losses between the campus meter and building meter, which is at approximately 480 V. To reflect these losses, the benchmarks are reduced by 5%.

8. <u>Floor Area Definition</u>
   The UC floor area definition used in development of the benchmarks is REVOGSF50.

9. <u>Building Classifications</u>
   At UC Merced, the following building types were classified as having "complex"-level benchmarks, though they may not be classified as containing "complex" space in the UC space database:
   - Telecom
   - Plant (as a Building)
   - Food Service
   - Rec Center (Natural Gas Benchmark/Target)