Zero Net Energy Case Study Buildings

Volume 1

Written by
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Foreword by
Peter Turnbull
Principal, Commercial Buildings, Pacific Gas and Electric Company

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Cover Photo: View of exterior sunshades of the Science & Engineering Building I at University of California, Merced. (Photo by EHDD Architecture)

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Foreword

Zero net energy (ZNE) buildings represent a new paradigm in building design—providing super-efficient structures that generate as much energy as they consume over the course of a year. This approach to design has the potential to make massive inroads into the total amount of *greenhouse gas* (GHG) emissions associated with building energy use supplied by non-renewable, carbon-based sources of power. Heightened concerns about the GHG issue are driving and transforming the leaders within the building industry to target this new level of building performance.

For decades, California has had the reputation of being the incubator and early adopter of transformative ideas and of demonstrating their practical feasibility. This reputation is certainly well-earned in the areas of energy and environment, with numerous examples of state policy initiatives supported by both public and private sector activities. California has been a leader in energy efficiency, for example, dating back to the days of the “energy crisis” of the early 1970s.

The graph below, documenting the California’s success in this area, has become known as the “Rosenfeld Curve” in honor of Dr. Art Rosenfeld, an early leader in energy efficiency. In 1974, Rosenfeld led the formation of the Center for Building Science at Lawrence Berkeley National Laboratory in Berkeley, California—the site of many technical and policy innovations over the past 40 years. This now-familiar chart shows zero growth in electricity consumption per capita in California over the past forty years in contrast to that of the U.S. as a whole.

In 2006, the state legislature passed and Governor Schwarzenegger signed Assembly Bill (AB) 32, the Global Warming Solutions Act. Its central requirement is that California reduce its GHG emissions to 1990 levels by 2020. Although the state’s Air Resources Board (ARB) is the lead agency for AB 32 implementation overall, important efforts in the building sector are also underway from the California Public Utilities Commission (CPUC), the California Energy Commission (CEC) and the governor’s office.

In 2008, the CPUC—with jurisdiction over the investor-owned utilities' efficiency programs—issued its Energy Efficiency Strategic Plan for Energy Efficiency which called for four "Big Bold" initiatives: two involved ZNE, targeting all new residential construction to be ZNE by 2020, with commercial new construction to follow by 2030. The CEC, which has jurisdiction over the energy efficiency standards within the state building code, has embraced the ZNE vision as well, and is aligning its code update efforts to incorporate ZNE by 2020 in the residential market.

Since California is the largest building owner and operator within its state boundaries, the governor's office has taken a number of actions involving energy efficiency at state facilities in recent years, including Executive Order B-18-12 (issued April, 2012). Among several provisions, this order calls for "all new State buildings and major renovations beginning design after 2025 be constructed as Zero Net Energy facilities;" it includes provisions for interim targets before 2025; and also calls for "50% of the square footage of existing state-owned building area [to move toward ZNE] by 2025."

Many have pointed out that California's ZNE goals and objectives are not legally binding. In this sense, these goals are aspirational in nature. But clearly the CEC's deliberate steps to integrate the ZNE vision into the state's building code, the CPUC's emphasis on ZNE in utility program efforts to promote efficiency and the governor's efforts to impact State of California buildings are powerful drivers providing a tremendous boost to the movement toward ZNE in the building design and construction industry. Not long ago, ZNE was commonly believed to be unattainable absent costly interventions and upgrades that would exist only in the province of wealthy eccentrics. In fact, the central finding of a recent study by Arup[1] under California utility sponsorship is that approximately 75% of the floor space to be constructed in the state starting in 2020 can be built to ZNE performance levels using "state of the shelf" technologies and systems.

This is not to say that building to ZNE is a well-known process with well-understood outcomes, or that reaching the goals is straighforward and automatic. There are many lessons to be learned by design professionals, building contractors, building owners, building managers, and finally by building occupants. To date, there are simply not enough examples built, measured, and verified as ZNE performers to form a critical mass given all of the different building types and climate variables in California, let alone nationally. Documentation of ZNE process and performance, together with dissemination of the learnings will be an important resource for building designers, owners, managers, occupants and other stakeholders as California tries to reach these high goals.

This publication, representing findings and experience from PG&E's ZNE Pilot Program, is one such effort to disseminate information. Consistent with state policy, PG&E's work in the pilot program in each instance focused first on achieving the maximum level of load reduction and energy efficiency in the building through integrated design practices and careful equipment selection before sizing on-site renewable energy systems to balance out the remaining energy requirement. (The least expensive kWh is still the one that no one has to generate!)

"At scale" normalization of the design and production of ZNE buildings will occur when the design professionals are comfortable with the process and results, and when building clients—the owners and developers—have confidence about the feasibility and value of this approach to building procurement. Sharing information about successful projects in the real world is a key step and the motivation for this publication.

-- Peter Turnbull, Principal, Commercial Buildings, Pacific Gas and Electric Company.

[1] Arup, December 2012, "The Technical Feasibility of Zero Net Energy Buildings in California", Pacific Gas & Electric Company.

Introduction

This monograph provides information about six non-residential buildings that were designed and built to perform at *zero net energy (ZNE)* consumption over the course of a year. Each has proven to be successful at achieving that level of performance, or better, for at least one year of post-construction occupancy.

Design of *zero net energy (ZNE)* buildings is a relatively new area of work within the professional community of building designers and only a small number of these designs have been built within the U.S. Fewer still have been occupied long enough to collect sufficient monitored data about their energy use and on-site renewable energy supply to demonstrate that the designs were in fact successful examples of ZNE performance. The first early successes are therefore valuable sources of insights and information about design process, design strategies, post-occupancy building issues and corrective measures taken to ensure actual ZNE performance.

This last point is one principal focus of these ZNE case study buildings, namely to present in some detail the problems discovered from reviewing the metered data once the building was occupied and what changes were made to the building and its use patterns in response to this information. Indeed, as discussed later in this publication, one of the common discoveries was that there were even problems with the monitoring systems, which delayed the analysis, diagnosis and correction process.

As the case studies illustrate, architects and engineers generally have the skills and experience to design ZNE buildings provided that this objective is consistently embraced in the early part of the process and involves integrated disciplines with each early decision-making step. Success is also the product of adhering to the following general four-step process, as will be illustrated by each of the case study buildings:

- Set the energy performance target
- Design to this target
- Build to this design
- Monitor, diagnose and correct actual performance

Before delving into the individual case study buildings, however, it is important to define terms, especially what is meant by the term, “*ZNE building”*.

Definition: A Zero Net Energy Building — A Question of Accounting and Metrics

Depending on how the accounting of energy use over the course of a year is done, there are multiple definitions of what is meant by a *zero net energy* or *ZNE* building currently used in common practice. This Introduction section describes three principal definitions of ZNE:

- “Site” ZNE
- “Source” ZNE
- “TDV” ZNE, the “Time Dependent Valuation (TDV)” metric in use in California’s building code.

The six case study buildings in this monograph use the “Site” ZNE energy accounting method. As ZNE is brought into building energy codes, however, and as ZNE rating and certification methods evolve, it is useful to understand the alternative methods of “Source” ZNE as well as the “TDV” metric for ZNE now in use in California’s building code.

As a practical matter, all three definitions have several aspects in common. First, the accepted time frame for ZNE accounting is one calendar year: energy consumption equals renewable energy production over a one-year period. Second, the dominant form of renewable energy production selected is solar photovoltaic (PV) energy: there are other sources that would meet the renewables definition, but they are rarely selected as the most cost-effective and practical solution *at the building level*. Third, "at scale" deployment of ZNE buildings presumes that the buildings are grid-connected: though again not a definitional requirement, grid-connectivity provides the most practical and cost-effective means of meeting ZNE performance targets. Last, all three ZNE metrics typically express the energy units in *kBtu*. ("TDV" ZNE employs a hybrid version of this energy unit: see the detailed discussion below.)

These different energy accounting methods arise from several factors including differences in

- How the "boundary issues" between the building and the grid are considered;
- How the fuel mix of the building and of the power grid are treated;
- How, and whether or not, the cost impacts associated with the *time* that energy is used (diurnally and seasonally) are accounted for.

Site ZNE

A *Site ZNE* building has an on-site renewable energy supply: the amount of energy used by the building over the course of a year is equal to the amount of energy supplied by the on-site system. For grid-connected buildings, the power drawn from the utility grid equals the power exported to the utility grid. This is known as *Site ZNE* since the line of transaction is drawn at the building site boundary. The case study buildings in this monograph are designed to meet *Site ZNE* criteria as individual buildings[1]. This metric is the simplest metric and the easiest to use in conjunction with metered on-site performance data[2]. **It is the one ZNE metric that can be directly metered and measured.**

ZNE rating systems such as the *Living Building Challenge*[3] from the International Living Future Institute (ILFI) use a site-based metric to document actual ZNE performance after the building is occupied. The New Buildings Institute (NBI) *Buildings Database*[4] of high performance buildings is likewise based on the *Site ZNE* metric as measured for at least one year.

Source ZNE

This second type of ZNE metric recognizes that there are large energy losses attributable to the generation of electric energy at the power plant as well as additional energy losses associated with its transmission and distribution to the building site. Since these losses cannot be avoided for grid-connected buildings, the *Source ZNE* metric accounts for these losses, attributing them to the building's energy use. By this definition, the line of energy transaction is no longer at the building site boundary, but extends to include the grid itself so that the energy demand impact of the building on the total system is properly counted. This energy accounting metric is known as *"Source" ZNE* since the source of the utility's energy supply is included in the energy-use accounting for the building.

A *source multiplier* is applied to the building's on-site energy use of electricity drawn from the utility grid to account for the grid system losses, especially combustion losses asociated with fossil-fuel generation. A commonly used multiplier is 3.0[5], accounting for total system efficiencies

[1] With the exception of the Science & Engineering Building and the Classroom/Office Building at the University of California, Merced, which are planned to be part of a campus of buildings that will perform together and on average as ZNE.
[2] A simple arithmetic conversion of kWh into kBtus is used, where 1.0 kWh = 3.413 kBtus. Energy use by fossil fuels is added in directly based on the consumption in kBtu. The *Site ZNE* metric is usually expressed in kBtu per square foot per year, a site "Energy Utilization Index" (EUI).
[3] http://living-future.org/lbc
[4] http://buildings.newbuildings.org/
[5] M. Deru and P. Torcellini, "Source Energy and Emission Factors for Energy Use in Buildings", National Renewable Energy Laboratory Technical Report NREL/TP-550-38617 (2007). http://www.

in the range of 30-35% from the power plant to the building site. In reality, source losses from electric power generation vary widely on a regional and seasonal basis. A "true" multiplier for a power grid with high penetration of renewable energy sources, hydroelectric energy and nuclear energy—generation sources *without* combustion losses—would be substantially lower (as much as 50% lower) than for a power system dominated by fossil fuel generation.

Despite these regional and seasonal differences in generation mixes, there is nonetheless a legitimate reason for the use of a single "average" source multiplier. In the U. S. Environmental Protection Agency's EnergyStar® Portfolio Manager® building benchmarking program, a single figure is used nationally so that building performance is evaluated on a normalized basis without penalizing (or advantaging) any given building based on the utility's generation mix[6].

The value of a source energy metric is also referenced by ASHRAE in its *Vision 2020* document, albeit for different reasons:

> *"[Source ZNE] tends to be a better representation of the total energy impact compared to a site definition. It is challenged, however, by difficulties in acquiring site-to-source conversions and by the limitations of these conversions."* [7]

It should likewise be noted that the source energy metric is a somewhat better proxy for approximating reductions in grid-related greenhouse gas (GHG) emissions than the site energy metric[8].

In terms of practical impacts, the use of a source metric (with its source multiplier) penalizes inefficient uses of electricity (e.g., electric resistance heat and incandescent lighting) and places a premium on highly efficient electric end uses (e.g., high performance heat pumps and LED lighting). There is also a source multiplier for on-site use of fossil fuels, but it is typically much small than for electricity. (ASHRAE[9] cites a source multiplier of 1.1 for natural gas).

Note that *Source ZNE* is a calculated metric based on "source kBtus in-and-out" and by application of a chosen source multiplier. As such, the impact for the fossil fuel source multiplier (approximately 1.1) is much smaller than for electricity (approximately 3.0). Irrespective of how source multipliers are obtained and applied, it is clear that use of a source metric requires a *calculation*, in contrast to a site metric, which can be *measured* directly.

Finally, if *Source ZNE* is used as a metric over the long term, changes in the electric power generation mix–not just regionally but also over time–would force changes in the source multipliers. If it is used as a building performance metric, these changes will in turn create changes in building design.

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nrel.gov/docs/fy07osti/38617.pdf.

[6] For a discussion of the purpose of determining a national average for the source multiplier, see EnergyStar® *Portfolio Manager®* Technical Reference: "Source Energy", *https://portfoliomanager.energystar.gov/pdf/reference/Source%20Energy.pdf?325e-437c.* The EPA has determined that source energy is the most equitable unit of evaluation of building energy efficiency for its EnergyStar® score: *http://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager/understand-metrics/difference.*

[7] "ASHRAE Vision 2020 / Producing Net Zero Energy Buildings", American Society of Heating, Refrigerating and Air-Conditioning Engineers, January 2008.
The document nonetheless goes on to point out that "site energy measurements" are used to define Net Zero Energy Buildings (NZEB) in Vision 2020 "through an agreement of understanding between ASHRAE, The American Institute of Architects (AIA), the U. S. Green Building Council (USGBC) and the Illuminating Engineering Society of North America (IESNA)", precisely because of the complications involved in using other methods including source energy.

[8] M. Deru and P. Torcellini, "Source Energy and Emission Factors for Energy Use in Buildings".

[9] "ASHRAE Vision 2020 / Producing Net Zero Energy Buildings".

Code ZNE
California's Code Metric: "Time-Dependent Valuation (TDV)"

Many building industry experts believe that mandatory requirements pertaining to ZNE are needed for ZNE to succeed "at scale." The State of California is taking steps in that direction. In its building code, California uses a hybrid energy metric known as *Time-Dependent Valuation* or *TDV*, with hourly economic multipliers applied to the site energy consumption (and production) as modeled for that building by energy simulation software used to document energy code compliance at the time of permitting the building. "Zeroing out" the TDV metric represents a code path to ZNE in California, the future objective for the state energy code for buildings.

Building codes exist to provide a baseline societal benefit and value consistent with public policy for life safety, health and human comfort, environmental impact and other societal objectives. The Warren-Alquist Act, California legislation first passed in 1975, explicity added building energy efficiency considerations into the building code: the law established the California Energy Commission (CEC) and chartered that agency with incorporating energy efficiency into the building code. Thus, the concept of enhancing societal value has been at the heart of Callifornia's energy code from the earliest stages. Declarations in the Warren-Alquist Act include[10]

> *"Electrical energy is essential to the health, safety and welfare of the people of this state and to the state economy",* and that
>
> *"Utilities should seek to exploit all practicable and cost-effective conservation and improvements of efficiency of energy use that offer equivalent or better system reliability."*

The energy code is designed to minimize electric infrastructure costs, land use impacts, air quality impacts and carbon emissions.

California introduced the TDV metric into code in 2005: the core concept was to place increased emphasis on saving "peak" energy—the most costly energy for the grid operators to produce, procure and deliver. The TDV metric creates a structure to accommodate separate economic multipliers for energy for all 8,760 hours in a year. (Before 2005, a single source multiplier was used for all hours.) Simply put, the TDV metric places high value on peak-saving measures. See the graphical illustration of this principle on the following page.

As implemented within the code, the TDV values are applied as hour-by-hour multipliers to the site energy total comsumption as computed by one of the state-certified energy analysis programs such as *EnergyPro*[11].

Under the Warren-Alquist Act, the energy code is required to be revised approximately every three years. The CEC is targeting its upcoming revisions to the code (often referred to as "Title 24") to support statewide goals for "all residential new construction to be ZNE by 2020" with non-residential buildings to follow by 2030[12,13].

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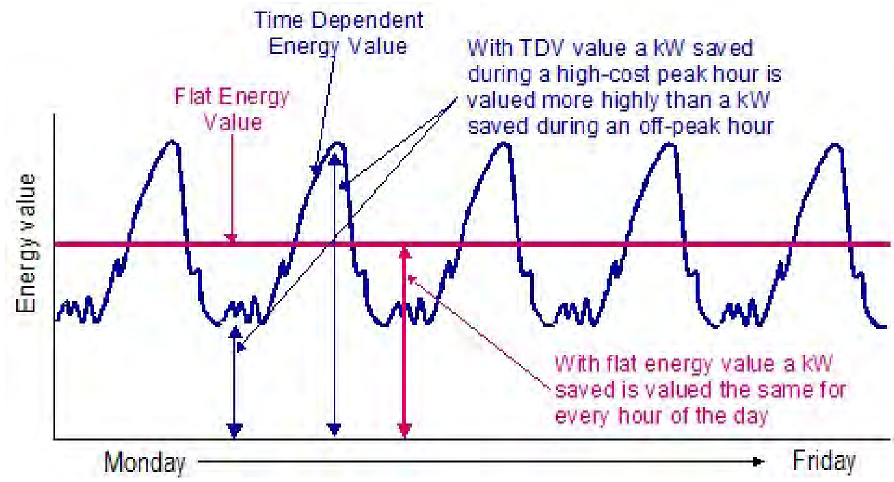
[10] *http://www.energy.ca.gov/2012publications/CEC-140-2012-001/CEC-140-2012-001.pdf*

[11] Note that the TDV multiplier values are applied only within the context of the building code and code compliance software; there is no one-to-one relationship between TDV values and actual energy consumption, actual utility rates or customer bills.

[12] "California Energy Efficiency Strategic Plan–New Residential Zero Net Energy Action Plan: 2014-2020", technical report by California Public Utilities Commission (CPUC) and California Energy Commission (CEC), Draft 14 October 2013.

[13] "California Energy Efficiency Strategic Plan–Zero Net Energy Action Plan: Commercial Building Sector 2010-2012", technical report by California Public Utilities Commission (CPUC) and California Energy Commission (CEC), June 2011.



Concept diagram: Time-Dependent Valuation (TDV) of energy saved through building design measures compared to flat energy-quantity valuation of pre-2005 California energy codes. (Courtesy TRC Energy Services--formerly Heschong Mahone Group).

In the 2013 “Integrated Energy Policy Report” or “IEPR”, the CEC includes the following definition of ZNE within the context of the energy code:

> *“A Zero-Net-Energy Code Building is one where the net amount of energy produced by on-site renewable energy resources is equal to the value of the energy consumed annually by the building, at the level of a single “project” seeking development entitlements and building code permits, measured using the California Energy Commission’s Time Dependent Valuation metric. A zero-net-energy code building meets an energy use intensity value designated in the Building Energy Efficiency Standards by building type and climate zone that reflect best practices for highly efficient buildings.”* [14]

Simply stated, a building in California is ZNE from a building code perspective when the TDV metric for that building calculates out to zero. It is important to note the strong emphasis on energy efficiency within this definition for ZNE: high, “best practices” levels of energy efficiency are an explicit *definitional requirement* for ZNE in the IEPR—simply zeroing out the metric without high levels of efficiency does *not* meet the California code definition for ZNE.

As a hybrid metric involving both energy and cost, TDV units are expressed as a “hybrid unit”: “$–kBtu/sq.ft. per year”. (See footnote 11 on the page ix.)

The TDV metric strongly influences the size of the on-site renewable energy system required to achieve TDV=0 over the course of a year. Due to the high TDV values attributed to on-peak energy, the TDV metric requires the smallest solar photovoltaic (PV) system of the three energy metrics under discussion in order to “get to zero”. This is the result of the fact that the building’s PV system will generally produce the largest amount of electric energy during summer months during hours that correspond closely to the time of peak demand on the grid[15].

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[14] “Integrated Energy Policy Report - 2013 IEPR”, California Energy Commission, Publication Number CEC-100-2013-001-CMF, pp 34-41. This section of 2013 IEPR provides an in-depth discussion of ZNE.

[15] The correlation is not exact: the air conditioining demand which drives the peak normally lags the time of peak solar production by several hours on any given day.

As noted in the Source ZNE discussion, accurate source energy multipliers vary regionally and over time. In a similar manner, the hourly economic multipliers of TDV as applied to site energy change over time, reflecting changes to the time and duration of system peaks and to changes to the load shape of the utility grid. Although the changes from code cycle to code cycle have been fairly small to date, the cumulative impact of changes over several code cycles going forward could be substantial, in turn creating changes to the most appropriate and cost-effective building design solutions.

Summary Comparison of the Three Principal ZNE Metrics

The table below summarizes the principal characteristics of the three ZNE metrics discussed in this Introduction and used in evaluation of building energy performance and ZNE. It is interesting to note that the size of an on-site solar photovoltaic system required to “zero out” the energy demand over the course of year will be different depending on the energy-use metric used.

Table: Comparison of Metrics Used in Evaluation of Building Energy Performance and ZNE

Energy Use Metric	Energy Accounting	Current Use	Solar PV System Sizing	Benefits	Issues
Site Energy	Total energy consumed at building site	Common metric for building designers and most ZNE building measurement methodologies	Largest	• Easily understood by both public and professionals • Can be directly metered • No multiplier–stable over time	• Fails to account for grid losses • Unless coupled with mandatory efficiency measures, can lead to large, costly PV systems
Source Energy	Total energy consumed at building site multiplied by “source multiplier” to account for utility grid losses	Certain building rating methodologies such as *Energy Star®*	Mid	• Easily understood by professionals • Accounts for source losses • Used nationally and internationally	• Not easily understood by the public • Not directly linked to meter • “Source multiplier” highly variable by region and over time–variability may impact building design solutions
TDV Energy (Code, California)	Total energy consumed at building site multiplied by “economic multiplier” to account for variable costs of grid operation	Energy code metric (currently used in California)	Smallest	• Accounts for societal costs associated with peak demand on utility grid • Smaller PV systems reduce overall building cost	• Not easily understood • Not directly linked to meter • Code only, not used outside California. • TDV hourly multipliers vary over time–variability may impact building design solutions.

Practical Barriers to ZNE and Related ZNE Issues

Even with the most energy-efficient design features, there are a number of reasons why some individual buildings will be unable to reach ZNE performance levels on their own by any of these metrics. These primarily involve a lack of access to renewable energy sources in one way or another. For example, practical restrictions such as the size and footprint of the building, the inability to provide enough physical space for on-site renewable energy systems, the lack of solar access at the site, or some combination of these–such as might happen in an urban environment–are all potential barriers to ZNE performance.

There are a number of ways that these constraints for on-site renewable energy production can be addressed. All involve some form of gathering and accounting of renewable energy from off-site sources. The following are some conceptual examples of this approach:

- A building adjacent to the subject building with an excess of on-site renewable energy could supply renewables;
- A group of buildings within a defined geographic boundary could install sufficient renewable energy capacity within that boundary to zero-out the energy usage by the group of buildings taken together;
- A building or group of buildings could directly purchase renewable energy from a non-adjacent site or agency;
- A building owner could purchase *renewable energy credits (RECs)* from a REC provider to offset usage.

There are, of course, significant code-related, commercial-practice-related and legal issues and barriers affecting each, depending upon the context. Generally, voluntary rating and certification programs provide latitude for significant creativity in handling the constraints. In contrast, legal compliance issues may be difficult to resolve with regard to mandatory compliance-based systems for which such solutions may be adopted.

There are discussions among building professionals about other possible definitions of ZNE. One prominent concept is that of a "zero net emissions" building in which the greenhouse gas emissions attributable to the consumption and production of energy at the facility would equal zero[16].

Other proposed definitions include the reductions in the embodied energy of the building, reductions in water use that correspond to energy use, and reduction in the transportation energy burden established by a building because of its selected physical location for that purpose. All involve plausible arguments for crediting reduction in energy demand, but there is at the moment no single type of definition, metric or certification system that accounts for these within a ZNE framework[17].

[16] Of the three metrics discussed, such a system might most closely resemble the *Source ZNE* metric, as suggested above.

[17] Only the *Living Building Challenge (LBC)* certification represents that a building is ZNE within an objective, verifiable system, but this certification system has additional requirements unrelated to energy use. Therefore, a building may perform at ZNE as determined using one of the three principal ZNE metrics but fail LBC certification criteria. This particular certification is therefore inherently limited.

The National Institute of Building Sciences (NIBS) is the organization chartered under the federal Energy Policy Act "to develop commonly agreed upon definitions for NZE and NZER[18] ". As of summer, 2014, NIBS is in the process of gathering detailed input from a broad group of stakeholders from industry, government, trade associations and the nonprofit sector involved in all facets of building design, construction and operations. The results of the exercise will be published and made widely available to government and industry to "support the developing demand for NZE and NZER buildings." The output of this effort is expected to develop and advance consensus understanding in this important area[19].

Targeting ZNE—Establishing the Right Energy Budget

As noted at the beginning of this Introduction section, design of a building for ZNE performance follows this general four-step process:

- Set the energy performance target
- Design to this target
- Build to this design
- Monitor, diagnose and correct actual performance

These steps can be followed for any of the three ZNE metrics described: *Site ZNE*, *Source ZNE* or *TDV ZNE*. Each case study project provides insights into the many different issues surrounding the process of design, building and performance monitoring for each specific type of building project. However, each project has a common approach to the first step: setting the energy performance target or *energy budget*. Targeting a cost-feasible, technically-feasible and operationally-feasible energy budget will minimize the required investment in a renewable energy system—often the most expensive component of a ZNE building. All of the case study buildings discussed in this monograph start with this idea: make the building as energy-efficient as possible and go from there.

A proven approach for initial targeting is to base the energy budget on a known set of benchmarks of measured energy use of comparative building types[20,21,22]. These benchmarks provide a feasible design target given the current state-of-the-art, which in turn provides a first estimate for the size of the renewable energy supply. The benchmarking approach for setting energy budgets was used for the two case study buildings at UC Merced (Case Studies #5 and #6.).

With "TDV=0" having been established by the CEC as the building code definition for ZNE in California, builders are likely to begin to emphasize it in preparation for the 2020 targets affecting the residential new construction market. Since "TDV=0" requires the smallest, least costly renewable system of the three metrics discussed in this Introduction, this definiton of ZNE will have first cost advantages compared to the other definitions for the foreseeable future.

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18 NZER is an acronym for "Net–Zero–Energy–Ready", which is a building with sufficiently low energy demand to achieve ZNE performance, but without the installation of any on-site renewable energy system. Note also that "NZE" and "ZNE" are used interchangeably; "ZNE" appears to be nomenclature used consistently on the California state level, while "NZE" seems to be preferred on the federal level.

19 http://www.nibs.org/?page=hpbc

20 K. Brown, "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.

21 Architecture 2030 Challenge and 2003 Commercial Buildings Energy Consumption Survey (CBECS), U.S. Energy Information Administration.

22 For laboratory buildings: http://labs21benchmarking.lbl.gov/

As indicated in the ZNE case studies in this monograph, early adopters in the building design community have used the *Site ZNE* metric to set performance targets for their ZNE building projects. These are typically given as a single number, the *EUI*, or *Energy Use Intensity*, representing an engineering unit of thousands of Btu (*British Thermal Units*) per square foot of building area per year, or “kBtu/sf-year”. The *Site EUI* energy budget established for each of the ZNE case study buildings in this monograph is given in the building description along with the actual *Site EUI* measured during the first few years of operation.

With this detailed introduction to the basic concepts of zero-net-energy buildings completed, the ZNE building case studies follow.

—Edward Dean, FAIA, Bernheim + Dean, Inc., with Peter Turnbull, Principal, Commercial Buildings, Pacific Gas and Electric Company

Case Study Projects ▷

CASE STUDY NO. 1

Packard Foundation Headquarters Building

PHOTO: JEREMY BITTERMANN

Packard Foundation Headquarters Building

Case Study No. 1

Data Summary

Building Type:Two-Story Office

Location: Los Altos, CA

Gross Floor Area: 49,000 gsf

Occupied: July 2012

Energy Modeling Software:
eQuest version 3.64

Modeled EUI (Site)
19.4 kBtu/sf-year

Measured EUI (Site)
20.7 kBtu/sf-year (2012)
14.1 kBtu/sf-year (2013)

On-Site Renewable Energy System Installed
285 kW (DC) Solar PV

Measured On-Site Energy Production
282,000 kWhr/year (2013)
19.6 kBtu/sf-year (2013)

Owner/Client
David and Lucile Packard Foundation

Design Team

Architect: EHDD Architecture, San Francisco CA

Structural Engineer: Tipping-Mar & Assoc., Berkeley, CA

Mechanical / Plumbing Engineer: Rumsey (Integral Design Group), Oakland CA

Electrical Engineer and Lighting Designer: Integrated Design Associates - IDeAs (now part of Integral Design Group, Oakland CA) and Janet Nolan, SF.

Landscape Architect: Joni Janecki & Assoc., Santa Cruz, CA

Daylighting Consultant: Loisos Ubbelohde, Oakland, CA

General Contractor:
DPR Construction

The Packard Foundation Headquarters is an appropriate first case study for this monograph: the project planning took an exemplary wide and thorough view of all energy and carbon emission issues, incorporated the best in current design thinking and created some technological innovations that help move the building industry forward in improved energy performance. The project represents a very high standard across all aspects of planning, design, construction and occupancy, creating a model for all aspects of zero net energy building design.

Completed and occupied in mid-2012, the building has experienced its first full year of operation, successfully demonstrating that the planning and design objectives have been well met. The building recently received a “net zero energy certification” from the International Living Future Institute (ILFI) as part of its rigorous certification program known as *The Living Building Challenge*.

As will be the case with the later case studies, the project discussion will follow the common process elements of target setting, designing to the target, building to the design and, finally, monitoring, diagnosis and correction. This four-step process will be specifically detailed by the following sequence of topics for each project:

- The design strategies to achieve zero-net-energy performance (site ZNE[1]);
- The energy modeling used as part of an integrated design approach;
- A comparison with the modeling results to the actual measurements after occupancy of energy use;
- Measured data (12 months) comparison of building energy use versus on-site renewable energy production, proving zero-net-energy performance;
- Any corrective measures required to overcome practical problems that arose after occupancy to reach or maintain ZNE performance.

A complete description of the project history for the Packard Foundation Headquarters, as well as other aspects of the building’s sustainable design, can be found in a report[2] commissioned by the Foundation and available through its website.

Background

Discussion about a new headquarters building for the David and Lucile Packard Foundation began in 2006, with building programming beginning in earnest in 2008. Because the Foundation engages in awarding grants in conservation and science, with an emphasis on those activities that lead to a reduction of carbon emissions around the world, a high level of sustainable design was a principal goal for the project. This included exceeding a LEED-Platinum standard for all areas of sustainability as well as the specific objective of constructing a facility that would use zero net energy over the course of a year and have a zero carbon footprint.

The Knapp Report[3] includes an extensive discussion of the actions taken by the Foundation and its consultants to address the zero carbon objective, which includes accounting for carbon emissions due to the worldwide activities of the organization and staff. This monograph focuses on the Foundation’s success in achieving the specific goal of annual zero net energy performance.

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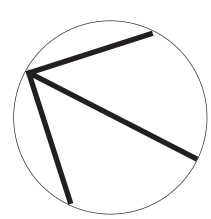
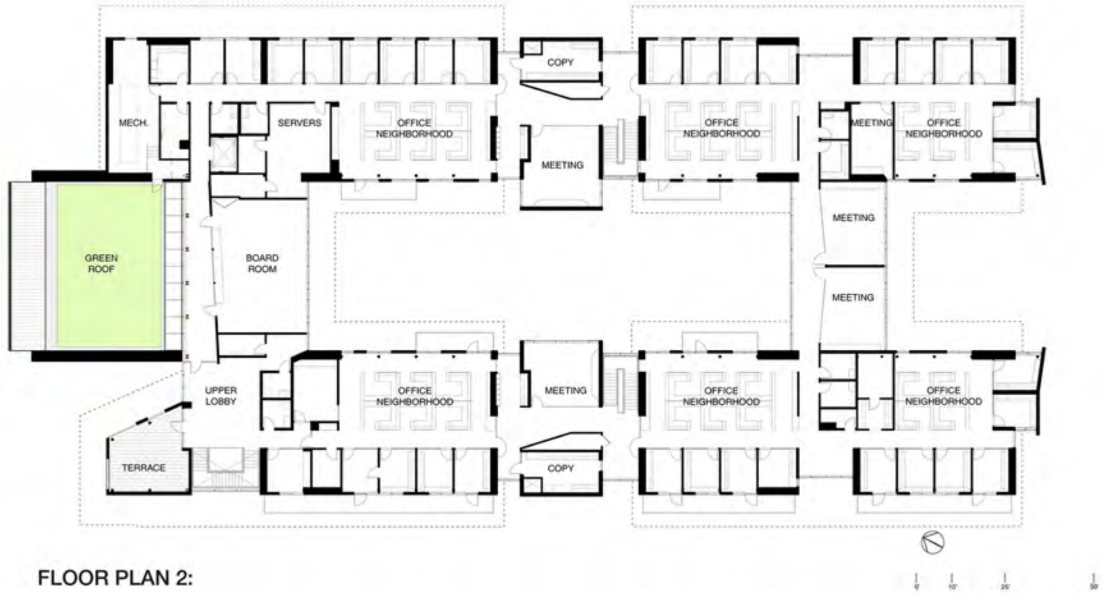
[1] See Introduction to this monograph for the definition of *site ZNE*.

[2] Knapp, Robert H., “Sustainability in Practice—Building and Running 343 Second Street”, David and Lucile Packard Foundation, October 2013, *http://www.packard.org/about-the-foundation/our-green-headquarters/.*

[3] *Ibid.*

Packard Foundation Headquarters Building General Site Plan

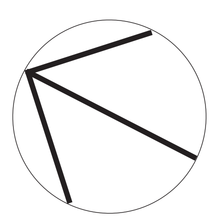




FLOOR PLAN 2:

FLOOR PLAN 1:

Packard Foundation Headquarters Building Floor Plans



Low Energy Design Strategies

Every aspect of the planning and design of the building was discussed in terms of the sustainability goals and, in particular, zero net energy performance. Beyond the organizational issues included in the zero carbon planning discussions, these included not only the traditional aspects of building programming, site planning and the building's physical systems, but also user behavior and supporting the green-conscious culture of the workplace. This focus of all of these discussions determined the final design outcome and the building environment in place today.

Planning / Concept

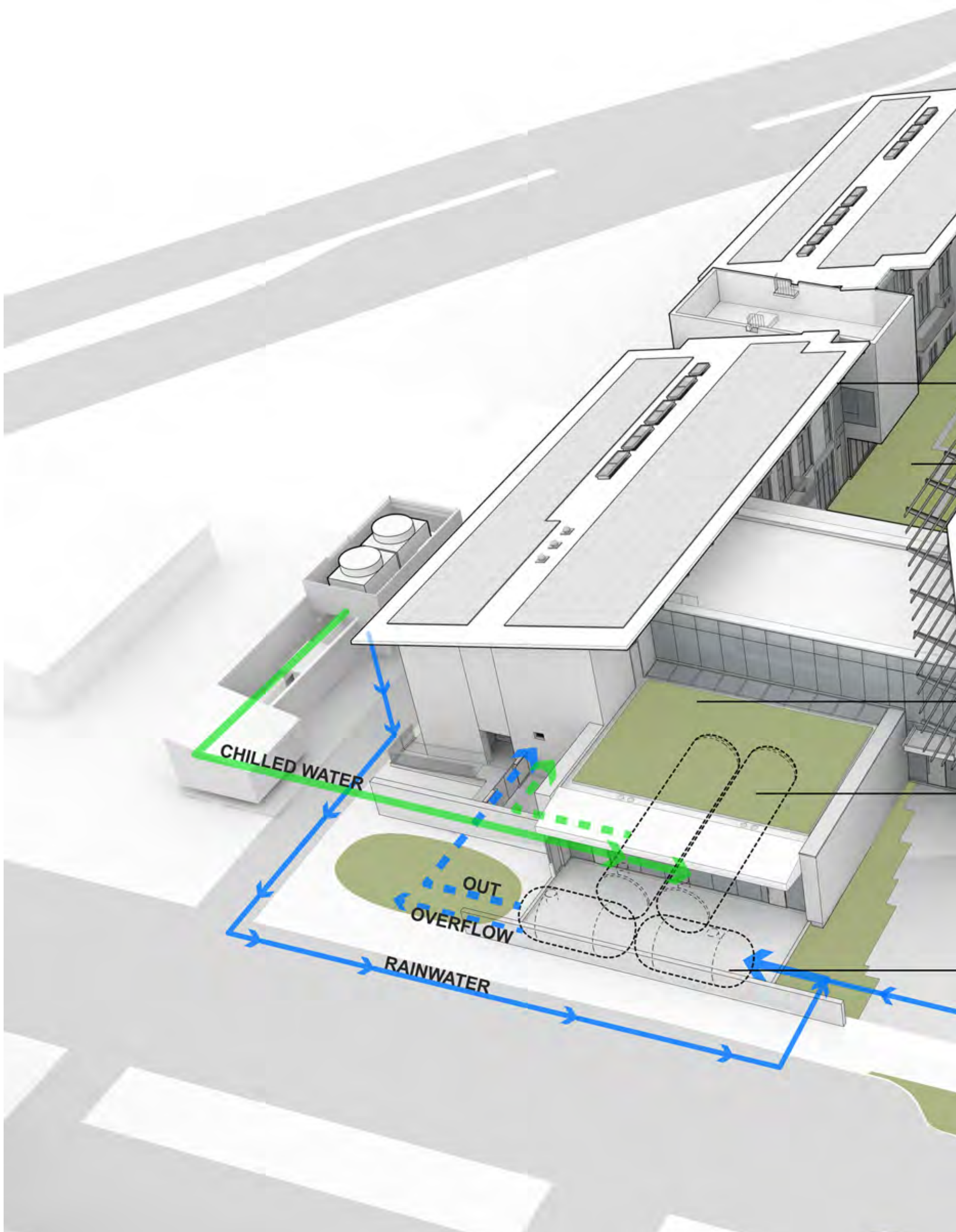
The Headquarters site is a triangular-shaped block in downtown Los Altos, CA, which was required to accommodate roughly 50,000 sq. ft. of building, parking and programmatically useful exterior space. Concept design studies, which included analysis of building forms to optimize thermal characteristics and daylighting, led to a two-wing, two-story scheme with a south-facing courtyard between the two narrow office blocks.

The narrow office blocks spaced apart by the green courtyard also provided opportunities for cross ventilation via openable windows in all office space. The shape of the site and the alignment of the city's local grid required the arrangement of primarily east- and west-facing facades. Given the warm climate in this location, this building massing required attention to proper solar control on windows while, at the same time, allowing ventilation and daylight openings.

Courtyard View Looking South (below)


PHOTO: JEREMY BITTERMANN

Programmatically, the office space was organized into twelve *neighborhoods*, some of which opened directly on to the central courtyard space. The neighborhood was a planning device that allowed the organization of certain services, including for example a print station to reduce the number of electrical printers normally at each workstation at that time. It also was initially thought of as a basis for the behavioral approach to energy conservation. (See below.)



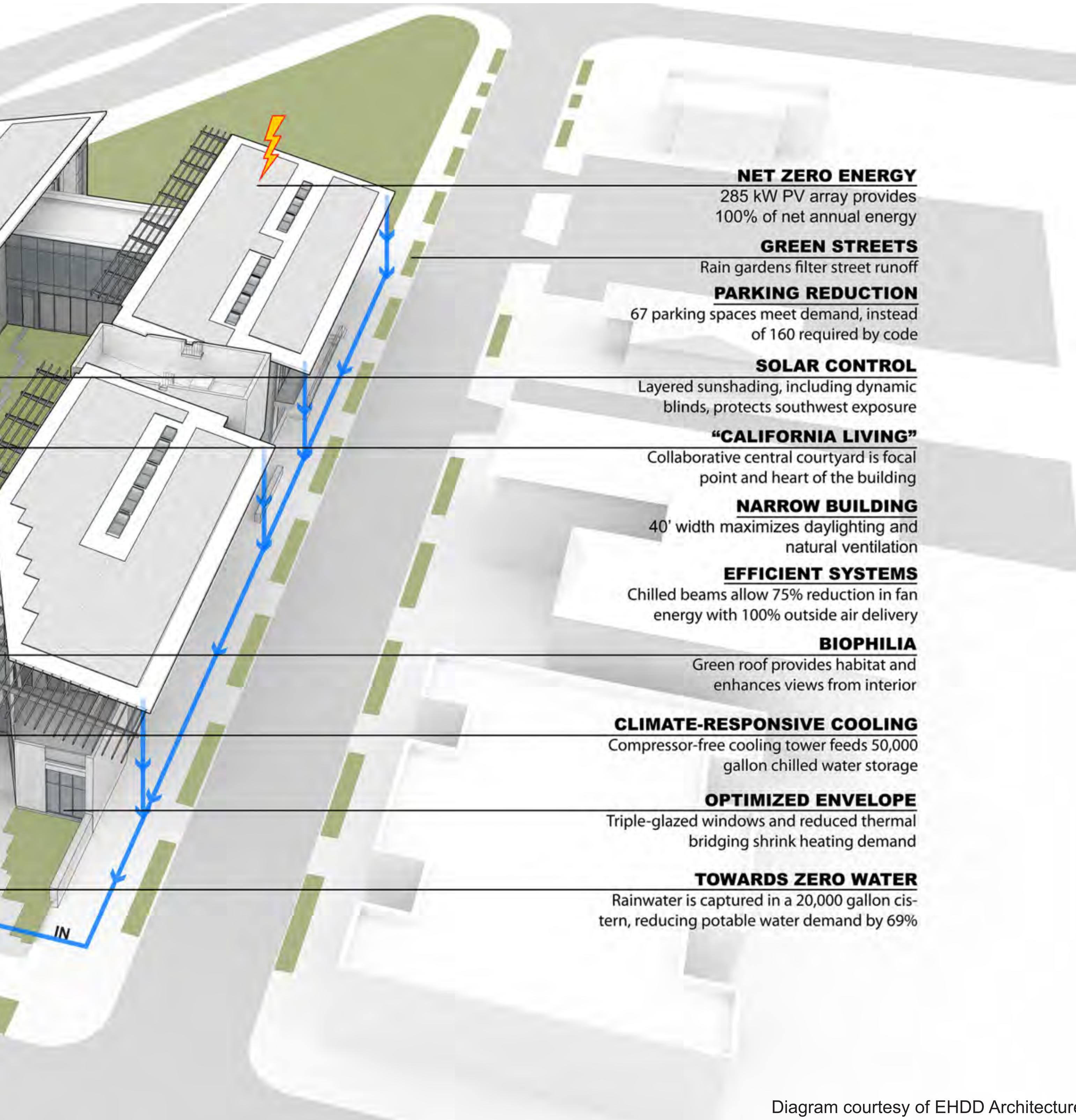


Diagram courtesy of EHDD Architecture

(Above) Overhang design for east-facing facade, allowing maximum daylight penetration while protecting against direct sun.

Building Envelope

The high perimeter building allows for good natural ventilation and effective daylighting of office space, but also increases thermal losses. Energy analysis indicated that the high perimeter envelope would result in lower energy demand when all factors are considered.

The building envelope satisfies two general requirements for a low-energy building: a high level of continuous insulation and a good seal at joints and other air leakage locations.

To avoid the *thermal bridging* effect of intermittent structural elements, the wood framed walls locate studs every 24", with a 1" thick layer of rigid mineral wool insulation applied continuously over the outside of the studs. The insulation between the studs is also mineral wool, which is preferred over fiberglass insulation for its higher insulating value, stiffness (avoiding loss of insulating value in handling at the construction site) and greater resistance to mold development. The net result is a wall with insulating value R-24.2, including the muted effect of *thermal bridging*.

The roof has a similar insulating approach, using a 2" thick layer of rigid mineral wool insulation over the structure and under the metal roof. Finally, for added insulating value, the concrete slab is placed on top of water-impervious insulation board to provide a high insulating value of R-23 in the floor. The 1" rigid wall insulation layer wrapping the wall continues below grade to provide perimeter insulation at the footing.

Windows make up almost 50% of the exterior wall area, which supports good daylighting of the largely perimeter spaces. To ensure good thermal characteristics of this part of the building envelope, the window glazing consists of *heat mirror* glazing units—two layers of clear glass with a suspended *heat mirror* film. A financial analysis indicated that the specification of this type of window would result in cost savings from a reduced size heating system and, more significantly, the planned solar photovoltaic system, which would more than offset the added cost of this premium glazing. (It is generally true that energy efficiency measures incur less cost than the corresponding energy production systems.)

(Below) Daylighting via skylights at interior conference room. *(Opposite page)* Automatically operating exterior blinds on west-facing facade.

Daylighting and Shading

With a building wing width of approximately 45 feet, good daylighting is possible virtually throughout the space. To ensure daylight penetration to the center, light shelves are added to direct the incident skylight inward. Because of the predominant east and west orientation of the long facades, the light shelves operate well for half the day, when the direct sunlight is incident on the opposite side of the building wing.

When direct sunlight is incident on the façade, exterior blinds are automatically operated to a position in front of the window and the blind louvers adjusted to block direct sun and to pass through diffuse daylight. The operation of the blinds still allows windows to be opened by the room occupant for natural ventilation purposes if the outdoor air temperature is appropriate. The occupant has control of an interior shade system, but the exterior blinds are operated by the building control system. Changes to the operation of the exterior blind system, which can be done on an individual basis, is carried out by reprogramming the control system. This is relatively easy to do given the sophistication and siimplicity of the control system interface. (See the discussion of the building control system on the following page.)

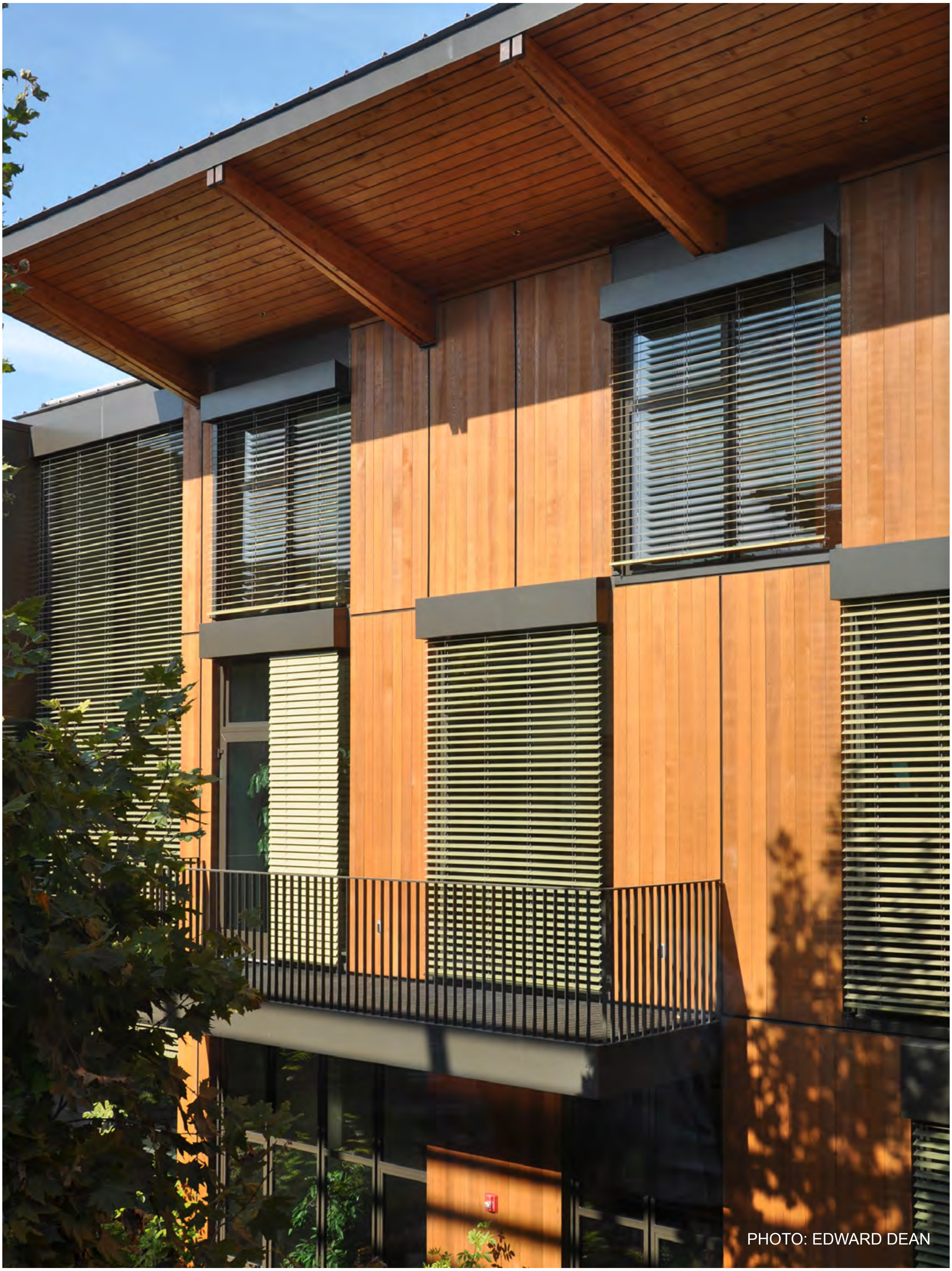
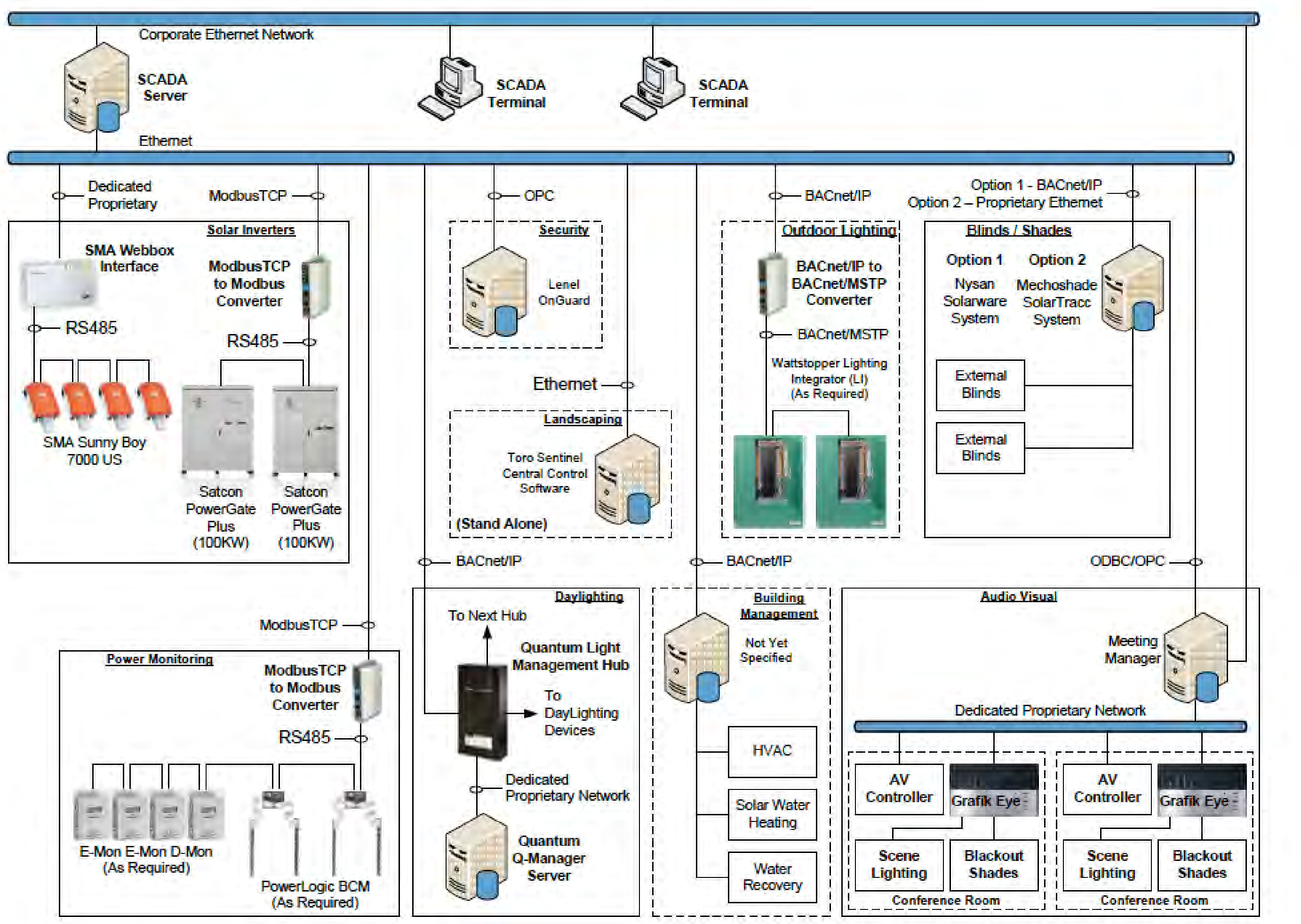


PHOTO: EDWARD DEAN



(Above) Diagram of the custom *automated control system* or *master control system* developed by Packard Foundation IT staff. (Diagram courtesy of Packard Foundation)

Controls

Zero net energy buildings by necessity are *smart buildings* since all the building features and systems, to be as energy efficient as possible, respond to changing weather, solar, daylight and occupant use conditions on a daily and seasonal basis. In the past, this changeability was met largely through the expenditure of energy, usually to overpower the variations in time. In current highly energy-efficient buildings, especially buildings of a larger size, the response to changes in conditions is carried out to some extent by occupant intervention, but it is primarily done by sophisticated building control systems.

Each building sub-system, whether it is lighting, daylight sensors, HVAC controls (BMS), CO_2 sensors, solar photovoltaic production or automatic blinds, generally has a unique set of processing protocols for its control system. As the need has grown for coordinating these systems for monitoring and data reporting purposes, the building controls industry has responded with integrating systems that “sit on top” of the component control systems. This is new technology and, as might be expected, communication issues sometimes make this a functional problem point during the early operation period of a *smart building*. (See discussion in later case studies in this monograph.)

While newer integrating controls systems are beginning to emerge in the industry, the Packard Foundation decided to invest in the custom development of its own version of such *automation controls*, given the importance of building operation in the success of the project. After all, the project location is the heart of Silicon Valley and the Foundation’s IT staff was eager to take on such a challenge. To increase the challenge, all possible building operations were to be part of the automation control system, including room scheduling, security and audio-visual systems. A simple web-based interface was developed to allow easy control by the building operations

(Above) Interior light shelves to improve daylight penetration in exterior office spaces.

manager as well as access to building performance information by others. A diagram of the *automated controls system* developed for this project is shown on the opposite page.

The Packard Foundation regarded the development of this system as a “grand experiment”, its technical contribution to the success of this particular project. But the Foundation also regarded this as a pioneering effort in an area of technology that needs to be improved quickly, with plans to share this information with the building industry so that future zero net energy building projects can use this type of system “off the shelf” with low perceived risk.

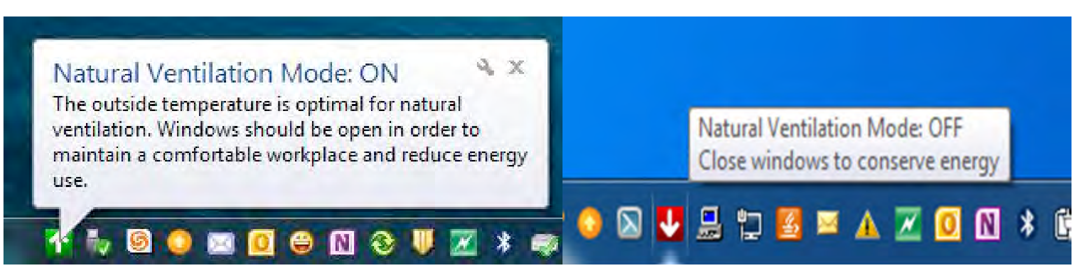
This innovation, developed by the client’s own staff of experts, has demonstrated successful operation over its entire occupancy period to date and is largely responsible for making this particular case study a new paradigm for building design.

Natural Ventilation

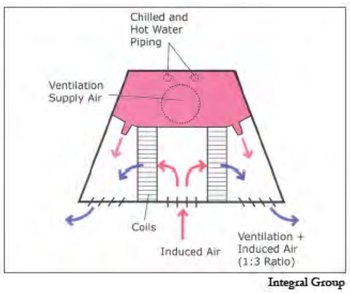
The building control system manages the operation of the exterior window shading, but the room occupants have complete control over the openable windows. The HVAC system is capable of meeting all cooling and fresh air requirements, so the natural ventilation is intended to provide users with a sense of control over their own comfort conditions as well as to reduce the cooling load when used by the occupants. This has two good outcomes: (1) user perception of a zero-net-energy building is one of comfort rather than the opposite; (2) HVAC cooling temperature setpoints can be higher than standard since the air movement of natural ventilation provides a sense of cooling comfort at higher air temperatures.

As a guide to the occupants about managing their own environments for comfort and low energy use, the Packard Foundation IT staff created some simple *apps*, so to speak, to alert them about changing outdoor conditions and as an advisory about beneficial actions to take if they choose to. Residing in the dock of each occupant’s computer monitor is a *natural ventilation status icon*—either a green up-arrow or a red down-arrow—which his set by the building’s *automation control system*. When the green arrow is present, windows may be opened for natural ventilation; when the red arrow is present, windows are recommended to be closed. When conditions change from one to the other, a pop-up similar to an email notice appears on the monitor as an alert. (See illustration below.)

These unobtrusive visual devices, while guiding user intervention in the operation of the building systems, nevertheless allow the occupant to determine the best personal conditions for comfort.



(Left) Image on computer screen of all staff, showing natural ventilation app and pop-up notices about option to open windows.(Image courtesy of Packard Foundation)



Active Chilled Beam
(Images courtesy of Integral Group)

Heating, Ventilation and Cooling Systems

The mechanical heating, cooling and fresh air ventilation systems are designed around the principles of utilizing the highest efficiency type of heating and cooling equipment, minimizing electricity-driven fan use, reducing energy loss due to the sheer amount of air ductwork to and from a building central plant and due to pressure drops in air ducts.

A high-efficiency air source heat pump (865 MBH) satisfies the first principle. When space heating, the heat pump delivers hot water to large thermal storage tanks, from which it is piped at 105°F to distributed local air handlers. During an early morning warm-up period, this system heats the building to a stable temperature that is basically maintained in this climate through normal internal loads only.

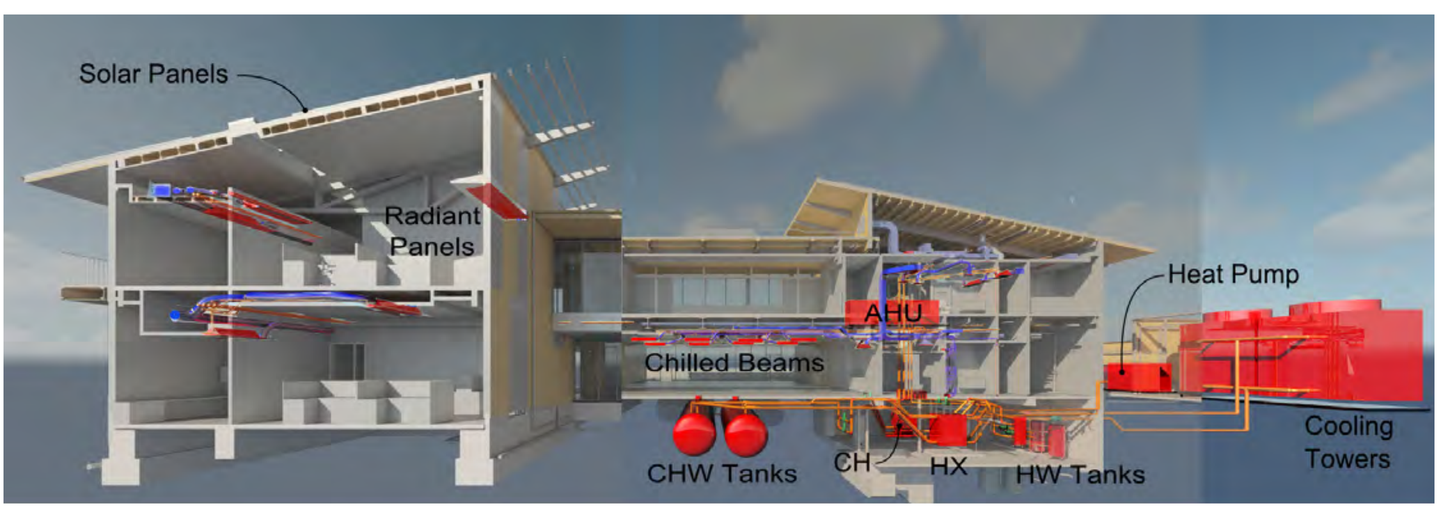
During the cooling season, a two-cell 480-ton cooling tower is used at night to create 50,000 gallons of chilled water via evaporative cooling, to be stored at 58°F in a chilled water storage tank for the following day's use. This off-peak cooling operation reduces energy cost due to lower utility rates at that time. For extreme cooling conditions, an 80-ton water-cooled chiller can be brought online to cope with daytime peak events.

To minimize electricity-driven fan use, rather than a single building central plant with the long duct runs to and from the plant, the system uses the set of distributed local air handlers mentioned above to provide 100% fresh air locally to the air distribution system of *active chilled beams* placed in the ceiling of the occupied space. The smaller fans used in these local air handling units inject the air near the chilled beam component, inducing room air to flow through the chilled beam and mix with the ventilation air. (See illustrations at left, above.)

The induced mixing of the air reduces fan power requirements as compared with alternative air distribution systems and allows the injected air to be at a higher temperature (68°F for the chilled beams).

Finally, the design engineers adopted the mechanical layout approach of *low pressure drop design*. Using 45° fittings instead of 90° elbows and specifying larger duct sizes significantly lowers air pressure requirements and therefore fan power requirements.

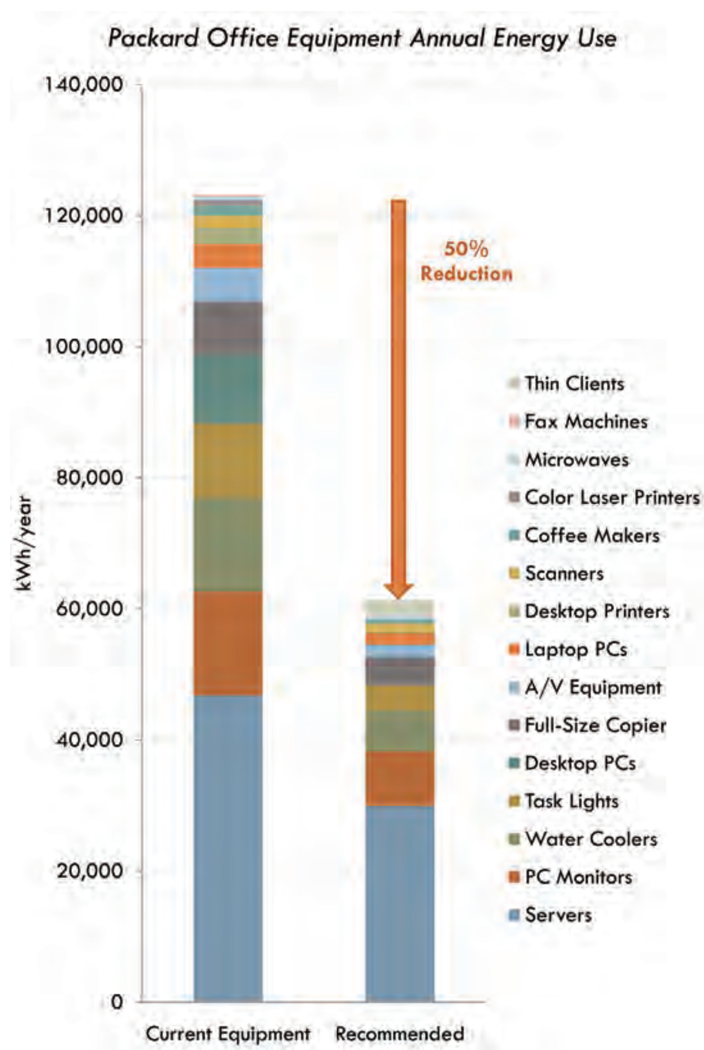
(Below) Mechanical System Diagram from Revit Model (Courtesy of Integral Group)



Plug Loads

During the early design phase, when energy analysis indicated that a large portion of the electrical load to be supplied by the solar photovoltaic system would be plug-in equipment loads, or *plug loads*, the design team realized that a better understanding of this type of load was needed in order to size the system properly. Following the concept of investing in energy efficiency to reduce the cost of the renewable energy production system, it became clear that identification of all equipment and selection of the most energy efficient type for the new building would provide the most cost-efficient design.

The team looked at typical office equipment, including desktop computers, servers and other types of common devices, in order to recommend low-energy brands and types of machines to be installed in the new building. The EPA rating *ENERGY STAR®* was found to be a reliable indicator for low-energy performance. From this research, an inventory of equipment was established that reduced the plug load by 50% compared to typical office buildings.



(Left) Plug Load Study result. (Diagram courtesy of EHDD Architecture)

Renewable On-Site Energy Supply

The on-site renewable energy system, a 285 kW (DC) solar photovoltaic system, has panels located on the building roofs and at the parking canopies. The shallow roofs slope toward the east and the west, but the efficiency loss is small (estimated to be 5%-10%) compared to the optimum slope and orientation, easily compensated by the addition of a few extra panels.

Lighting

High efficiency light fixtures using T-5HO lamps were used in standard office spaces, for an average lighting power density of 0.7 watts/sq. ft. The overall design of the electric lighting follows the *Task/Ambient* approach, namely ceiling-mounted suspended fixtures and task lighting at each workstation. This approach recognizes that less light is needed for walking around than

for the work tasks and uses two types of light fixtures to produce the minimal comfortable light levels needed for each, resulting in a reduction in the amount of energy needed to light the entire space.

Lights are dimmed in response to daylight sensors and switched on in response to infra-red occupancy detectors. In the private offices, there is a combined infra-red detector and an ultrasonic detector to control on/off. By combining the two, false detections by the highly sensitive ultrasonic device, capable of detecting slight keyboard activity, are avoided since the infra-red must confirm the presence of an occupant.

Because the technology was not advanced enough at the time that this building was designed, LED light fixtures were not specified. (Recent improvements in the technology would likely have led to a different specification for both linear pendant fixtures and downlights.)


PHOTO: JEREMY BITTERMANN

Commissioning

Given the innovation level of the building design, the entire project team planned a thorough approach to the commissioning process for this building. Initially, a group called the *Post Occupancy Services Team,* or *POXc*, worked to ensure that the building was operating properly at start-up. Shortly afterward, a follow-up group called the *Tiger Team* was formed to manage operations from move-in to completion of post-occupancy commissioning. Included were the beginnings of energy measurements and communicating with building occupants about building performance.

Occupant Behavior ("User Commissioning")

The Packard Foundation leadership recognized that building users have as much a role as the designers and builders in achieving the goal of ZNE performance. Communication of information about the building's features and performance was central to promoting supportive behavior on the part of the occupants.

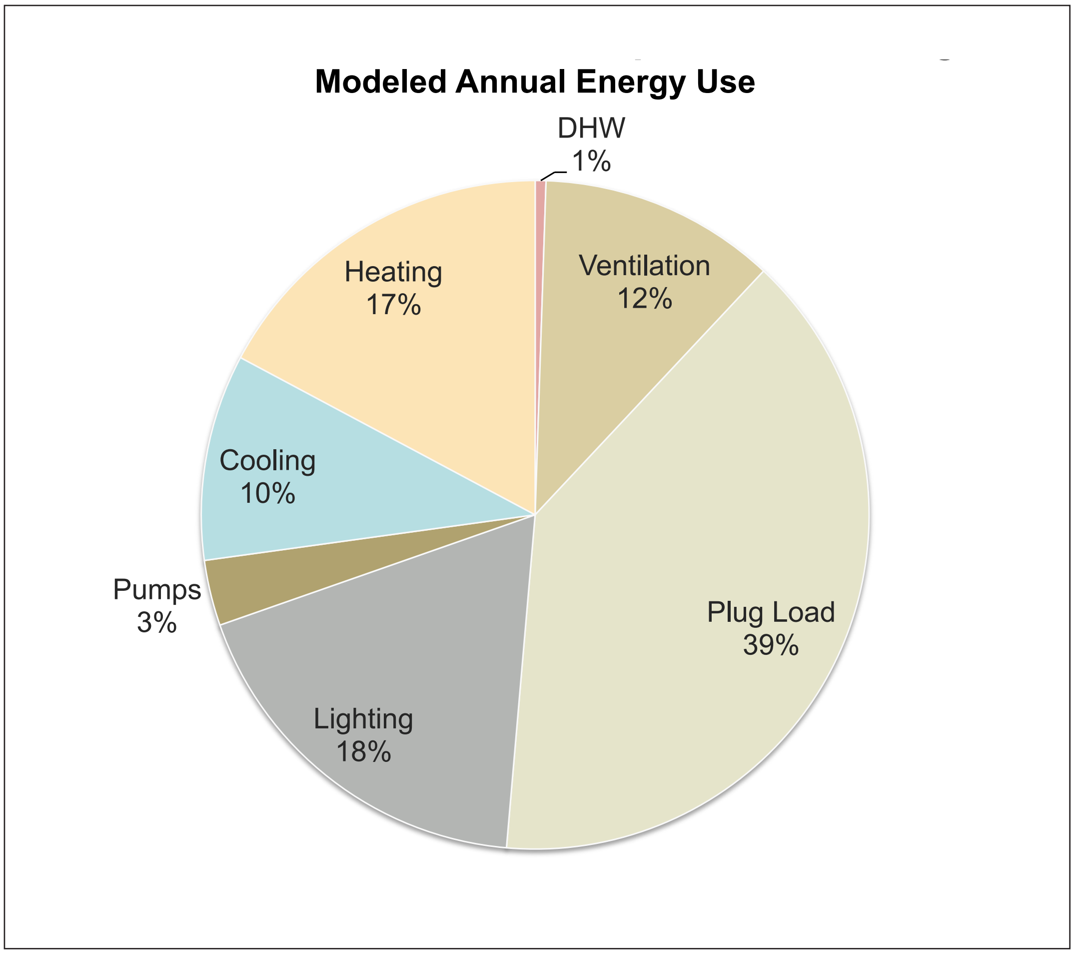
Initially, the idea of user engagement was very proactive, with the selection of "neighborhood ambassadors" from each of the twelve office neighborhoods created in the initial planning process. The idea was that the ambassadors would inform themselves about the building's sustainability features, track performance and communicate back to their neighborhood co-workers. In the end, this proved to be marginally important because of how well the building itself communicated with occupants (via the prominent dashboard screen at the building entry as well as ready access at each staffperson's monitor) and because the building provided such an apparent level of comfort for the occupants. An example of the former is the installation of a *natural ventilation status icon* described in the paragraphs above.

Building occupants are not required to respond to these system cues with the designated behavior, but rather to do whatever is comfortable for them as individuals. The fact that the building remains very comfortable has lessened the sense that behavior control needs to be invoked for any reason. The building continues to perform at the ZNE level with the range of behaviors of the building occupants.

Energy Design Analysis and Energy Performance - *Modeling versus Initial Post-Occupancy Measurements*

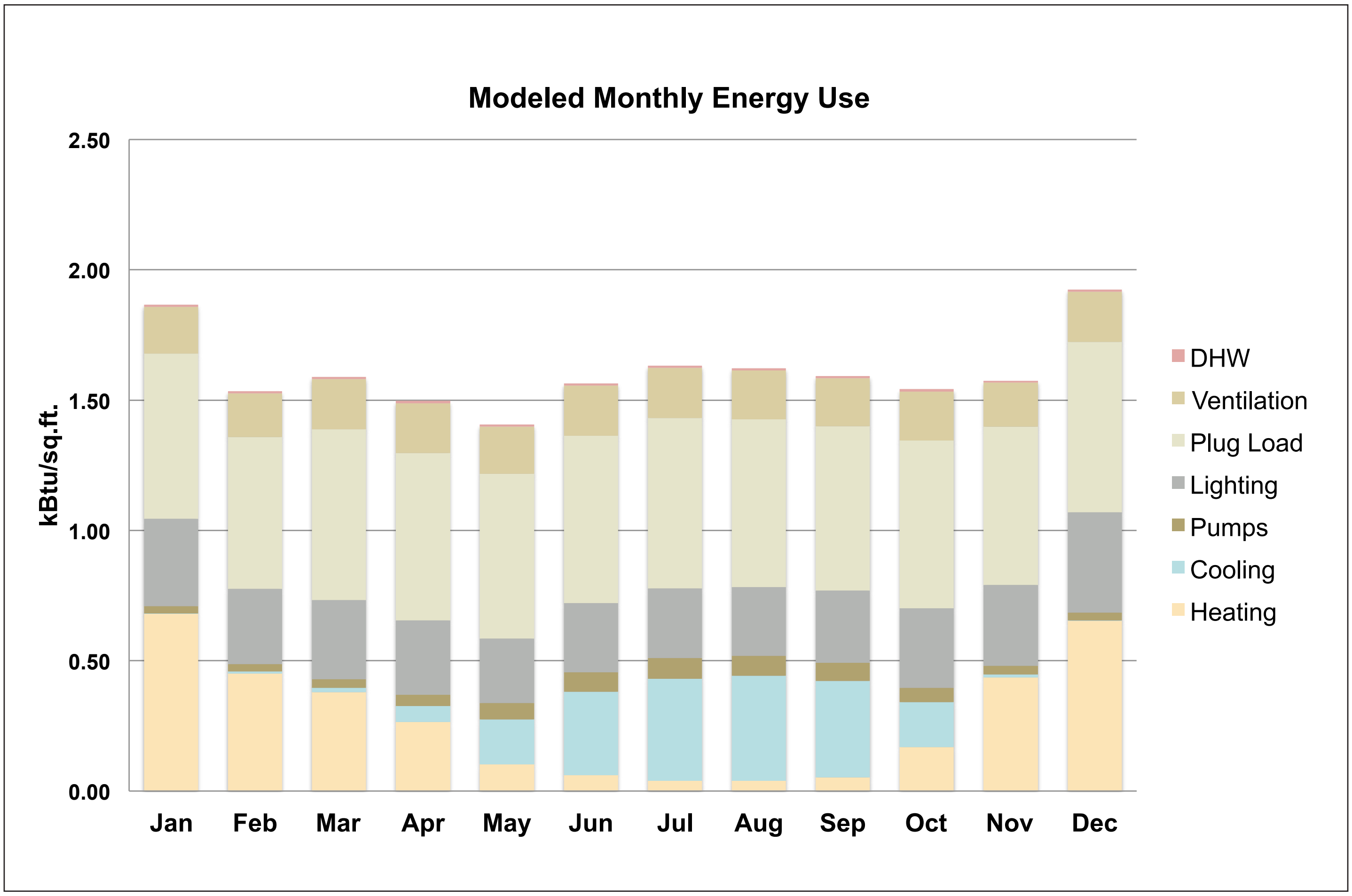
Energy Use – Modeling

The modeling for the Packard Foundation Headquarters office building was carried out using eQuest version 3.64. In the final analysis, the model showed a predicted EUI of 19.4, an energy demand value that could be met using solar photovoltaic panels in the building roofs alone. Since the impact of occupant behavior on the actual demand was unknown, additional panels were placed on canopies over the visitor parking area as a conservative cushion to guarantee ZNE.



Modeled Energy Use (Annual)

278 MWhr per Year
Modeled EUI = 19.4



Energy Use – Actual Measurement and Comparison to Modeling Results

The Tiger Team and the full-time building engineer have aggressively pursued a thorough post-occupancy commissioning process and promoted staff engagement in the goal of maintaining a ZNE performance through the early years of occupancy. Daily monitoring and trouble-shooting have kept the building on track to achieve this goal. The lobby dashboard display, available also on individual desktop monitors, is watched carefully for any trending away from the ZNE track.

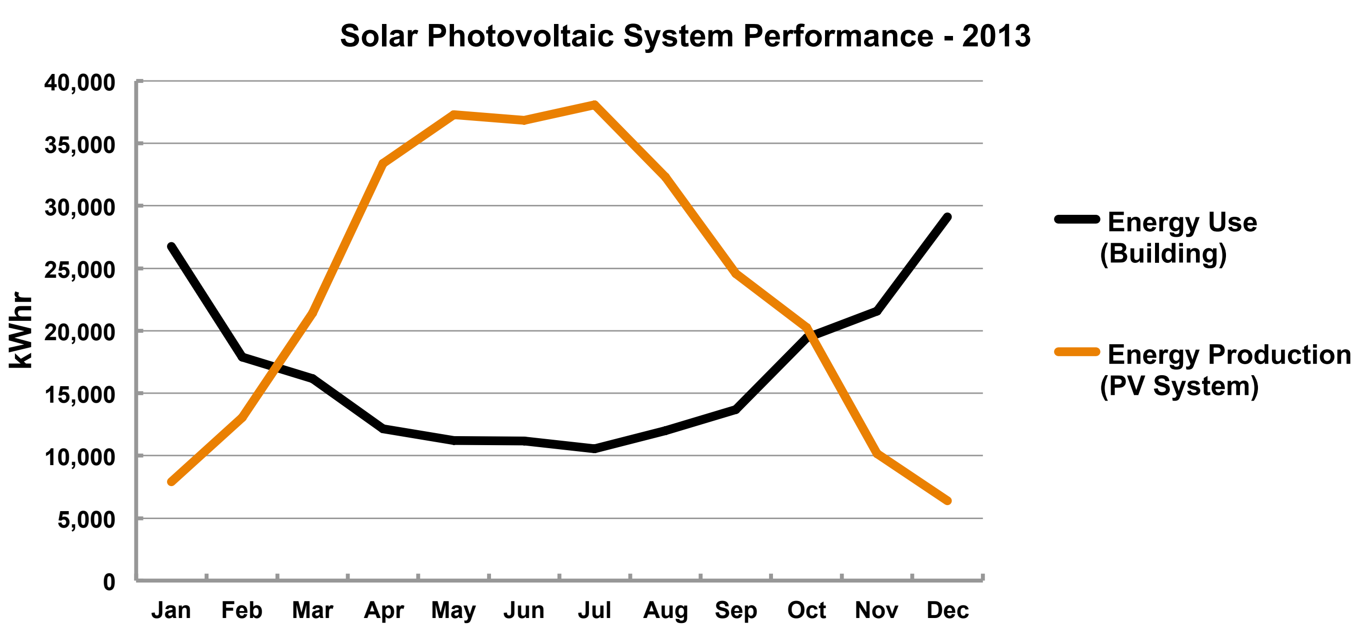
The metered data for energy use through the entire year of 2012 shows that the building's performance is very close to the modeling prediction overall. It's interesting to note, however, that the heating energy use was higher than modeled, while the cooling energy consumption was less. The design engineers report that this is a pattern that is observed on other low-energy buildings as well—heating energy consumption is often underestimated by the modeling programs. It is thought that this is due the general effects of thermal bridging and assuming that the envelope can be built within a small tolerance, especially with regard to building tightness. Gaps in insulation installation and failure to seal points of air leakage during construction likely lead to higher actual heating loads than calculated in the ideal models.

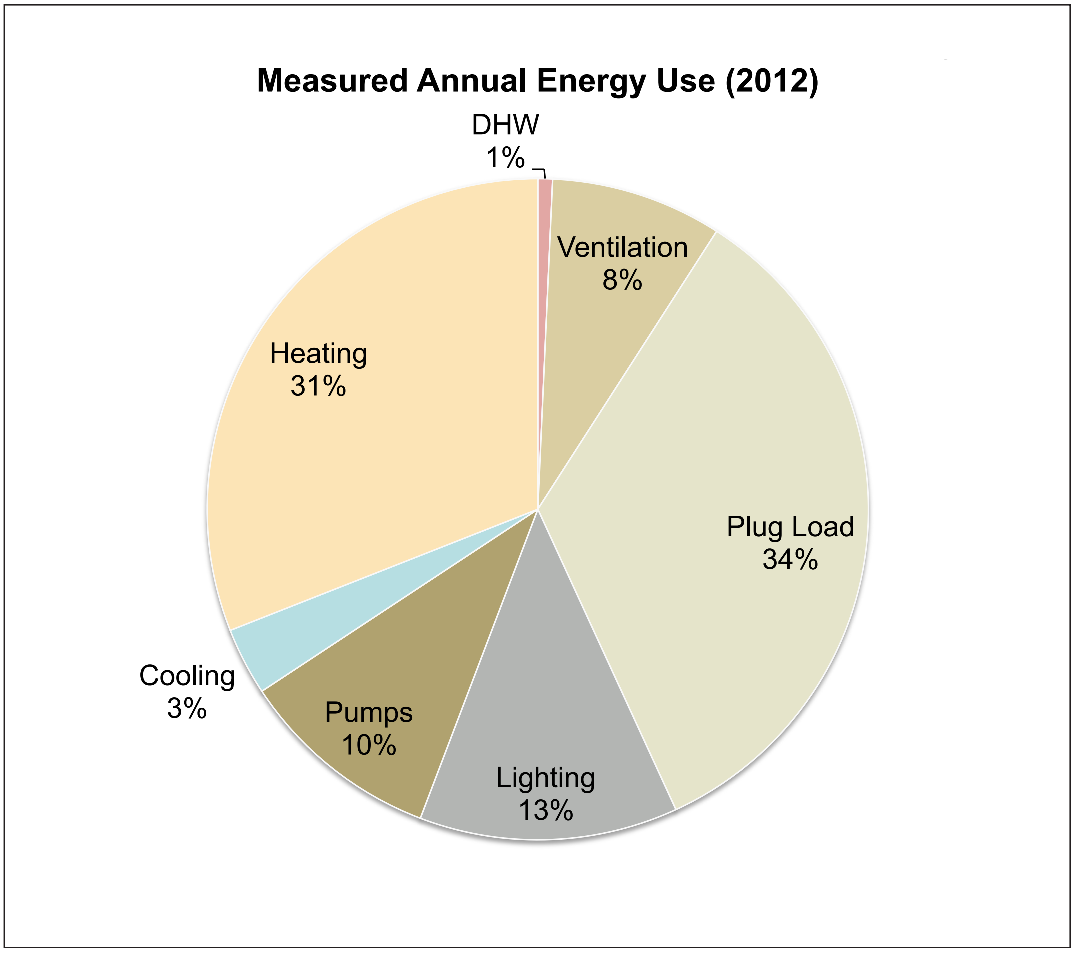
On the other hand, the lower cooling energy may be partly due to an initial assumption that dehumidification would be needed to ensure that condensation does not occur on the active chilled beams. The attentiveness of the building occupants to natural ventilation and other interventions that reduce cooling demand may also have been a factor.

Energy Production versus Energy Use — Zero Net Energy Performance

The extra solar photovoltaic generation capacity installed as a guarantee of ZNE performance proved unnecessary in 2013. This was an exceptionally clear year with California experiencing virtual drought conditions and the level of energy production was high. The graph immediately below displays the renewable energy production of the solar photovoltaic system compared with the energy used by the building over the course of the year 2013.

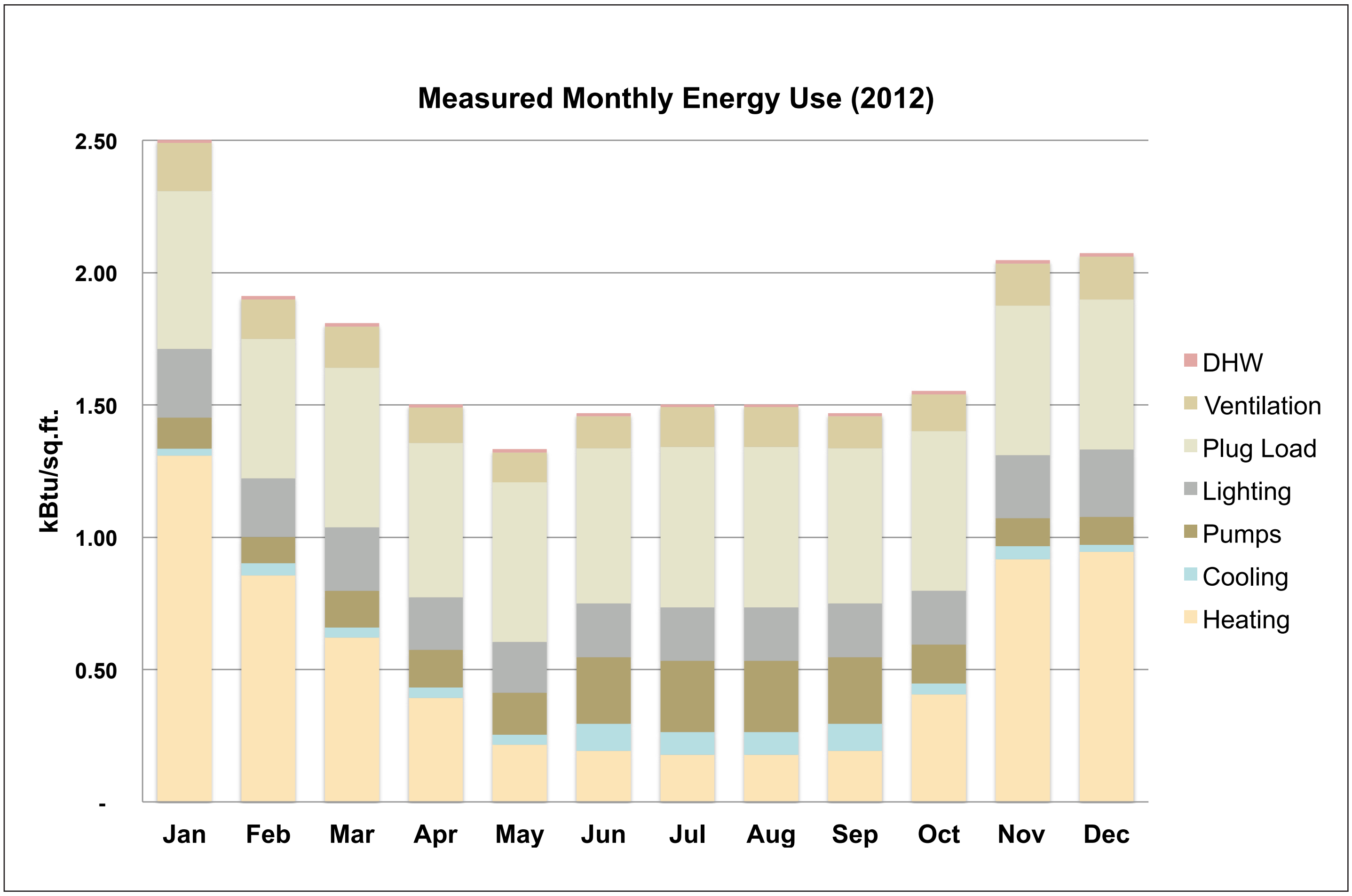
The "accumulated" net energy curve in the graph on p. 22 shows the net energy balance as the year proceeds, with the building initially using more energy than produced in the winter months and then reversing the balance through the sunny mid-year. A *zero net energy* building would end the year in December at the zero line, indicating a net zero balance of energy production and use. Given the high net annual production, the Packard Foundation Headquarters Building was a net-energy-producing building in 2013.

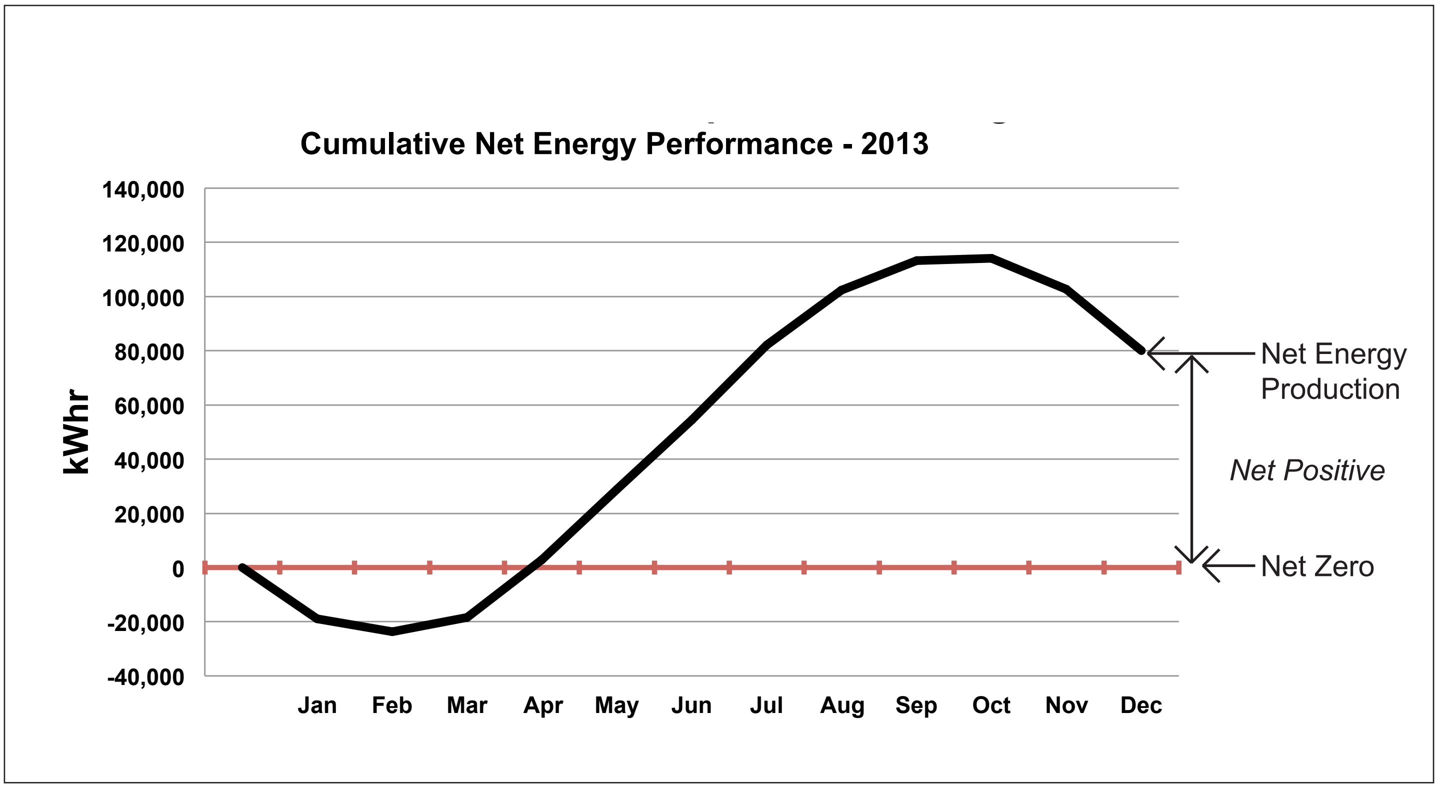




Measured Energy Use (2012)

298 MWhr per Year
Actual EUI = 20.7





Post Occupancy: Observations and Conclusions

Post-Occupancy: Controls and Monitoring

The strength of the monitoring and data collection activity is a model of its kind. The ease of access to the data reporting as part of the overall *automated controls system* provides virtually instantaneous feedback to the occupants and the managing building engineer. Aside from an initial minor failure at one of the inverters on the solar photovoltaic system, which was quickly corrected, all systems communications have worked as intended.

Post-Occupancy: HVAC

Soon after occupancy, the air source heat pumps failed, creating a cold building in the morning and immediately raising questions among the building occupants about the relation of the failure to the ZNE design. The cause was determined to be the inability of the specific type of heat pump, residential in quality, to operate effectively in a commercial application such as this comparatively large building. The replacement heat pumps were specified to be a hardier type of equipment, more capable of operating near or at their lower temperature limit, and the operation has been without incident since.

Packard Foundation leadership reported that some discussion about this event was necessary to make the point that the heat pumps were not the innovative basis for their new approach to building design. The analogy discussed with staff was that the organization's new "hybrid car" just had several tires unexpectedly go flat. However, this failure event had the unfortunate effect, according to the design engineers, of generating a "myth" that the building does not have the heating capacity that it needs.

The system of distributed air handling units serving the active chilled beams did not employ any heat recovery components on the relief air. With the experience of the first year of operation, the design engineers now regard heat recovery with direct outside air systems (DOAS) as an important feature to include in future designs. The design engineers also note that larger thermal storage for heating would have improved performance when in heating mode.

With regard to cooling, the Foundation ultimately approved a small rise in the chilled water temperature as it passes through the active chilled beams. This is more energy efficient and reduces the amount of time that dehumidification is required. The dehumidification feature is now used only in summer and is not needed during the swing seasons or winter.

Post-Occupancy: Natural Ventilation

Over the course of 2013, the building users used the natural ventilation features as planned and it was discovered that the occupants availed themselves of outdoor air even when it was at relatively high temperatures. The system initially signaled the occupants using the monitor alert system described above to close windows when the outdoor air temperature exceeded 65°F, admittedly a conservative setpoint. As the occupants experienced the system over time, the building engineer adjusted this setpoint to higher temperatures. There are now days when the outside air temperature is 70°-75°F and the office spaces are fully naturally ventilated and the mechanical cooling system is turned off.

Post-Occupancy: Lighting

Initially, there was a post-occupancy commissioning issue with the daylight sensors. The light fixtures in the office spaces were dimming up and down over short periods, creating an annoyance to users. The cause was the direction of the daylight-detecting photocells associated with the light fixtures, which were incorrectly aimed at wall surfaces that brighten when lights were turned on and darken again when lights are turned off. The cycling of the lights resulted from this cycling change in wall brightness. By aiming the photocells where only daylight would be perceived, the cycling of the lights was eliminated.

The design engineer found that the instructions for directing the photocells were not included in the shop drawings for installation. A contributing factor was the change in third-party pre-occupancy commissioning agent for the lighting in the middle of the process and a failure to communicate the issue properly.

Post-Occupancy: Energy Metering Systems

After the first three months of operation, the metering system installed in the Packard building was found to be missing data. For energy use, there is an overall energy use meter and sub-metering for each circuit at the panel boards. PG&E's meter at the point of service entry is very accurate and it was known that the individual metering of the solar photovoltaic panels was also accurate. The difference between the two should have equaled the total recorded by the building circuit meters. However, about 5% of the data appeared to be missing.

The issue was determined to be incorrect sizing of the current transformers (CT), which were too large for a building with such low electric loads. Replacing the CT's allowed the meters to detect all of the lower levels of current and the readings were confirmed to be correct. As a result, however, several months of performance data had to be abandoned. With the end of 2013, the building was able to confirm one year of good energy data for reporting.

Post-Occupancy: Plug Load

At the time of move-in, the Packard Foundation IT staff introduced virtual server software (*VM-Ware®*) to the building network, which reduced the number of servers required for the system. This in turn made the pre-purchased UPS system oversized for the actual server load. The IT staff noted that about 1/3 of the capacity of the UPS was not being utilized, though the equipment had to be fully charged. As an example of creative load reduction, the IT staff tapped into the available unused power for use with audio-visual equipment. Load reduction can be fixing a wasteful problem, but it can also be squeezing more energy out of a system in creative ways.

Post-Occupancy: General

Measurement and reporting of energy use is essential to tune the building's operation and to reduce energy use. This metering and reporting delivers a large amount of data that needs to be processed by the client's building management staff. Well-conceived building management software similar to that developed specifically for this project will make this task significantly easier and lead to more efficient operation of ZNE buildings. This particularly successful aspect is one of several that are helping to shape the state-of-the-art of ZNE buildings.

CASE STUDY NO. 2

Stevens Library at Sacred Heart Schools

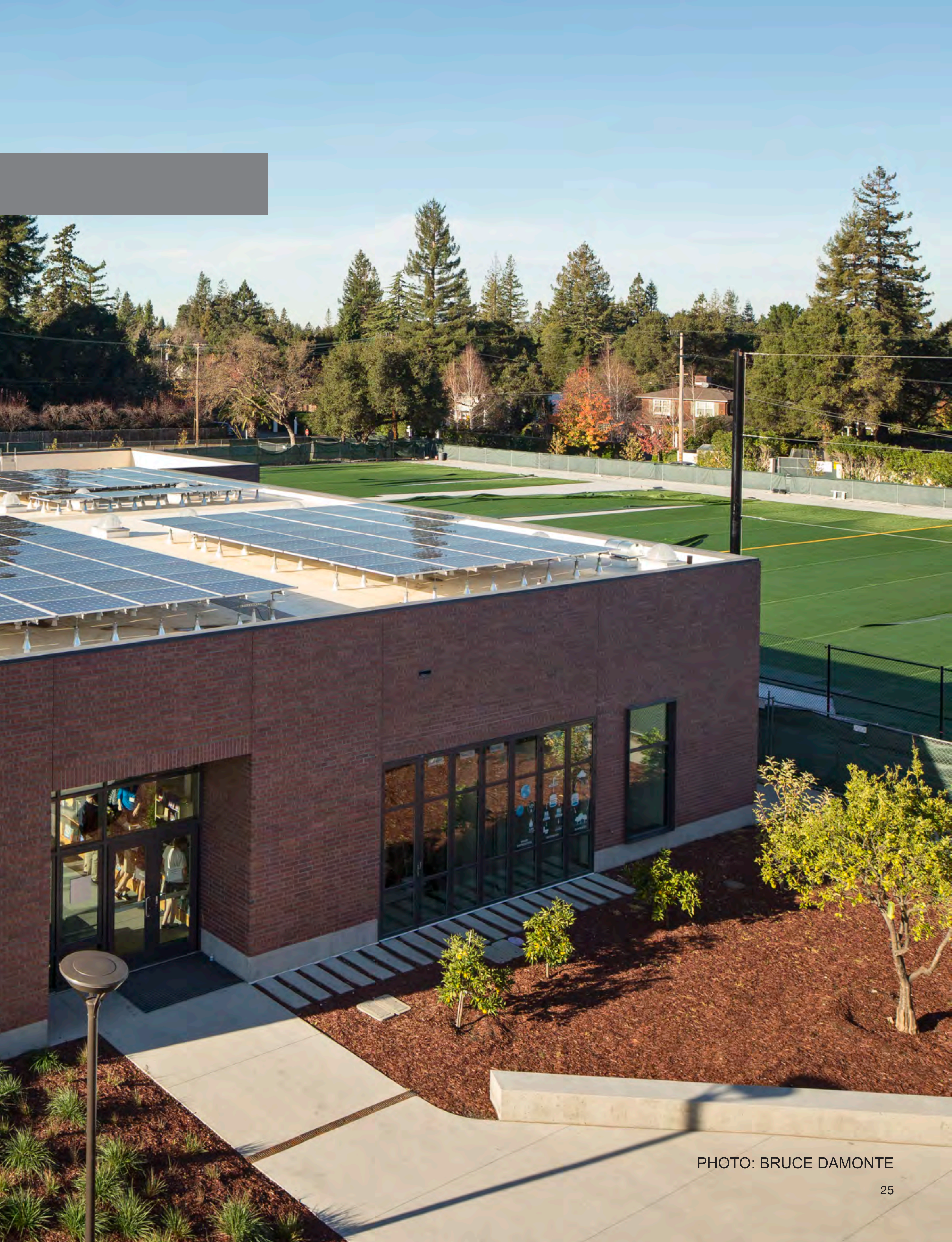


PHOTO: BRUCE DAMONTE

Stevens Library at Sacred Heart Schools

Case Study No. 2

Data Summary

Building Type: K-12 School Building

Location: Atherton, CA

Gross Floor Area: 6,300 gsf

Occupied: September 2012

Energy Modeling Software: eQuest version 3.64

Modeled EUI (Site)
27.0 kBtu/sf-year

Measured EUI (Site)
16.9 kBtu/sf-year (2013)

On-Site Renewable Energy System Inatalled
40 kW (DC) Solar PV

Measured On-Site Energy Production
53,730 kWhr/year (2013)
29.1 kBtu/sf-year (2013)

Owner/Client
Sacred Heart Schools

Design Team

Architect: WRNS Studios, San Francisco CA

Structural Engineer: Hobach Lewin, Palo Alto and San Francisco, CA

Mechanical / Plumbing / Electrical Engineer: Interface Engineers

Lighting Designer: Interface Engineers

Landscape Architect: BFS, Palo Alto, CA

General Contractor
Herrero Brothers

Elementary and high school ("K-12") projects are very good candidates for achieving ZNE design and performance because they are generally one or two stories in height with good opportunities for daylighting and sufficient roof area for the right-sized solar photovoltaic system. The Sacred Heart Academy Library, completed and occupied in 2012 as part of the new Lower & Middle School campus, exclusively serves the small K-8 campus and is intended as an educational demonstration of environmentally sustainable design.

The building is seeking *Net Zero Energy Building Certification* under the Living Building Challenge. It is also being monitored by a third party measurement and verification team under the *Zero Net Energy* program activities of the Pacific Gas & Electric Company.

Background

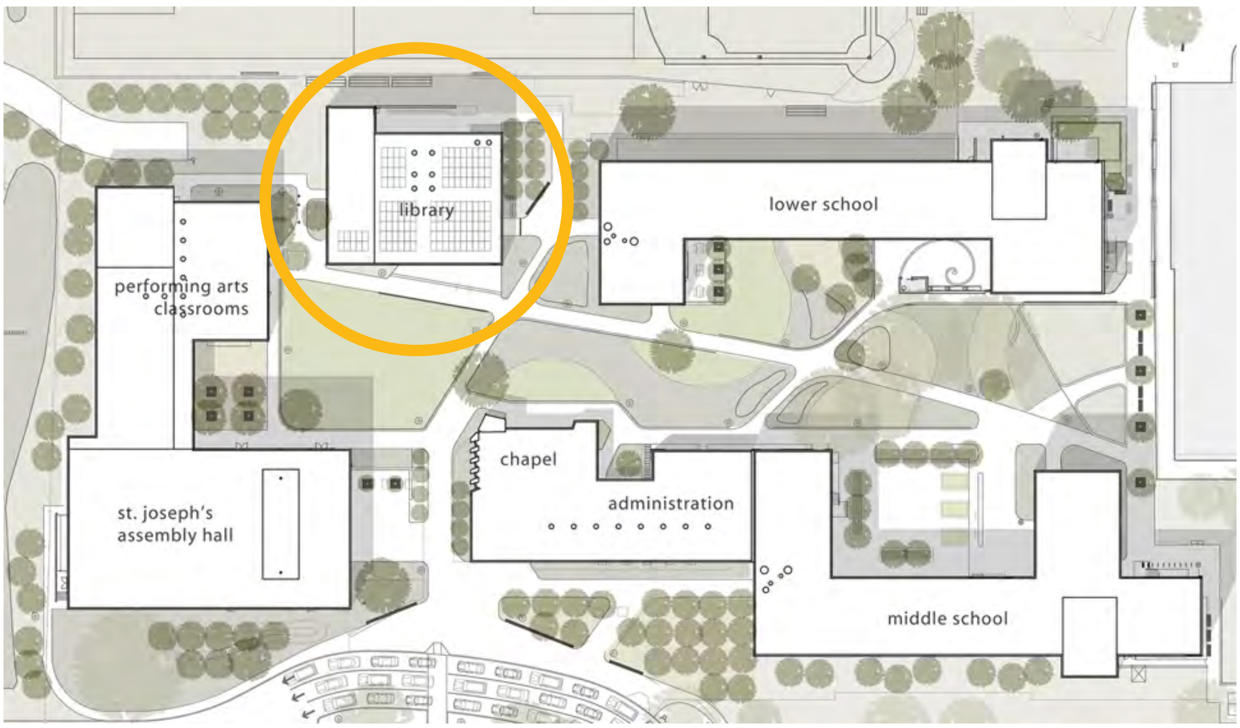
Sacred Heart Schools launched a building program for a new K-8 campus, completing four new buildings by the fall of 2012. This client was guided in the planning of these buildings by one of the five goals of the organization's educational programs, namely "to teach students to be stewards of the earth's resources." To this motivated client, this educational goal meant that the new building program should encompass the core concepts of sustainability.

The A/E team was commissioned to design these four buildings to a high level of sustainable design and approached the design of each with the same type of integrated design process. A *ZNE* design for the new school library was not an initial client objective. Rather, it was the result of the design discussions with an A/E team that believed in the idea and an advocate on the client side that promoted it. The communication of the zero-net-water and zero-net-energy performance was seen as a strong asset to the educational program. This convergence of commitment motivated the client's building committee and provided the confidence that such a design approach was practical and without unusual risk.

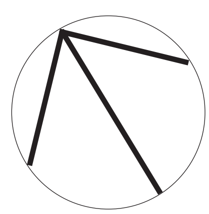
In the end, all of the buildings on the middle school quad were designed to be *ZNE-Ready*, including appropriate roof space for the installation of solar photovoltaic panels, conduit to these roofs for the future installation and adequate space in each building electrical room. The library was selected for the initial installation of the PV system and thus is fully ZNE.

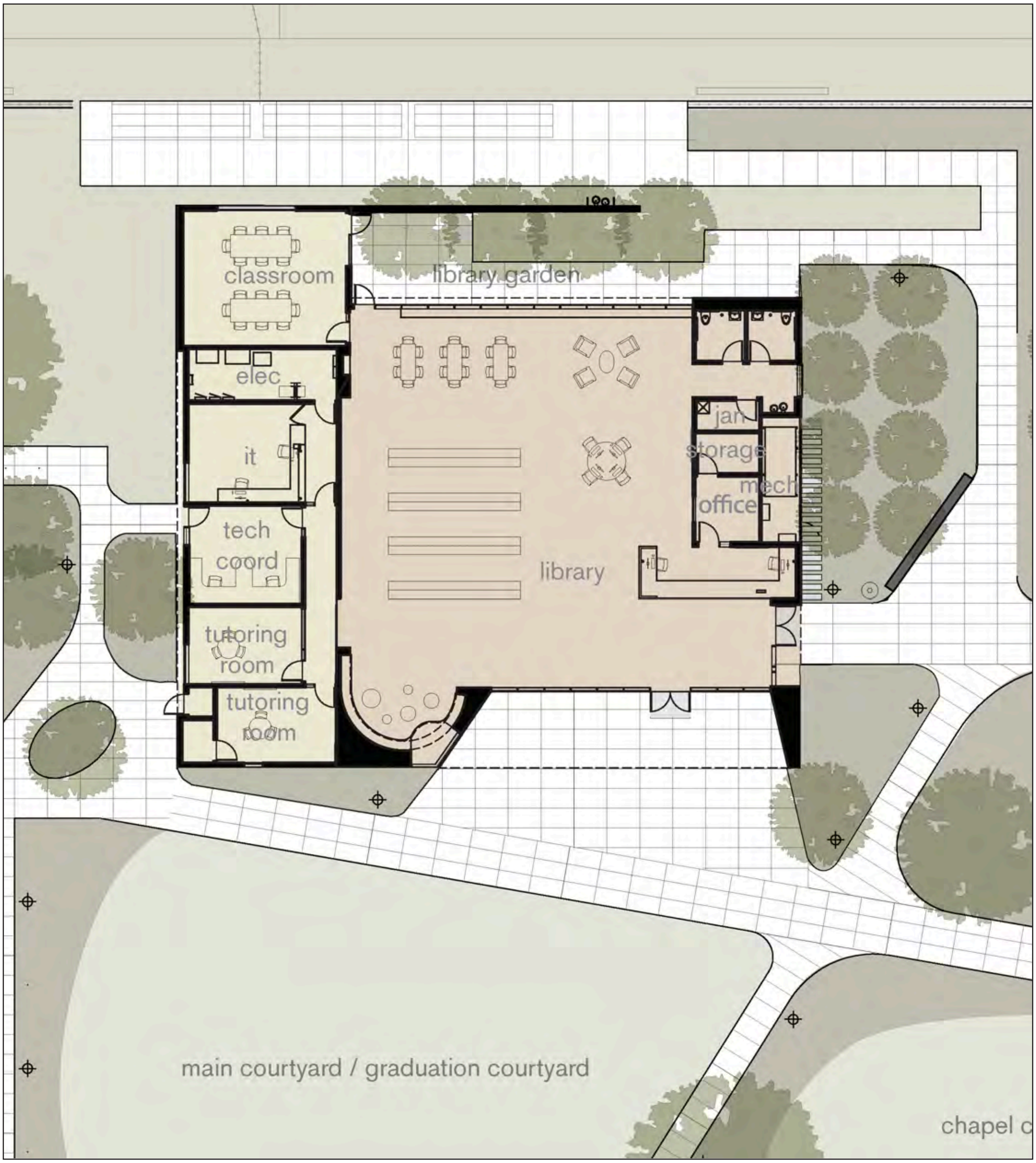
Of particular note is that the construction budget was set at a very modest level and any building features or systems supporting a ZNE approach, including a solar photovoltaic system, had to be included within the constraints of the established budget—no extra funds for ZNE. The result was a very simple architectural design approach that succeeded in meeting the budget constraint while reaching a ZNE performance level.

PHOTO: BRUCE DAMONTE

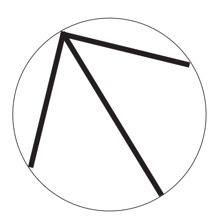


Sacred Heart Schools Lower and Middle School Campus Plan





Stevens Library Floor Plan



Low Energy Design Strategies for Stevens Library

While the low construction cost budget pointed at a simple shape and standard details for the building, this also led to ample flat roof area for a solar photovoltaic system. The cost issue also drove a number of other design decisions as described in the paragraphs below, but low energy performance was not compromised in seeking solutions to minimize cost. Simple, straightforward solutions for energy-related features and systems became the design approach.

Planning/Concept and Building Envelope

The library program required a largely open main space for stacks, seating and computers with optimal low-glare conditions. The building envelope, therefore, is essentially a simple box with carefully placed tall windows that are deeply set back on the southerly side and some top-lighting at the roof for visually comfortable daylighting. The tall windows with high performance glazing contain operable components and are located opposite each other to allow for cross ventilation under appropriate outdoor conditions.

The framing originally was all wood stud construction, but was switched for cost reasons to metal stud framing centered at 24”. To compensate for the introduction of the thermal bridging effect that accompanies metal stud construction, 1-inch thick rigid insulation was added to the walls and 2-inch rigid insulation at the roof to form a continuous insulating layer around the building. The final result is a building envelope insulated to an economic but sufficient level, with R-15 walls and a R-38 white-colored roof.

While this envelope would not be characterized as *heavily insulated*, it is sufficient to keep the overall energy demand low enough so that the total annual energy demand can be met by the high-efficiency roof-top solar photovoltaic panels. Generally, however, it is more economic to save energy through efficiency measures than to produce energy through solar PV panels. In this case, because any over-production may be used in the future for the other buildings on the quad, the maximum number of solar photovoltaic panels were installed on the roof.

(Below) View of Southwest Elevation

PHOTO: BRUCE DAMONTE

PHOTO: BRUCE DAMONTE

Care was taken to detail all conditions where insulation gaps might occur at floor-to-wall and wall-to-roof transitions, and to seal the entire building envelope to prevent unwanted air leaks. This sealing is an essential efficiency measure to keep heating and cooling loads low

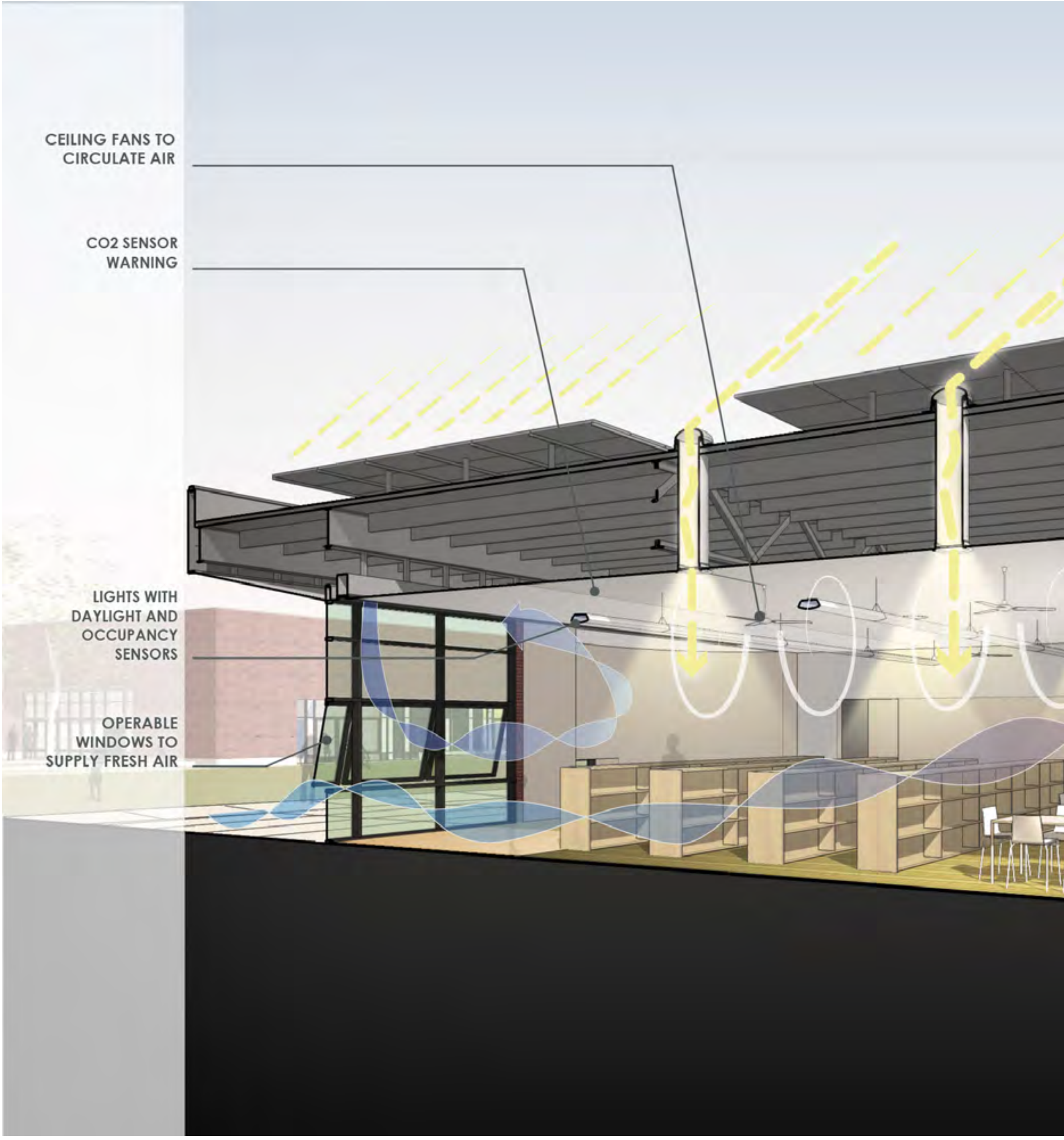
The window glazing is a high performance double-glazed system using color-neutral low-e Solarban 70XL coupled with an inner lite of conventional clear glass. This specification provides a low U-value equal to 0.28, a low SHGC (solar heat coefficient) of 0.28, while maintaining a visible light transmittance of 64%.

Daylighting and Electric Lighting

The top-lighting was provided by the introduction of a number of *solar tubes* at the roof, carefully located between solar photovoltaic panels to avoid shadowing effects. The high efficiency linear fluorescent direct/indirect light fixtures are continuously dimmed in response to available daylight, although the dimming can be overridden by staff.

Heating, Cooling and Ventilation

The low construction budget dictated a number of decisions about the approach to the HVAC systems in this building. A radiant heating and cooling system using a heat pump and circulating heated or chilled water in the concrete slab is generally a preferred approach for a ZNE build-

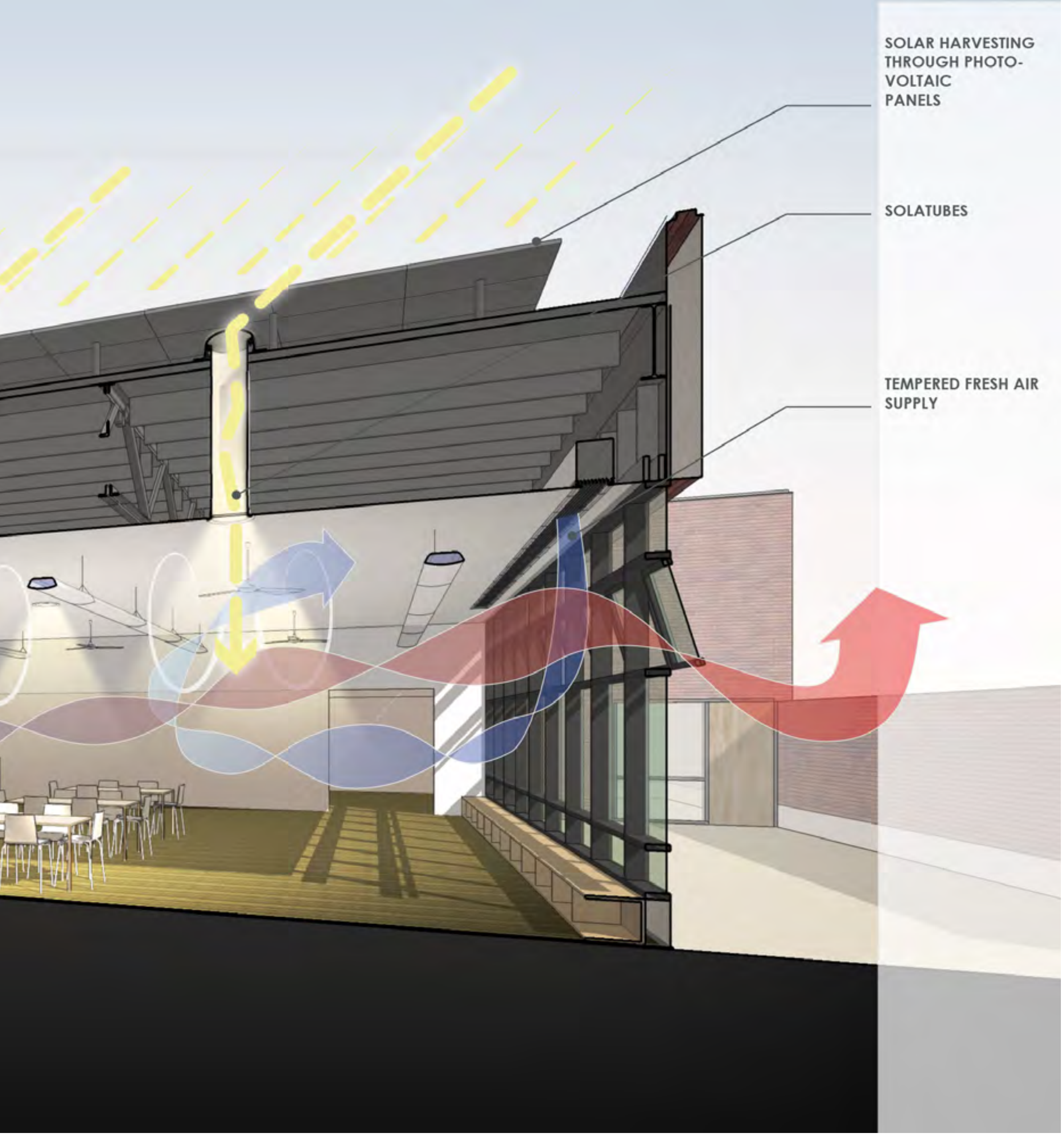


ing in this climate. This is due to its high efficiency combined with a level of occupant comfort at a wider range of temperature setpoints. Because this type of system has a higher first cost, however, and the fact that the client preferred a carpeted space, the decision was made to use a package unit utilizing an efficient air-air heat pump with both indirect and direct evaporative cooling sections. This solution works well in the warm but dry climate of this part of northern California. For potentially extreme temperature days, a compressor was added to the unit to provide mechanical cooling on those rare days.

The engineers decided to use the principle of *displacement ventilation* to move air through the large open space. Rather than using large energy-consuming fans to move the air, the system uses small fans and injects air via low velocity air nozzles at the perimeter windows and the air makes its way via natural pressure back to exhaust air openings. In addition, the ductwork is oversized to reduce pressure losses and no ducts are used on the return air side.

This type of system is unusual for buildings of this small size, but this application shows that high system energy efficiencies are possible at this scale of use.

The system has additional advantages of avoiding air drafts and system noise since the air moves at low velocity. In addition, the air can be injected at 65°F rather than 55°F, making the outside air economizer, or *free cooling*, available for more hours throughout the year. And, as a



(Left) Diagram of low-energy design features (Courtesy of WRNS Studio)

final nod toward the impact on energy use of the occupants' perception of their thermal comfort, slow-moving ceiling fans were installed to augment the perception of air movement. The comfort conditions produce by this air movement allows for higher temperature setpoints for cooling.

Plug Loads and Special Loads

Occupancy sensors combined with *ENERGY STAR®* rated equipment supplied to the building users reduces the amount of plug loads in this building. The intensity of computer use with this user group is less than other types of buildings; nevertheless, even with the energy efficient equipment and sensors, the plug load is still a sizable part of the total electric load in the building.

This building also included a system of pumps for the building's rainwater collection system that feeds the irrigation system and a gray water system that collects water from all the buildings on the quad and treats it adequately so that it can be used to flush toilets in all buildings. As a shared system, the gray water pumps could be partly excluded from the accounting of energy use for the library alone, particularly as solar photovoltaic panels are added to the other buildings and the entire energy demand/supply accounting becomes a campus rather than an individual building calculation. For this case study, however, all of the measured pump energy is included in the final building performance charts. (The project is still a net producer.)

Controls

The control systems in the building are basically self-contained, where all the controls are integrated into each component and are programmed at the factory. The specific package unit cre-

(Right) View of portion of roofscape consisting of solar photovoltaic panels laid flat and tubular skylights.

ated for this building is fairly complex in the way that it stages on multiple levels of cooling, but in general, the library control systems are relatively standard.

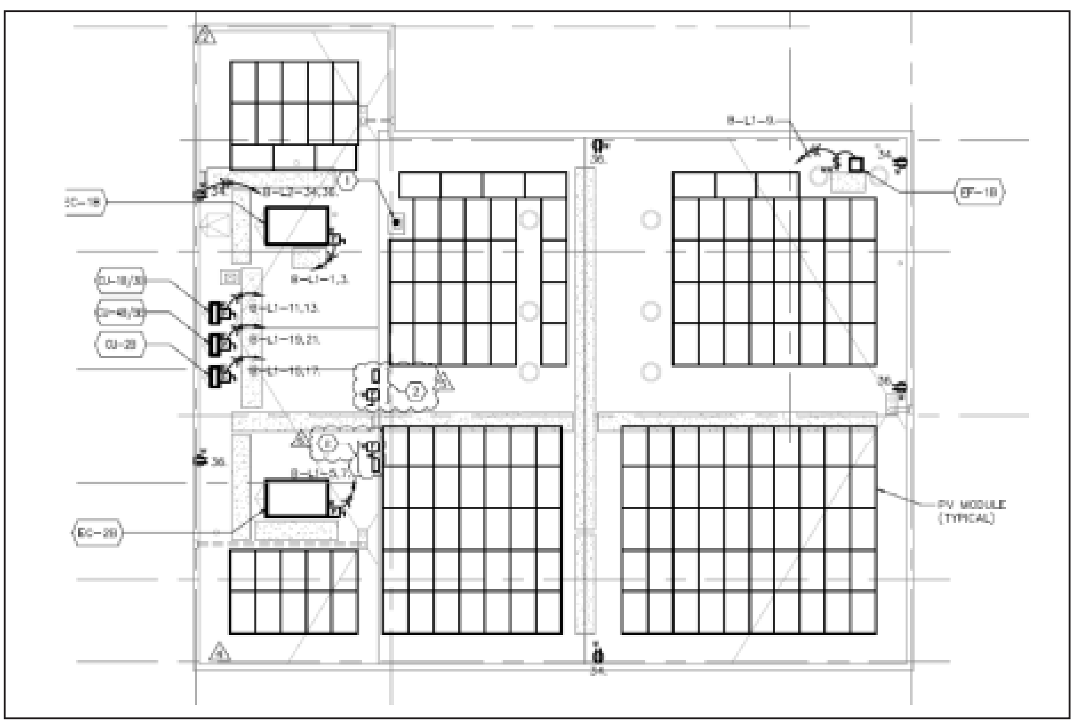
All systems are tied into the BMS (building management system) including HVAC operation, lighting, and systems metering. Although the systems are stand alone they are still monitored and controlled by the Delta control system which is a BACNET system.

The BMS was heavily used during the first few months for system diagnostics, optimizing start and stop times, and reset schedules to optimize comfort and energy conservation.

Renewable On-Site Energy Supply

The 40 kW system shares the building roof with the package HVAC unit and the *solar tubes*. The high-efficency system (310 watts per panel) was sized simply to fill out the available roof space, with the understanding that the actual building demand would deviate from the predicted load. The modeling results indicated that the 40 kW system would be ample to produce a ZNE performance and the measured results have borne this out. (See the PV system production graph on p. 38.)

The solar photovoltaic panels are horizontal, primarily to avoid shading of one panel by another in the densely packed array. This conformed to an esthetic look that was preferred by both the architect and the local building agency–a local ordinance from the 1970's restricts visible solar panel arrays on buildings. A drawback with horizontal panels is that debris and water stains can collect on the flat surfaces, requiring regular cleaning to keep performance at an optimal level.



(Left) Roof Plan / Power Plan (Courtesy of WRNS Studio)

Energy Design Analysis and Energy Performance - *Modeling versus Initial Post-Occupancy Measurements*

Energy Use – Modeling

The A/E team approached the design of the four campus buildings using the same integrated design process for energy and water systems. This meant that each of the four buildings was modeled for whole building energy use, evaluating energy-related building features and systems for lowest energy demand within the budget constraints of the project. It was recognized early in the process that the Library building could achieve zero-energy performance based on this modeling information.

Since the building was also seeking full certification under the Living Building Challenge, particular attention was paid to rainwater collection and incorporation of a gray water system. As noted in the building system description above, this water recycling system serves all four buildings of the middle school quad, with the equipment located within the Stevens Library facility. The pump energy associated with the water recycling system is therefore included in the overall energy use total for this single building. However, during the design phase of the project, this load was not included in the energy modeling of the library since it was being designed at the time separately from the building systems.

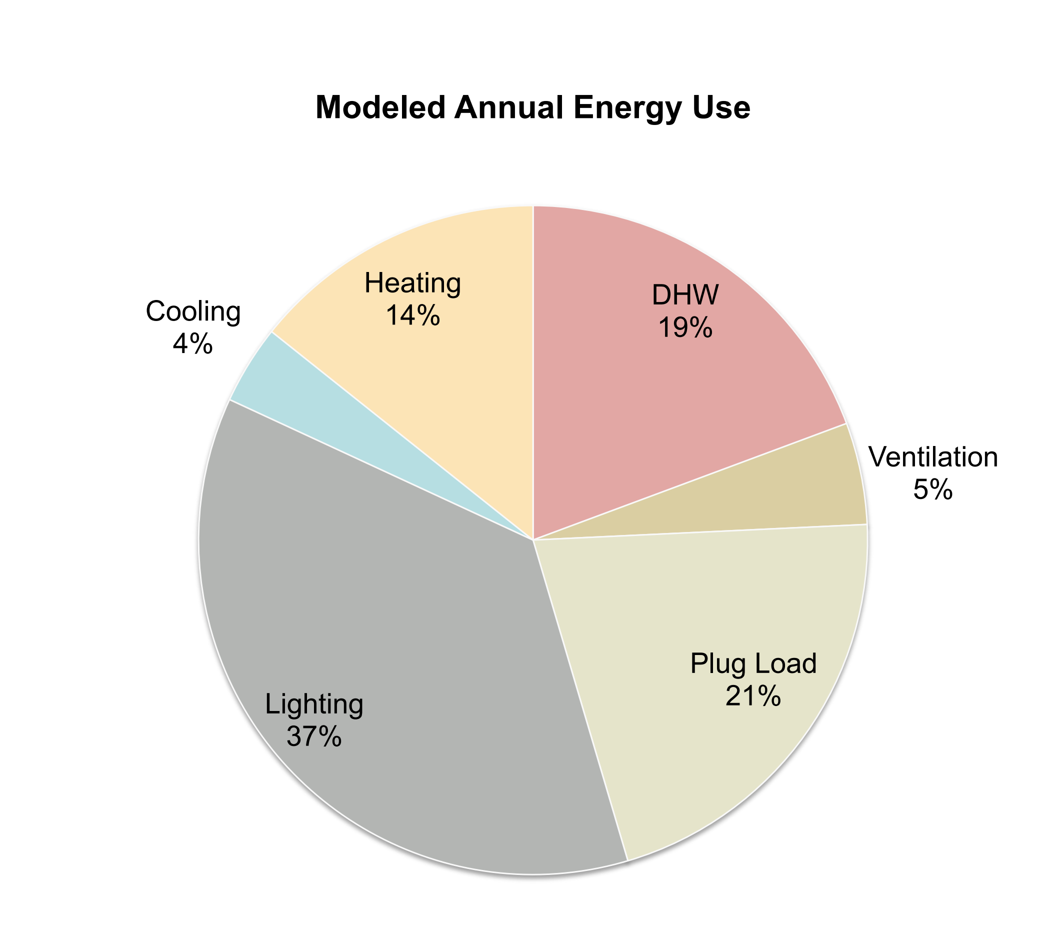
The energy modeling for the Library was carried out using eQuest version 3.64. The results are shown in the charts on this page and the facing page. In the final analysis, the model showed a predicted EUI of 27.0 kBtu/sq.ft. per year, not including the water recycling pumps, which is well within the range necessary for a zero net energy building. *PV Watts* was used to estimate the size of the solar photovoltaic system to be installed, using the assumption of 1500 kWhr (AC) per kW (DC) installed, yielding a 40-kW size for the system.

Energy Use – Actual Measurement and Comparison to Modeling Results

The building has meters installed on the principal subsystems, which are domestic hot water (DHW), lighting (interior and exterior), plug load and the package HVAC unit. Since the water recycling pumps serving the rainwater collection and gray water system are actually located within the Stevens Library and are powered by the on-site solar photovoltaic system, the energy used by these pumps was metered and included in the overall energy use for all systems within the building envelope.

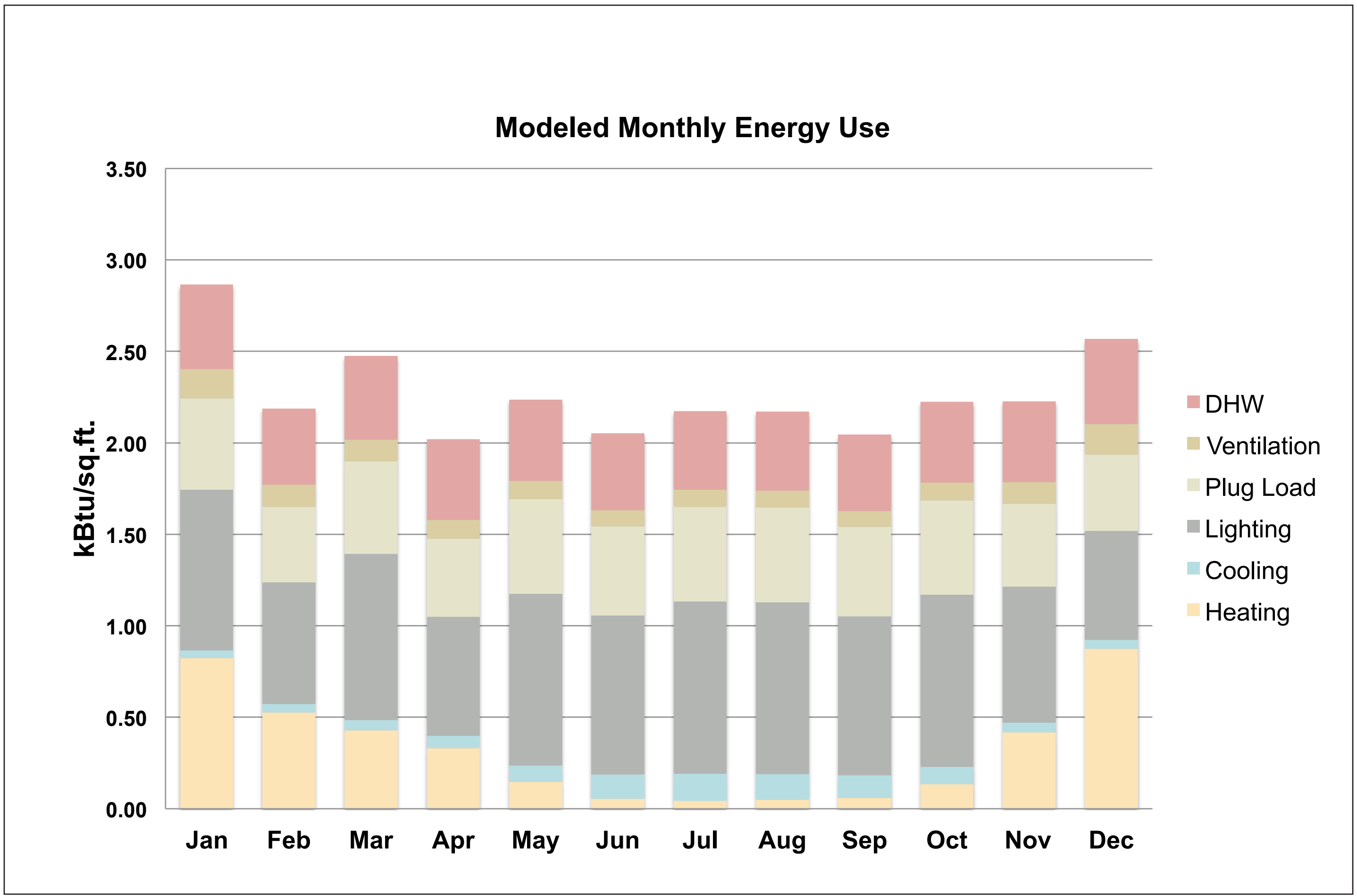
The set of meters installed by the contractor produces data that is recorded by the Building Management System (BMS). A typical problem with this standard approach to metering is that the BMS may not be programmed to produce all data that is meaningful during the measurement period and the interpretation of the data is often not easy to understand. For this library project, a second set of power meters was installed with additional measurement points, which was also separate from and not monitored by the BMS. This proved useful in uncovering a flaw with the first set of meters recording to the BMS (see the discussion below) as well as providing a finer analysis of where the energy was being used in the building.

Since the package HVAC unit is a heat pump, which can operate in either heating or cooling modes, the energy use is actually a combination of the energy used for heating, cooling and to drive the small fan. The second set of meters included a separate meter that was placed on the fan, and the heating and cooling energy use was also obtained by recording when the heat pump was in heating or cooling mode. The energy used for heating, cooling or simple ventilation could then be separated into these three different categories of energy use.



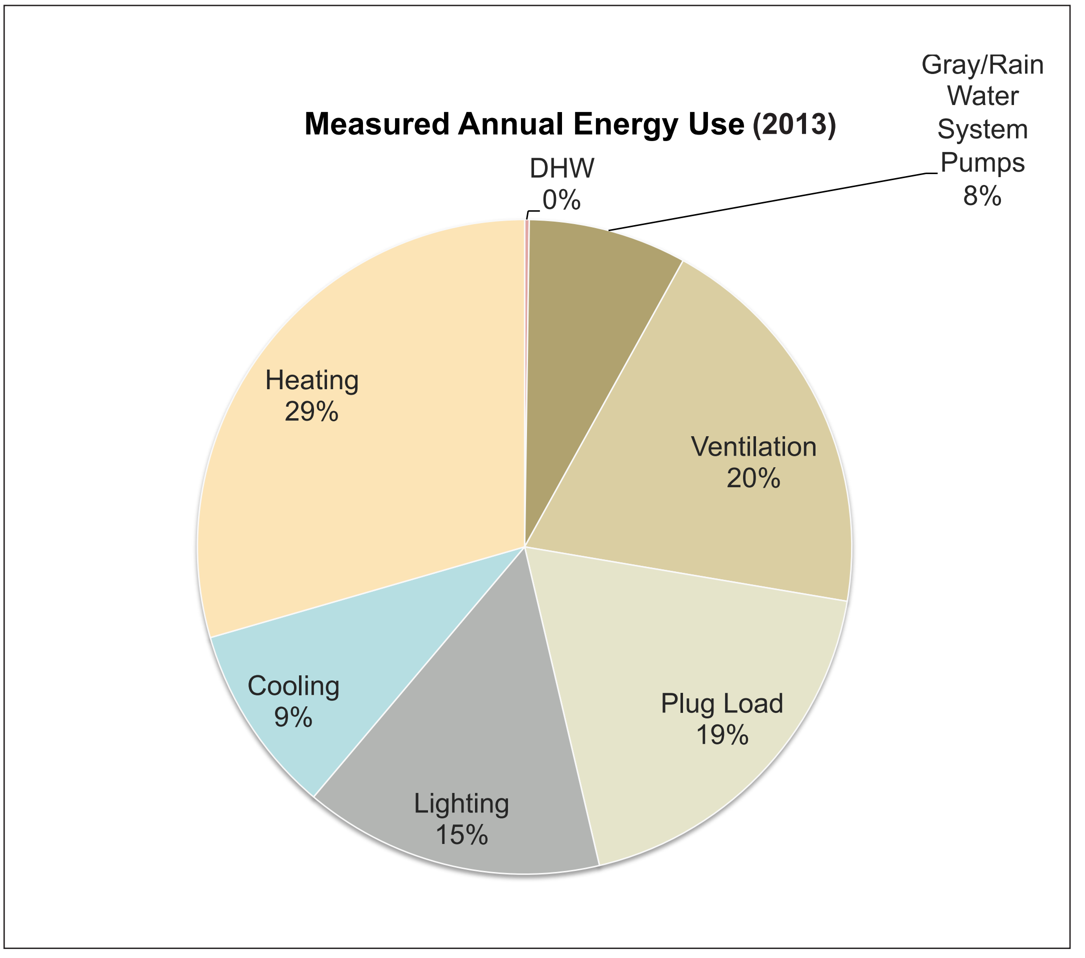
Modeled Energy Use (Annual)

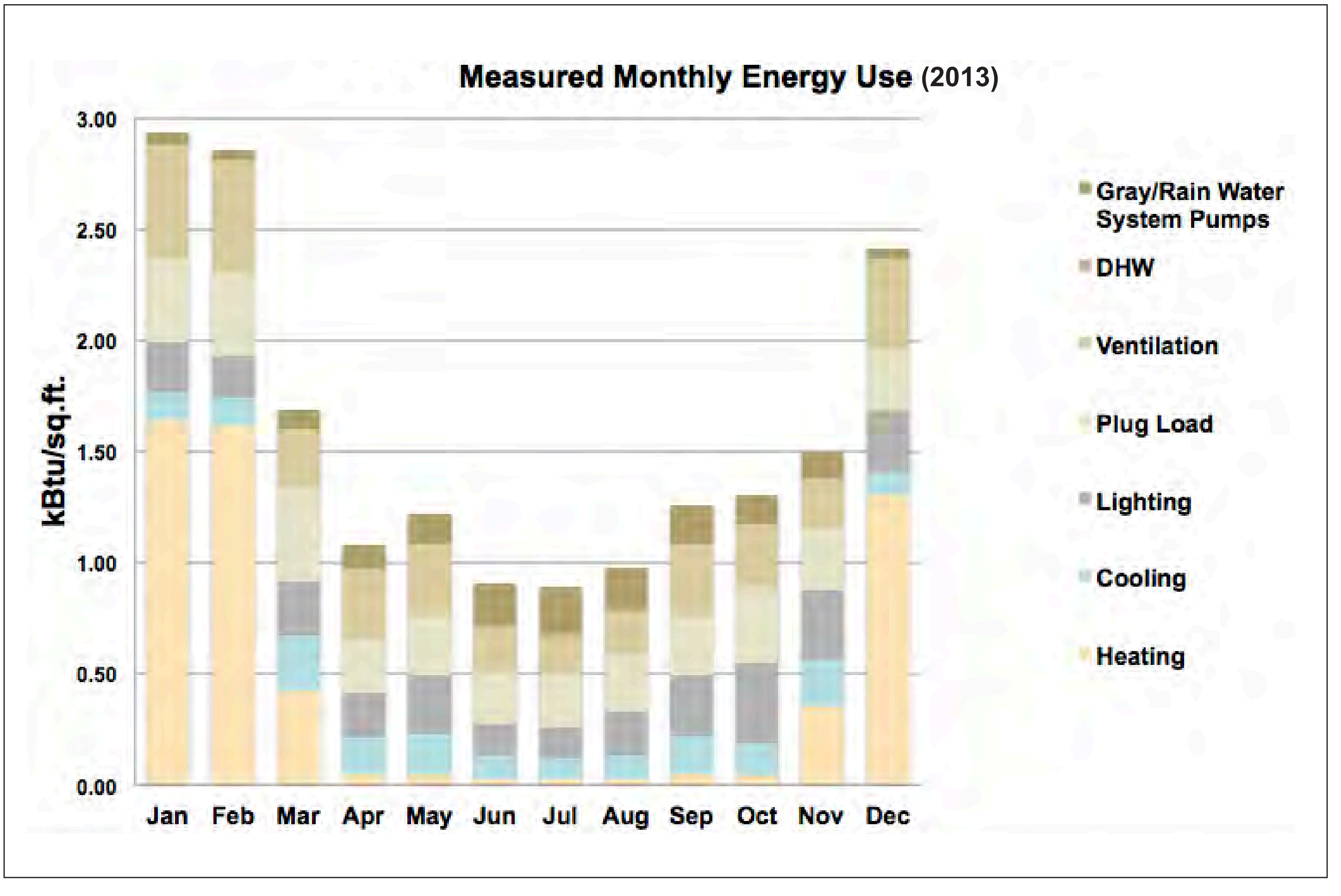
50 MWhr per Year
Modeled EUI = 27.0



Measured Energy Use (2013)

35.1 MWhr per Year
Actual EUI = 19.0





It is interesting to compare the results of the modeling with the actual measured results, due to the differences between the two, even given the additional load imposed by the water recycling system. The differrences point out the importance of the assumptions used in the modeling for occupant use intensity, scheduling and the impact of such technologies as occupancy sensors.

For the domestic hot water use, for example, the modeled demand was based on the population of the four school buildings and a reasonable assumption about how often hand-washing would be done in the library building. Actual use was very much less, perhaps because of time actually spent in the library compared to the other buildings.

Modeling software design can also affect results that differ from actual measurements. *eQuest* has difficulty modeling the effect of daylighting in interior zones, resulting in a predicted use of interior lighting even in the presence of daylighting from the roof. The daylight from the *solar tubes* in the center of the large interior space is apparently not being modeled appropriately with this software. In fact, actual measured lighting energy consumption is a small fraction of the modeled consumption (~0.2 kWhr/sf versus ~2.5 kWhr/sf).

In addition, the school's culture of concern about sustainable buildings has led to lower use of electric lights than assumed in the model; while the model assumes continuous dimming, the library staff simply turn off the lights when the space is under-occupied. The same effect can be seen with the plug load category—half the use predicted by the model. While plug load is difficult to estimate without a detailed accounting of equipment to be used in the building, there is still a zealous use of the off-switch by the occupants.

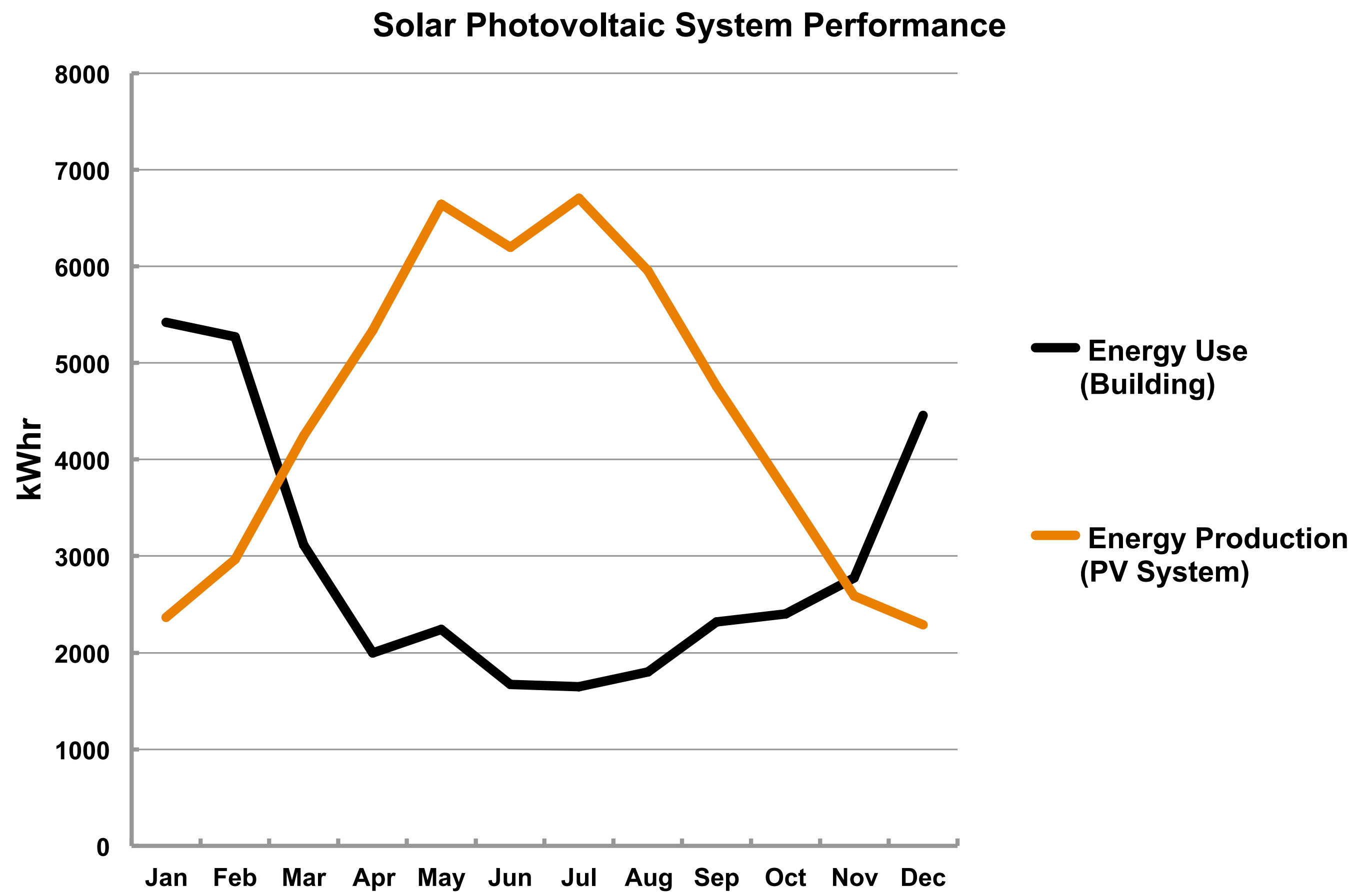
It is interesting to note that the energy used by the water recycling system is approximately 8% of the total energy used in the building for all other occupant purposes. The system is used for all four buildings, so the amount of energy used is much larger than can be expected for a single-building system.

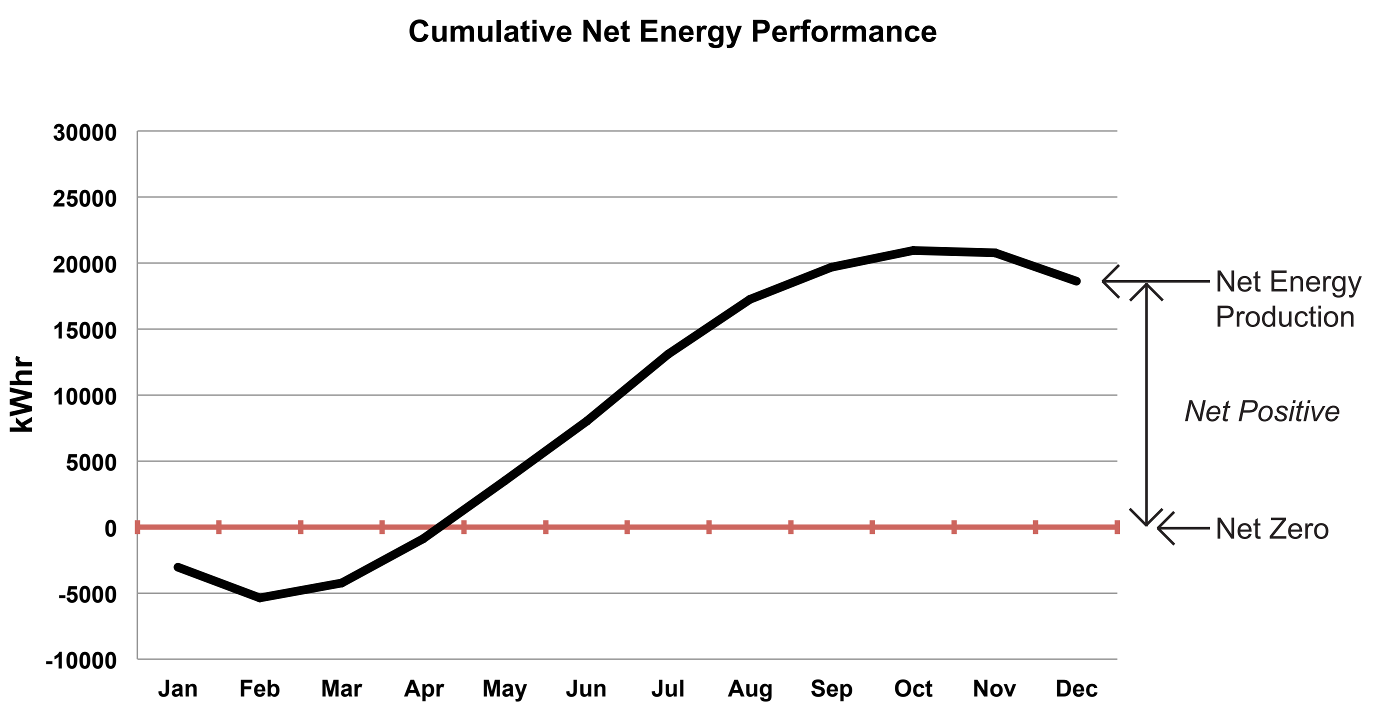
The end result of the actual use patterns is that the building (and its occupants) is performing at an exceptionally low EUI = 19.0 kBtu/sf-year, compared to the modeled number of EUI = 27.0 kBtu/sf-year. With the solar photovoltaic system sized to balance the latter annual number, the result is that the building is currently producing much more energy over the course of a year than it is consuming.

Energy Production versus Energy Use — Zero Net Energy Performance

On the basis of *Site ZNE*, as defined in the Introduction to this monograph, the results of the energy measurements in the first year of occupancy indicate that the Stevens Library is performing better than ZNE. In fact, the solar photovoltaic system produced more energy at the end of one full year than the building was importing from the utility grid. It is performing as a net producer of renewable energy. The graph on the next page shows the energy produced each month by the building's solar photovoltaic system compared with the energy used by the building. As expected, there is energy being imported from the grid during the winter season and a net export of energy during the sunny summer period.

Another way to indicate ZNE is a cumulative energy production over the course of a year, as shown in the second graph on the following page. In this graph, the net production each month becomes the starting point of the following month's net production amount. The curve goes down at first, since net production is negative in the winter, then starts to rise as there is more sun in the spring and summer, turning down again as the net production goes negative again as the fall and winter approach. For a ZNE building, the curve will just return to the zero point at the end of the year. As can be seen in the graph for Stevens Library, the curve is still above zero at the end of the year, indicating a net production of energy over the year.


Solar Photovoltaic System Performance
kWhr
8000
7000
6000
5000
4000
3000
2000
1000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Energy Use (Building)
Energy Production (PV System)


Cumulative Net Energy Performance
kWhr
30000
25000
20000
15000
10000
5000
0
-5000
-10000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Net Energy Production
Net Positive
Net Zero

Post Occupancy: Observations and Conclusions

Post-Occupancy: Controls and Monitoring

When the second set of power meters were installed, a discrepancy was noted between its readings and the data being recorded by the BMS. The difference was determined to be caused by the current transformers (CTs) of the first set of meters, a common error in low energy buiding monitoring. When these meters were replaced, the result was then a consistency of measurement with the two sets of meters.

There have been two initial outright failures of the monitoring and data communication systems. The first was with the recording and communication of data from the solar photovoltaic system, and the second was communication of data from the four campus buildings to the flat screen display of the energy dashboard, which is located in the library building.

The solar photovoltaic panel system initially produced the expected amount of energy but the data was not being sent from the inverter. The problem was compounded when the inverter manufacturer went out of business. A third-party interface and monitoring module had to be developed ultimately to resolve the problem.

The failure of the communication from the BMS systems of the four buildings to the flat screen display located in the library caused some initial consternation with the client since the display of the energy dashboard for these buildings was planned to be part of the curriculum for the middle school students. The communication problem between the BACnet protocols and the dashboard took some time to resolve.

Post-Occupancy: HVAC

Initial occupancy occurred during the late fall of 2012 and winter of 2013, which included some below normal cold days. During times of strong heat demand, the heat pump was found to turn off. Examination of the problem revealed that the internal controller was defective and had to be replaced.

In addition, there were complaints about the building being too cold in the morning. The issue was that the heat pump was taking too long to heat the space from the setback temperature of 55°F, not atypical of this type of equipment compared to a gas-fired boiler. It was determined that the simplest immediate solution was to put the setback temperature at 65°F, with the system startup beginning at the same time. The change in setback temperature resulted in an increase in heating energy consumption as measured, compared to that in the design modeling.

Post-Occupancy: Lighting

One of the remarkable results of the first year's performance data is that the lighting energy use is so much lower than expected by the energy modeling: less than 1 kBtu/sf annually compared to the modeling total of 10 kBtu/sf. The size of the difference illustrates the general observation that lighting energy use in buildings with good daylighting is often overestimated in the modeling. This seems to be the result of the complexity of the interactions among the lighting system, the available daylight, and the daylight and occupancy controls: sophisticated lighting design software in the hands of a skilled modeler can yield excellent results, but energy modeling software does not include this level of sophistication.

Post-Occupancy: General

The expectation of owners and users should be that post-occupancy commissioning should continue for at least two seasons, so that there is adequate time for a thorough "shake-out" of the operating systems, particularly the control systems and the overall building management system, allowing the accumulation of enough measured performance data to tune the building properly. This was the case with the Stevens Library, which is now well into its second season of operation and exceeding performance expectations in all aspects.

CASE STUDY NO. 3

IDeAs Office Building

PHOTO: DAVID WAKELY

IDeAs Office Building

Case Study No. 3

Data Summary

Building Type: Office
Location: San Jose, CA
Gross Floor Area: 6,557 gsf
Occupied: April 2007
Energy Modeling Software: eQuest version 3.51

Modeled EUI (Site)
24.8 kBtu/gsf-year
Measured EUI (Site)
18.7 kBtu/gsf-year

On-Site Renewable Energy System Inatalled
30 kW (DC) Solar PV

Measured On-Site Energy Production
40,432 kWhr/year
21.9 kBtu/sf-year

Owner/Client
David and Stephania Kaneda

Design Team
Architect: EHDD Architecture, San Francisco CA
Structural Engineer: Tipping Mar, Berkeley CA
Mechanical / Plumbing Engineer: Rumsey Engineers (now part of Integral Design Group, Oakland CA)
Electrical Engineer and Lighting Designer: Integrated Design Associates - IDeAs (now part of Integral Design Group, Oakland CA)
Landscape Architect: MPA Design, San Francisco CA

General Contractor
Hillhouse Construction

This small commercial office building is one of the first measured and confirmed zero net energy buildings in the United States. Completed and occupied in 2007, the energy performance of the privately-owned 6,557 sq. ft. structure has been carefully documented, confirming that it has annually sent slightly more electrical energy back into the public utility grid over the course of the past five years than it has consumed. The design strategies, commissioning measures and post-occupancy adjustments made to some of the building systems describe a model approach applicable to similar building types in California.

Background

In 2005, David Kaneda and his firm, Integrated Design Associates—*IDeAs* (recently merged with Integral Group, Oakland, California), purchased a small tilt-up concrete building that had been built in the 1960's in a suburban shopping center south of San Jose, California, to house a bank branch office. The plan was to renovate the structure extensively to house his staff of engineers specializing in electrical engineering and lighting design, but the vision was to transform the structure into a high performance green building in every aspect and to demonstrate that it was feasible technically and financially to build a zero-net-energy and zero-net-carbon building within existing constraints and using existing technologies.

The building is a renovation of an existing building. Because of the extent of the renovation work, it is best characterized as "deep retrofit." Like every building project with a ZNE goal, as we now know, the process of its design necessarily involved full integration of all design disciplines in the early design phases, analyzing and evaluating every aspect that would affect the energy "bottom line." In the case of this project, the contractor was selected early and was also involved throughout the process. Understanding the need for the early, integrated design decision-making and how it would make a ZNE performance possible within the typical constraints of this type of building is an important part of the achievement of this project.

Low-Energy Design Approach for the *IDeAs Office Building*

With the basic requirement that available on-site renewable energy balances the total building energy load over the course of a year, the approach taken with this project was to simultaneously determine how low the load could reasonably be set with "a reasonable cost premium" and how much renewable on-site energy could be realistically harvested. The encouraging result of this quick study was that there would be enough renewable energy available through a standard application of solar photovoltaic panels on the roof and an added canopy to satisfy an achievable annual energy demand of approximately 20,000 Btu/sf-year.

This target energy budget set the parameters for the design and specification of the different building components that affected the total energy use. The following is a description of each of these component features and systems.

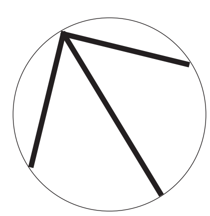
Building Planning and Building Envelope

Given the large open space desired for the engineering staff workstations within the small office building, the plan concept is simple: place the open workstation along the south side of the building where a new large glazed area of sliding doors and windows are located and individual offices and conference space along the north side with no exterior windows but a shared open view toward the south.

Many alterations were done to the basic building envelope, including the addition of daylight-providing skylights, high performance windows and added insulation. The skylights were distributed

PHOTO: DAVID WAKELY

IDeAs Office Building Site Plan



LEGEND

1 OPEN OFFICE
2 RECEPTION
3 CONFERENCE
4 WORKROOM
5 BUSINESS OFFICE
6 PRINCIPAL OFFICE
7 TENANT SPACE
8 KITCHEN
9 SERVER ROOM / ELEC.
10 MECHANICAL ROOM

to provide even daylight to the spaces below and were limited in number (17) to provide just the right thermal balance while meeting the overall optimum daylighting design.

The daylighting design is indicative of a common issue with ZNE buildings that utilize solar photovoltaic (PV) panels for on-site renewable energy: the daylight collection features essentially compete with the PV panels in the harvesting of the sun's energy. Not only must the balance of the two be carefully coordinated in the design, but the design has to respect the simple geometric requirement that one type of building feature will not cast shade on the other. For this building, where the PV panels are built integral to the roofing system, the roof framing is deliberately sloped enough to prevent this shading of the PV panels by the skylights and their curb framing.

The glazing for the building was selected generally for both high thermal performance and good visible light transmission. For the skylights, the glazing is clear but prismatic, which minimizes direct glare conditions, an important factor in good overall daylight design. The potential direct solar beam problem is also prevented by deep, flared skylight wells.

The window glazing is a spectrally selective glass with good visible light transmission (63%), low U-value (0.29, a low heat conduction value) and a low shading coefficient (0.31, a low fraction of solar heat gain and less than half that of regular double-glazing).

A continuous horizontal canopy made up of glass PV panels provides shading for the large new glazing area that is inserted into the cutout in the south wall. These particular PV panels are used in this location partly for demonstration purposes, justifying the extra cost. Operable windows are located in the exterior for local supply of fresh air.

Wall insulation levels were improved to approximately R-20 by adding fiberglass batt insulation to the inside of the concrete shell. The roof insulation was easily upgraded to R-30, while the roof membrane is white in color to provide high reflectance (80%) and a "cool roof". It is interesting to note that the building envelope was not sealed to make a "tight" building, preventing leakage of temperate air; this is significant in how it affected the HVAC system design.


PHOTO: DAVID WAKELY


PHOTO: DAVID WAKELY

Interior Lighting

Installed interior light fixtures using T8 lamps were state-of-the-art energy-efficient light fixtures in 2007, when the building was completed and ready for occupancy. The fixtures were supplied with dimming systems activated by daylight sensors in the space and which dimmed the lights continuously in response to available daylight.

As part of using the building to evaluate different types of fixtures, several different types of high efficiency fixtures with dimming capability were specified. With one type, the dimming system is controlled at the electric panel with control software loaded on to a specific computer in the office. The latter allowed users to modify the lighting schedule as desired for more efficient operation of the lights. A second type of fixture had the dimming controls built into the fixture itself rather than a programmable device at the panel. Each of these types of approach to dimming in response to daylight availability resulted in issues that had to be resolved during the post-occupancy period; these will be discussed in a later section of this case study.

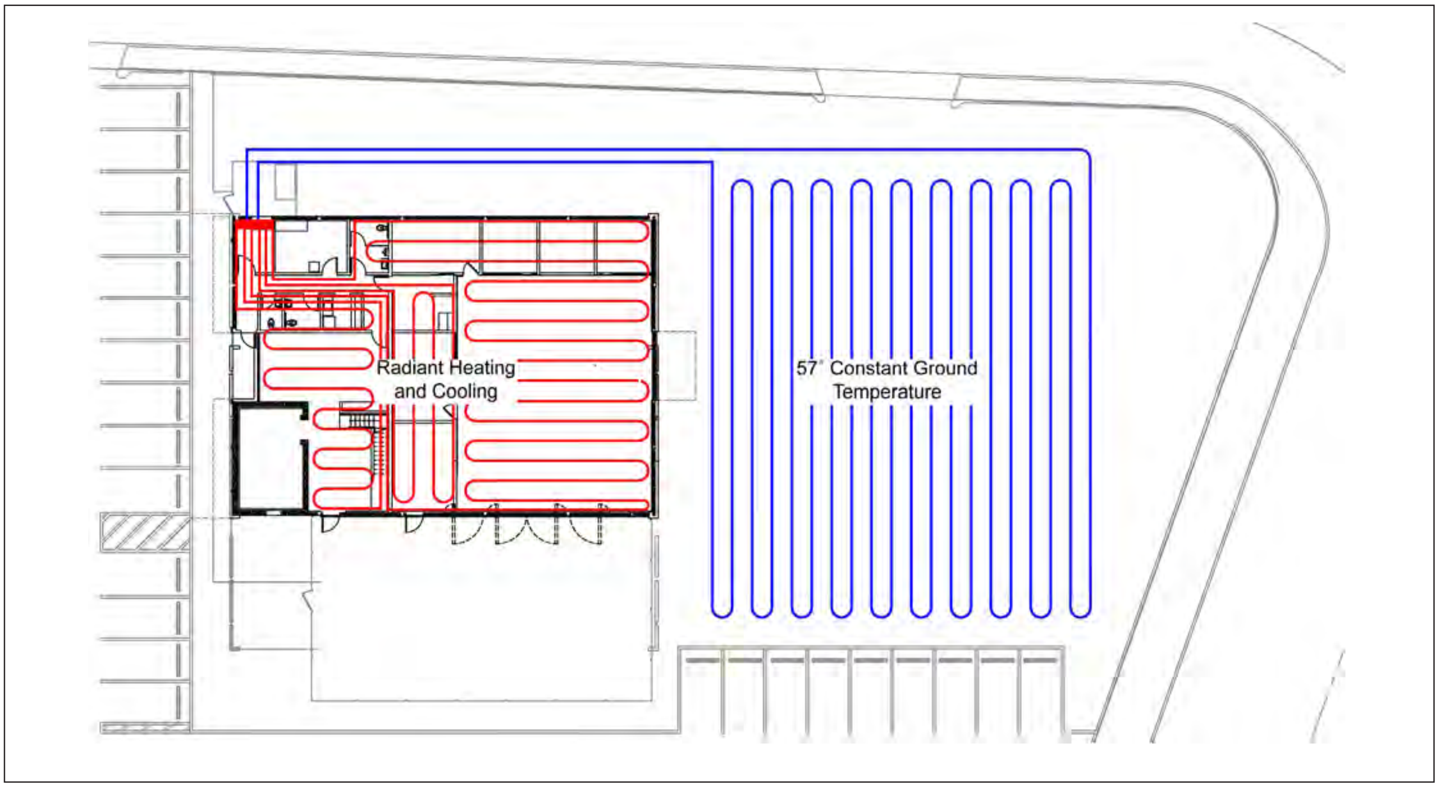
Heating, Cooling and Ventilation

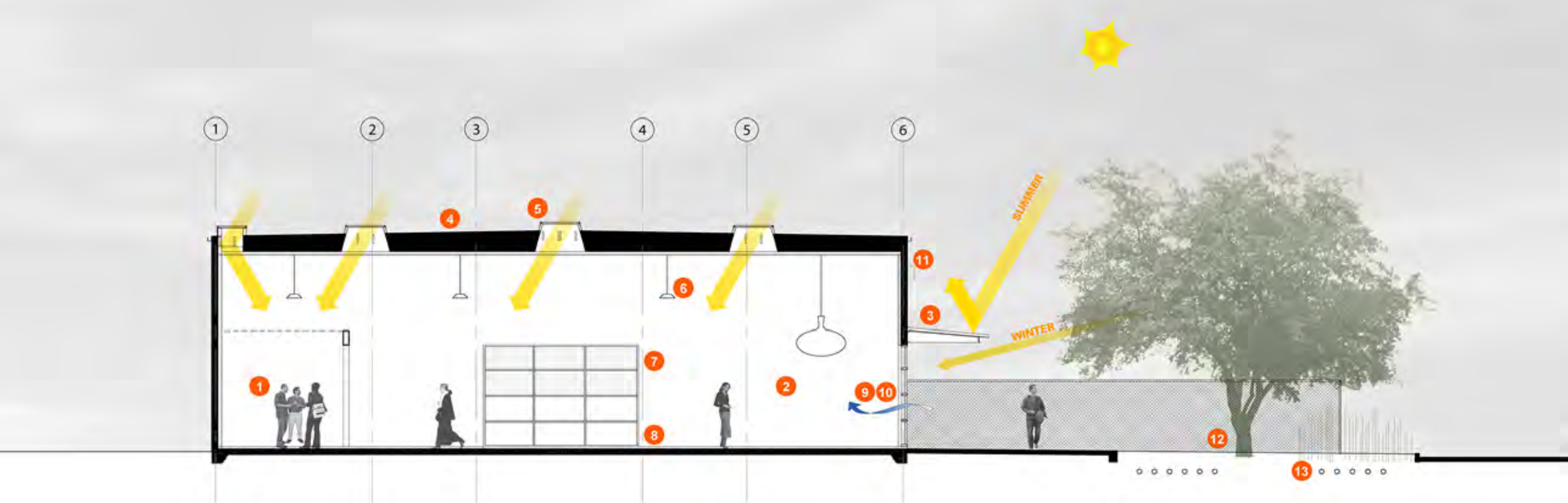
The HVAC system consists of a ground-source heat pump system with a hydronic radiant floor system in a concrete floor slab, with natural ventilation and a back-up fan-driven fresh air ventilation system. The ground-source heat pump piping is a horizontal coil installation in the area to the east of the building, which was originally part of the shopping center parking lot. (Diagram below.) The hot water for the radiant floor system when used for heating is supplied by a solar thermal system; the heat pump acts as a backup and maintains the hot water temperature in the system thermal storage tank. The chilled water for the radiant floor when used for cooling is made by the heat pump, with the heat dumped into the ground via the coil installation.

The backup fresh-air ventilation system has a supply fan only. A general building exhaust fan was determined to be unnecessary because of the small size of the building and the inherent “leakiness” of the building envelope.

The system operates in a type of “mixed mode” design. When outdoor air temperatures are comfortable, the fan does not operate and natural ventilation via occupant control of the windows is used. The intermediate condition, when outdoor air temperatures are still comfortable but internal loads create a need for a small amount of cooling, the occupants are expected to operate the windows to provide the needed cooling.

(Opposite and below) Energy system diagrams. (Courtesy of Integral Group).





1 private office
2 open office
3 sunshade w/ building integrated photovoltaics
4 roof w/ building integrated photovoltaics
5 skylight
6 energy efficient and occupancy sensor controlled light fixtures
7 electrochromic glass
8 radiant heat floor
9 natural ventilation
10 high performance glass
11 reduction of outdoor light pollution
12 water efficient landscaping
13 ground source heat pump

zero gas usage

zero CO_2 emissions

0' 4' 8' 16'

When full heating or cooling mode is required, however, the heat pump operates to provide the appropriate water temperature in the radiant system and the supply fan operates at a fixed speed to provide the fresh outdoor air. Building occupants normally operate the windows to close under these conditions. The fan is designed only to provide fresh air since the heating and cooling is done via the radiant slab and it was originally designed to operate whenever the heat pump was activated. This type of operation, while workable in practice, resulted in some energy use inefficiency, which is discussed below.

There are separate ventilation fans provided for toilet room exhaust and the server room. By design, the server room does not have a separate cooling system, which generally requires a continuous power supply. The server room was located specifically on the north side of the building with the least external load amount and *night purging* is used to cool the room down at night. With minimal external loads, the server room normally floats through the following warm day without excessive interior temperatures. In addition, the server room itself is programmed for a higher temperature than normal for such spaces. Note: the servers are reported to have functioned well for the past five years without apparent ill effects on the equipment.

Electrical Plug Loads

Plug strips at each workstation are identified as either *controlled* electrical outlets or *fixed* outlets. The controlled outlets have built-in occupancy sensors to manage equipment that can be turned off when not in use. Fixed outlets remain at full power availability at all times. These are required for computer CPU's but the flat screen monitors can be plugged into the controlled outlet. (The staff choose to plug cell phones into the fixed outlet so that charging is not interrupted.)

In 2007, each engineer's workstation included one high efficiency flat screen monitor with a typical CPU box on the floor. Since then, for productivity purposes about half of the staff have

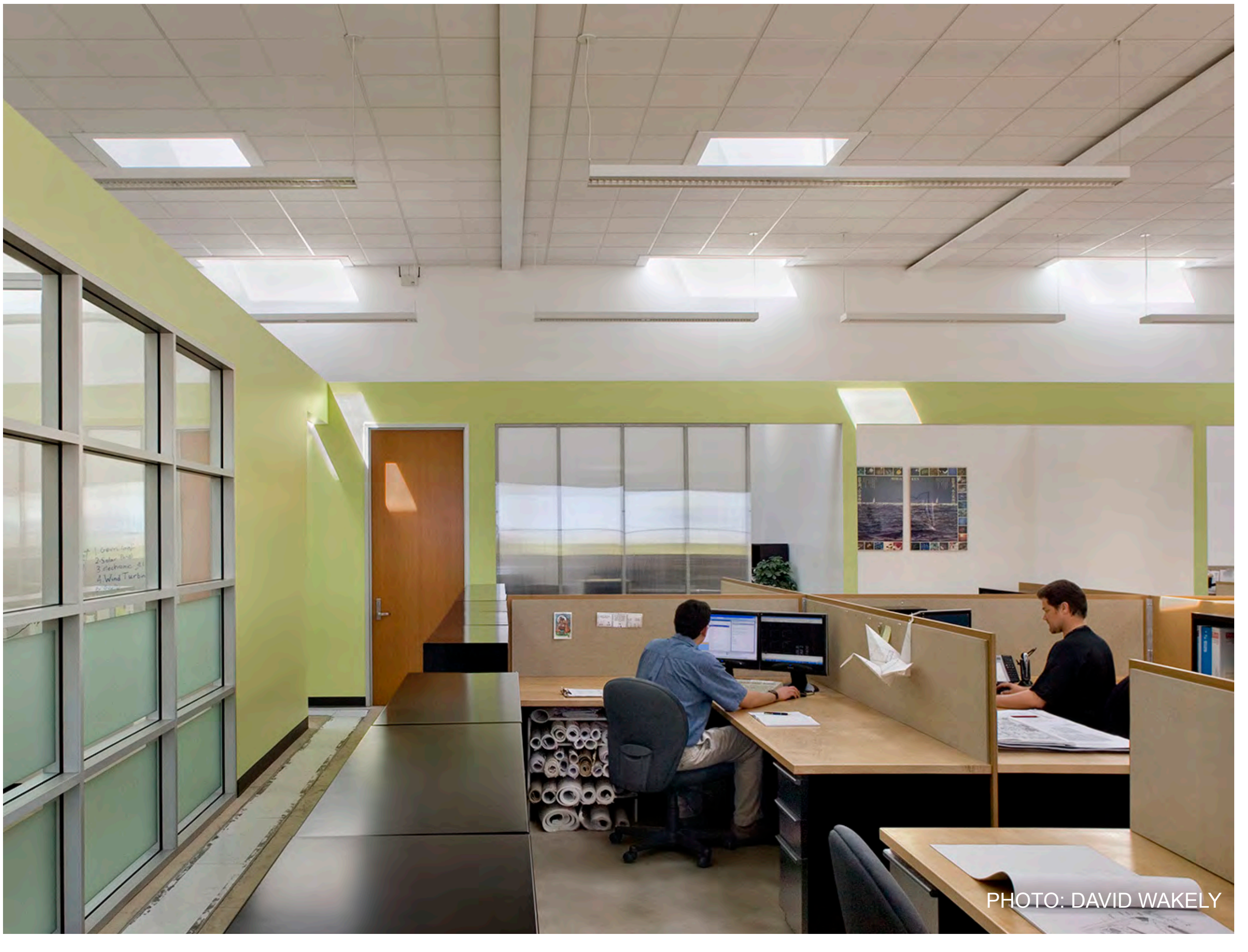


PHOTO: DAVID WAKELY

replaced their desktop machines with laptops plus two smaller flat screen monitors. The laptops use less energy but the power required for the second monitor eliminated the energy savings.

Desk telephones that normally appear as a plug load component are not used in this building. Instead, *IDeAs* staff use a voice-over-IP system and connected headsets.

The primary plug load is computer equipment as other plug loads such as radios and tape players have disappeared as internet streaming has emerged. This trend, plus changes made during the post-occupancy period (to be discussed below), has lowered the plug load significantly over the past five years.

Renewable On-Site Energy Supply

A building integrated solar photovoltaic system ("BIPV system") is built into the single-ply PVC roof membrane system. This system avoids the many roof penetrations necessary to attach a PV panel support structure. However, this also required that the owner purchase the system. A third-party lease arrangement (PPA) was considered initially but was not a viable option in 2006. The choice of a BIPV system from an early manufacturer of this type of product involved a risk for the building owner regarding the service and warranty of the system over a standard period of time (20 years). When the building was designed, however, other options had the perceived greater risk of water leakage from multiple roof penetrations. (As it turned out, the manufacturer of the BIPV system entered bankruptcy in 2010, putting the system warranty into question.)

A second type of panel, a laminated mono-crystalline photovoltaic panel, is used as the shading canopy for the south-facing storefront glazing.

PHOTO: EHDD

Energy Design Analysis and Energy Performance
Modeling versus Initial Post-Occupancy Measurements

Energy Use - Modeling

The whole building energy modeling for the *IDeAs Building* was done in 2002 using the eQUEST interface version 3.61 of the DOE-2 analysis engine using modeling assumptions based on the well-known schedule patterns for the owner/occupant. The modeling analysis early in the design process showed a building EUI (site energy) tabulated at 24.8 kBtu/gsf-year, about 25% above the energy use target of 20 kBtu/gsf-year. A bar chart showing the results of the modeling analysis by month is shown on the facing page.

Energy Use – Actual Measurement and Comparison to Modeling Results

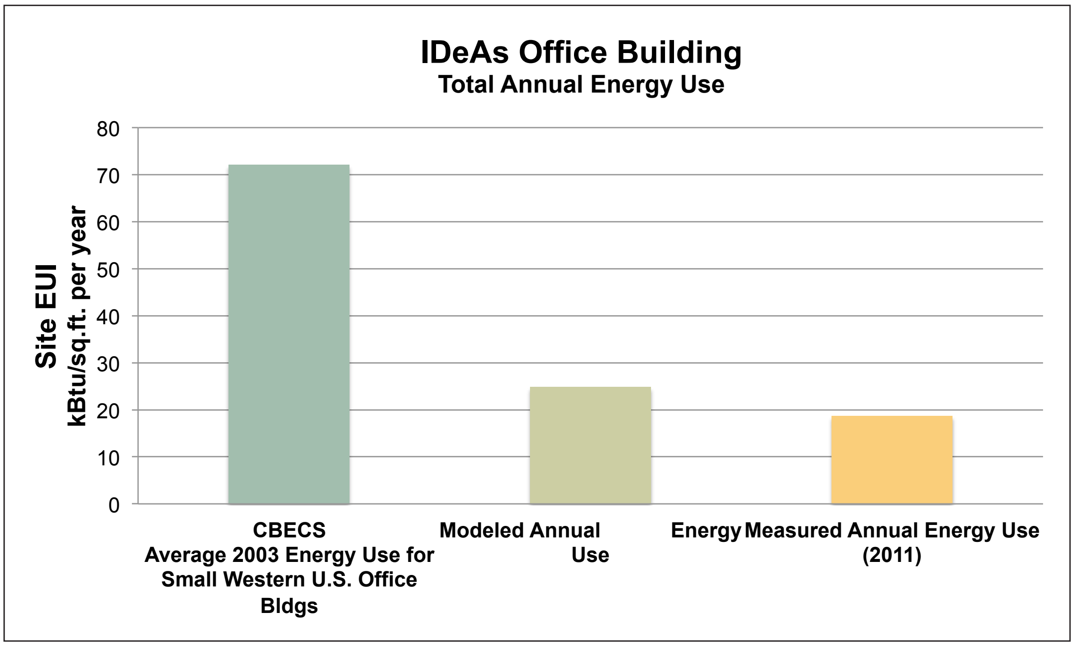
Metered data for energy use and energy production has been collected for this building since it was occupied in 2007. For energy use, there is an overall energy use meter and sub-metering for each circuit at the panel board. The solar photovoltaic system is monitored both in the aggregate (the entire system) and by the individual panel.

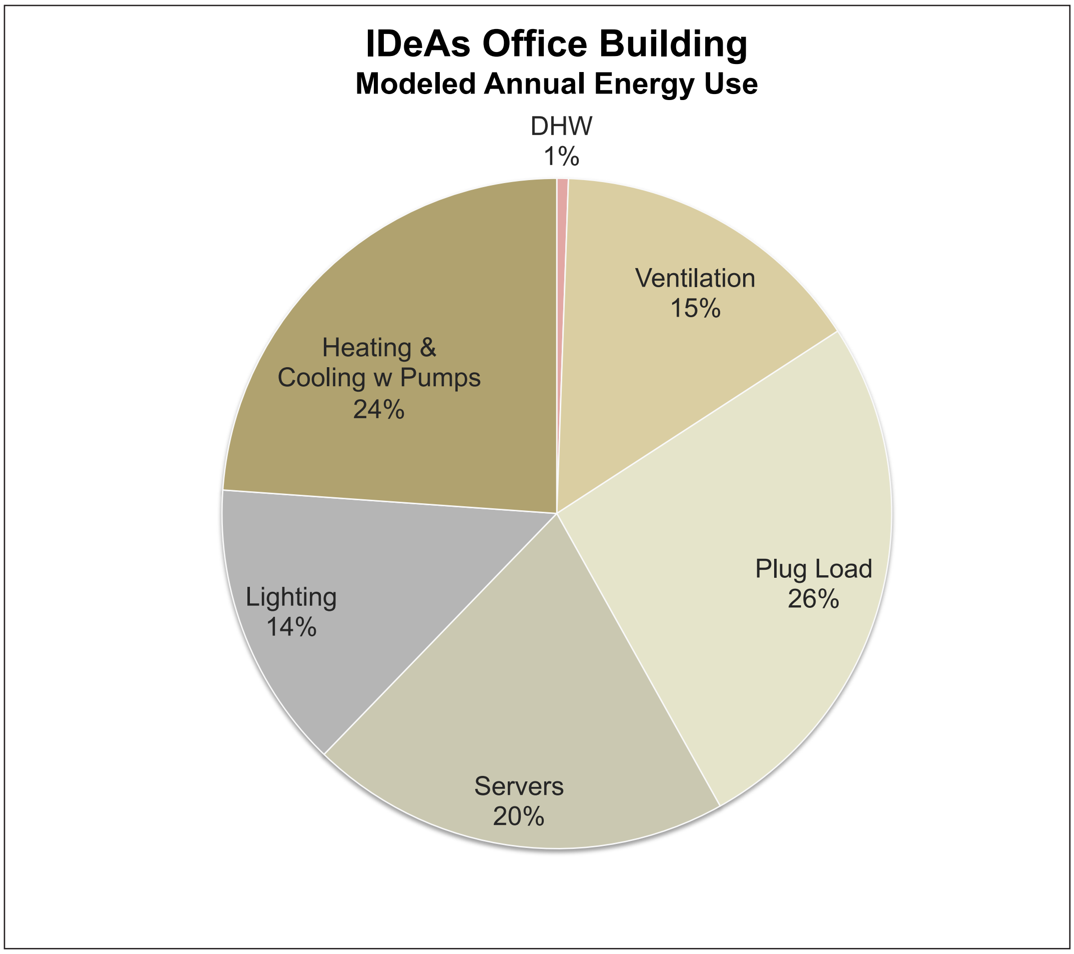
One of the initial post-occupancy issues was the observation that the metered data for energy use did not match the metered data for the solar photovoltaic system production combined with the PG&E meter for power drawn from the grid. Change-out of some defective meters did not correct the problem and it was determined that the meters were sized for too high a load and can be inaccurate for lower energy demand. Replacing the type of meter resolved the issue and recording of good data started shortly afterward.

As noted above, the measurement of the building's annual energy use was substantially better than the modeling results over the course of the past four years. For the year from July 2011 to June 2012, the total energy used was 36,000 kWhr with an EUI = 18.7 Btu/sf-year compared to the modeling result of 47,700 kWhr and EUI = 24.8 Btu/sf-year.

The average EUI of office buildings in the western region of the U.S. between 5,000 sq. ft. and 10,000 sq. ft. as recorded in the 2003 CBECS (Commercial Buildings Energy Consumption Survey[1]), is 72.1 kBtu/sf-year. The EUI for the *IDeAs Building* is less than 30% of this average amount. (See the bar chart below.)

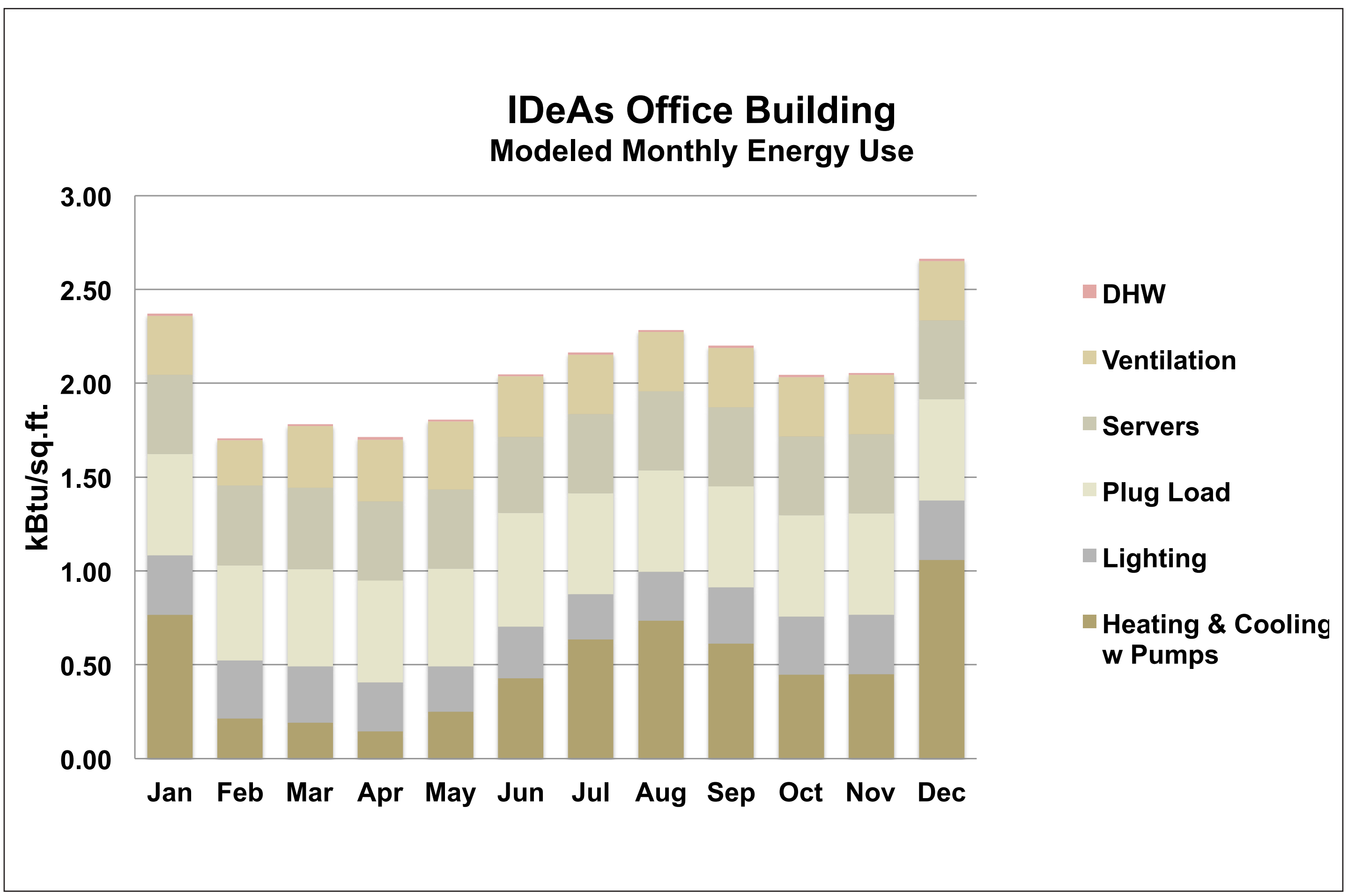
[1] U.S. Energy Information Administration, *EIA Commercial Buildings Energy Consumption Survey*, Table C5





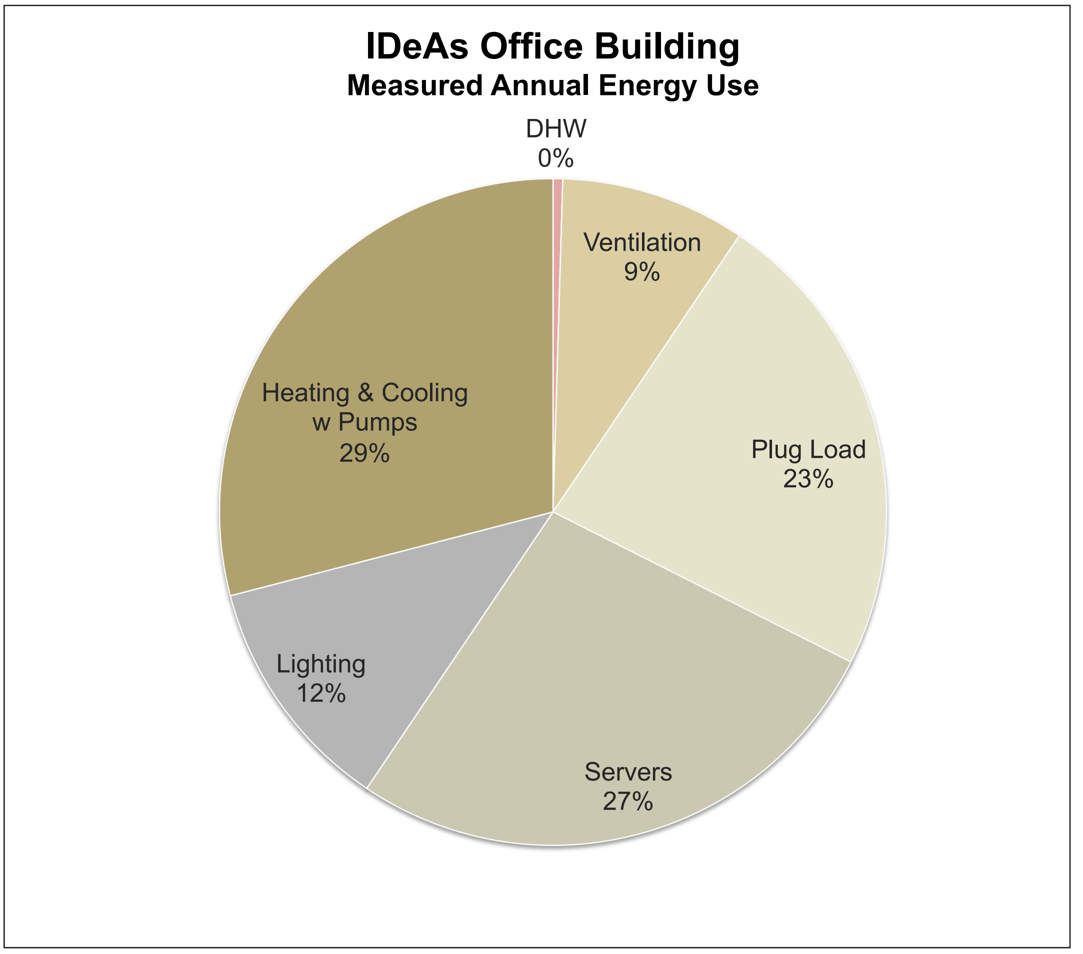
Modeled Energy Use (Annual)

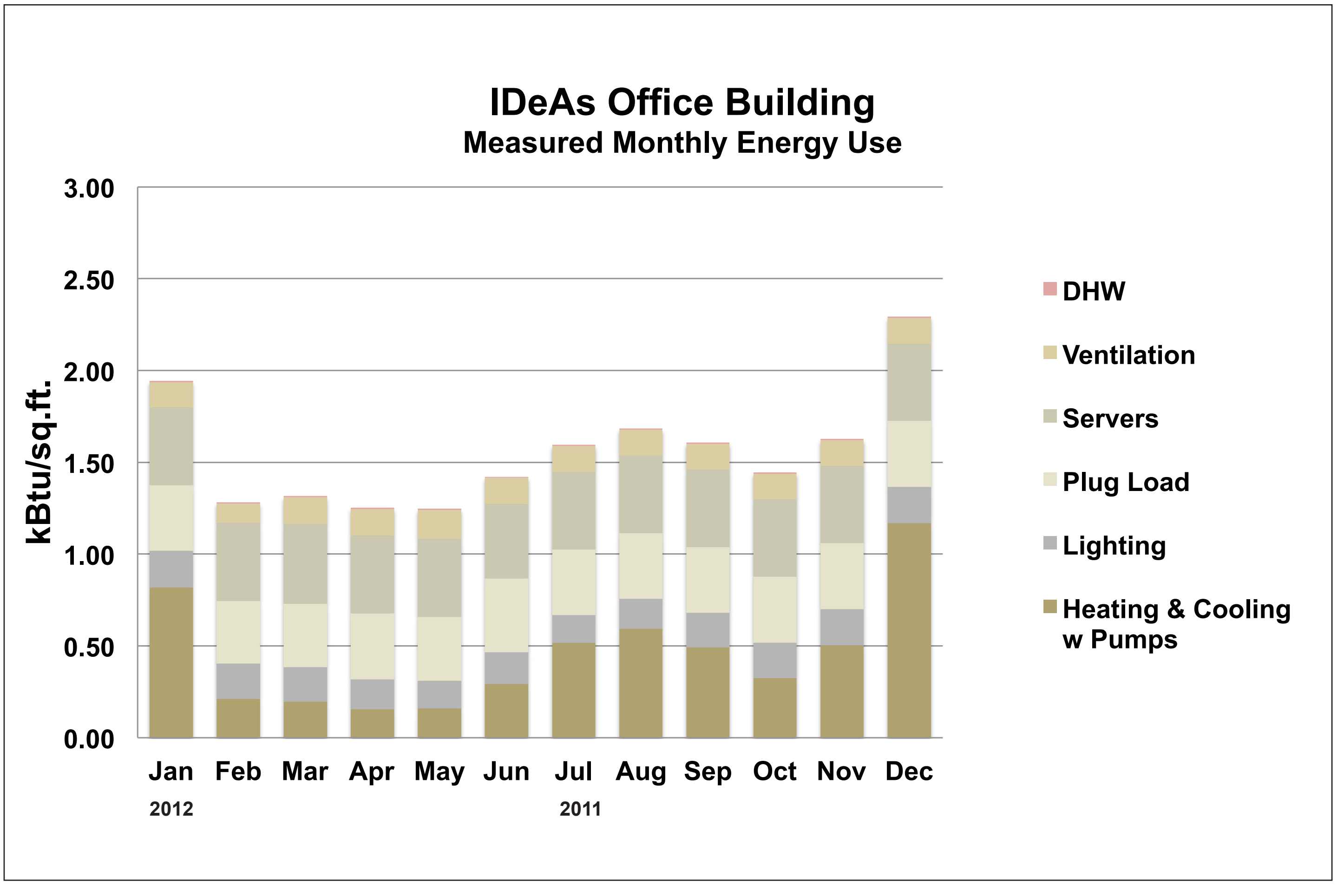
47.7 MWhr per Year
Modeled EUI = 24.8



Measured Energy Use (2011-2012)

36.0 MWhr per Year
Actual EUI = 18.7

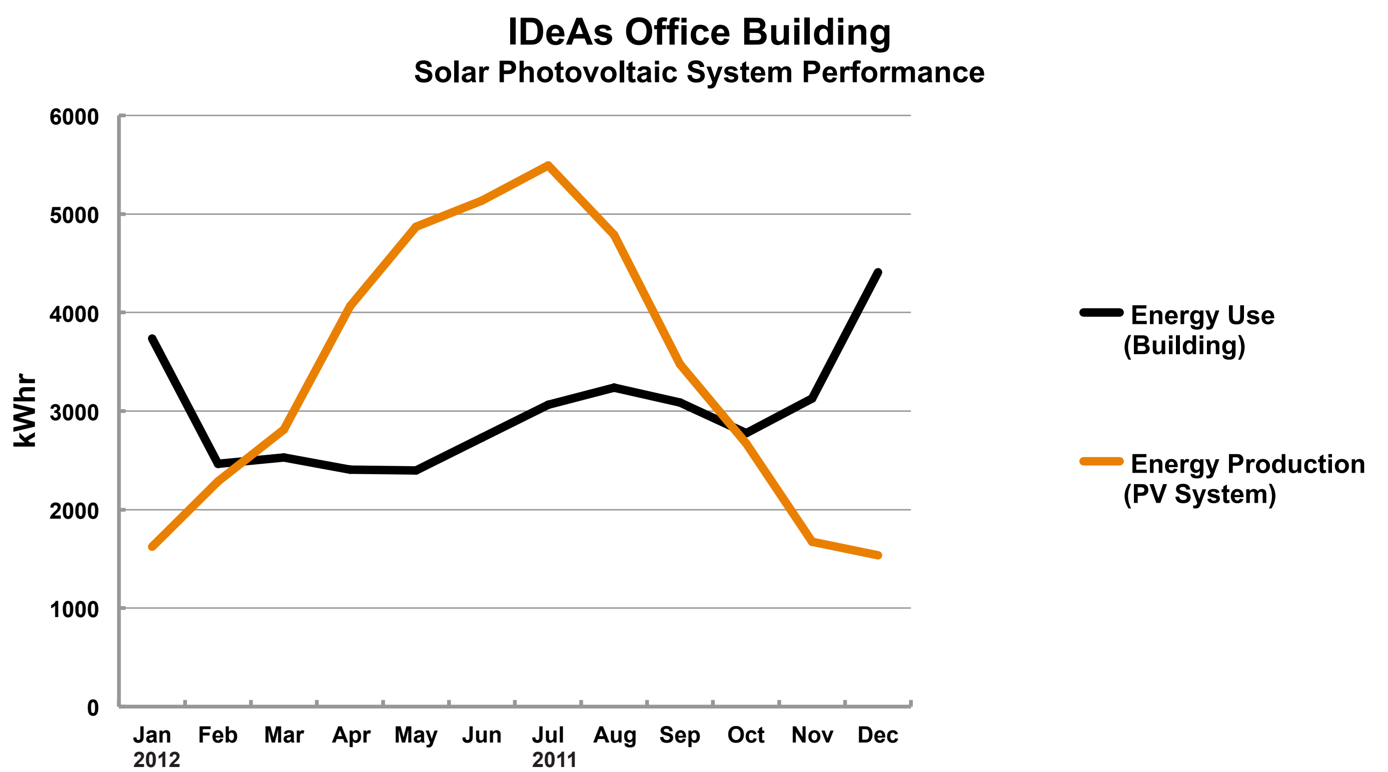


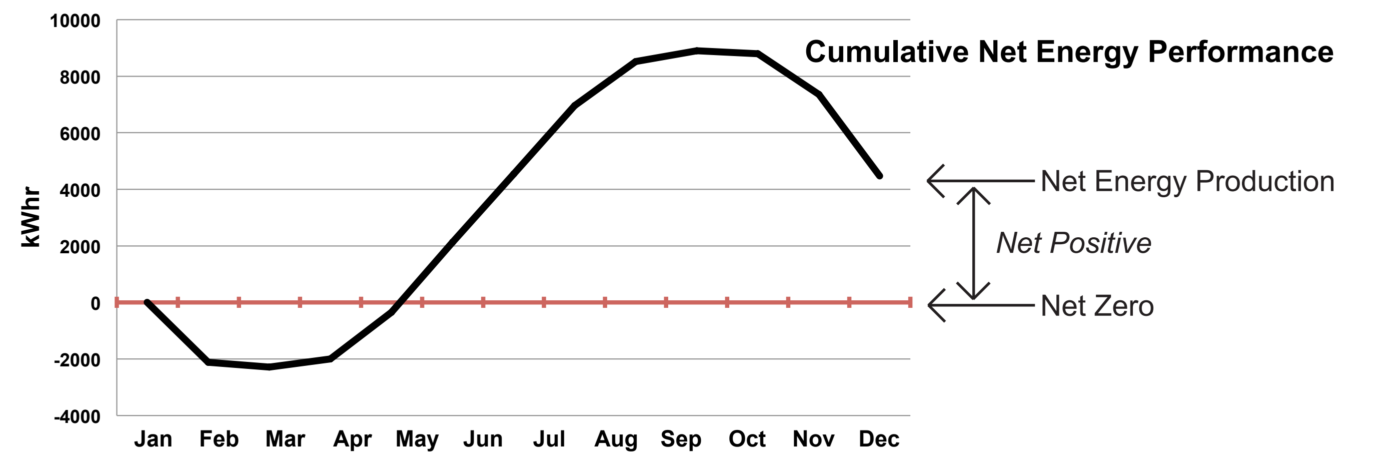


The measured energy use by type of energy end use for 2011-2012 is shown in the pie chart on the facing page. This is accompanied by the monthly measured performance for this same period with the same monthly breakdown of each category of energy use. The relative size and importance of the plug load (including the servers) in buildings with such low energy loads is apparent from these charts.

Energy Production versus Energy Use: Zero Net Energy

The solar photovoltaic system monitors the real-time power and electric energy produced from both types of panels, both DC at the panel arrays and AC after the inverter. A graph showing the electric energy production of the system over the course of a year from July 2011 to June 2012 is shown below (half-year data transposed for clarity). Also below, a graph of the *cumulative energy production* over the course of a year shows that the building is currently performing better than net zero and is a *net energy producer.* In this graph, the net production each month becomes the starting point of the following month's net production amount. The curve goes down at first, since the net production is negative in the winter, then starts to rise as there is more sun in the spring and summer, turning down again as the net production goes negative again as the fall and winter approach. For a ZNE building, the curve will just return to the zero point at the end of the year.





Post-Occupancy: Controls and Monitoring

As noted above, the early measurements of electricity use in the building circuits were flawed by some meter malfunctions and by the inaccuracy of some meters with regard to low energy flows because of characteristics of the current transformers (CTs), as was also observed with Case Study No. 2 and No. 3. When the data was analyzed and compared, the apparent inaccuracy of the meters was detected. The issue was resolved by replacing meters and verifying that the new results were internally consistent.

The accuracy of energy use metering is a consistent issue with low-energy buildings that are being monitored and analyzed. It would be useful to include metering system checkout as part of the regular commissioning process.

The lighting control systems presented a number of problems and issues with regard to energy use that were eventually solved. The lighting control industry has advanced in the past five years to correct and avoid some of these issues, but it is useful to note the experience with this building and how the owner and occupants, with their expertise with these particular systems, worked to resolve them.

When the meter accuracy problem was solved and accurate data on energy use for each of the circuits was analyzed, the *IDeAs* staff found that the lights were still consuming a base level of electric energy even when full daylight was available and the lights should have been off. Study of the issue revealed that the dimming controls never shut off the lights completely but maintained a low level of power that was not discernible from the lamp appearance.

The staff worked with the light control system manufacturer to develop controls that completely shut off the power to the light fixture without adversely affecting lamp startup or the continuity of light level change. Since the operating system for the controls is located with a device at the electrical panel, it was relatively easy to change out the system to the new version that completely shut off the lights in adequate daylight conditions.

The problem was the same with the second type of light fixture and control system, where the dimming controls were built into the light fixture rather than a separate device at the electric panel that communicated wirelessly with the light fixture dimmer. This type of fixture made it impractical and costly to retrofit or replace the dimming control system. In addition, the occupant control of the light schedule was executed through proprietary software that was installed on a specified laptop in the office. The software compatibility with the Windows operating system became an obstacle to operation of the lights since the upgrades to the operating software always lagged behind Windows operating system upgrades and there was no backwards compatibility.

To solve both of these problems, the *IDeAs* staff decided to abandon the built-in light controls at these types of fixtures and to replace them with a new wireless dimming system with the central operating system located at the panel box and with an online site for scheduling the lights. The online site removed the software compatibility issue by moving the maintenance of the software to the manufacturer rather than the user. Replacing the dimming system for these fixture types incurred an expense for the owner but removed the energy drain at the fixtures under good daylight conditions.

Conclusion: wireless, web-based dimming control systems with the dimming operating system located in a hardware device at the electric panels is a "best practices" approach to daylight-responsive lighting systems.

Post-Occupancy: HVAC

After routine commissioning of the HVAC system was completed, the *IDeAs* staff noticed from the metering data that the ventilation fan was operating at night. Looking into this, the staff found that the operation of the fan, which is intended only to provide fresh air for the occupants, followed the operation of the radiant floor system. In other words, rather than operate in response to the occupancy of the space, the fresh air ventilation fan would turn on whenever the radiant floor system was operating to provide heating or cooling to the space.

Because of the time lag effect of the mass of the concrete slab, the radiant floor system would often start operating several hours before staff were scheduled to occupy the space so that comfortable space temperature would be reached at that time. On colder winter days, the time required would often mean that the radiant floor system would operate through the night. The net result as observed in the metered data was that the fresh air ventilation fan was providing outside air when there were no occupants in the building.

The immediate solution to this was to disconnect the ventilation fan operation from the radiant floor system operation and to use a time clock to schedule the fan operation. While this improved the energy efficiency of the operation, the best solution is to connect the ventilation fan to CO_2 sensors in the occupied spaces; when the threshold CO_2 level is detected, the fan will turn on and operate to provide the required amount of fresh air. Below this threshold, the fan will not operate. This approach is being planned for installation.

Post-Occupancy: Lighting

Metering data analysis revealed that the emergency lighting system battery ballasts were continuously using a large amount of power, which amounted to an unexpected *phantom load* (that is, an energy use by equipment in standby operation even though the equipment is apparently not operating). The *IDeAs* staff is currently investigating possible alternative emergency lighting technology that is not characterized by such a high phantom load.

Post-Occupancy: Plug Load

The IT system for the building, considered part of the *plug load* for the building and by far the largest component of that category of energy load, originally included six servers located in the separate server room. (The design for the cooling of the server room is discussed in the system design section above.) After the building was occupied, *VMware* was installed on two of the servers and as a result four of the servers could be removed. This reduction to one-third of the number of server machines greatly reduced the total plug load.

In the future, as systems move to *cloud* servers, there would no longer be a need for on-site servers and the server room. This is expected to have a significant impact on the reduction of plug load demand for individual buildings at the site boundary, although the load is effectively shifted to the off-site server facility. However, the intrinsic efficiencies of an off-site server facility will still make this an overall better option.

Network printers were originally planned to be continuously operational in a stand-by condition with a manual shut-off. In reviewing the metered data, the staff realized that the printers were not being turned off at close of business. The building controls were therefore modified so that the printer circuits would be turned off when the security alarm was set.

As part of the smart operation of the office computers, local occupancy sensors and *sleep mode* software put the workstation computer into a low energy demand mode in order to minimize *phantom* plug loads in the building. When the building is not occupied, the computers remain in sleep mode rather than being turned off so that system updates can be installed at night and also to provide off-site access to staff.

Post-Occupancy: General

This building is one of the earliest successful ZNE projects and provided much valuable experience for the architects and engineers involved. As of this date (2014), the building has been in operation for seven years and has been a good proving facility for the design engineers, who still occupy the building as their own office. As an early adoption, the facility is a good illustration of the application of advanced design ideas using the technologies available at the time. It has contributed to the collective advancement of the understanding of the best approaches to ZNE design in general.

CASE STUDY NO. 4

Watsonville Water Resources Center

PHOTO: BRUCE DAMONTE

Watsonville Water Resources Center

Case Study No. 4

Data Summary

Building Type: Office/Lab
Location: Watsonville, CA
Gross Floor Area: 16,000 gsf
Occupied: November 2009
Energy Modeling Software: eQuest version 3.51

Modeled EUI (Site)
56.9 kBtu/sf-year
Measured EUI (Site)
51.4 kBtu/sf-year

On-Site Renewable Energy System
70 kW (DC) Solar PV (design)
96 kW (DC) Solar PV (roof system—*see discussion on p. 67*)
254 kW (DC) Solar PV (ground system)

Measured On-Site Energy Production
160,000 kWhr/year (roof system)
34.1 kBtu/sf-year (roof system)
392,000 kWhr/year (ground system)
83.7 kBtu/sf-year (ground system)

Owner/Client
City of Watsonville

Design Team
Architect: WRNS Studio, San Francisco CA
Structural Engineer: JEC Structural Consulting, Oakland, CA
Mechanical / Plumbing Engineer: Rumsey Engineers (now part of Integral Design Group, Oakland CA)
Electrical Engineer and Lighting Designer: Integrated Design Associates - IDeAs (now part of Integral Design Group, Oakland CA)
Landscape Architect: Bellinger Foster Steinmetz

General Contractor
Devcon Construction

The American Institute of Architects designated the project one of the AIA/COTE Top Ten Green Projects of 2010[1]. The building is designed to demonstrate the integration of sustainability concepts especially for water but also for energy. The discussion in this case study focuses exclusively on the energy aspects of the design, both the design process and the building performance, particularly as it pertains to the goal of a ZNE building design.

By every indication, the Watsonville Water Resources Center (WRC) is performing as a ZNE building. Some idiosyncracies of the metering system and load grouping at this plant make the definitive results seen in the previous three case studies impossible to pinpoint in this case, but ZNE performance appears nearly certain.

Background

The new 16,000 sq. ft. Watsonville Water Resources Center is part of the Watsonville Area Water Operations Center, a water recycling facility that provides recycled water to farmers throughout the nearby coastal areas of this part of central California. The building provides the office, laboratory and educational spaces associated with the water recycling plant.

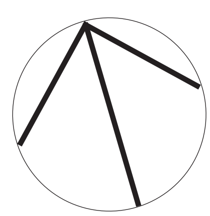
Similar to other ZNE projects, the brief for the Watsonville WRC project did not originally include a mandate for a ZNE design. This came about due to the combination of one aspect of the client's stated mission, in this case demonstration of "environmental stewardship", with an A/E team committed to achieving ZNE performance if possible within the client's financial and operational constraints.

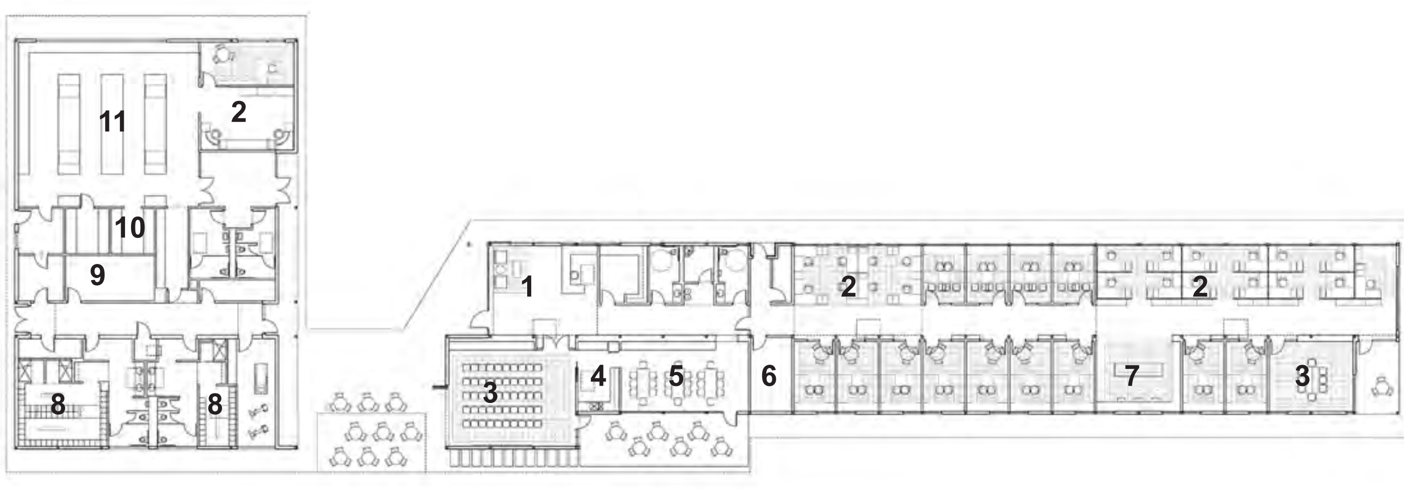
[1] For details on this award, see http://www2.aiatopten.org/hpb/overview.cfm?ProjectID=1731

Aerial view of project site (looking south): Building (circled) and Water Recycling Plant

PHOTO: BRUCE DAMONTE

Watsonville Water Resources Center General Site Plan

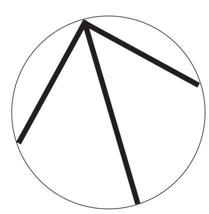




LEGEND

1 RECEPTION
2 OPEN OFFICE
3 CONFERENCE/CLASSROOM
4 KITCHEN
5 STAFF BREAK ROOM
6 SERVER ROOM / ELEC
7 CONTROL ROOM
8 LOCKER ROOM
9 MECHANICAL ROOM
10 FUME HOOD
11 WATER QUALITY LABORATORY

Watsonville Water Resources Center Floor Plan



With the understanding that sustainable water resources are bound up with sustainable energy resources, the client ultimately supported the ZNE design objective when the A/E design team demonstrated that this objective could be achieved within the prescribed project cost budget. The design team was given neither additional project budget nor design fees to produce this type of building design and to confirm its performance through energy modeling. They nevertheless were able to accomplish this and the client fully embraced the concept.

The design team was given the project with a mandate to meet a tight construction budget and to work with the construction manager and general contractor from the beginning. The HVAC system design was carried out using a design-build process, where the design engineer completed 50% Construction Documents, reviewed the final drawings of the design-build mechanical contractor and provided construction observation services. With the public-project construction budget, this process required a set of low-energy design strategies that was practical, affordable and “state-of-the-shelf”.

Low Energy Design Strategies

To meet the tight construction budget, basic economic measures of building planning and design were assumed from the outset. These included very simple building form and low cost building systems. The challenge then was to utilize effective passive systems in addition to standard components to accomplish the low energy use level required for a ZNE building.

(Below) View of entry area

PHOTO: BRUCE DAMONTE

Planning/Concept and Building Envelope

For this coastal marine climate and a building of this type and size, the best design strategies are daylighting and natural ventilation. Heating was expected to have a more significant energy demand than cooling, so a design approach utilizing passive solar heating was a cost-free way of lowering energy demand.

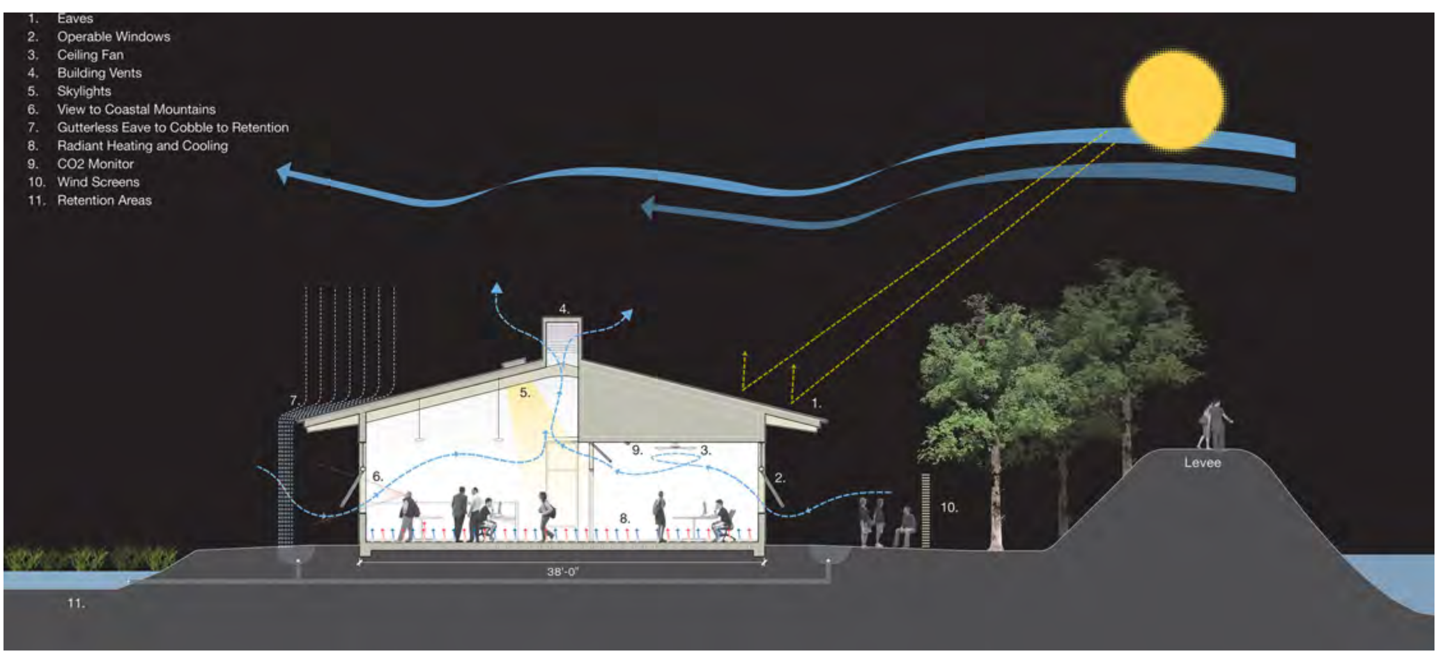
The building shape therefore is an elongated wing 290 feet in length for all program areas except the single laboratory space and the staff support areas. The orientation of this building office wing, with the long façade facing roughly south, sets up the easy capture of the prevailing marine breezes from that direction for the natural ventilation features. Likewise, with a width of only 43 feet, the building form can optimize solar gain in the heating season while shading in the cooling season, and can provide for optimal daylighting conditions for the office spaces on both sides of the building.

The functionally constrained laboratory and its support spaces are located in a second building wing—one that is larger and contains the various other equipment and building support spaces.

The building is basic Type 5 construction, namely wood framing using 2X6 studs centered at 24”, with wall cavities filled with fiberglass batt insulation. For economy reasons, no rigid insulation was added to the exterior of the building envelope to mitigate the limited amount of thermal bridging at the studs. Similarly, the basic roof framing is spaced glulam beams with 2X6 wood nailers centered at 24” spanning between the glulam beams with continuous rigid insulation under a standard metal roof.

The final result is a building envelope insulated to an economic but sufficient level, with R-16 walls and an R-45 metal-covered roof system, including all the effects of the thermal bridging.

(Below) Diagram of low-energy design features (Courtesy of WRNS Studio).



As usual with careful building envelope design and construction, conditions where insulation gaps might occur at floor-to-wall and wall-to-roof transitions were inspected and the entire building envelope was sealed to prevent unwanted air leaks. For a Type-5 wood frame building, this sealing and caulking is an essential efficiency measure to keep heating and cooling loads low.

The window glazing is a high performance double-glazed system using color-neutral low-e Solarban 60 coupled with an inner lite of conventional clear glass. This specification provides a low U-value equal to 0.28, a low SHGC (solar heat coefficient) of 0.39, while maintaining a visible light transmittance of 70%.

Daylighting and Electric Lighting

Daylighting is a particular strength of the low-energy design approach with this building. The narrow width of the building combined with tall windows allows daylight penetration throughout. In addition, skylights were added in areas where daylight could be blocked by intervening walls of closed offices. The result is not only a very effectively daylit space from a technical point-of-view, but also a strong architectural interior space that derives its spatial interest from the daylighting solution.

The electric lighting is provided by standard direct/indirect fixtures with high efficiency T-8 lamps, using the required continuous dimming controls in response to daylight availability.

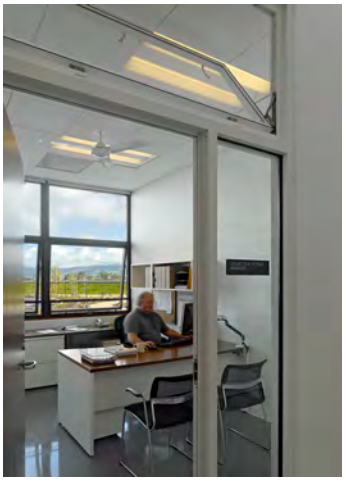

PHOTO: BRUCE DAMONTE

Heating, Cooling and Ventilation

The preferred design approach for heating, cooling and ventilation for a building of this type is to minimize fan energy use normally associated with central plant systems. The design engineers also took the opportunity to capitalize on a steady source of cooled water available at the adjacent water recycling plant.

The original concept therefore was to use the basic idea of a water-source heat pump for heating and cooling, with delivery of heating hot water or chilled water to a radiant slab system in both wings of the building. Ventilation in the office wing is provided separately by occupant-operated natural ventilation, backed up by mechanical ventilation via distributed air handling units that operate only if CO_2 limits are exceeded. Known as dedicated outside air systems (DOAS), they utilize only small local fans for the backup ventilation, satisfying the objective of minimizing this type of electric energy use.

When the system was priced in mid-design, the cost was determined to be too high for heat pump equipment of the size necessary to meet both heating and cooling loads. For this reason, and because the client had not yet embraced ZNE as a confirmed project goal, a more conventional approach for radiant heating, namely a gas-fired condensing boiler, was incorporated into the design, while a much smaller heat pump is designated for the cooling operation. All of the advantages of the low-energy design approach were maintained, but the idea of a solution that did not utilize carbon-based fossil fuel was no longer viable.



This also would mean that a zero-net-energy measurement and verification would have to account for the equivalent energy use by the gas-fired system. For the building to be designated as ZNE, measurement of total annual energy export from the site and the utility's meter measurement of total annual energy import would have to show enough excess energy export to balance the equivalent energy used in the form of gas. In the absence of any balancing excess exported electric energy, the building would be only zero-net-electric-energy. This issue is discussed in detail later in this case study.

As noted, the fresh-air ventilation system is separate from the heating and cooling system. The ventilation system starts with occupant-operated openable windows when fresh air or cooling are desired. The interspersing of open office areas with closed offices optimizes the cross ventilation patterns for comfortable air movement. To increase the temperature range for perceived comfortable conditions, the office spaces have large, slow-moving room fans to increase gentle air movement.

In addition, for warm days when interior ventilation and air movement needs to be increased, air can be drawn up in the high space to ventilation "chimneys" visible on the roof, which function as outlets for the passive ventilation air draft.

The distributed air handling units located in attic space below these chimneys in the office wing provide mechanical ventilation when natural ventilation via the openable windows and other pas-

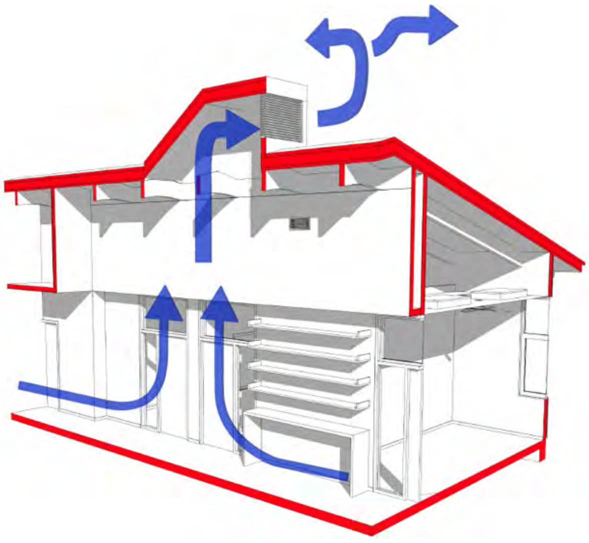


Diagram courtesy of WRNS Studio

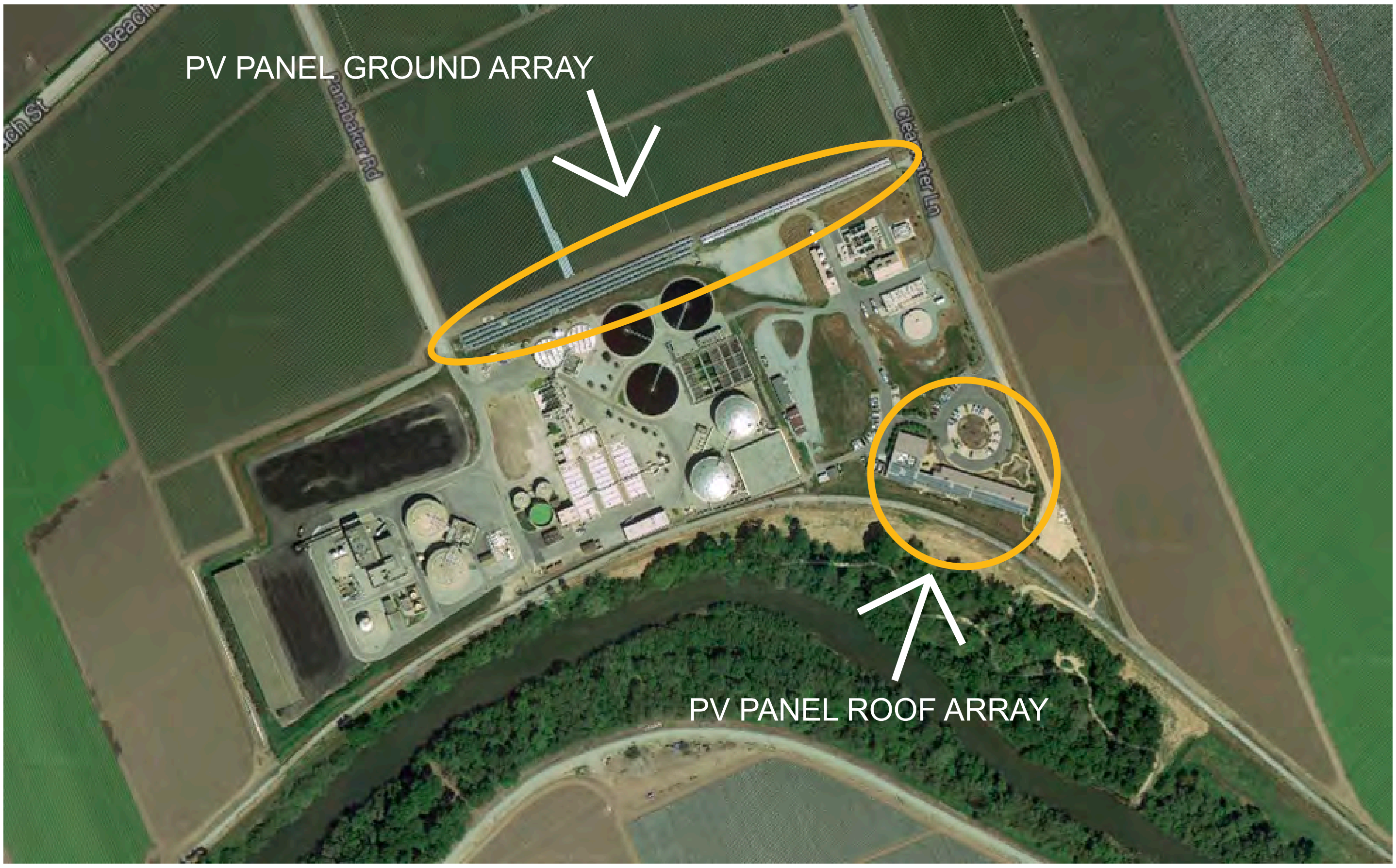
sive means are not sufficient. Air is drawn up and out mechanically through the same chimney air outlet. These air handling units also operate at night during the cooling season if directed by the building management system (BMS) to "night purge" with cool night air so that the building is pre-cooled for the following day's operation. The night purge operation shifts peak electric demand to less expensive hours of operation and reduces the necessary capacity of the heat pump system.

The laboratory wing is served by a *low-pressure-drop* air system for cooling. The unit is sized for low air velocity, reducing fan and motor sizes. The radiant floor heating system is used in the laboratory wing as well. Laboratory fume hoods are located in an isolated room so that the laboratory space can utilize openable windows and natural ventilation as the occupants desire. Since this water quality laboratory has no unusual safety issues, as is sometimes the case in laboratory environments, the client schedules the mechanical ventilation to be shut down at night to eliminate unnecessary energy use. There is, as a result, no night purging operation for this building wing.

Plug Loads

As in most low-energy buildings, plug loads account for a large portion of the total energy used. Plug loads used in the energy modeling are based on available public information for office space, equipment lists and inventories from the client for the laboratory and other program specific spaces. Use patterns in the modeling were also built up from observation and experience on previous projects. With metering for individual circuits in place, actual measurements show how much actual plug load energy use has deviated from these modeling assumptions.

PHOTO: BRUCE DAMONTE



Solar photovoltaic panel ground array (below).

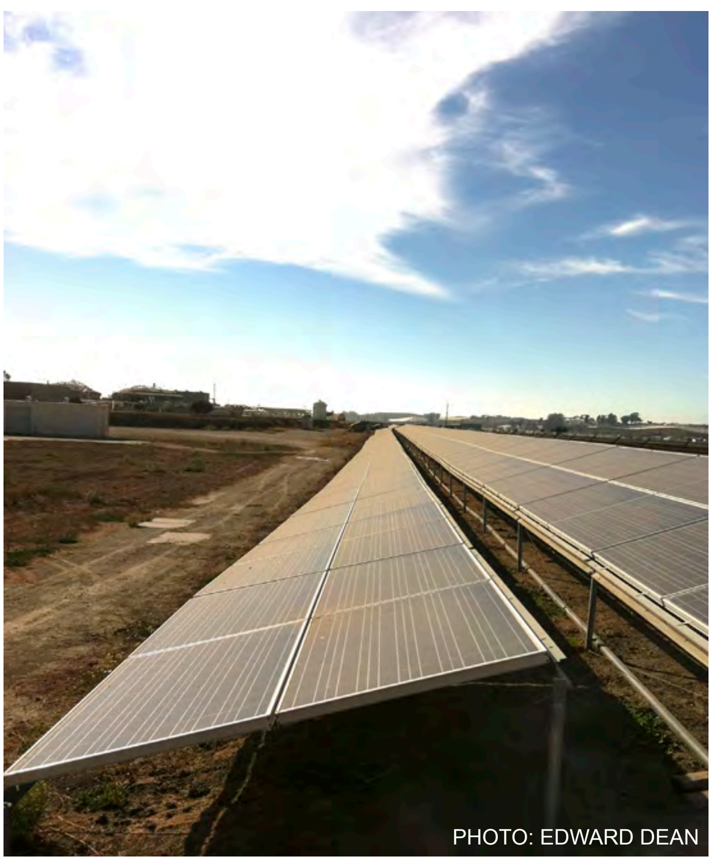


PHOTO: EDWARD DEAN

Solar photovoltaic panel roof array (below).

PHOTO: EDWARD DEAN

Renewable On-Site Energy Supply: Solar Photovoltaic System

Based on initial energy modeling for the building's predicted energy demand, the design team also determined the required size and specifications for the on-site renewable energy supply needed to achieve ZNE performance over the course of a year. A 70 kW (DC) system located on the south-facing, shallow-sloped roof of the office wing would meet the expected peak design load in summer and produce enough electric energy to ensure that the building achieved ZNE annual performance.

Because of the construction budget limitations, the client opted to seek an additional funding mechanism for the purchase and installation of this solar photovoltaic system. This separate process of funding and constructing the system required two years to complete, primarily for cost efficiency reasons. The City of Watsonville determined that the competitive bid process for the system would be optimized if the overall installation actually were larger than just the system for the Water Resources Center building. The City therefore bundled together a number of other facilities and locations as part of the separate system contract, including some of the plant load at the adjacent Water Operations Center. For this reason, it has become difficult to isolate the performance of the Watsonville WRC at the same resolution as the previous case studies in this monograph.

As a result, the solar photovoltaic system at the site today consists of a 96 kW (DC) array on the roof of the Water Resources Center office wing and a 254 kW (DC) array located on the ground along the northern border of the overall site. This combined system provides solar electric energy to both the Water Resources Center building and a 350 hp water recycling pump at the adjacent plant. Because there is only one utility meter for these two loads and the combined ground and roof solar arrays, it is not possible to distinguish between the energy supplied to the building and that supplied to the large pump. In addition, the energy use of the pump, essentially a type of *process energy* not normally "counted" as building load, varies quite a bit and depends on the demand for recycled water by local agriculture. In drought years, such as now occurring in California, the demand is higher than normal. Therefore, in any given year, more energy may be drawn by the pump than by the building from this combined system.

The net effect is that, even though the solar photovoltaic system now installed on the roof of the office wing would likely be sufficient (per the performance modeling) to produce a ZNE annual balance for the building alone, much of the power produced by the roof array is being used by the large water recycling pump. The measured data for 2013 shows this result (see discussion below).

In a change from the original design intent of providing a solar photovoltaic system on the roof sized to produce ZNE performance for the building in isolation, the City of Watsonville intentionally combined the roof and ground arrays, and added the pump load, in order to make the combined energy load/supply systems perform at 80% of ZNE for the combined building and process loads. Under current utility rates and tariffs for such facilities, this is a common, economically prudent practice.

Controls

The building has a standard building management system (BMS) for control of heating, cooling and ventilation. CO_2 sensors engage to control the mechanical ventilation. As noted above, the ventilation system in the laboratory is programmed to turn off during night hours and start up two hours before the building opens.

There is a standard switchover from heating operation to cooling operation at a selected point in the season. Interestingly, the office wing to this date has not used the cooling system. General lighting is dimmed in response to daylight availability.

Energy Design Analysis and Energy Performance - *Modeling versus Initial Post-Occupancy Measurements*

Energy Use – Modeling

The energy modeling for the Water Resources Center was carried out using eQuest version 3.51. All of the final design strategies described above were incorporated into the final energy analysis, including a typical pattern of use for the occupant-operated natural ventilation and the gas-fired high-efficiency boilers for radiant slab heating.

The model shows a predicted energy use of 267 MWhr and an EUI of 56.9 kBtu/sq. ft. per year, including energy from both gas and electric sources. The dominant energy use is expected to be plug load, with heating on the office wing and the cooling primarily in the laboratory wing of the building.

See the summary of the modeling results on the facing page. Note that the EUI for this mixed-function laboratory/office building is in the range of 50-60, which is generally double what is considered a good design benchmark for the annual energy use of a basic office building in this climate. However, laboratories have a much higher energy demand per unit floor area; buildings that include some laboratory space have a much higher EUI than simple office space.

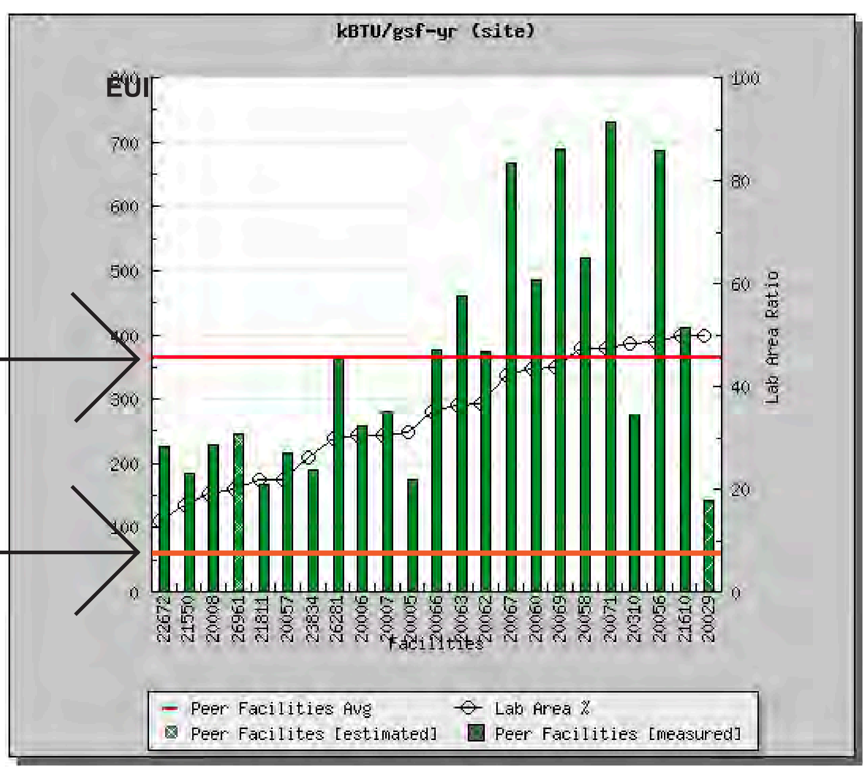
Since one of the criteria for a good ZNE design is a low EUI as compared with other buildings of a similar type, the Watsonville WRC was benchmarked against other recently-completed mixed-function laboratory buildings in the same climate zone, with similar laboratory functions and similar size, and with a comparably small fraction of the building area given over to laboratory space. That is, the laboratory space in the benchmarking comparison is only a minor fraction of the total building area.

The benchmarking was done using the Labs21 benchmarking tool[1] and the results are shown in the figure below. As the benchmarking exercise shows. the Watsonville Water Resources Center has an exceptionally low EUI, as desired in a model ZNE case study building.

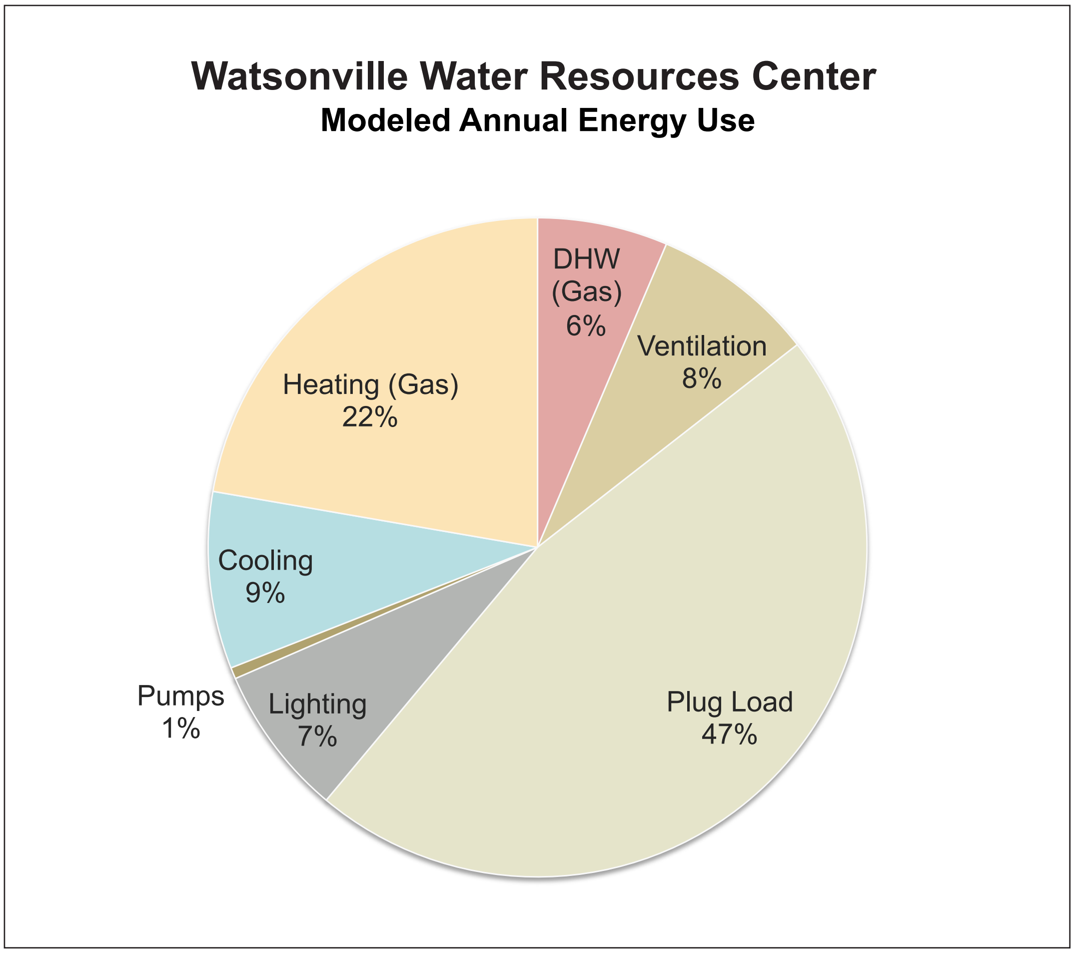
[1] http://labs21benchmarking.lbl.gov/

Average EUI for Peer Buildings

EUI for Watsonville WRC

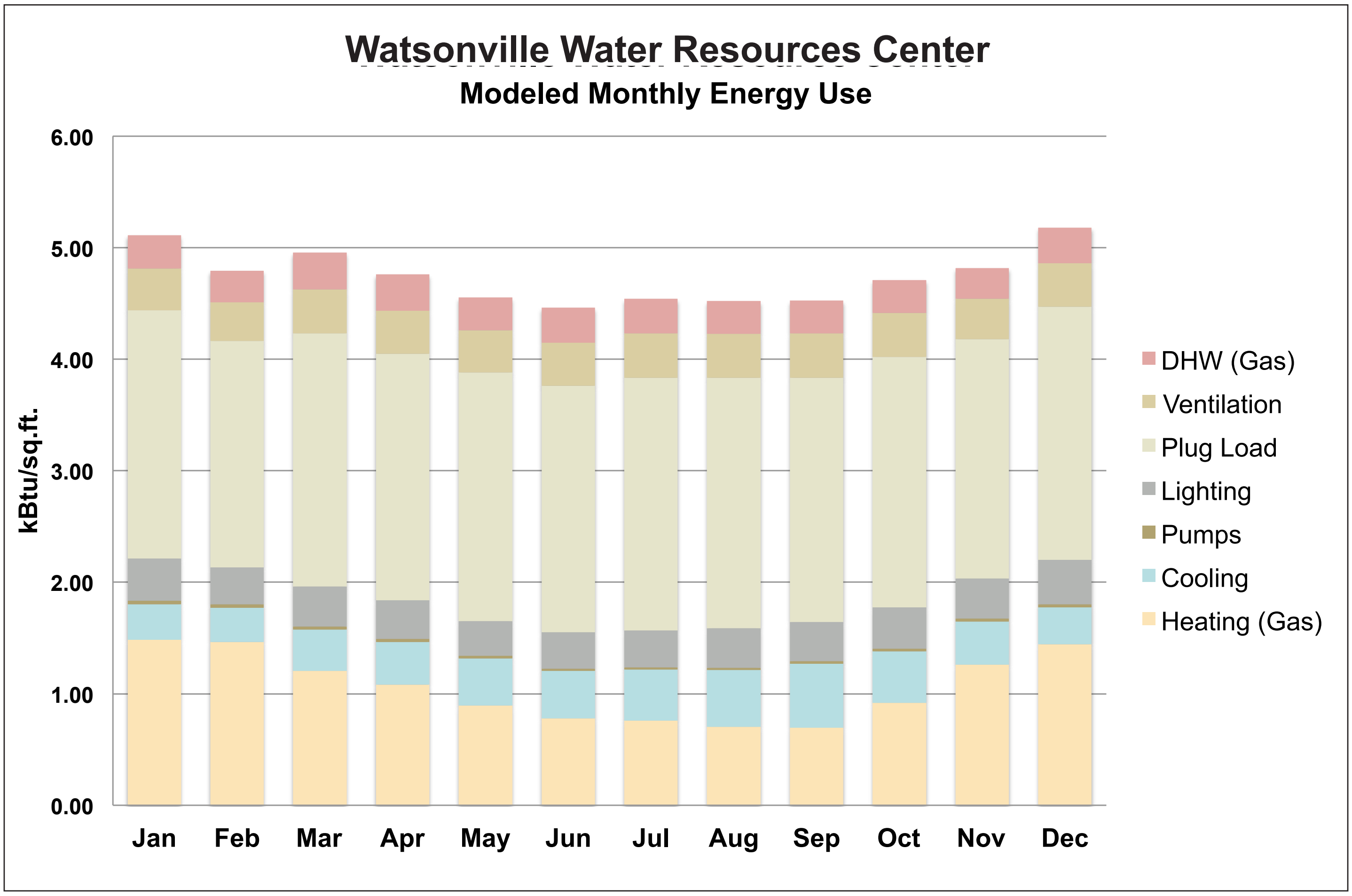


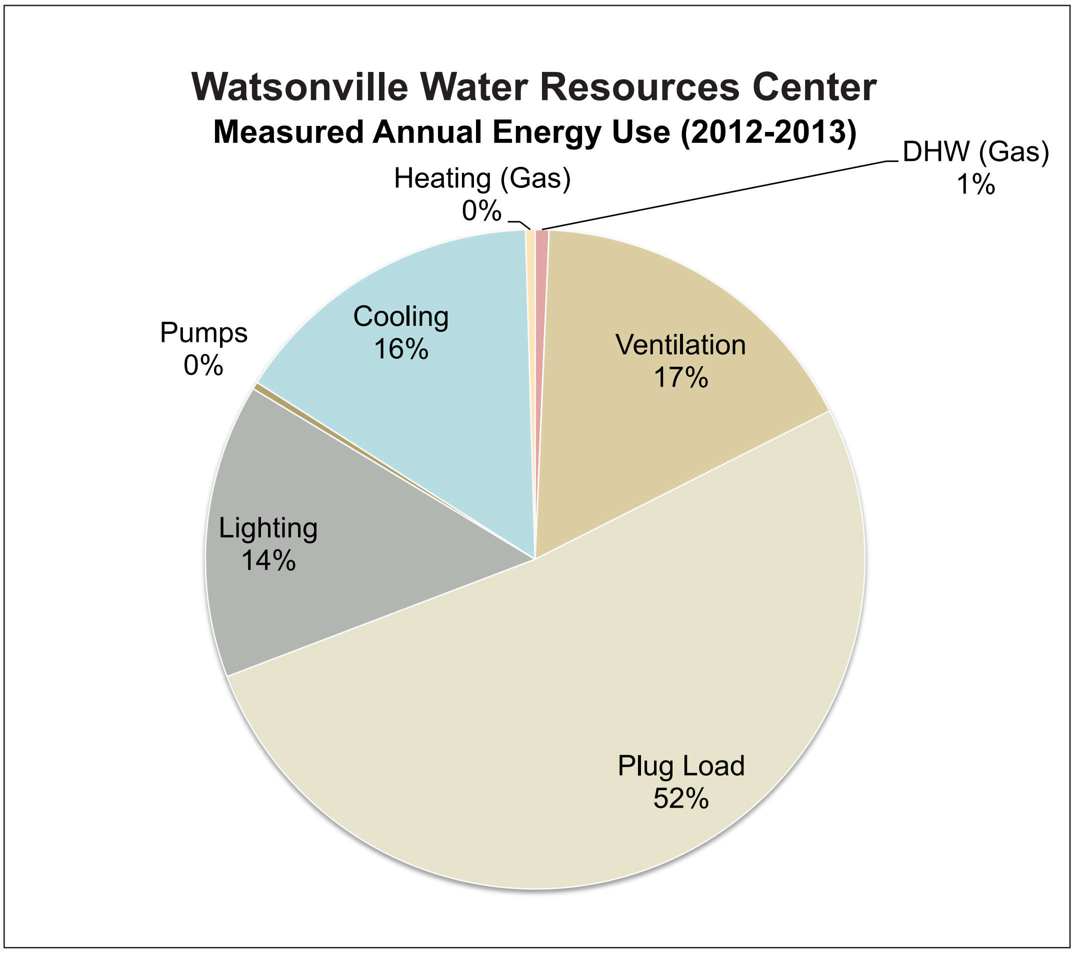
(Right) Chart of benchmark EUIs for comparable project types. (Edward Dean)



Modeled Energy Use

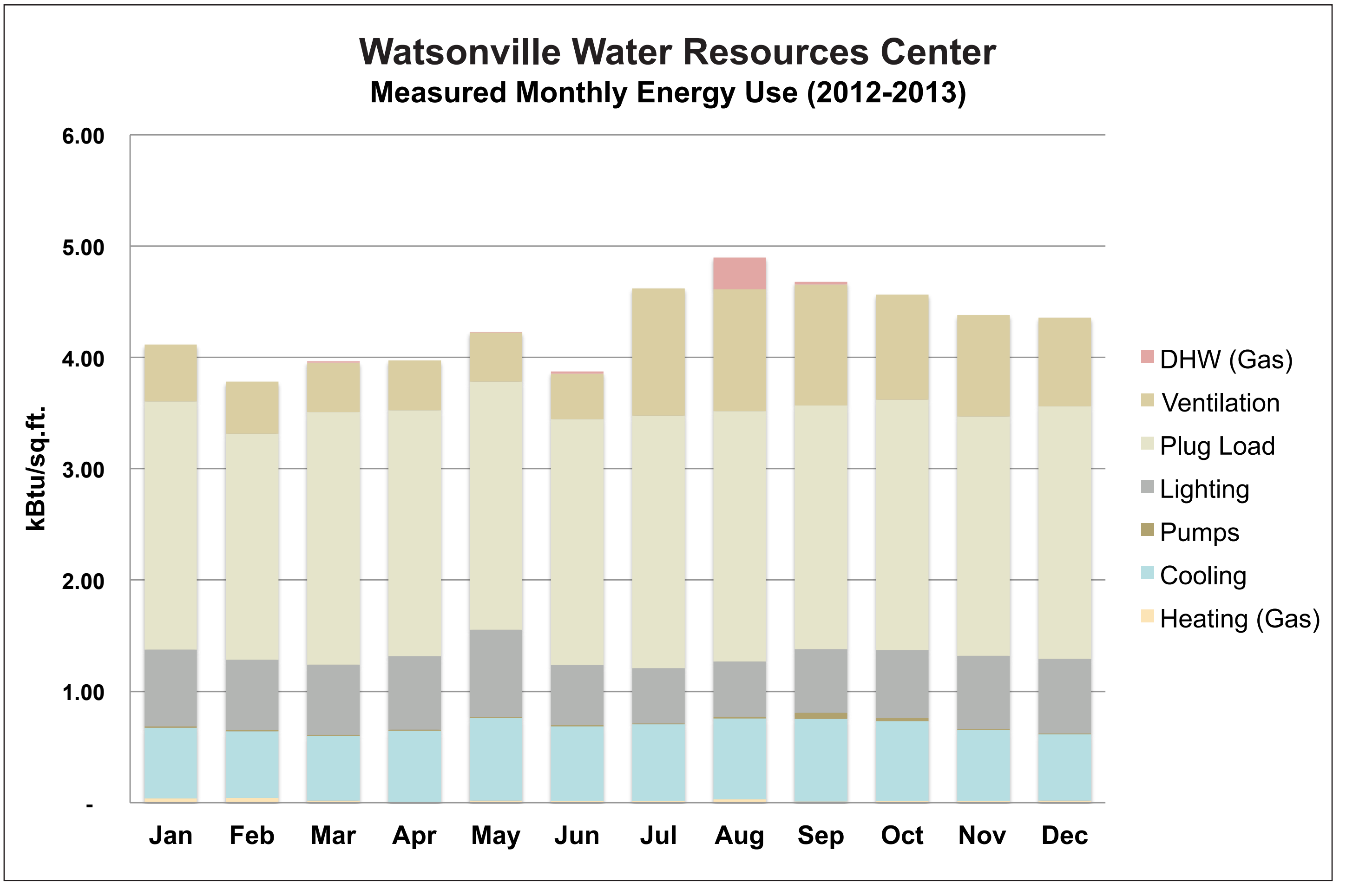
267 MWhr per Year
Modeled EUI = 56.9





Measured Energy Use

241 MWhr per Year
Actual EUI = 51.4



Energy Use – Actual Measurement and Comparison to Modeling Results

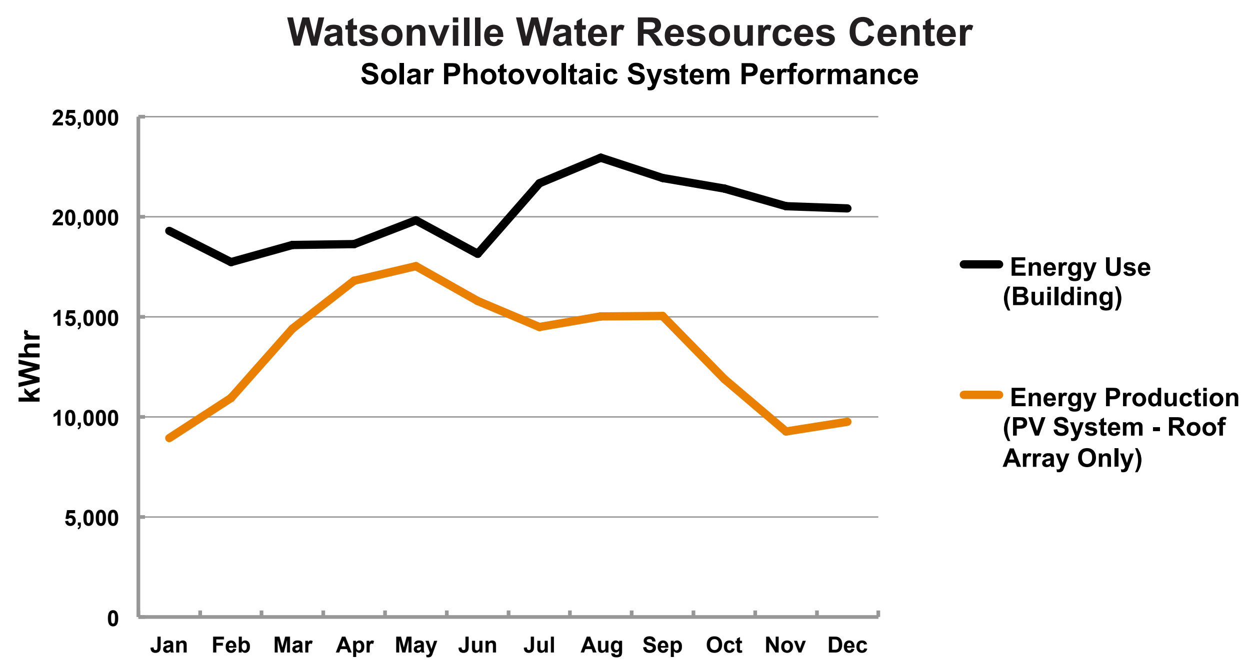
A summary of the energy use measurements of the building, metered and recorded in 2010-2011, is shown on the facing page. This measurement data indicates significant differences between the modeling and actual building use in some categories of energy use. There was also missing data for the building plug loads because of inadequate programming of the BMS to record and communicate that important measurement information. The latter appears to be a persistent issue with post-occupancy monitoring of low-energy buildings, as noted in the prior case studies in this monograph, and needs attention by both design teams and building owners.

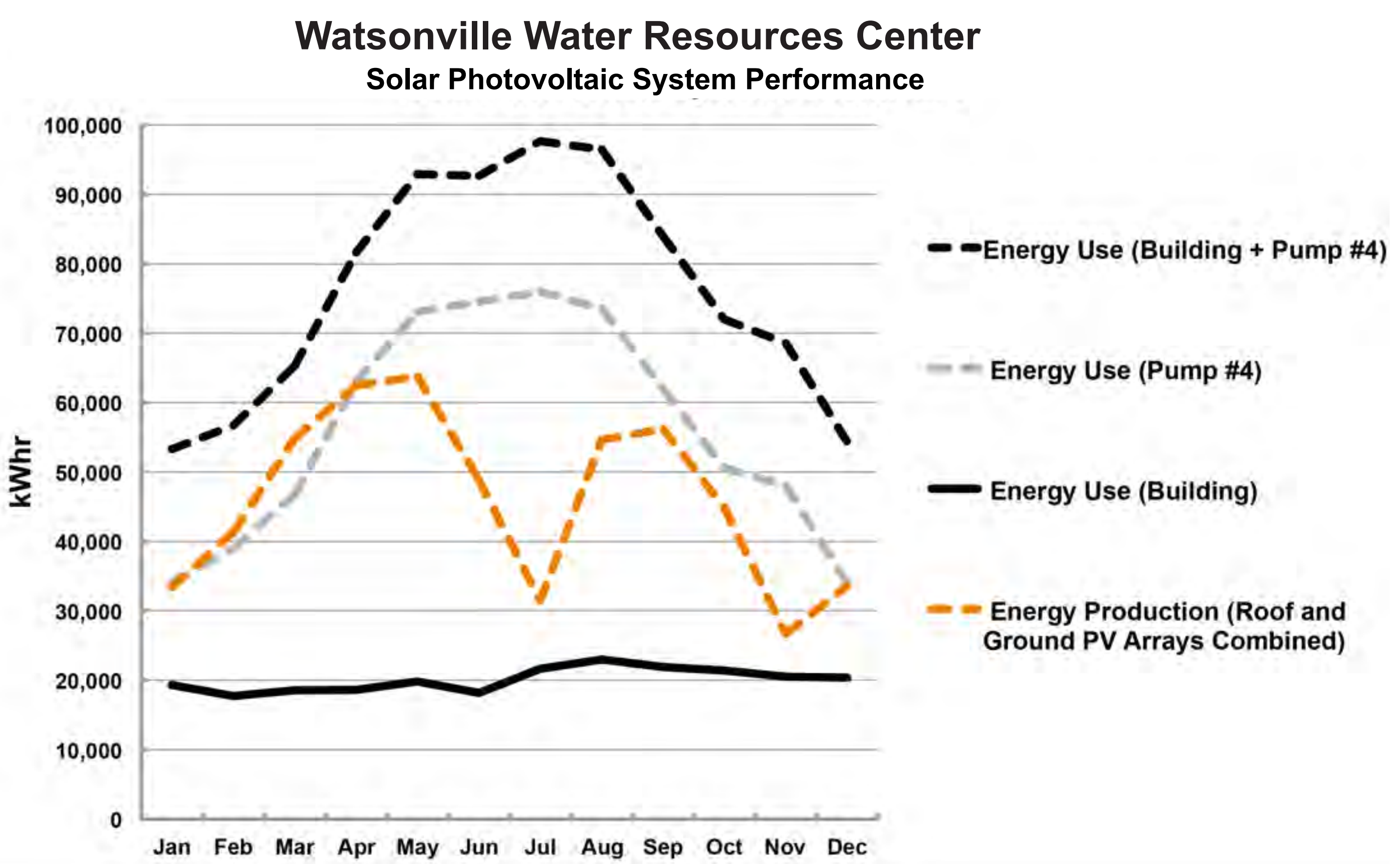
The heating energy used was much lower in this first year than predicted by the energy model, which may be explained by the very clear skies during the heating season of the year of measurement and the passive heating effect of the predominantly southern exposure of a long, thin building. Domestic hot water use was also significantly less than that predicted by the model, which may simply be the result of unexpected use patterns by the occupants at this facility.

On the other hand, the lighting energy used was nearly double that assumed in the model, no doubt due to unexpected use patterns. The higher lighting energy use may also partially explain the reduced heating load since this extra energy from the warm lamps would ultimately reside in the space as heat. The cooling energy used, almost entirely in the laboratory wing of the building, was 60% higher than modeled; again, the likely cause is simply use patterns and hours of operation different from the modeling assumptions.

Ideally, these differences between measured and modeled energy use would be reported to the facility manager, commissioning agent and design engineers so that appropriate actions could be taken, including involvement of the building users. The building designers and managers for the Watsonville WRC are beginning to address this issue.

Because of this problem of the missing plug load data, the modeled total for plug load is used in place of the absent measured total for plug load for the purposes of presenting the measured results in all other categories of energy use. Therefore, the quantities shown in the charts on the facing page are actual measured data for the first year of occupancy, with the exception of the plug load, for which the modeling assumption is used. With this one caveat, the building's actual energy use in the first year of post-occucpancy measurements totaled 241 MWhr and an EUI = 51.4 kBtu/sq. ft. per year.


Watsonville Water Resources Center
Solar Photovoltaic System Performance
kWhr
25,000
20,000
15,000
10,000
5,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Energy Use (Building)
Energy Production (PV System - Roof Array Only)


Watsonville Water Resources Center
Solar Photovoltaic System Performance
kWhr
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Energy Use (Building + Pump #4)
Energy Use (Pump #4)
Energy Use (Building)
Energy Production (Roof and Ground PV Arrays Combined)

Energy Production versus Energy Use: Zero Net Energy

Measurements of the energy used by all of the systems in the building were started in 2010 and preceded the installation of the solar photovoltaic system in 2012. Due to the separate sources and timing of the recorded information, the energy use and energy production results reported in this case study are not coincident in time. They nevertheless provide a good comparative set of data for each, particularly since the weather patterns for the two different years were very similar.

Verification that the Water Resources Center is actually performing at ZNE is not possible to confirm exactly at this time because of the service and metering issues discussed previously. As noted, the City chose the most cost effective approach for bidding and purchasing the PV system, which was to enlarge the system and include additional electric loads of other city facilities and equipment, including a very large water recycling pump at the adjacent Water Operations Center. Isolation of the Watsonville WRC building loads in relation to the energy production of the PV system cannot be done at the same level of certainty as the other case studies in this monograph.

The graphs on the facing page show the performance of the combined building/pump loads and both arrays for the PV system. The upper graph shows that the roof-mounted array is providing about 70% of the first-year demand for the building. The lower graph indicates a large demand from the recycling pump, which drew a large amount of power from the roof panel array.

Post-Occupancy: Controls and Monitoring

Monitoring of the building energy system and data measurement began with initial occupancy near the beginning of 2010. However, it was soon discovered that energy data was being recorded but not stored and six months of data were lost as a result. The BMS system was set for recording too detailed a level of data, inconsistent with the memory/storage capacity of the system. With a programming reset, the system began recording data in July 2010.

The systems were shown to be operating as planned. A failure of the electric DHW heater, caused by a manufacturer's issue unrelated to the ZNE design, caused a switch to a gas-fired DHW heater.

Post-Occupancy: HVAC

The HVAC system in general has been operating as designed and no significant problems were apparent in the first year of operation. The office and the laboratory wings have proven to be comfortable thermally and the total energy use for heating, cooling and ventilation have been approximately what was expected.

Post-Occupancy: Acoustics

A common complaint among occupants of high performance buildings is the poor room acoustics. The Water Resources Center is no exception: the hard surfaces with little acoustic absorption material combined with the absence of the "white noise" of operating equipment such as fans and air blowing through ductwork and diffusers have led to post-occupancy reports of poor acoustic quality. This can be mitigated by installation of absorptive acoustic materials and attention to standard acoustic design for certain noise sources such as footfall, telephones and office equipment.

Large ceiling fans were installed in the office spaces as part of the ZNE design strategy, since gentle air movement allows a sense of comfort at higher air temperatures. However, the contractor installed a generic controller instead of the manufacturer's controller and the result was very noisy operation. The result is that occupants appear not to be using the ceiling fans as intended, negating the intended effect and likely resulting in higher energy use for cooling since higher temperature setpoints for cooling could not be used.

Post-Occupancy: General

The principal issue that emerged during the post-occupancy period was the inability to obtain the complete set of measurement data needed to evaluate the building's energy performance. Additional work on the BMS system would no doubt resolve this problem. In general, however, the building's overall total energy use appears to be less than that indicated by the design modeling and consistent with the goal of ZNE performance. This is expected to be confirmed once the data issue is resolved.

PREFACE TO CASE STUDIES NO. 5 AND 6

University of California, Merced

Toward A Zero Net Energy Campus by 2020

PHOTO: STEVE PROEHL

University of California, Merced

Preface to Case Studies No. 5 and 6

PHOTO: EHDD

PHOTO: JOHN ELLIOTT

Zero Net Energy Campus Planning and Building Design: The Backstory

The University of California at Merced (UC Merced) is referred to as "the first new research campus of the 21st century" for the University of California and was officially opened in the fall of 2005, utilizing student residence halls and the new main library building as the venue for campus activities. Six months later, two other main buildings opened for use: the *Classroom & Office Building* and *Science & Engineering Building I*, both of which are the subject of case studies in this publication.

Planning for the campus began years before; sustainability in all aspects was a driving principle in its planning and design. The *UC Merced 2009 Long Range Development Plan* (LRDP) summarizes much of this work and looks ahead ten years as the new campus grows and develops in every respect. Because of the centrality of sustainable design to this Plan and its overall quality, The American Institute of Architects' Committee on the Environment (AIA COTE) awarded it the national designation as one of the 2012 COTE Top Ten Green Projects in the United States.

"This project is showing the way in regards to employing district-scale systems effectively. By using systems that are bigger than individual buildings, they are demonstrating that economies of scale are an important component of the continuing evolution of sustainable design." –AIA COTE Jury

The "Triple Zero Commitment"

One of the principal features of the 2009 LRDP that led to the 2012 national AIA COTE award is its *Triple Zero Commitment.* Mandated by the Regents of the University of California and the State of California, this *Commitment* is, when the campus is fully built out, (1) to consume zero net energy; (2) to produce zero landfill waste; (3) to produce zero net carbon emissions, that is, to be *carbon neutral*.

These ambitious goals are supported by a number of initiatives that the University has undertaken, which are spelled out in some detail in the *UC Merced Sustainability Strategic Plan (2010)*. With regard to the commitments to *Zero Net Energy (ZNE)* and *Zero Net Carbon (ZNC)*, the three principal objectives or initiatives are:

1. Maximize energy efficiency in building design and operations - with an initial goal to consume half the energy and demand of other university buildings in California and exceed Title 24 by 30% in all new buildings by 2010.

2. Achieve campus zero net energy usage through renewable energy generation by 2020.

3. Achieve zero net greenhouse gas emissions by 2020, prioritizing on-site and regional offsets.

In other words, the objectives of the ZNE plan involve an emphasis on energy-efficient building design and, as noted in particular, building *operations*, combined with a gradual introduction of on-site renewable energy generation using arrays of solar photovoltaic (PV) panels, wind turbine generators, biomass systems and geothermal systems.

This plan is being implemented, with the energy performance budgets for new buildings being steadily lowered as experience is gained and the on-site renewable energy supply is incrementally increased. As the new campus grows and buildings are added in each of the four phases up through 2020, the overall energy-efficiency of the new campus buildings will increase (their energy budgets will be reduced as determined to be technically feasible) and more on-site re-


Sacramento
Bay Delta
Stockton
San Francisco
Modesto
Merced
Sierra Nevada
Madera
Santa Cruz
Fresno
Hanford
Visalia
Coast Ranges
Bakersfield
San Luis Obispo
Tehachapi Range

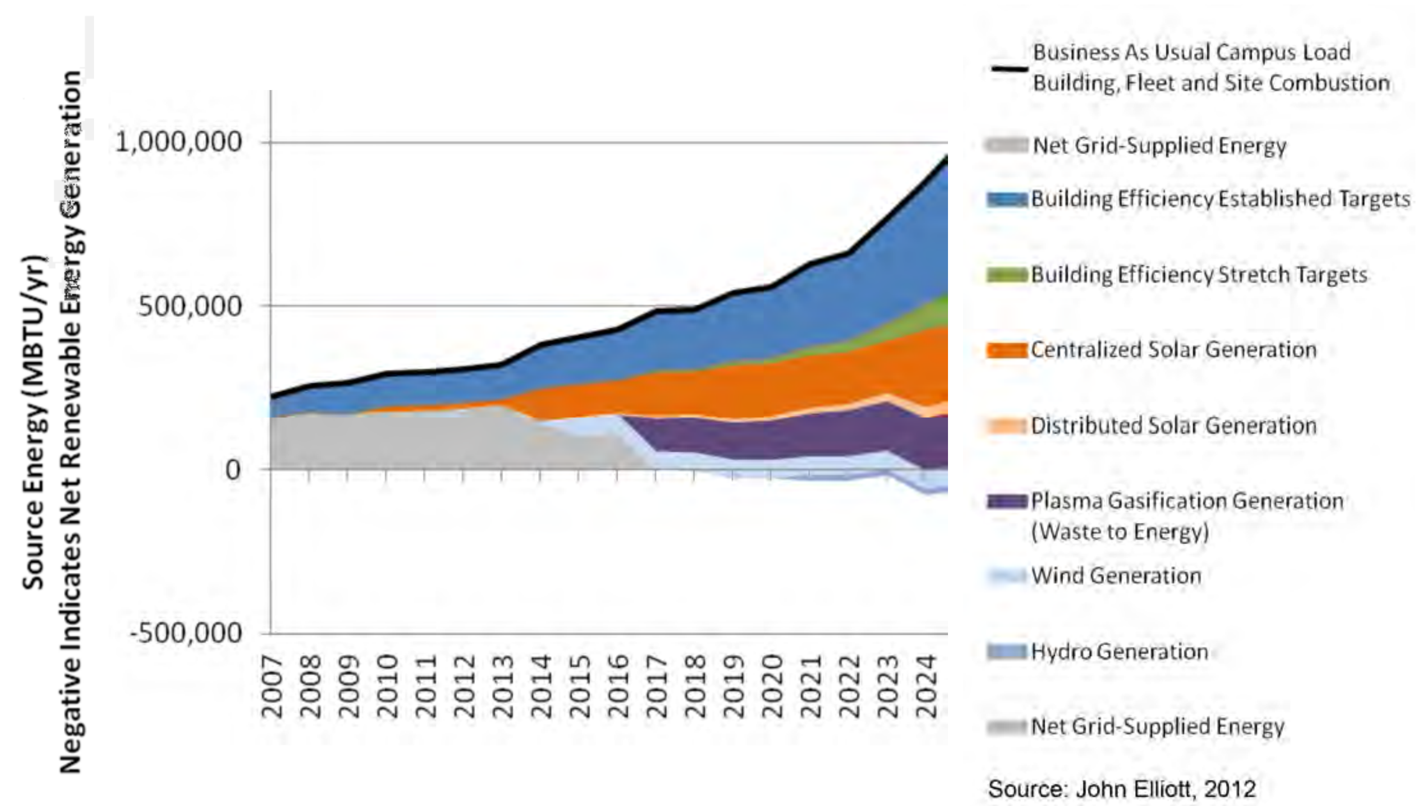
newable energy supply will come online. The plan is that overall, the campus as a whole will achieve ZNE in 2020, as detailed in the graph below.

"ZNE Buildings" at UC Merced

This is the context of the two case study buildings located at the UC Merced campus, the Science & Engineering Building I and the Classroom & Office Building. These two buildings do not meet the ZNE "Site" definition in the narrow sense of the term since they do not have renewable energy systems directly attached to them; they will be powered through renewable energy systems established at the campus level as targeted by 2020. However, the critical factor for these two buildings (as with subsequent buildings as the campus is built out) is that they meet a targeted performance level so that the planned renewable energy systems will in fact be adequate to achieve the campus-wide ZNE goal. Therefore, a focus on *building operations* is essential in meeting (and exceeding!) targeted performance goals.

The two buildings are being included as case studies because they will ultimately (in 6 years) be part of an ensemble of campus buildings performing to a zero net energy level. The two buildings

(Below) Graph of UC Merced campus plan for energy use through 2024. Note campus is planned to be net positive by 2020. (Courtesy of John Elliott).

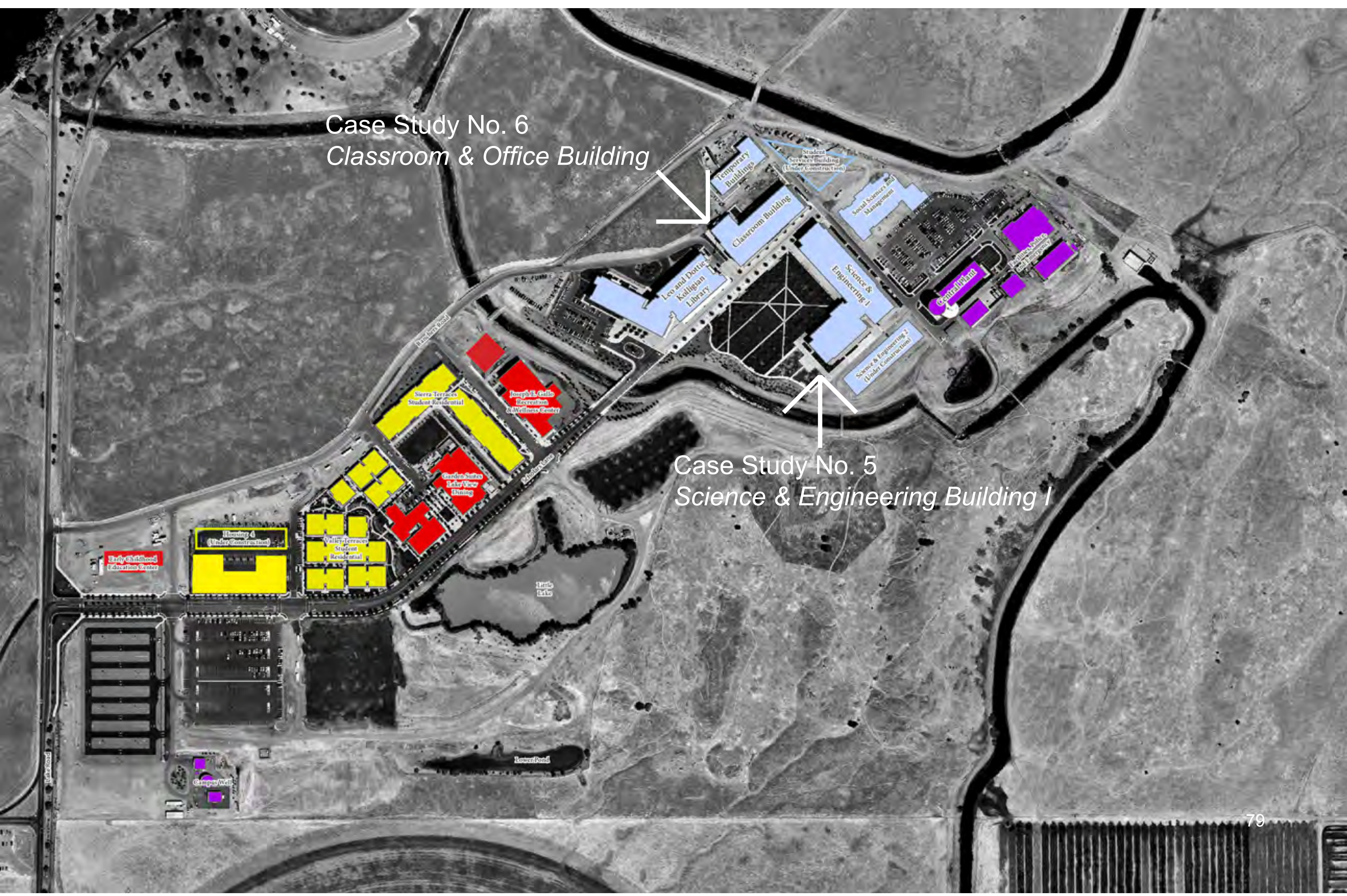


also make good case studies because significant post-occupancy work has been done to adjust the building energy systems to lower the energy demand in these buildings below the original energy budget design levels. This was done based on observed data from the building management system (BMS) and electricity-use meters on all electric circuits.

In other words, the buildings' actual measured *Energy Use Intensity* (EUI)[1] is now lower than the original energy design budgets (target EUI) due to responsive actions taken by the University's Facilities Management group. The nature of the performance issues discovered and these responsive actions are applicable to other buildings of similar design and can assist these similar buildings to lower their actual EUI. Beyond this, because of the presence of energy use submetering and the ability to observe real-time performance, the staff have experimented with innovative ways of reducing energy demand by working directly with the building users. The latter will be discussed in the case study for *Science & Engineering Building I*.

For these several reasons, there is very good value in examining these two buildings in the context of ZNE case study buildings.

[1] EUI is given in units of kBtu/sf per year.



Energy Demand: Setting Design Energy Budgets at UC Merced

The approach to establishing energy budgets for buildings at UC Merced is the *Benchmarking* method discussed in the Introduction. In 2002, Karl Brown of the California Institute for Energy Efficiency (CIEE) and the University of California Office of the President, proposed a benchmarking method for the design of all new buildings for the University of California based on actual data for energy use and peak electric load at current UC campuses[2]. This method was specifically developed in anticipation of the design and construction of an entirely new UC campus at Merced, "built from scratch", where there was a mandated initiative for an advanced design for a carbon neutral, energy-efficient campus.

A key concept to this benchmarking approach is to use real data for comparable buildings under typical use patterns rather than create performance targets based on comparisons to hypothetical designs, which is the approach of energy codes and standards. This was seen as more likely to lead to achieving the goal of actual zero net energy performance for all campus buildings by 2020.

The benchmarks, created primarily through a rigorous statistical analysis of data from the existing post-1999 buildings on other UC and California State University (CSU) campuses, provide "baseline" numbers for three broad categories of buildings: (1) laboratory buildings; (2) classroom, office and library buildings; (3) housing, student services and recreational. The energy budgets for new buildings are set based on a fixed percentage of these benchmark numbers[3]. The idea is that the University will verify the feasibility of meeting these energy budgets and then ratchet down the percentage in subsequent phases based on the measured results of the early phase buildings.

The facing page shows a chart of these benchmark targets for the building EUI, the common measurement of annual energy use in buildings. The table lists the current energy design budgets based on 50%-of-benchmark targets for the significant categories of energy use and energy demand.

For Phase 1 buildings, two of which are case studies in this publication, the percentage was set at 80%-of-benchmarks. As an example, the Phase 1 laboratory building annual total energy budget was set at an EUI = 263 kBtu/sf-year and the Phase 1 classroom/office building annual total energy budget was set at an EUI = 57 kBtu/sf-year. Because these buildings are currently performing much better than targeted, close to 50%-of-benchmark levels according to ongoing measurements and data collection, the current Phase 2 building energy budgets are set at this 50% mark[4].

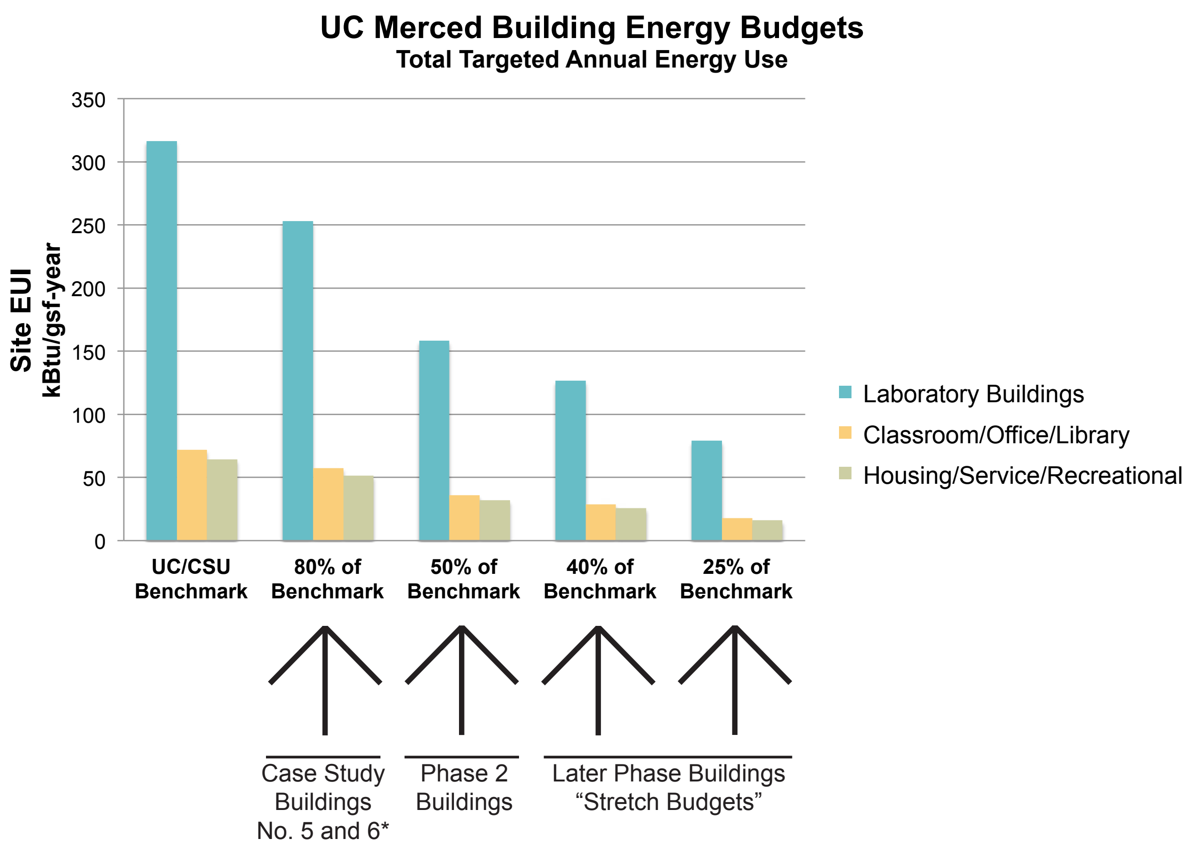
In addition, the campus set similar "stretch" standards on a building per-square-foot basis for the peak power demand, peak natural gas use and the peak tons of chilled water from the campus central plant relative to the benchmarks. By using disaggregated energy commodities the campus was better able to evaluate development of building design features, a capability that is lost if only EUI is considered[5]. However, for comparison to other buildings in general, the EUI is the usual reference number considered for energy budget targeting for ZNE buildings of different types.

Metered performance measurements indicate that the budgets can be lowered to 40%-of-benchmark and this will be investigated in the next phases of design and construction. There is an ultimate goal of 25%-of-benchmark for future phases, known as "Striving to 25", which would

[2] K. Brown, "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, May 2002.
[3] The benchmark numbers are based on *site energy* accounting and include all *plug loads*. (See *Glossary of Terms* for definitions.)
[4] *UC Merced Design Standards*, Version 3, December 2010, Energy, Ch. 5: Mechanical, Electrical, Plumbing and Facilities Support, Table 5.1.
[5] Private communication with John Elliott, Former Director of Sustainability, UC Merced (3/2014).

possibly be achieved on a trajectory toward 2020, ensuring that the campus as a whole would reach ZNE by that year.

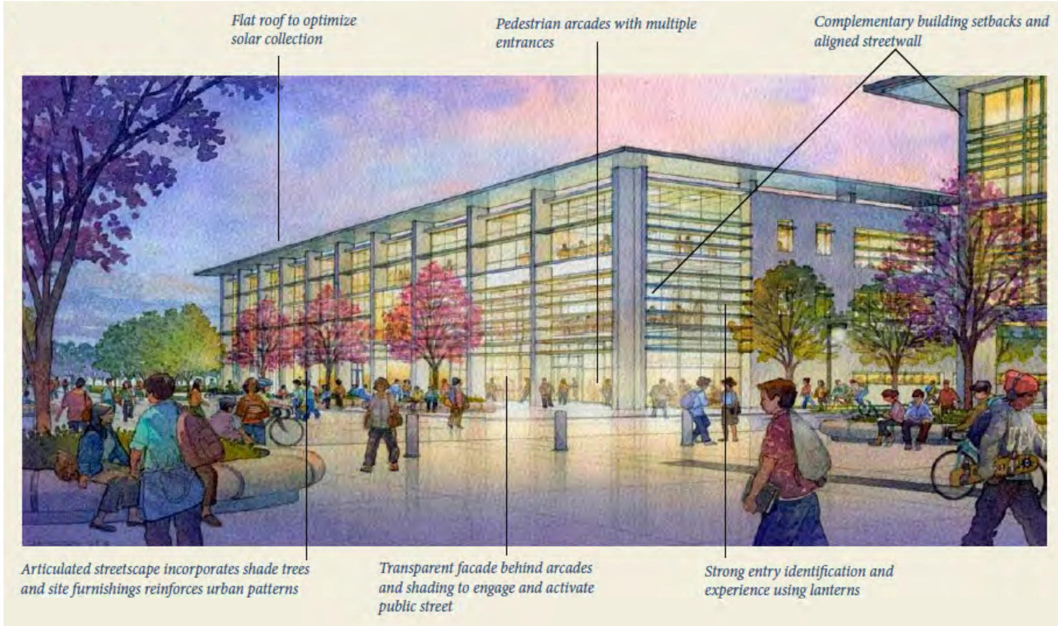
As noted above, the significance of this type of benchmark used at UC Merced is that it represents actual energy use data as measured and includes all thermal energy from fossil fuel and electric energy used for building systems and plug load. The measurements of actual data during occupancy would determine whether the energy budgets were achieved in reality. If not, the data would point in the direction of what changes could be made to reach these prescribed energy budgets. This correction activity is the principal subject of the following case studies.



*These buildings are actually performing at approximately 50% of benchmark.

Table: Current UC Merced Building Energy and Demand Budgets - All Categories
(50% of UC/CSU Benchmarks)

	Energy Use Benchmark Targets			Maximum Demand		
	EUI (Site) (kBtu/gsf-yr)	Annual Electric (kWh/gsf-yr)	Annual Thermal (kBtu/gsf-yr)	Peak Power (Watts/gsf)	Chilled Water (tons per 1,000 gsf)	Heated Water (kBtu/hr per 1,000 gsf)
Laboratory Buildings	158	20	90	3.4	1.9	21
Classroom/Office/ Library	36	7.6	10	1.8	1.0	6
Housing/Service/ Recreational	32	5.3	14	1.3	0.7	9



Low-Energy Building Design Strategies at UC Merced

To reach the low-energy use targets, the University established a set of design strategies that could be applied to all new buildings at the campus, taking advantage of the site microclimate and making the buildings as adaptive as possible. Architecturally, these design strategies necessarily affect the character and style of the campus environment, as is typically the case when integrating energy efficient design practices in the initial design phases.

The *UC Merced 2009 Long Range Development Plan* (LRDP) specifically calls for a "unique architectural identity for the campus by employing passive environmental systems" and clearly indicates that all new buildings should employ certain low-energy design strategies that are effective in this microclimate to create this identity. This idea is picked up and expanded upon in the Physical Design Framework document[6], which establishes specific principles for building planning and design features that support the goal of distinguished architecture that can ultimately be part of a zero-net-energy performing campus.

These design strategies and building features common to all UC Merced buildings are:

- Sunshades to protect glazing and exposed building walls but to maximize daylight availability to interior spaces;
- Pedestrian arcades along south and west facades to shade walls and windows specifically for those orientations;
- Separate entrances to building spaces on the ground level rather than a single building entrance with internal corridors; this minimizes internal conditioned space while activating shaded outdoor spaces.
- High insulation levels for walls and roof, airtight building envelope and flat roofs to accommodate future solar photovoltaic system installation.

These low-energy design strategies were employed as required for the two case study buildings in this publication and the commonalities of the two projects will be obvious. The additional strategies used as well as the programmatic differences distinguish them from one another.

Energy Supply: Central Plant Hot & Chilled Water Supply and Renewable Energy Sources

The long range plan for the campus to have a 100% renewable energy supply by 2020 requires the gradual introduction of these energy sources, which consist of arrays of solar photovoltaic (PV) panels, wind turbine generators, biomass systems and geothermal systems. The LRDP

[6] *Physical Design Framework*, UC Merced Physical Planning, Design and Construction (PD&C), 2010

CREDIT: DOUG JAMIESON

PHOTO: JOHN ELLIOTT

envisions these renewable systems integrated with the campus landscape and symbolic of University's sustainability goals at UC Merced.

PHOTO: RICHARD CUMMINGS

In the meantime, between 2010 and 2020, the new Central Plant will supply heated water and chilled water for the new buildings using primarily natural-gas-fired boilers and utility grid-supplied electricity to power the centrifugal chillers. To meet the imposed limit on peak electric power demand on the grid, the chillers utilize the cooler night temperatures and off-peak utility rates to generate chilled water at night and store it in a two-million gallon thermal energy storage tank.

With the off-peak production of chilled water and the night-purging operation of the individual building ventilation systems to pre-cool the building, UC Merced has flattened its daily demand curve for electric power and minimized the rate paid for utility-generated electric power.

Program of Building Performance Monitoring

Because of the ultimate plan for the UC Merced campus to reach zero-net-energy performance for its entire ensemble of campus buildings, all new buildings are carefully metered in the energy and power categories defined by the benchmark targets. The energy required for Central Plant heated water and chilled water is also included in the metering and analysis of total building energy use.

The performance data is essential to confirm both that the energy budget is being met and to determine the effect of improvement strategies that are devised and put in place during the first years of occupancy. Using metered data to inform and guide the commissioning process, as well as for post-commissioning improvements, to lower energy use will result in higher and more persistent energy savings[7]. It will also guide the setting of feasible energy-use benchmarks for specific types of buildings and can identify those measures with the best potential for energy savings.

It is the latter objective that is particularly important since the ability to set new "stretch" budgets depends on showing the feasibility of lower energy use in the first phase of building design and construction. Getting to a level of 25%-of-benchmark budgets is the key to successfully achieving ZNE by 2020. Toward this end, UC Merced (with the assistance of Lawrence Berkeley National Laboratory) developed the *Energy Performance Platform (EPP)*[8], a customized energy information system that relies on an extensive metering infrastructure that has been established for all campus buildings.

The discussion of each two case study buildings, the *Science & Engineering Building I* and the *Classroom & Office Building*, includes a detailed analysis of the results of the metered performance data and the resulting work to correct, adjust and improve the overall energy performance in the post occupancy phases. This is the primary focus of this case study document.

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[7] K. Brown, M. Anderson, J. Harris, "How Monitoring-Based Commissioning Contributes to Energy Efficiency for Commercial Buildings", *Proceedings of the 2006 ACEEE Summer Study of Energy Efficiency in Buildings*, (#485-Panel 3)

[8] A. Mercado, J. Elliott, "Energy Performance Platform: Revealing and Maintaining Efficiency with a Customized Energy Information System", *Proceedings of the 2012 ACEEE Summer Study of Energy Efficiency in Buildings*, Washington, D.C.: American Council for an Energy-Efficient Economy.

CASE STUDY NO. 5

Science & Engineering Building I

PHOTO: STEVE PROEHL

Science & Engineering Building I

Case Study No. 5

Data Summary

Building Type: Laboratory
Location: Merced, CA
Gross Floor Area: 180,339 gsf
Occupied: January 2006

Energy Modeling Software
Trace 600
Modeled EUI (Site)
119 kBtu/gsf-year
Measured EUI (Site) - 2009
207 kBtu/gsf-year
Measured EUI (Site) - 2011
188 kBtu/gsf-year

Owner/Client
University of California, Merced

Design Team
Design Architect: EHDD Architecture, San Francisco CA
Architect-of-Record: Leo A. Daly, San Francisco CA
Structural Engineer: Rutherford & Chekene, San Francisco CA
Mechanical, Electrical & Plumbing Engineers: Arup, Los Angeles CA
Lab Planning: GPR Planners Collaborative
Lighting Designer: JS Nolan & Associates, San Francisco CA
Landscape Architect: Peter Walker & Partners, Berkeley CA

General Contractor
Flintco, Inc.

The ***Science & Engineering Building I*** laboratory building houses both dry and wet teaching and research laboratories with related support spaces and faculty/staff spaces for the School of Natural Sciences and the School of Engineering. This building was designed simultaneously with the new *Library* building and the *Classroom & Office Building*, with direct interaction and coordination among the three A/E teams. The *Classroom & Office Building* is the subject of the second case study at the UC Merced campus and designated Case Study No. 6.

Low-Energy Design Approach for *Engineering & Science Building I*

Setting a design energy budget at 80% of the UC/CSU benchmark for laboratory buildings required an *integrated design approach* by the A/E design team to ensure that this target could be achieved. The UC Merced energy budget for this type of building in 2003 was:

- EUI = 257 kBtu/gsf-year
- Peak Power Demand = 5.38 watts/gsf
- Peak Chilled Water Demand from the Central Plant = 2.99 tons (35.9 kBtu/hr) per 1,000 gsf
- Peak Hot Water Demand from the Central Plant = 34 kBtu/hr per 1,000 gsf

As operated, the building is performing better than its benchmark target by a wide margin–EUI = 188 versus the benchmark target of 257. Modeling results, however, indicate that much greater reductions may be possible. (See data summary at left.) This is the one case study of the six in this monograph where such a wide difference between modeled energy use and measured energy use was observed. This issue is discussed in this case study on p. 92.

In order to ensure that the low EUI budget could be realized, the general building planning and the design of each of the building component systems, the building envelope, interior lighting, HVAC (heating, cooling and ventilation) and electrical plug load, were all considered together in an integrated manner from the first phase of the design. Energy efficiency informed every design decision.

Building Planning and Building Envelope

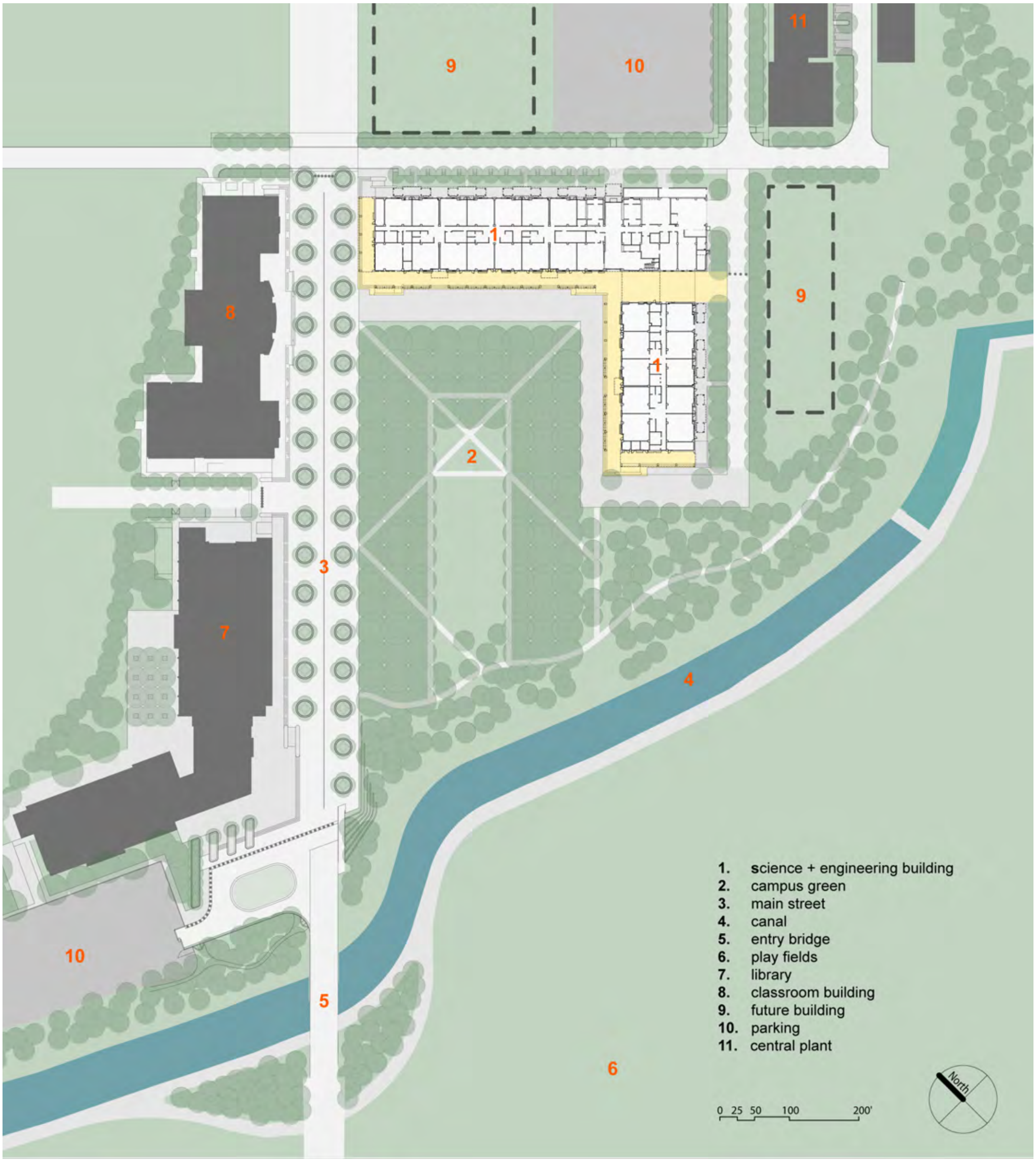
Following the general design guidelines established for all campus buildings[1], the *Engineering & Science Building I* utilizes separate entrances to each of the major spaces on the ground level rather than a single building entrance and a system of internal corridors. This reduces the amount of internal conditioned space and activates the exterior arcade spaces with student and faculty circulation. Consistent with this approach, the most heavily used program spaces, the teaching laboratories, are located on the ground floor, while the research laboratories and offices are located on the upper levels.

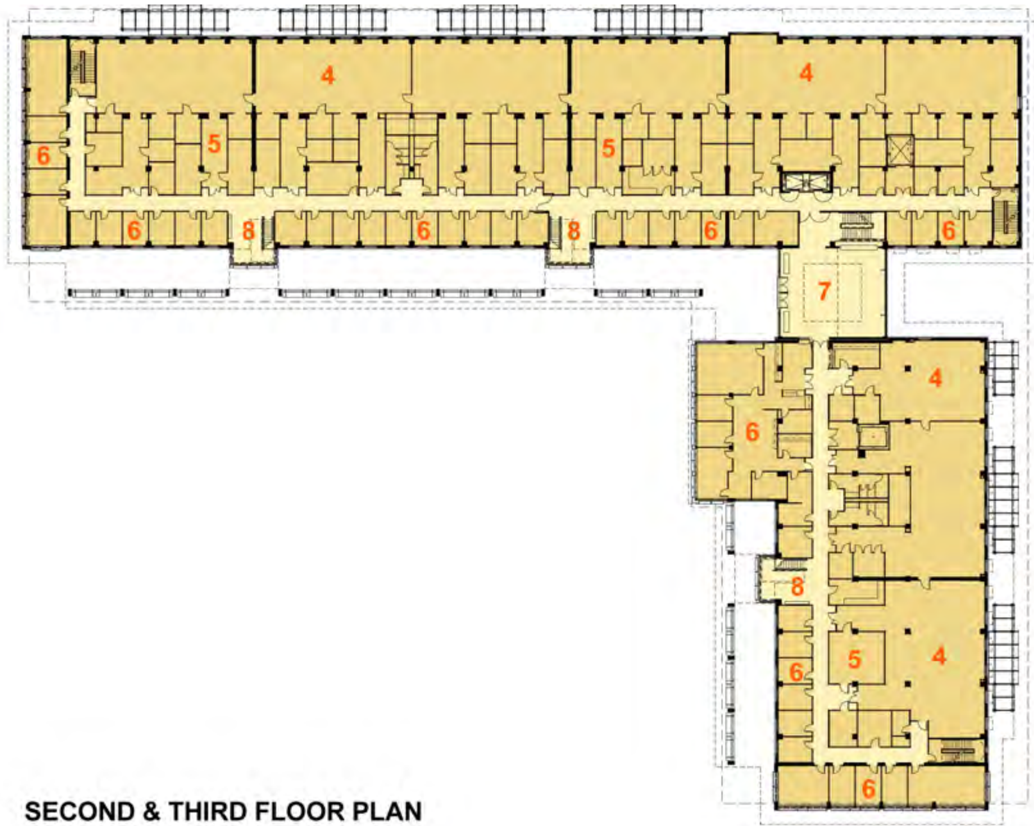
Another common feature is the location of light-filtering pedestrian arcades on the southerly facades of the building, which face common outdoor plazas or quads. These arcades provide shading of the walls that receive the brunt of the sun's heat impact while also creating outdoor social spaces. The arcade design on each building uses a system of *brise soleil* (horizontal sun shades) to admit daylight while shading the exterior walls.

In the case of The *Engineering & Science Building I*, the sunshades are made from a ceramic-fritted glass that blocks much of the direct sunlight while transmitting some daylight. A design-day

[1] *UC Merced Physical Design Framework*, Physical Planning, Design and Construction (2010) pp. 79-80.


PHOTO: EHDD

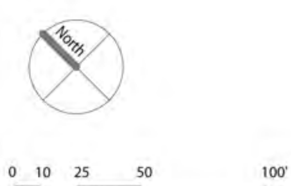

1
2
3
4
5
6
7
8
9
10
11
1. science + engineering building
2. campus green
3. main street
4. canal
5. entry bridge
6. play fields
7. library
8. classroom building
9. future building
10. parking
11. central plant
0 25 50 100 200'
North



SECOND & THIRD FLOOR PLAN

GROUND FLOOR PLAN

1. arcade
2. passageway
3. class labs
4. research labs
5. lab support
6. offices
7. gallery / lantern
8. communicating stair



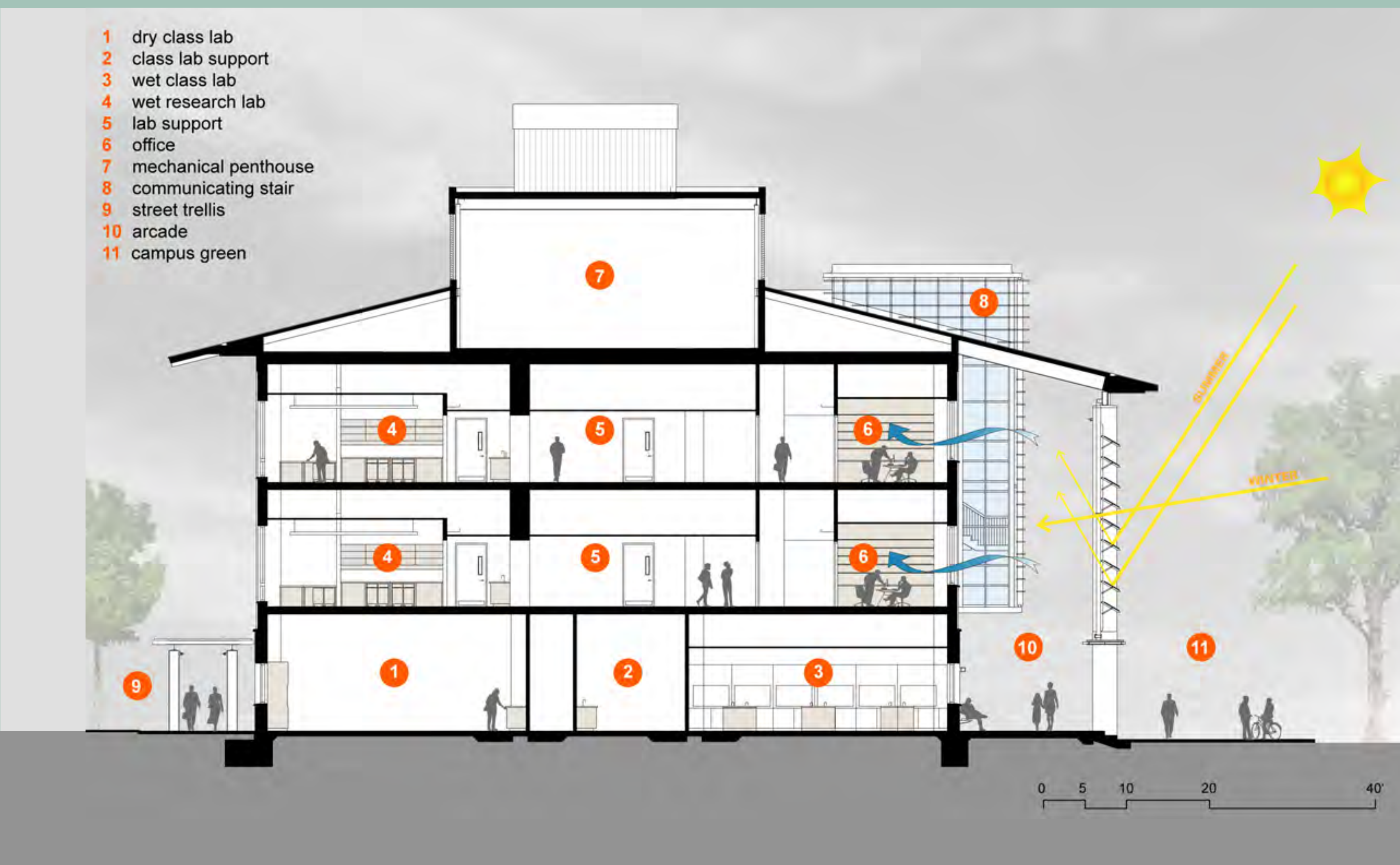
of September 21, the day of the peak heat gain condition during the year, was selected for the design of the sunshade geometry relative to the solar incidence angles. The sunshade design prevents direct solar impact on the exterior southwest-facing walls.


PHOTO: EHDD

Additional building envelope features that effectively lower the base EUI for the building are:

- A relatively narrow floor plate in order to maximize daylight penetration and the possibility of natural ventilation to spaces not requiring controlled air flow, thus reducing lighting and ventilation loads.
- Sun control provided for windows and glazing on the other elevations, reducing the cooling loads.
- Glazing system that is highly-transmissive of visible daylight (70%), low U-value (0.29, a low heat conduction value) and a low shading coefficient (0.44, a low fraction of solar heat gain and half that of regular double-glazing). No reflective or tinted glazing is used in order to maximize daylight collection for the reduction of lighting loads.
- Massive exterior walls to absorb heat gain during the day and shed the heat in the cool of the Valley night.
- High roof insulation levels (R-34) under a white-colored "cool roof" thermoplastic membrane, primarily to reduce cooling loads.


PHOTO: RICHARD CUMMINGS


1 dry class lab
2 class lab support
3 wet class lab
4 wet research lab
5 lab support
6 office
7 mechanical penthouse
8 communicating stair
9 street trellis
10 arcade
11 campus green
SUMMER
WINTER
0 5 10 20 40'

Interior Lighting

The use of energy-efficient light fixtures led to an average installed lighting load of 1.1 watts/gsf, 20% below Title-24 requirements at the time. The lighting design was coordinated for all Phase 1 buildings for both energy efficiency and operations coordination by developing a master fixture schedule. At the time of the Phase 1 projects, the lamp of choice for energy efficiency was the T-5. For lamp dimming purposes, the T5HO lamp was not used.

Heating, Cooling and Ventilation


Laboratories for the 21st Century: Best Practices

Low-Pressure-Drop HVAC Design for Laboratories

Introduction

EPA

The heating, cooling and ventilation system for the building was designed following several of the *best practices* outlined by the Labs21 Program[2]. These include separate heating and cooling using the room terminal coils to meet room requirements, with pre-cooling of outside ventilation air using an evaporative cooler, and a low-pressure design to minimize fan power requirements.

The system design for each wing of the building is a variable-air-volume (VAV) system, which allows the supply and exhaust airflows to vary based on actual space needs. As in almost all laboratory designs, all of the ventilation air passes through the system only one time. The VAV system therefore will result in a much lower EUI than if a constant amount of air is continuously circulated through the building (a *Constant Volume* system).

Each wing is served by two equal-sized supply fan units and an exhaust system made up of four exhaust fans. Energy-saving *variable frequency drives* (VFD's) on the supply fans provide control of the amount of heating or cooling air being delivered to a room based on a signal from a duct-mounted static pressure sensor. (This is noted here because of a post-occupancy issue pertaining to the pressure sensor location inside the duct.)

There is also no mixing of heated or cooled air streams in the design. Only heating or cooling at the room terminal unit occurs to meet the room requirements. During the summer, the hot dry outside air is pre-cooled using an indirect evaporative cooler at the roof-mounted fan unit, then further cooled at the terminal unit. During the winter, the cold outside air is preheated at the fan unit and further heated at the terminal unit to meet specific room requirements. In the intermediate seasons, there is no pre-heating or pre-cooling; all heating and cooling occurs at the terminal unit.

The system also utilizes a number of methods of low-pressure design for the ductwork and other components to reduce the fan power needed to move the air through the system. Given the large amount of energy expended for this purpose in a laboratory building, this is one of the important features of the mechanical system design.

Finally, the system design includes occupancy sensors in the laboratories, both motion sensors and infrared sensors, to control the electric lighting. These sensors also send a signal to the building management system (BMS) that controls both the temperature of the air at the terminal unit and also the exhaust airflow through the fume hood above the required minimum level for safe operation. When the room is scheduled to be unoccupied, the BMS resets the space temperature requirements and the minimum required fume hood exhaust airflow. (This is particularly noted here because of both a post-occupancy issue pertaining to the control system as well as current efforts to improve performance via programming of the "setback" operations.)

All of these design features together effectively lower the EUI for the building and, as required as part of the energy budget, also keep the peak power demand and peak demand on the Chiller Plant below the stated maximums.

(Opposite page) Diagram of low-energy design features (Courtesy of EHDD Architecture).

[2] *Labs for the 21st Century*, sponsored by the U.S. Environmental Protection Agency and the U.S. Department of Energy, http://www.labs21century.gov/. See also Labs21 Best Practice Guides: http://www.i2sl.org/resources/toolkit/bpg.html

Electrical Plug Loads

Management of plug loads is a concern in all low-energy buildings and circuit metering is revealing the large impact of these user-controlled electrical loads. In laboratory buildings, plug loads make up a large percentage of the total energy demand due to high wattage equipment such as cryogenic freezers and high energy lasers. UC Merced staff are working with lab users to determine if these loads can be reduced or managed to minimize energy use. Some of this equipment is installed without meters, which introduces an locally unmetered electric energy load. This is referred to as “unrecorded plug load” in the measurement summary charts.

Energy Design Analysis and Energy Performance
Modeling versus Initial Post-Occupancy Measurements

Energy Use - Modeling

As noted in the introduction to this publication, computer-based modeling of the energy performance of buildings continues to be a developing area of technology. Assumptions in the modeling analysis about patterns of use and hourly variations in site weather conditions strongly affect the resulting performance outputs. Therefore, the ability to show during the design phase that the building will meet targeted energy budgets is limited and cannot be *predictive*. In some ways, the design modeling is an *ideal* of a well-operated building with energy-conscious users. As has been discovered with the close measurement of new low-energy buildings, the ideal is usually not *real* and actual performance falls short of the design model results. It is through diligent correction and adjustment of the building systems and the attentive work with the building users that the ideal can be achieved.

The modeling for the *Science & Engineering Building I* was done ten years ago in 2002, using *Trace 600* software. Under the modeling assumptions described in the energy analysis report[3], the building EUI (site energy) is tabulated at 119 kBtu/gsf-year. The 80%-of-benchmark EUI target for this type of building, as noted above, was 257 kBtu/gsf-year. The design modeling result was therefore 46% of the energy budget and equivalent to 37%-of-benchmark EUI, an unlikely achievement, as was borne out by actual performance measurements. In reality, thermal and electrical *process loads* are simply not predictable and consistent in buildings like this one, rendering whole building energy modeling difficult and problematic (that is, much “real” load simply does not appear in the modeling).

	Energy Use Benchmark Target			Maximum Demand		
	EUI (Site) (kBtu/gsf-yr)	Annual Electric (kWh/gsf-yr)	Annual Thermal (kBtu/gsf-yr)	Peak Power (Watts/gsf)	Chilled Water (tons per 1,000 gsf)	Heated Water (kBtu/hr per 1,000 gsf)
Energy Budgets (80%-of-Benchmark)	256.3	32.6	145.0	5.4	3.0	33.6
Energy Modeling Results*	119.2	23.8	38.0	5.2	2.3	35.6

**Energy Analysis Report, Science & Engineering Building I, UC Merced*, Ove Arup & Partners California Ltd., January 2003.

This result illustrates the limits of design modeling, which by itself is a good indicator of the relative impact and effectiveness of design strategies and therefore a powerful design tool, and also the wisdom of establishing benchmarks based on real performance data.

As it turns out, the actual measurements of this building’s energy use show that it performs significantly below the 80%-of-benchmark EUI set by the University, though not to the optimistic level tabulated by the design modeling.

[3] *Energy Analysis Report, Science & Engineering Building I, UC Merced*, Ove Arup & Partners California Ltd., January 2003.

Energy Use – Actual Measurement

Metered data has been collected for the building since the first year, 2006-2007. This includes data from the large array of individual building meters as well as data from a set of meters on the amount of hot water and chilled water coming to the building from the Central Plant. All of the energy use in the building continues to be measured and accounted for, including that coming from the Central Plant in the form of heated or chilled water.

For reasons unrelated to the subject of this publication, the formal commissioning process for the building was interrupted and had to be taken over by the UC Merced facilities group. As a result, the post occupancy adjustments spanned both the regular commissioning period and the post-commissioning period. Part of the normal commissioning activity involved verifying the measurements being recorded by the meters, which was carried out by UC Merced with the assistance of Lawrence Berkeley National Laboratory (LBNL).

As reported in the 2009 CIEE measured performance case study for the *Science & Engineering Building I*[4], the initial recorded data contained gaps, errors and implausibilities that resulted in the need to replace or recalibrate some meters. Once the subsequent measured results were evaluated and verified by LBNL to be "reasonable and consistent with all available data, including energy balances with master utility meters"[5,6], the performance of the building in a fully operational year could be recorded and reported.

The results of the first year of energy use data analysis showed the overall effectiveness of the design strategies employed for this building to exceed significantly the target of 80%-of-benchmark. The first-year EUI (site energy) was measured at 207 kBtu/gsf-year, which is 64%-of-benchmark. The peak power demand, peak chilled water and hot water demand from the Central Plant were measured at similar performance levels below the target benchmark[7].

At the time of these first measurements, the UC Merced facilities group began a program of response to observed energy use trends of each subsystem to make corrections and to improve the building's overall performance. These observations and corresponding improvements are described in the following section.

Beyond these adjustments to the building components, the UC Merced group has been working with users to tailor their use patterns in program-supportive ways and to make the energy system controls more responsive to the users' actual needs. This work with the users has resulted in a more energy efficient operation of the building and more awareness of energy use on the part of all users. This particular post-commissioning activity is proving to be the most interesting—and in some ways the most innovative—in terms of making even more significant reductions in total annual energy use. See the following section on continuing post-commissioning work.

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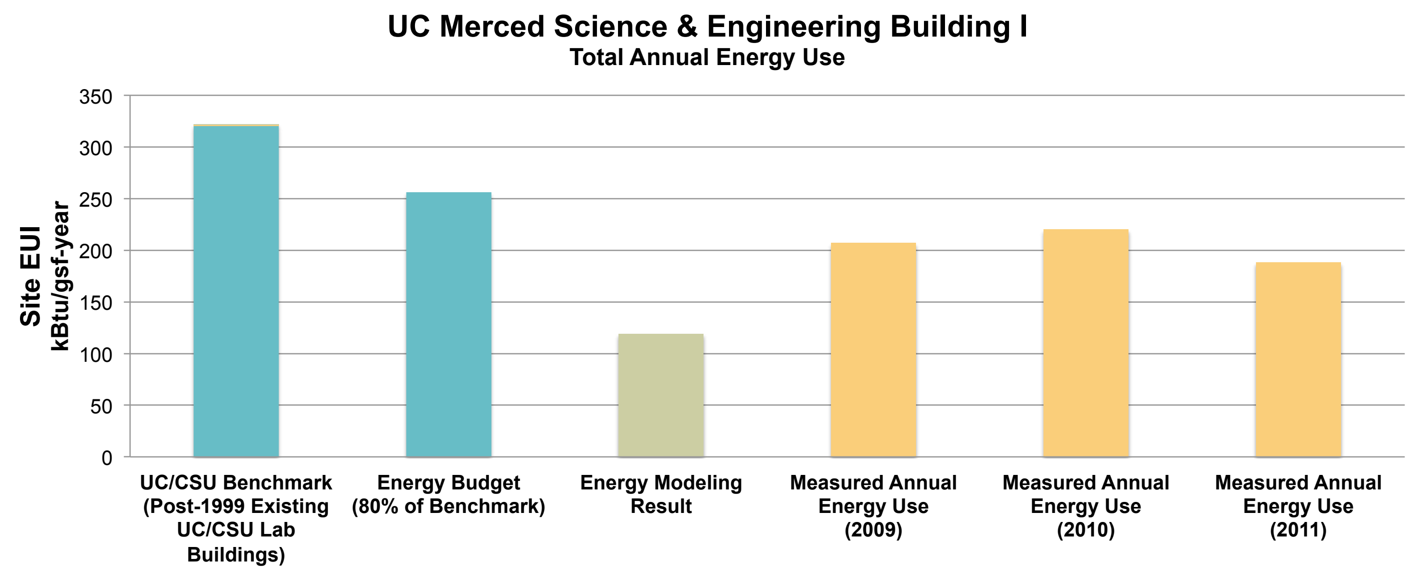
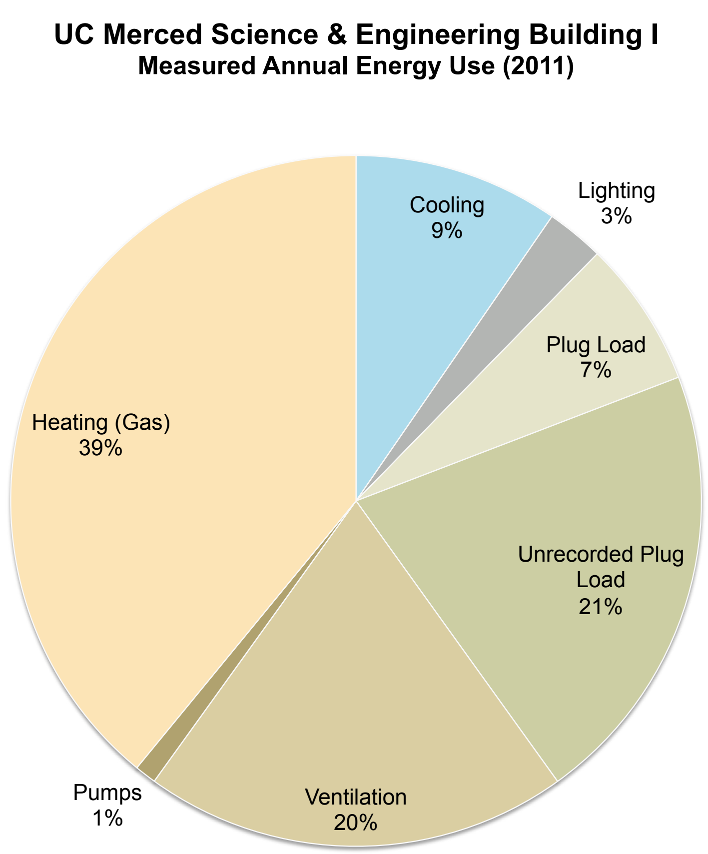
[4] "Measured Performance Case Study: Science & Engineering Building I, UC Merced", California Institute for Energy and the Environment (CIEE) and the New Buildings Institute (NBI), 2009

[5] *Ibid.* p. 4.

[6] It should be noted here that interviews with owners and A/E teams for several ZNE projects indicated that problems with metering are commonplace and troubleshooting meter performance should be part of the regular commissioning process. Likewise, organization and analysis of data from all energy sub-systems should be set-up at the beginning and verified to be in a usable form. Finally, there should be periodic reporting of the organized data to confirm the quality and usefulness of the information.

[7] *Ibid.* p. 6.





Measured Energy Use (2011)

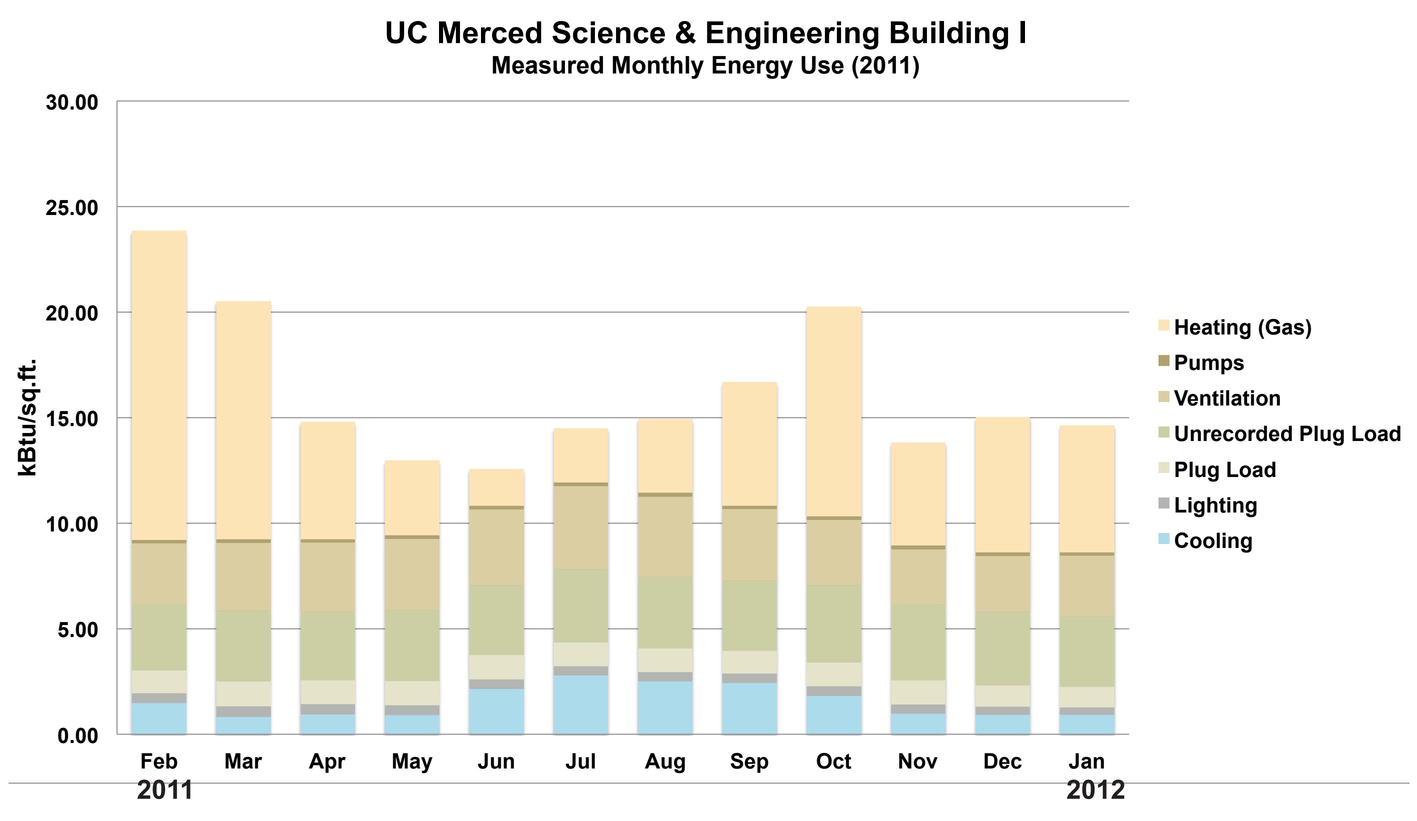
9,926 MWhr per Year
Actual EUI = 187.9

Building data analysis from 2009 through 2011 shows energy use at roughly 69%-of-benchmark, with most recent data for 2011 showing a performance of about 59%-of-benchmark. While more data collection is required to see a trend, it appears that post-commissioning activities are resulting in improved savings. In fact, many of the building start-up problems described later in this section were being addressed and resolved during 2011, so recorded performance after that year is expected to be much better, dropping below 50%-of-benchmark.

he bar chart on the opposite page shows three years of recorded performance versus the design budget and the result of the design modeling in 2002.

The charts below show the 2011 energy use breakdown by category both annually (pie chart opposite) and monthly (bar chart directly below)[8]. Note the predominance of the metered plug load and the unrecorded plug load due to energy intensive laboratory equipment installed without meters.

[8] EUI based on a *Building Gross Square Feet (BGSF)* determined with calculation on 27 August 2007. (Source: Min Jiang, Design & Construction, UC Merced).



Post-Occupancy Adjustments to Lower Energy Use: HVAC Systems

The value of recording and reviewing the energy use patterns of the building systems is obviously to identify locations of higher consumption than expected and opportunities to improve the overall efficiency by changing components or operations. UC Merced has been continuously engaged in this monitoring and evaluation activity since 2006, when the building opened, and has steadily made system changes that have resulted in improvements in the energy performance.

The charts in the previous section reflect the improved performance and the building's EUI (site energy) has been reduced to 185 kBtu/gsf-year. The following subsections describe the principal issues and adjustments made to the building systems based on observed data over the past six years.

Correction of Basic Control System Issues

One of the largest consequences of the interruption of the commissioning process was the discovery after occupancy that the building's control system was incompatible with the campus BMS. Buildings on the UC Merced campus are controlled using a central BMS so that all buildings can be scheduled from one center. Based on the instructions from the BMS, the individual building's control systems are supposed to operate the various system components according to those instructions. For *Science & Engineering Building I*, there are two local building control systems—laboratory ventilation and space lighting.

Metered data immediately revealed that schedule changes made with the BMS were not resulting in any effect on the local building control systems. The communication "protocols" of the two systems were different: the campus BMS uses "BACnet protocols" while the local laboratory ventilation control system uses "LonTalk protocols". A great deal of time was required for the staff at UC Merced, working with the engineers of the control system manufacturers, to recommission the controls and solve the compatibility problem. The solution ultimately was to set up a separate computer specifically to coordinate the control systems.

The importance of this problem solution was that many energy efficiency measures of the building design could not be implemented nor could the building be placed into a setback mode as allowed by the building schedule.

For example, the important low-energy strategy of *night purging*, a method of pre-cooling the building at night with the use of low-temperature outdoor air, could not be used to reduce the peak cooling load on the following day and reduce cooling energy demand. Normally, the laboratory ventilation at night could be reduced to four air-changes per hour (4 a.c./hr) from the day-operating rate of 6 a.c./hr and still carry out the night purging operation. This is a significant amount of fan energy; once the communication problem was solved, the electric energy use by the fans and the peak power demand on the Central Plant were greatly reduced.

For UC Merced, this problem was the most significant one encountered because it affected the low-energy operation of the building as intended in the design and because it required so much time to solve. It was at least two years in the observation, solution and implementation to bring about the basic system operation as intended.

The principal outcome of this experience is that UC Merced has enacted the future requirement that any control system specification for new UC Merced buildings in subsequent phases must be entirely BACnet protocol to ensure compatibility with the central campus system.

Correction of Location of In-Duct Sensors

Energy meter data also revealed that an excessive amount of air was being delivered to some spaces. A study of this issue revealed that the differential pressure sensors located inside the air ducts and used to control the amount of airflow were not positioned properly. Moving the sensors to a position just before the last VAV valve ensured a proper reading of airflow and therefore the most efficient functioning of the system.

This mispositioning of the pressure sensors is not an uncommon experience; the location of pressure sensors in laboratory supply air ductwork should therefore be checked and evaluated during the commissioning process to avoid the resulting failure to meet design airflow requirements along with excessive energy use.

Correction of Design Air Flow Rates

As part of *best practices* in laboratory design required by UC Merced for maintaining minimum ventilation rates for safety and maximum ventilation rates for energy efficiency, the design ventilation rate was set at six air changes per hour (6 a.c./hr). The design engineers set this rate for the supply side of the system. The exhaust side operated at an air flow rate higher than that established as the maximum design flow rate at the exhaust fume hood. By adjusting the exhaust air flow rate to 6 a.c./hr as originally intended, energy was saved by reducing the ventilation fan speed to achieve this rate.

Correction of Supply Fan Speed Controls

It is noted in the HVAC system description that two fans serve each floor of the building; the second fan assures that airflow will continue through the lab spaces if the first fan fails. When the two fans are both normally operating, they each are supposed to operate at comparable lower speeds to provide the required ventilation air. These fans were designed with a control logic known as “PID loop”, which is basically a type of “cruise control” for the fan and which should result in this equal fan power operation.

However, measured data from these fans showed that the design of the control system’s PID loop was erroneously causing one fan to operate at 100% full power while the second fan was operating at 30% full power. This operation had a major impact on the energy used by the two-fan combination since higher fan power operation literally has an exponential effect on the energy demand for that fan. The fan operating at full power was responsible for an exaggerated amount of energy use compared with the other fan.

Once alerted by the measurements, the controls engineers changed the control logic so that both fans operated at the same speed, still moving the same amount of air as required for the laboratory space. This simple adjustment resulted in an energy savings for all fans in the building of about 35% compared to the pre-correction operation. See the accompanying chart, which shows the comparative energy use under the two conditions of fan operation.

Discovery and Replacement of Failed Exhaust Fan

Another advantage of close monitoring of the energy use using the installed meters and online viewing of the data analysis is the discovery of system problems that normally go undetected, at least for long periods of time, because of the backup systems in place to cover for system component failure. These failures often result in a significant increase in energy use that are normally only detected through diligent review of energy bills.

An example of this occurred in *Science & Engineering Building I* six years after the building was occupied. As described in the description of the design of the HVAC system, there are four exhaust fans that are constantly operating at various speeds to remove exhaust air via the laboratory fume hoods. These exhaust fans are linked together so that in the event of failure of one fan, the other three fans increase their speed to make up the difference. Again, because the energy use by a building fan increases exponentially with the increase in fan speed, such a failure will result in a sizable jump in energy use.

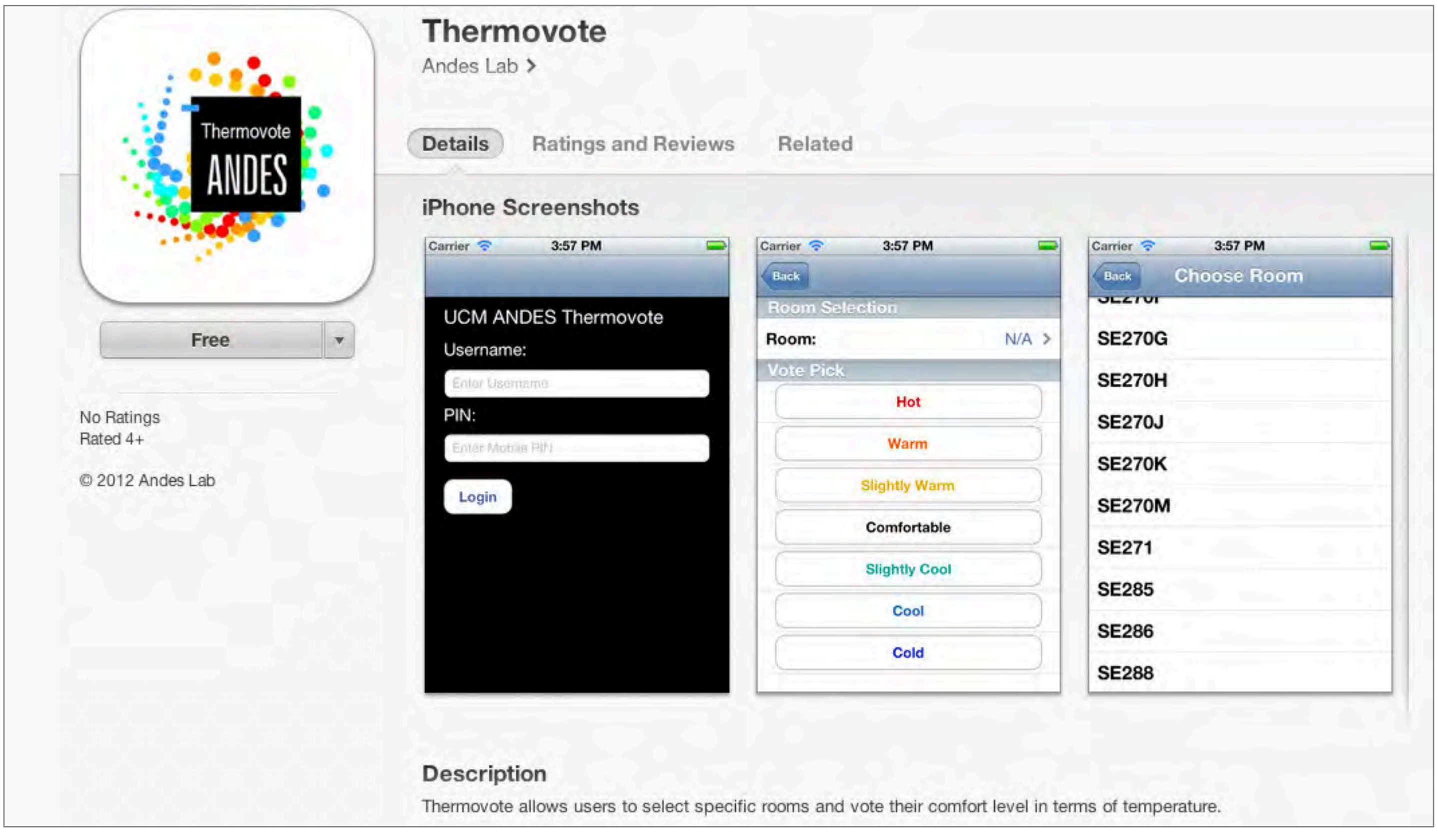
Such an exhaust fan failure occurred in early 2012 and the increase in fan speed of the other three fans was not detected by the building control system. The failure would have gone unnoticed except that the building energy-use metering system picked up the spike and was noticed by the UC Merced facilities staff who were monitoring the energy performance on a routine basis.

New Methods of Setting Controls for Thermal Comfort

On the experimental side, some innovative work is being done for setting comfortable conditions in general group spaces, which are not determined by a fixed thermostat schedule or pre-determined temperature setting. A number of spaces in the building are now having space temperature set by a “crowd choice” method: occupants “vote” on whether the space should be warmer or cooler. When a balance of choices is achieved, the temperature is set. Voting is done using smartphones and an app known as *Thermovote*[9].

Energy use reductions are being achieved in part because everyone in the group accepts the voting decision and no attempts are made to override the space conditions on an individual basis. The system also provides a very fine-tuned response to transitory environmental conditions such as the amount of radiant energy during that occupied period.

As more experience is gained with this concept of space comfort controls, alternatives to a fixed thermostat setting could be developed for certain types of occupied spaces.



Post-Occupancy Adjustments to Lower Energy Use: Lighting Systems

Correction of Lighting Control System Operation

During early occupancy of this building, there was also a lack of connection between the campus BMS and the building’s lighting control systems. As in the case of the HVAC system, it was discovered that schedule changes programmed into the campus BMS did not affect the building lighting controls. With the correction to this problem, UC Merced staff were able to tune the building operation to the room schedules and reduce the energy use through setbacks and light level reductions.

Initially, the effort was to standardize a menu of lighting control strategies for the laboratory and large spaces that were as simple as possible and that could work with the lighting control system that was installed in the building. There was some difficulty with the latter even after the main communication problem with the campus BMS was solved. This was due in part to proprietary

[9] Mac version: https://itunes.apple.com/us/app/thermovote/id508965143?mt=8
Android version: https://play.google.com/store/apps/details?id=com.thermovote.andes&hl=en

software issues, but since the migration of the lighting control programs to the Web this has become easier to coordinate for the facilities staff.

It should be noted that building design specifications for lighting controls only describe features required for these systems and necessarily do not deal with optimal operation strategies. This is the task of the building owner and operator, which should be undertaken as part of the overall commissioning process. For UC Merced, this is an evolving task, the results of which are showing continued progress in energy use reduction.

Setting the lights to be turned on and off according to a strict schedule, as valuable as that is for energy reduction, is only half of the story of opportunities for lower energy use by reducing lighting load. UC Merced staff realized that by such non-interactive scheduling, people are removed from the possibility of controlling the lights to match their actual needs and use patterns. The result is that there is a sizable amount of time when lights are turned on in unoccupied spaces.

The staff therefore worked to involve the laboratory users to set a controls program that suited their needs rather than set up something that they would constantly override and cause the user-involved program to become counter-productive. Combined with infra-red and motion-detection occupancy sensors, UC Merced staff are evolving a highly efficient lighting controls program.

The lighting control logic that was established for the building starts with lighting control zones that are based on general room use or, in the case of individual rooms, occupant's request. Each lighting zone is part of a "scheduling area", which includes the HVAC equipment components related to the same space or room. In this way, the lighting and HVAC are linked by the control system and operate together to serve the space.

There are three possible lighting operations for interior spaces set by the control system:

1. Lighting is strictly scheduled *on* and *off*. This is a basic approach in public spaces such as hallways and lobbies. Local manual switches are overridden to be inactive during the scheduled *occupied* period.

2. Lighting is scheduled *occupied*, but not turned on. The lights only turn on if someone enters the zone and uses a manual light switch. The lights then remain on until the end of the scheduled period, when all lights turn off. This is a typical operation in private zones such as laboratories where users have complete control of the lights. Manual light switches can also override the *unoccupied* schedule for one-hour increments; the link to the HVAC system signals a ramp-up of space conditioning for the override period.

3. Lighting is scheduled to turn *on* at sunset and off when the schedule expires. This type of schedule is used in zones at the building perimeter with a large amount of daylight. Manual light switches can override the schedule for one-hour increments.

Exterior lighting is set to operate on a sunset-to-sunrise schedule. The time at which each of these events occurs is updated daily.

New Methods of Lighting Control and Efficiency of Use

While this scheduling logic for lighting control has been very effective in lowering electrical energy use, UC Merced staff are exploring some additional methods to shave lighting energy use even further.

The staff continue to work closely with building users to establish both lighting and connected HVAC schedules that support rather than potentially inhibit transparent environmental system operation. Regular meetings with the users lead to a schedule that has user buy-in. If ongoing experiments have specific requirements for airflow, these can be programmed into the schedule also.

The staff are also evaluating use of "smart" occupancy sensors that are connected to the campus BMS and result in the system's "learning" of occupancy patterns that can then be more closely built into the schedule.

CASE STUDY NO. 6

Classroom & Office Building

PHOTO: TIM GRIFFITH

Classroom & Office Building

Case Study No. 6

Data Summary

Building Type: Classroom
Location: Merced, CA
Gross Floor Area: 103,000 gsf
Occupied: January 2006

Energy Modeling Software
eQuest v. 2.55
Modeled EUI
37 kBtu/gsf-year
Measured EUI (Site) - 2008
44 kBtu/gsf-year
Measured EUI (Site) - 2009
41 kBtu/gsf-year
Measured EUI (Site) - 2010
36 kBtu/gsf-year

Owner/Client
University of California, Merced

Design Team
Architect: THA Architecture, Inc., Portland OR
Structural Engineer: Forell Elsesser, San Francisco CA
Mechanical Engineer: Taylor Engineering, Alameda CA
Electrical Engineer: The Engineering Enterprise, Oakland CA
Plumbing Engineer: Capital Engineering, Sacramento CA
Lighting Designer: JS Nolan & Associates, San Francisco CA
Landscape Architect: Peter Walker & Partners, Berkeley CA

General Contractor
Swinerton Builders, Inc.

The ***Classroom & Office Building*** provides basic classroom and departmental office space for Phase 1, the launch state for the new UC campus. Like the *Science & Engineering Building I,* this building was one of the three major buildings designed simultaneously with the new *Library*; the *Classroom & Office Building* is the subject of the second case study project located at UC Merced.

Low-Energy Design Approach for the *Classroom & Office Building*

The UC Merced energy budget for this type of building in 2003 was set at 80% of the UC/CSU benchmark for classroom buildings:

- EUI = 57.4 kBtu/gsf-year
- Peak Power Demand = 2.88 watts/gsf
- Peak Chilled Water Demand from the Central Plant = 1.6 tons (19.2 kBtu/hr) per 1,000 gsf
- Peak Hot Water Demand from the Central Plant = 9.6 kBtu/hr per 1,000 gsf

As in the case of the *Science & Engineering Building I*, the *Classroom & Office Building* is performing better than its benchmark target by a wide margin. Because the three initial buildings were designed together, the three A/E teams were organized by UC Merced to coordinate and review each other's work. This ensured a common approach to the integrated design solutions and the same vocabulary of building components that ensured a sense of common place for the new campus. As with *Science & Engineering Building I*, energy efficiency informed every design decision.

The results of the modeling for the *Classroom & Office Building*, the least programmatically complex of the three buildings, showed an annual energy use (EUI) at about 65% of the budgeted EUI.

Building Planning and Building Envelope

Following the pattern established with the other buildings, there are separate entrances to each of the large auditorium and lecture hall spaces on the ground level in order to avoid a large lobby and extended corridors. This is consistent with the objectives of reducing the amount of internal conditioned space and activating the exterior arcade spaces with student and faculty circulation.

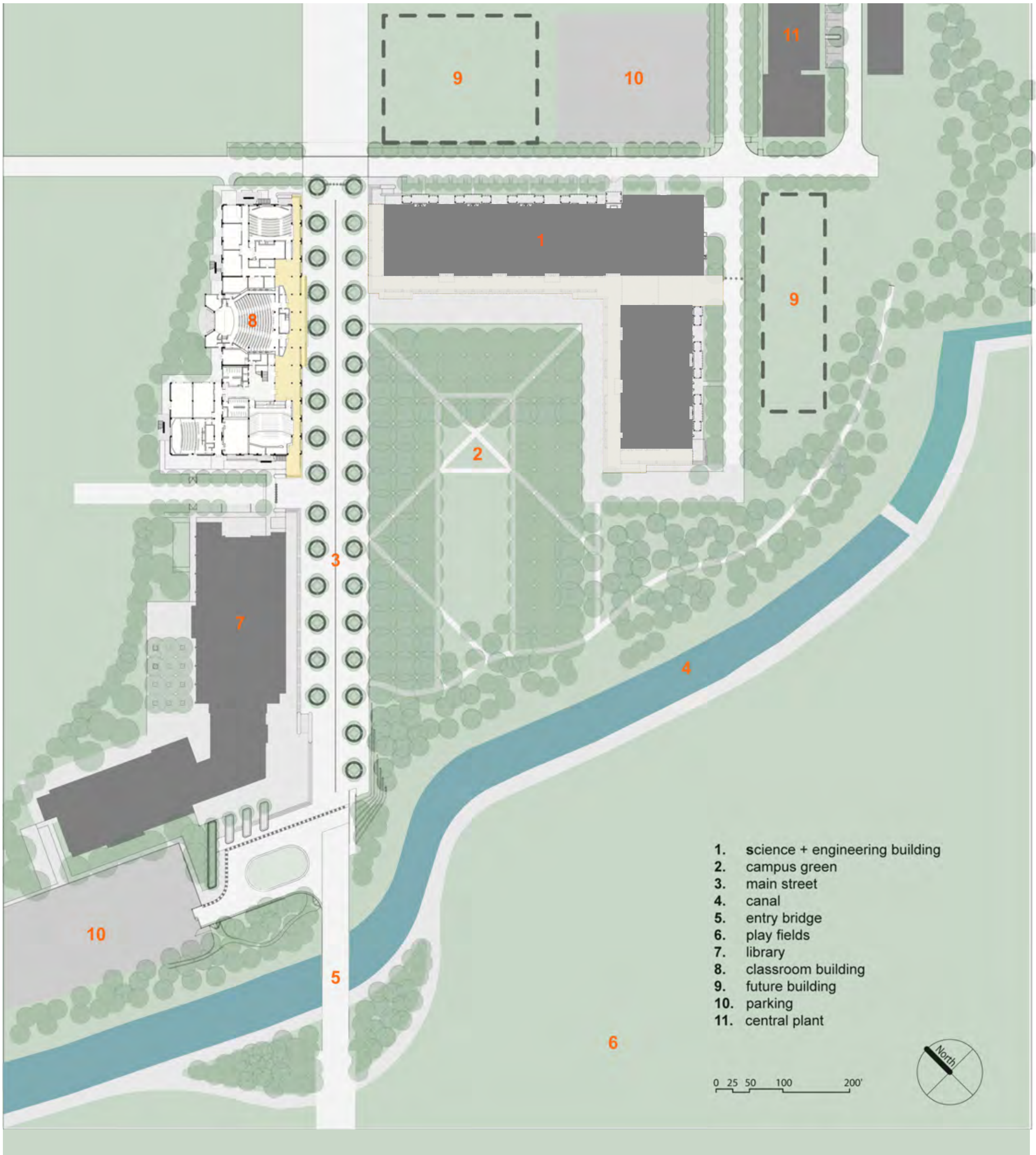
Related to this, the building also adopts the common feature of light-filtering pedestrian arcade on the sun-exposed facade of the building facing southeast and the common outdoor quads. The arcade is the principal required architectural elements that provide shading of the walls that receive the brunt of the sun's heat impact while also creating outdoor social spaces. Like the two other three-story buildings built in Phase 1 to shape this original quad, the arcade design uses a system of horizontal sunshades to admit daylight while shading the exterior walls.

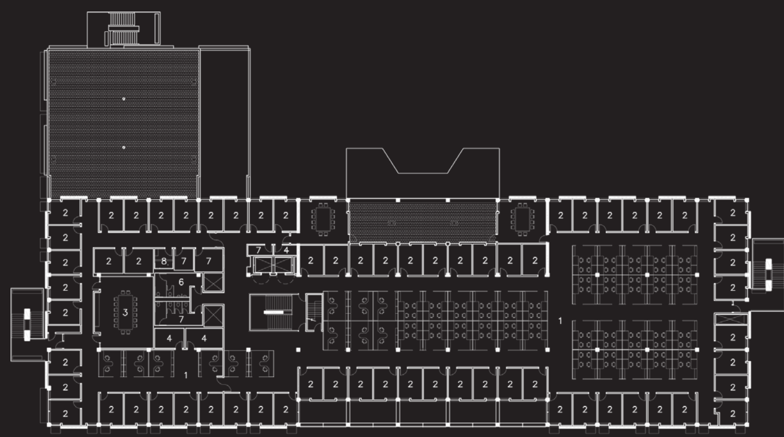
For noise control and acoustic isolation, cross ventilation is not a viable cooling strategy with this building. Natural ventilation occurs via operable windows only at spaces bordering the perimeter. Similarly, the depth of the building and density of small rooms limits daylighting to the perimeter spaces and, at the third floor level, roof monitors for the land-locked general use departmental spaces.

The following is a summary of low-energy design strategies for the building envelope features, which effectively lower the base EUI for the building are:

- Operable windows for exterior offices;
- Daylighting for perimeter zones and roof monitors for the open office area on the top floor;
- Sun control provided for windows and glazing on the southerly elevations, reducing the cooling loads;

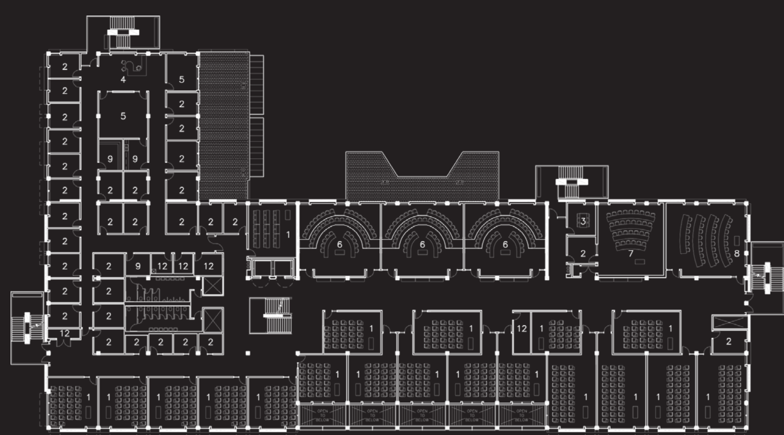

PHOTO: KACEY JURGENS


1
2
3
4
5
6
7
8
9
10
11
1. science + engineering building
2. campus green
3. main street
4. canal
5. entry bridge
6. play fields
7. library
8. classroom building
9. future building
10. parking
11. central plant
North
0 25 50 100 200'



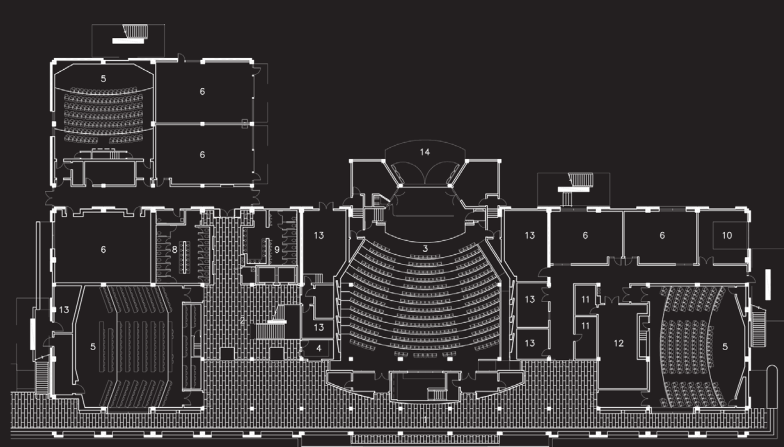
THIRD FLOOR PLAN

1 OPEN OFFICE AREA
2 OFFICE
3 CONFERENCE
4 SUPPORT
5 WOMENS
6 MENS
7 MECHANICAL / ELECTRICAL / UTILITY
8 SHOWER



SECOND FLOOR PLAN

1 CLASSROOM
2 OFFICE
3 CONFERENCE
4 RECEPTION
5 DEAN'S OFFICE
6 CASE STUDY ROOM
7 VIDEO CONFERENCE ROOM
8 COMPUTER LAB
9 SUPPORT
10 WOMENS
11 MENS
12 MECHANICAL / ELECTRICAL / UTILITY



FIRST FLOOR PLAN

1 ARCADE
2 LOBBY
3 AUDITORIUM
4 TICKETS
5 LECTURE HALL
6 CLASSROOM
7 CONFERENCE
8 WOMENS
9 MENS
10 RECEIVING
11 OFFICE
12 A/V ROOM
13 MECHANICAL / ELECTRICAL / UTILITY
14 AMPITHEATER STAGE

- Glazing system that has good daylight transmission (47%), low U-value (0.31, a low heat conduction value) and a low shading coefficient (0.40, a low fraction of solar heat gain and half that of regular double-glazing). No reflective or tinted glazing is used in order to maximize daylight collection for the reduction of lighting loads;
- Massive exterior walls to absorb heat gain during the day and shed the heat in the cool of the Valley night;
- High roof insulation levels (R-34) under a white-colored "cool roof" thermoplastic membrane, primarily to reduce cooling loads.

Interior Lighting

The energy-efficient light fixtures were used to achieve an average installed lighting load as follows:

- Classrooms and offices 0.75 watts/sf
- Auditoriums and conference 1.10 watts/sf
- Service spaces 0.50 watts/sf

The lighting design was coordinated for all Phase 1 buildings for both energy efficiency and operations coordination by developing a master fixture schedule. At the time of the Phase 1 projects, the lamp of choice for energy efficiency was the T-5. T5HO lamps were not used because of limitations on dimming this lamp type.

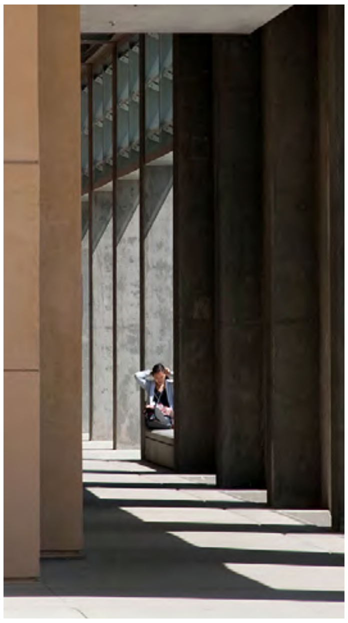


PHOTO: KACEY JURGENS

PHOTO: KACEY JURGENS

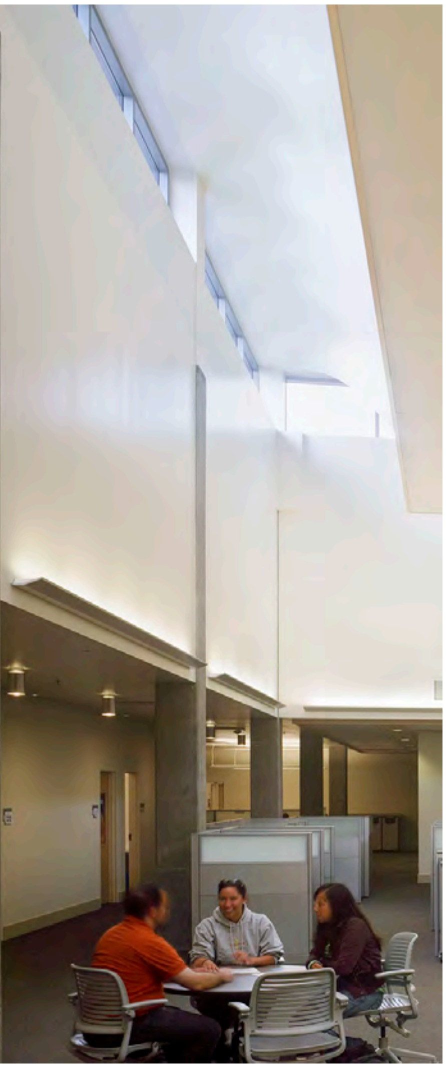


PHOTO: TIM GRIFFITH

Heating, Cooling and Ventilation

The heating, cooling and ventilation system for the building was designed following similar best practices adopted in the two other buildings. These include separate heating and cooling using the room terminal coils to meet room requirements and a “low-pressure design” to minimize fan power requirements.

The system design is also a variable-air-volume (VAV) system, which allows the supply and exhaust airflows to vary based on actual space needs. A minimum amount of outside air is circulated during the heating and cooling seasons with the zone fresh air requirement controlled by CO_2 sensors that adjust for changes in the occupancy of auditoriums and conference spaces. The Central Plant provides the heated and chilled water for the seasonal heating or cooling demand respectively.

There is also no mixing of heated or cooled air streams in the design. Only heating or cooling at the room terminal unit occurs to meet the room requirements. If cooling is being applied via the cooling duct, for example, then the other duct remains neutral and carries return air or outside air to temper the supplied cooling air. The reverse occurs if heating is being applied in winter.

The system also utilizes a number of methods of low-pressure design for the ductwork and other components to reduce the fan power needed to move the air through the system.

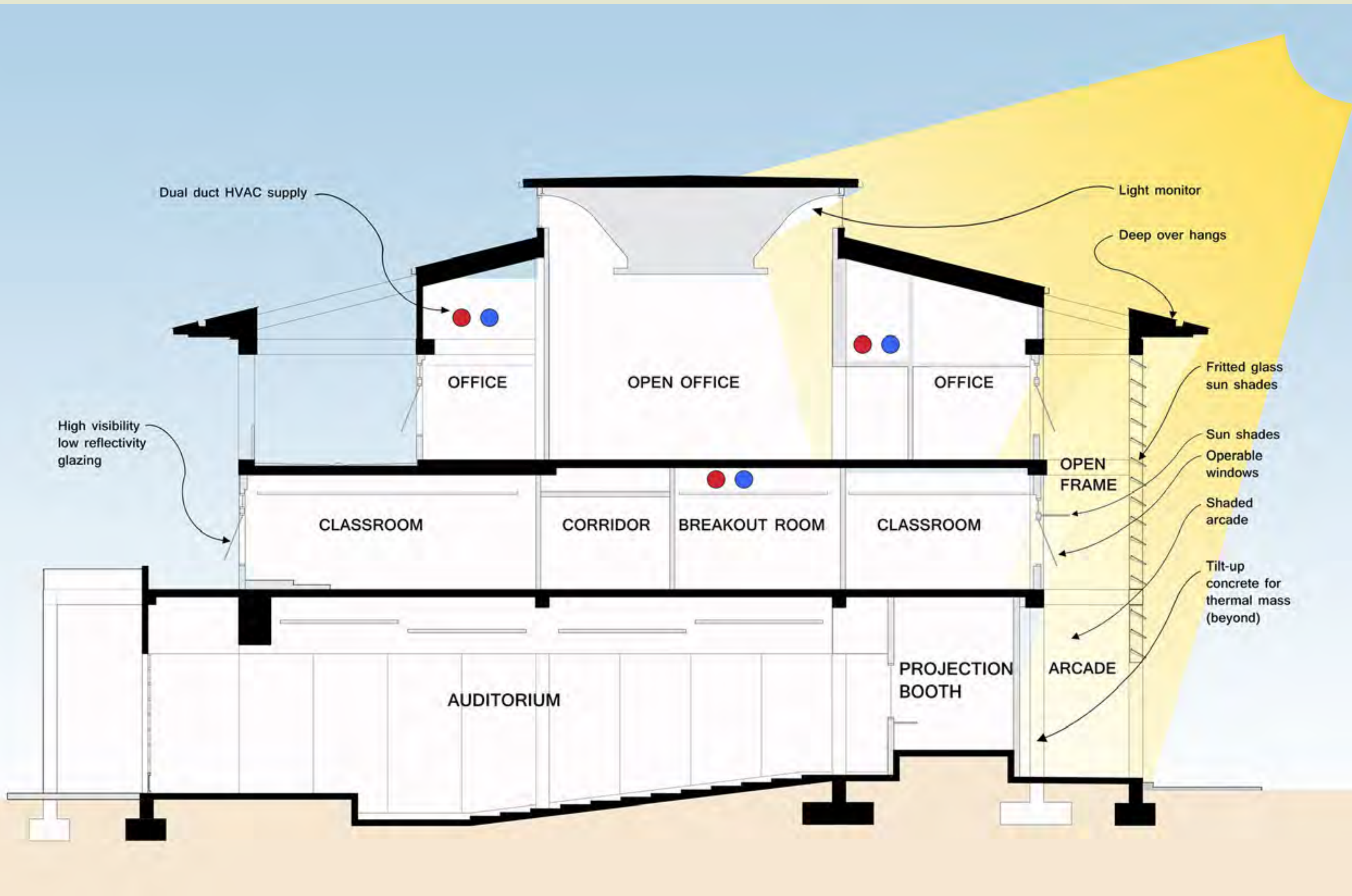
Just as in the laboratory building, the system design includes occupancy sensors, both motion sensors and infrared sensors, to control the electric lighting. These sensors also send a signal to the building management system (BMS) that controls the temperature of the air at the terminal unit. When the room is scheduled to be unoccupied, the BMS resets the space temperature.

All of these design features together effectively lower the EUI for the building and, as required as part of the energy budget, also keep the peak power demand and peak demand on the Chiller Plant below the stated maximums.

Electrical Plug Loads

As noted for the laboratory case study building, the Classroom & Office Building as designed included plug loads in the traditional way, only as part of the overall equipment load in watts/gsf. A/E teams working on buildings in later phases are considering the impact of plug loads in more detail and the facilities group at UC Merced is working to reduce this type of load initially and to manage it after occupancy. Performance measurements of all the UC Merced buildings include all plug load circuits.

(Opposite page)
Diagram of low-energy design features (Courtesy of EHDD Architecture)


Dual duct HVAC supply
Light monitor
Deep over hangs
OFFICE
OPEN OFFICE
OFFICE
High visibility low reflectivity glazing
Fritted glass sun shades
Sun shades
Operable windows
Shaded arcade
Tilt-up concrete for thermal mass (beyond)
OPEN FRAME
CLASSROOM
CORRIDOR
BREAKOUT ROOM
CLASSROOM
AUDITORIUM
PROJECTION BOOTH
ARCADE

Energy Design Analysis and Energy Performance
Modeling versus Initial Post-Occupancy Measurements

Energy Use - Modeling

The whole building energy modeling for the *Classroom & Office Building* was done in 2002 using the eQUEST interface version 2.55 of the DOE-2 analysis engine. Under the modeling assumptions described in the energy analysis report[1], the building EUI (site energy) is tabulated at 37.3 kBtu/gsf-year. The 80%-of-benchmark EUI target for this type of building was 57.6 kBtu/gsf-year. The design modeling result was therefore 65% of the energy budget and equivalent to 52%-of-benchmark EUI. Actual measurements over a three-year period of occupancy have borne out the accuracy of this modeling analysis.

These results, both modeling and actual measurements, encouraged the use of 50%-of-benchmark energy budgets for buildings designed in subsequent phases since this goal was demonstrated to be entirely feasible within project cost budgets and existing building technologies.

	Energy Use Benchmark Target			Maximum Demand		
	EUI (Site) (kBtu/gsf-yr)	Annual Electric (kWh/gsf-yr)	Annual Thermal (kBtu/gsf-yr)	Peak Power (Watts/gsf)	Chilled Water (tons per 1,000 gsf)	Heated Water (kBtu/hr per 1,000 gsf)
Energy Budgets (80%-of-Benchmark)	57.6	12.2	16	2.9	1.6	9.6
Energy Modeling Results*	37.3	7.7	11	1.9	1.5	5.0

* *Detailed Energy Analysis Report*, *University of California, Merced, Academic Building*, Taylor Engineering, December 2002.

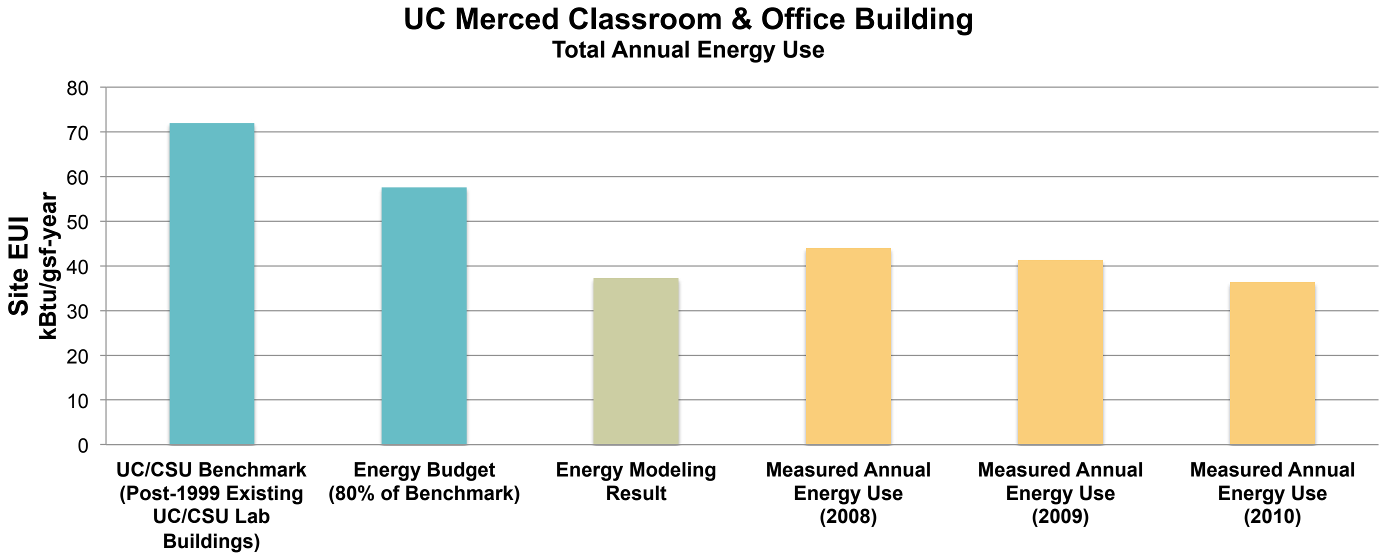
Energy Use – Actual Measurement

Metered data has been collected for this building since it was occupied. This includes data from the large array of individual building meters as well as data from a set of meters on the amount of hot water and chilled water coming to the building from the Central Plant.

As reported in the 2009 CIEE measured performance case study reports for the Phase 1 buildings[2], the initial recorded data in general contained gaps, errors and implausibilities that resulted in the need to replace or recalibrate some meters. Once the subsequent measured results were evaluated and verified by Lawrence Berkeley National Laboratory (LBNL) to be "reasonable and consistent with all available data, including energy balances with master utility meters"[3], the performance of the building in a fully operational year could be recorded and reported.

The results of the first year of energy use data analysis showed the consistent overall effectiveness of the design strategies employed for the three principal Phase 1 buildings, including this *Classroom & Office Building,* to exceed substantially the target of 80%-of-benchmark. The first-year EUI (site energy) was measured at 44.0 kBtu/gsf-year, which is 61%-of-benchmark. The peak power demand and peak hot water demand from the Central Plant were measured at similar performance levels below the target benchmark. The only exception with initial measurements was the peak chilled water demand from the Central Plant, which was recorded at 85%-of-benchmark[4].

[1] *Detailed Energy Analysis Report, University of California, Merced, Academic Building*, Taylor Engineering, December 2002.
[2] "Measured Performance Case Study: Classroom and Office Building, UC Merced", California Institute for Energy and the Environment (CIEE) and the New Buildings Institute (NBI), 2009
[3] Ibid, p. 4
[4] Ibid, p. 5



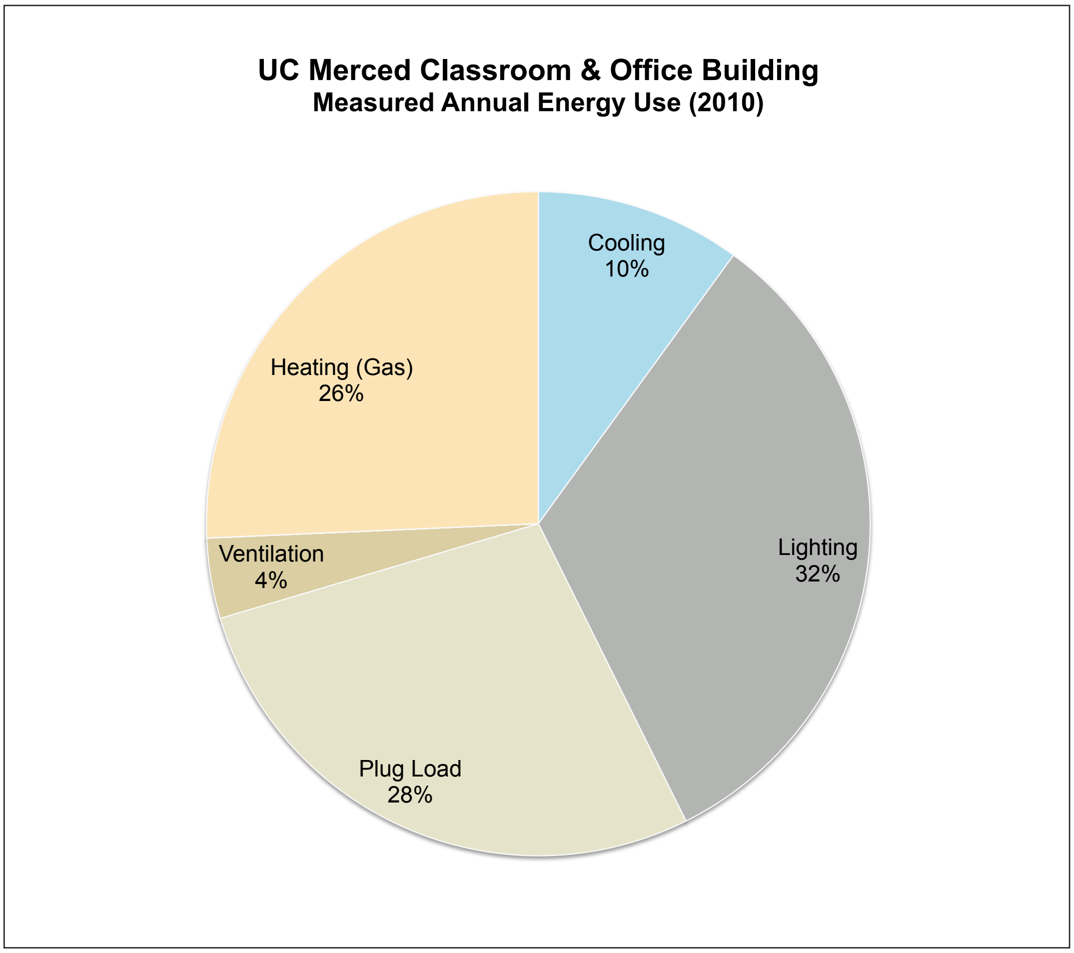
While the peak chilled water demand did not achieve the target of 80%-of-benchmark in actual performance, all other metrics were substantially below the 80%-of-benchmark target levels. The computer modeling for this metric indicated that it would be close to the target, only 7% below, and therefore most susceptible to failing to meet the target during actual occupancy. This proved to be the case.

The explanation for this failure to meet the benchmark target for the peak demand for chilled water from the Central Plant could lie in the nature of this building type or in the specific design, but discussions with both the design engineer and the UC Merced staff indicate that this particular benchmark seems to be based on an “insufficient data set”. The UC/CSU benchmarks for chilled water demand assumed a certain diversity in order to map a campus-level value to the building level. This involved a certain amount of uncertainty at the time, but data collection from the new buildings will help establish a better benchmark.

Also, in the case of this building, the client and design team relaxed this particular peak demand target since analysis showed that shaving the chilled water demand peak resulted in an increase in the peak electric demand. These conclusions have resulted in a modification of the approach to this particular benchmark target for future UC Merced buildings.

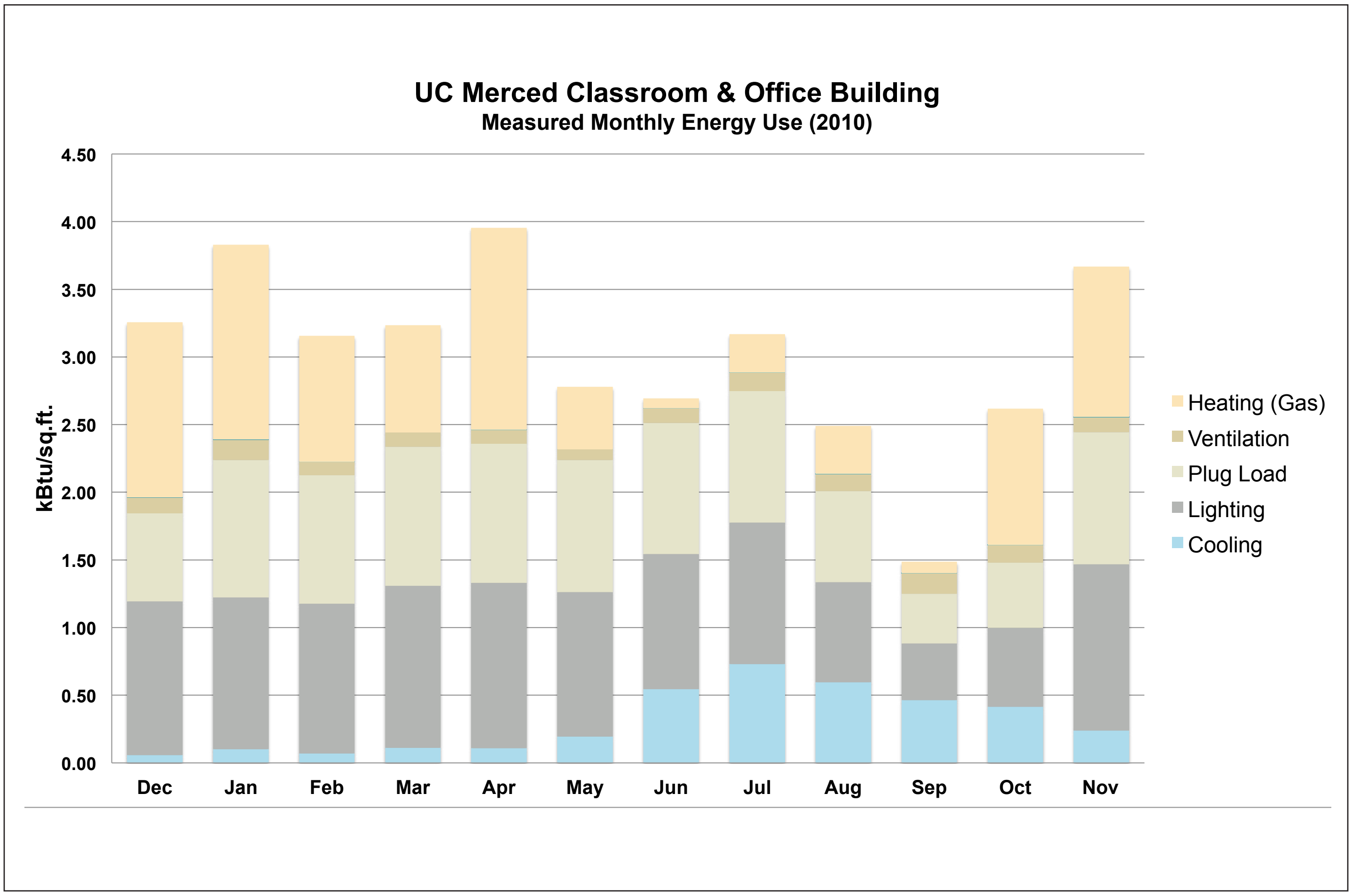
For the most important benchmark target, the annual energy use intensity (EUI), the building data analysis from 2008 to 2011 shows a slight but steady decline from an initial EUI of 44 kBtu/gsf-year to a current value for the EUI not far from the modeling result, 36.3 kBtu/gsf-year. The continued steady decline in energy use is attributable to the post-commissioning activities of the UC Merced facilities group, who now monitor the energy use data reported for each of the Phase 1 buildings and observe the energy use trends of each subsystem.

The energy performance results are shown in the charts on the facing page.



Measured Energy Use (2010)

1,097 MWhr per Year
Actual EUI = 36.3



Post-Occupancy Adjustments to Lower Energy Use: HVAC Systems

As discussed in the previous case study section, the value of recording and reviewing the energy use patterns of the building systems is obviously to identify locations of higher consumption than expected and opportunities to improve the overall efficiency by changing components or operations. UC Merced has been continuously engaged in this monitoring and evaluation activity since 2006, when the two case study buildings opened, and has steadily made system changes that have resulted in improvements in the energy performance.

The charts on the facing page reflect the improved performance: the principal measure of building annual energy use, the building's EUI (site energy), has been reduced to 38 kBtu/gsf-year. The following subsections describe the principal issues and adjustments made to the building systems based on observed data over the past six years.

Correction of Basic Control System Issues

The same control system issues experienced with the Science & Engineering Building I created difficulties with the system operations of the Classroom & Office Building during the first year of occupancy, and for the same reasons. The building's local control system was incompatible with the campus BMS.

To recap this issue:

Buildings on the UC Merced campus are controlled using a central BMS so that all buildings can be scheduled from one center. Based on the instructions from the BMS, the individual building's control systems are supposed to operate the various system components according to those instructions.

Metered data revealed that schedule changes made with the BMS were not resulting in any effect on the local building control systems. The communication "protocols" of the two systems were different: the campus BMS uses "BACnet protocols" while the local laboratory ventilation control system uses "LonTalk protocols". A great deal of time was required for the staff at UC Merced, working with the engineers of the control system manufacturers, to recommission the controls and solve the compatibility problem. The solution ultimately was to set up a separate computer specifically to coordinate the control systems.

The importance of this problem solution was that many energy efficiency measures of the building design could not be implemented nor could the building be placed into a setback mode as allowed by the building schedule.

For UC Merced, this problem was the most significant one encountered because it affected the low-energy operation of the building as intended in the design and because it required so much time to solve. It was at least two years in the observation, solution and implementation to bring about the basic system operation as intended.

The principal outcome of this experience is that UC Merced has enacted the future requirement that any control system specification for new UC Merced buildings in subsequent phases must be entirely BACnet protocol to ensure compatibility with the central campus system.

Post-Commissioning Work: HVAC System Coordination with Room Scheduling

Just as in the case of the *Science & Engineering Building I*, the UC Merced staff have been working during the post-commissioning period to coordinate the detailed building schedule with the HVAC temperature and ventilation requirements for the *Classroom & Office Building.*

Certain rooms such as classrooms, auditoriums and conference rooms are scheduled through an online reservation system known as *Astra*. The campus BMS system, with the solution of the coordination problem with the local building HVAC control system, now can adjust the temperature setpoints and/or vents according to the *Astra* scheduler. This linkage of the space scheduling software with the campus BMS by the UC Merced staff is providing energy saving dividends. Classrooms can be put into a non-occupancy mode, for example, where there is minimal ventilation air and the space temperature is allowed to float.

Post-Occupancy Adjustments to Lower Energy Use: Lighting Systems

Adjustment of the Lighting Control System Operation

The experience with the *Classroom & Office Building* followed that of the *Science & Engineering Building I*. Namely, the post-commissioning issues with lighting were the same: during early occupancy of this building, there was also a lack of connection between the campus BMS and the building's lighting control systems. As in the case of the HVAC system, it was discovered that schedule changes programmed into the campus BMS did not affect the building lighting controls. With the correction to this problem, UC Merced staff were able to tune the building operation to the room schedules and reduce the energy use through setbacks and light level reductions.

These setbacks were established in the *Classroom & Office Building* for the auditoriums, conference rooms and classrooms. The lighting in private office spaces is controlled by local motion and infrared occupancy sensors. Each lighting zone is part of a "scheduling area", which includes the HVAC equipment components related to the same space or room. In this way, the lighting and HVAC are linked by the control system and operate together to serve the space.

The lighting control logic for the common area spaces is as follows:

1. Lighting is strictly scheduled *on* and *off*. This is a basic approach in public spaces such as hallways and lobbies. Local manual switches are overridden to be inactive during the scheduled occupied period.

2. Lighting is scheduled *occupied*, but not turned on. The lights only turn on if someone enters the zone and uses a manual light switch. The lights then remain on until the end of the scheduled period, when all lights turn off. This is a typical operation in classrooms and conference rooms, where users have complete control of the lights. Manual light switches can also override the *unoccupied* schedule for one-hour increments; the link to the HVAC system signals a ramp-up of space conditioning for the override period.

3. Lighting is scheduled to turn on at sunset and off when the schedule expires. This type of schedule is used in zones at the building perimeter with a large amount of daylight. Manual light switches can override the schedule for one-hour increments.

Exterior lighting is set to operate on a sunset-to-sunrise schedule. The time at which each of these events occurs is updated daily.

Conclusion ▷

Observations

In the six ZNE buildings discussed in this monograph, some common issues and conclusions about ZNE building design and performance are apparent. All buildings shared common process elements—in each case the design teams engaged in:

- Target setting
- Designing to the target
- Building to the design
- Monitoring, diagnosis and correction

At this point there are, to be sure, imperfections in this developing area of building design and construction; experience, feedback and new building technologies are needed to achieve solutions scalable to widespread practice. Several observations based on these case study buildings are examined below together with resulting conclusions about near-future industry development.

Target Setting: Motivation and Purpose for Pursuing a ZNE Design

The back stories of the case study projects all indicate that the choice to pursue a ZNE design resulted primarily from a client's commitment to such an environmental goal, often promoted by a highly motivated A/E team. This was always accompanied by the confidence of the client in the ability of the design team to deliver a ZNE-performing building within acceptable budget constraints. With the project vision established, the entire team (client and A/E team) worked together at the beginning of the process to establish the energy-use and energy production targets that would guide all design decisions along the way.

> *As the case studies show, these buildings were able to achieve ZNE performance because the targets were clear and deliberate from the beginning, a prerequisite for successfully reaching the envisioned goal.*

Designing to the Target: Building Modeling Versus Actual Performance

Once a performance target of ZNE is established, the A/E team uses whole building energy modeling as a method of determining approximate performance based on many assumptions about building schedule and occupancy, internal plug loads and a set of weather data points for a statistically-determined representative year. Inevitably, initial modeling efforts are approximations owing to the large number of variables. However, as noted in the paper by Brown *et. al.*[1], with new ZNE policy goals as well as new disclosure requirements in some cities and states, there is an increasing expectation that building energy modeling results should more accurately align with actual measured building energy use. In addition, the size of the energy production system—in most cases by far the most costly component of "getting to zero"—is often determined from the results of the energy modeling of the building. It is therefore imperative that modeling software improves in "predictive" capability, especially with regard to the new building technologies being employed for low energy performance.

Modeling what the actual performance of a building will be after it is built and occupied is both an art and a science. Being able to compare modeling results from the design phase with actual measured performance when the building is occupied will provide designers with a better sense of this art. In the Packard Foundation Headquarters building and several other ZNE buildings, for example, the design engineers noted that energy models typically underestimated heating energy use. The explanation offered is that ideal construction tolerances are assumed in the energy modeling software, which are not normally attained in the field. Similarly, lighting energy use by high performance systems with daylighting and occupancy controls is often overestimated, as in the case of the Stevens Library. The modeling inaccuracy for lighting seems to be the result of the complexity of the interactions among the lighting system, the available daylight, and the

[1] K. Brown, A. Daly, J. Elliott, C. Higgins, J. Granderson, "Hitting the Whole Target: Setting and Achieving Goals for Deep Efficiency Buildings", Proceedings of the 2010 ACEEE Summer Study, Panel 3 Paper 734

daylight and occupancy controls: sophisticated *lighting design* software in the hands of a skilled modeler can yield excellent results, but *energy modeling* software does not include this level of sophistication. Engineers are now starting to factor such experiences into the modeling of these types of loads in their current projects.

At present, the ability to show during the design phase that the building will meet targeted energy budgets has limitations, especially with complex buildings: design professionals cannot guarantee a certain level of performance as measured during the post occupancy period.

> *Establishing the practice of comparing the results of a whole building energy model of the pre-constructed design with the measured energy use data from the occupied building will improve the industry's energy modeling capabilities. As design professionals gain experience and the design analysis tools improve, the basis for setting realistic future energy performance targets will also generally improve. This is an important area for continued research and software product development.*

Building to the Design: Building Metering Issues

ZNE buildings do not assume that internal environmental conditions will be maintained, if necessary, by an expenditure of extra energy to overcome deviant factors from the exterior environment that affect comfort and functionality. Rather, the building features and systems are specifically designed to be in efficient and economical balance with the exterior environment so that energy demand is minimized. ZNE buildings therefore usually employ new approaches (from the standard industry perspective) to the design of these features and systems, which may or may not have a cost premium (a subject of much current discussion).

"Building to the Design" is therefore a major current concern as the industry shifts and adopts the new design approaches as they are tested and prove out over time. Part of this process involves the recognized need for post-occupancy building commissioning as well as the need to avoid the use of "value engineering" (unless it is *true* value engineering considering life cycle cost and not just blunt cost reduction) to remove high-performance features. It is also important that a building metering sub-system be included in the design and specification so that it can be verified that the performance objective was in fact achieved or, perhaps more importantly, to help identify measures that need to be taken to "get to zero". By reviewing several years of this metered data it is possible to sort out problem issues, to confirm the effectiveness of selected design strategies and to help the building manager make good decisions about the building operation.

In relation to the last point, the experience with the case study buildings discussed in this monograph has led to the interesting conclusion that the building metering sub-system itself must be commissioned and validated. **In all six buildings studied, the monitoring systems needed post-occupancy adjustments to function properly.** We need to have as much *accurate* data as possible about the energy use of each building subsystem, component and electric circuit once these low-energy buildings are occupied. In several cases, faulty data recording or outright failure was discovered during the measurement and verification process some time after initial occupancy.

The clients and A/E teams for the ZNE case study buildings described in this monograph recognized the importance of post-occupancy monitoring of the building performance and installed meters on each electric panel and, in the case of the UC Merced buildings, on the hot and chilled water from the campus central plant as well. It is most useful if the circuits are segregated by end-use so that metering can be done at the breaker level on the main distribution board, which is relatively inexpensive since breakers can have metering at little additional cost. This is now standard practice for new buildings at UC Merced[2].

In the case of the Science & Engineering Building I at UC Merced, the early problem was with the metering system itself. There was an initial period of troubleshooting, including even some assistance from Lawrence Berkeley National Laboratory, before the data stream was deemed to be representative of actual energy use.

The normal commissioning process does not include the metering system—whether the meters are working correctly and whether the data is accurate. John Elliott, former Director of Sustain-

[2] Private communication, John Elliott, Former Director of Sustainability at UC Merced, Mar. 2014.

ability for UC Merced, reports that some of the meters used were found to be off by 300%, simply due to faulty equipment.

In the case of the IDeAS Office Building and Packard Foundation Headquarters office building, the meters did not match the current transformer (CT) ratios in the electric circuit. That is, the CTs of the meters were too large to accurately measure the relatively small amount of current in the wires, rendering the measurement inaccurate. Using meters with properly sized CT's or higher quality meters that can pick up the small loads solves this problem and results in accurate data.

This effect was detected in these two case study buildings by comparing the energy flow at the site utility meter and the energy production meter at the PV system, both of which are highly accurate metering systems. The net difference should equal the energy use as reported by the building meters. The initial inaccurate readings by the meters were detected as a result of this comparison, which also later confirmed the accuracy of the metered data after the metering system was overhauled. Reconciling the building sub-metering system with the utility metering system is thus a critical step in this aspect of the commissioning process.

Finally, the *Building Management System* (BMS) is usually used as a source of energy use data, but this introduces another source of possible data collection problems. The programming of the BMS is often done by software engineers who are not experienced with building energy systems and what how to organize the most useful method of reporting all the data. This programming can also be peculiar to the individual software engineer, which can make later troubleshooting difficult. Data reporting problems were experienced in some case studies, most notably in the Watsonville Water Resources Center, where data was initially lost due to a programming-based issue and where plug load data could not be deciphered from the data. This case demonstrates the need for a consistent approach, communication between the programmer and the design team, clear and transparent documentation, and system validation.

The common lesson from these experiences is that the energy metering system itself requires a commissioning process and the quality of the data that is being reported must be carefully assessed. Once this initial period of metering sub-system "tuning" is completed, the data collection and analysis can be started.

Monitoring, Diagnosis and Correction: Creating "Actionable" Information

When the building energy use data streams are deemed to be accurate and are compiled over a period of time, there is a lot of complex information that needs to be synthesized into a form that is "actionable" by the building manager. This includes reports about specific systems and components and, ideally, programmed warnings about anomalies or changes in the patterns of energy use. Clients and owners are typically wary of the time required for this on the part of building managers, and rightly so, especially if they are not trained to deal with the form of the data reporting. It is not useful for the building manager to receive, literally, many thousands of fault alarms over the course of a year, as has been reported in the literature. The need is rather for reports about specific systems and components and, ideally, programmed warnings about anomalies or changes in patterns of energy use that are clear and "actionable."

At UC Merced, two postgraduate assistants were assigned the task of monitoring the data, organizing reports and alerting facilities staff to such changes in use patterns. This monitoring called attention to the failure of one of the four exhaust fans, for example, as reported in the case study for the Science & Engineering Building I. This would otherwise have gone unnoticed for a long period of time, and points to the need for automated reporting systems for larger facilities, few of which have the luxury of high-quality, low-cost student assistance.

As noted in the Packard Foundation Headquarters case study, the client's in-house IT team developed a software package that monitors the control systems of all the different energy-related building systems, records the data being produced and presents all the information in a user-friendly format for the building manager. This software "sits on top" of the set of all control systems, including the BMS, and allows the building manager to receive alerts from any part of the building infrastructure, as well as to change operational schedules from automatic window-blind operation to room temperature and lighting settings for common rooms—all with the click of a mouse.

This is a developing area for software commercialization, with similar versions currently available on the market to typical building owners. Software *packages with this type of functionality can be an important and effective key to successful monitoring and reporting of energy use and production data for all buildings. To a large degree, it will also make building monitoring and maintenance less of a burden for an owner's maintenance and operation staff, providing exactly that desired situation of having easily "actionable" information for the normal type of building manager.*

Final Observations: Standard Reporting of Energy-Use and Production Data

ZNE buildings can rightfully claim that level of performance only if the occupied completed building actually performs at a ZNE level as confirmed by actual energy use and production data. Although definitions vary, as described in the Introduction section of this monograph, all definitions view ZNE is an *annual* metric; therefore, performance data from a stable 12-month post-occupancy time period is required.

The building's performance necessarily changes to some degree as it ages—changes in occupancy patterns can cause large changes in energy use, as can weather variability from year to year. Over time, the building shell and building systems may get modified, affecting energy use. Some of the case studies show that attention to building performance in the first year after occupancy can actually improve performance significantly--not a surprise since buildings and building systems rarely operate perfectly from day one. The general observation is that correctly measuring the first year's performance from the beginning of occupancy is critical to tuning the building so that ZNE operation is actually achieved.

As ZNE performance becomes integrated into California's building code (and possibly into codes in other states), there will be a growing need to have a standard method of reporting performance. This is a developing area of work that warrants attention. Building code systems and metrics for analysis and compliance will continue to reside at the state level. However, a standardized system for reporting and/or rating building post-construction performance that is consistent nationally (or even internationally) should be considered, including the following factors:

- Reasonable accounting for source energy impacts and *greenhouse gas* (GHG) emissions (which vary widely on a both a regional and seasonal basis);
- Allowances for renewable energy procurement for individual buildings where it is not feasible to locate a sufficient amount of renewable energy production at the building site to fully offset the consumption of the building;
- Emphasis in design on "efficiency first" measures (to avoid oversizing the renewable energy production systems, usually the most expensive component system of a ZNE building);
- Provisions accommodating multi-building developments (e.g., residential subdivisions or campus-style mixed-use developments) that aspire to ZNE at the campus or district level.

Beyond reporting or rating systems, full-scale *ZNE certification* programs warrant consideration. There are several fledgling systems in the market today (the *Living Building Challenge* and *Earth Advantage*'s "Net Zero" certification come to mind). Acceptance and deployment of such systems at scale (similar to the current industry position of LEED™), with provisions to incorporate and address substantial regional differences in climate, building practices, consumer preferences, utility grid fuel mix–among several issues–is likely to remain a challenge. Implicit within the concept of certification is the sustained performance of the building over time, through some form of "re-certification," so that progress continues toward lower greenhouse gas emissions.

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