# Zero Net Energy Case Study Buildings
*Volume 3*

Written by
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Introduction by
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*September 2018*

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*Cover Photo: View over the solar photovoltaic array at the J. Craig Venter Institute Laboratory in La Jolla, California. Photo by Nick Merrick, Hall Merrick Photographers*

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# Foreword

**Much has changed in the market for ZNE since we published Volume 1 of this series four years ago**. And the news is mainly good. The market for ZNE has exploded. Policy and legislative mandates to reduce GHG emissions on both the energy supply and energy demand sides continue to ramp up even as they begin to force changes in the dynamics of building-grid interaction. Importantly, the commercial real estate market is beginning to reflect the full value of high performance, low emissions and ZNE.

**An Exploding Market.** Although the total number of ZNE buildings is still small in absolute terms, *the rate of increase* of ZNE buildings in both residential and non-residential markets is soaring: to wit, the New Buildings Institute (NBI) reports a 700% increase in non-residential ZNE buildings since 2012; the Net Zero Energy Coalition (NZEC) reports 33% growth in 2016 in residential markets followed by 70% growth in 2017. In Volume 2 of this series, published in 2016, we documented Sharp Development's 32,000 square foot project *435 Indio Way* in Sunnyvale, CA—two years later, this small developer is now on ZNE retrofit project number six, demonstrating a model that can be replicated rapidly (more on this later).

On the other end of the "scale" spectrum, the State of California continues to accelerate ZNE plans in its own fleet of buildings: the State's management memo implementing the Governor's order B-18-12 states that "All new state buildings, major renovations, and build-to-suit lease beginning design after October 23, 2017 . . . shall be designed and built following cost-effective energy efficiency strategies for achieving ZNE." On the residential side, we now have entire subdivisions, such as De Young Properties' *EnVision* in Clovis CA, being built to ZNE. Although this series of *Zero Net Energy Case Study Buildings* is focused on California, much is happening in other cities and states throughout North America: in the NZEC 2017 inventory of ZNE projects, six of the top twenty cities for ZNE are in California . . . but fourteen are in other states (and Canadian provinces). Momentum is clearly building, and not just in California.

**Greenhouse Gas (GHG) Reduction: Still the Driver, with New Wrinkles.** As we stated in our *Foreword* in 2014, in Volume 1 of *Zero Net Energy Case Study Buildings*,

> "GHG issue(s) are driving and transforming . . . leaders within the building industry to target this new level of building performance."

Likewise, the power grid serving our building stock continues to get "cleaner," and at an accelerating rate. California passed AB 32 in 2006, mandating a 20% reduction in GHG emissions compared to 1990 levels by 2020; successor legislation SB 32, signed in October, 2016, mandates an extension of that law to require a 40% reduction by 2030. California is on target to reach these goals.

As of July, 2018, California has more than 830,000 solar projects totaling more than 6800 MW (www.californiadgstats.ca.gov). Although clean and renewable, this power is available a little less than 20% of all annual hours, calling out the need for flexible, responsive building loads, grid-level and behind-the-meter storage, and associated grid infrastructure improvements to enable these advances.

Not so long ago, policy makers were concerned about the air quality impacts of running relatively dirty "peaker" plants during summer afternoon heat storms: with the increased availability of solar photovoltaic systems (PVs), the emissions profile of the grid for spring and summer afternoon power in California is now at its lowest of any time of the year. In fact (and further turning conventional wisdom on its ear), some of the highest emissions on the California power grid now occur in the middle of the night in fall and winter, causing policy makers to rethink what we typically consider to be "off peak" charging and storage opportunities with available capacity—simply put, we want to store clean power, not dirty power! (In fairness, the off-peak hours are not "dirtier" than they used to be—it's more that the other hours are far cleaner.)

*(Below)* Aerial view of Butte College campus near Oroville, with some of the solar PV arrays that form the renewable energy system installed as a regular feature of its ongoing facility plan. See Case Study No. 15 in this Volume 3 of *Zero Net Energy Case Study Buildings*.


PHOTO: PETERSON PROVIDEO

Long-term, the most successful GHG mitigation strategies on the demand side of the grid will almost certainly revolve around dynamic load flexibility and grid-responsiveness. Although trends are emerging, optimizing the grid emissions profile is likely to be a moving target as we move toward 2050; the ability of buildings to respond *dynamically* to the target will be key.

**The Challenge of our Time: Accessing "New" Value Streams for "Old" Buildings.** In new construction, knowledgeable builders can achieve ZNE performance levels for little or no incremental cost. Of course, on the order of 70-80% of the building stock that will be in service in 2050 has already been built. Further, a large amount of GHG is embedded in the concrete and steel in these buildings, tilting the scale toward preservation. Reaching the GHG emissions goals is clearly a challenge for our time, an all-of-the-above endeavor: we need more efficiency, we need a cleaner power grid, we need to electrify end use, we need renewable thermal fuel. Everything!

To focus back on the efficiency piece, it's fair to say we have structured our energy efficiency industry around ROI and payback based solely on the energy cost savings. Regulators demand cost-effectiveness, but only from the perspective of metrics reflecting energy cost savings. Under this schema, it only makes sense to pursue those measures that pay for themselves with energy savings over some time frame. Utility programs and ESCO efforts have been structured accordingly. But renovating existing buildings to performance levels consistent with ZNE in or-

*(Opposite Page)* View of entrance to *435 Indio Way*, Sunnyvale, CA, which is documented in Volume 2 of this series. This building demonstrates that high performance equates to higher market value, with the lease premium commanded by this building greatly exceeding the value of the energy cost savings.

der to meet the GHG challenge requires *roughly 50%* savings across the entire building stock: such projects, on average, will cost much more than what the energy cost savings alone will pay for.

Taking a high level view, energy bills are +/- $2 per square foot for the bulk of the commercial building stock (recognizing that there are plenty of outliers), and about half that for residential buildings. To get the 50% savings equates to a roughly $1 per square foot per year bill savings. With favorable assumptions, the math on this savings works out to a net present value (NPV) of about $15 per square foot (using modest interest rates and a 20 year project life). So, from this perspective, $15 per square foot becomes the available budget to work with—a little under $500,000 for a building like the aforementioned *435 Indio Way* building in Sunnyvale, CA (documented in Volume 2 of *Zero Net Energy Case Study Buildings*).

We should consider what this developer *actually did* to renovate the building and make money: instead of investing $500,000, this developer invested a total of about $3.5 million in the building: about $1.6 million, or about $50 per square foot, represented the incremental cost of high performance and ZNE features. Why did it make sense to for this developer to spend *triple* the plausible value of the energy savings NPV?

It's all about capturing the value stream: the high performance features make the building more healthy, more comfortable, more resilient—simply a better place to work. Accordingly, it commands a higher lease rate (and also, as the developer points out, is leased months more quickly than competing buildings). The lease premium commanded by this building is in the range of +/- $4 per square foot per year, dwarfing the value of the energy cost savings of $1 per square foot per year (although that $1 still counts!). Although there are no pro-forma line-item values for "more healthy, more comfortable, more resilient," on a *de facto* basis, the market has spoken with respect to this building.

Of course, this model only "works" in competitive private commercial real estate. A school district, for example, cannot extract a "rent premium" from an individual school; generally, these value streams are not available to the many buildings in the public sector—but it does not mean these value streams do not exist. Similar challenges are present in residential market valuation and pricing. A challenge in the coming years will be around finding new methods to document, communicate and access these new value streams. We need better methods of capturing and assigning value to what are sometimes called "non-energy benefits."

**All of California.** With the completion of this third volume of *Zero Net Energy Case Study Buildings*, we have documented 17 non-residential projects across the state, from north to south, comprising coastal to valley climate zones. We have reported on public buildings, private buildings, offices, research facilities, schools and universities, museums, libraries and other building types, seeking to broadly represent the commercial building stock, demonstrating ZNE feasibility across it. Similar efforts are ongoing in residential markets.

Going forward, we recognize that despite the rapid growth and momentum of the ZNE market in California and elsewhere, ongoing efforts to build a capable building design and construction infrastructure will need to continue to ramp up. We are on track to meet the grid-side challenges associated with GHG reduction. As an industry, we need to continue to work on capturing and realizing the full value of high-performance, ultra-low emissions buildings—not just the energy cost savings, but the full value of the comfort, health and resilience of ZNE.

*—Peter Turnbull, Principal, Commercial Buildings, Pacific Gas & Electric Company*

PHOTO: DAVID WAKELY

# Introduction

This third volume of the series of books, Zero Net Energy Case Study Buildings, is similar to Volume 1 and Volume 2 in that it contains a series of detailed case studies of well-designed, recently-constructed buildings that use an annual total of zero energy[1].

The similarities go beyond the use of the same metric for ZNE. They include descriptions of the design process, the design strategies utilized for each building type, the renewable energy systems, the results of energy modeling and comparison with post-occupancy energy measurements, a common charting method for the data about the ZNE performance and finally post-occupancy evaluations and "lessons learned".

On the other hand, Volume 3 departs from these previous two volumes in some significant ways:

- Some of the case study buildings are part of a larger "campus" of buildings, where the solar PV system is not necessarily associated directly with the building (i.e., its roof). The single building model does not apply. We are beginning to see the ZNE concept expanded to include multiple buildings and district-scale solutions, for which these case studies are providing some insights.

- Designed systems in a couple of the case studies include energy storage to allow peak-power reduction and thus savings in energy charges by the connected electric utility. This will grow in importance as a design consideration as the nature of the electrical grid and structure of the public utilities inevitably change in the future.

- Many of the case study buildings are programmatically complex and traditionally have high energy use, a particular challenge to the design teams and requiring non-conventional solutions. The on-site location of the renewable energy system to support the intensity of energy demand has a limit in these cases and other types of solutions are needed as ZNE in all types of buildings becomes more widely applied.

Some of the case studies of Volume 3 point toward a developing issue as the 2030 goal of all-ZNE buildings (new construction) gets closer, namely where to put all the excess power generated by these buildings during the middle of the day and how to meet the new kind of peak power demand created by all these electric buildings on dark days and in the evening. This is an emerging issue that will be addressed in the next few years, partly as a result of the success of the penetration of ZNE buildings in the building industry in California.

This is the *Duck Curve* conundrum.

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[1] We'll footnote here immediately because of the inevitable discussion that starts about the definition of "zero net energy" (ZNE) in this context. For this entire series of *Zero Net Energy Case Study Buildings*, we use ***Site ZNE*** for this definition. That is, the amount of energy used by the building over the course of a year is equal to the amount of energy supplied in that period of time by the renewable energy system.

See the Introduction to Volume 1 for a thorough discussion of the various definitions of ZNE and why *Site ZNE* is chosen as the metric for these case studies over metrics mandated by the U.S. Department of Energy (*Source ZNE*) and the State of California Title-24 energy code (*TDV-ZNE*). Basically, *Site ZNE* is the simple net metering definition that is *measurable*, does not require calculations and is easily understood by the general public. (Often, it is the only type of data collected by the owners of these buildings.)

### The *Duck Curve* Conundrum

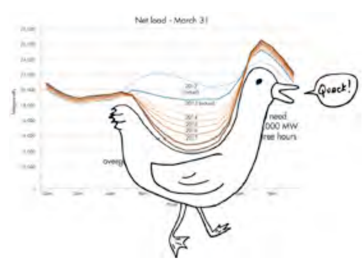
In 2008, the National Renewable Energy Laboratory (NREL) published the results of the first study[2] of the impact on the electric power grid of the then-future integration of the large-scale solar PV systems. This became a concern with the advent of various initiatives to encourage the installation of these systems to provide carbon-free electric power to buildings and transportation. The statewide goal of ZNE buildings throughout the building industry soon followed and the relatively sudden drop in the cost of the PV systems made this issue more pressing.

This study, along with subsequent studies by CAISO[3], found a specific change in the general shape of the typical 24-hour demand profile that would be met by the conventional power plants owned by public utility companies, becoming more pronounced as more and more solar power was added to the grid. This change in the demand profile, labeled the *Duck Curve* by CAISO in 2013, would have profound implications for the statewide electric grid, the public utility planning and the design of the renewable energy systems in ZNE buildings.

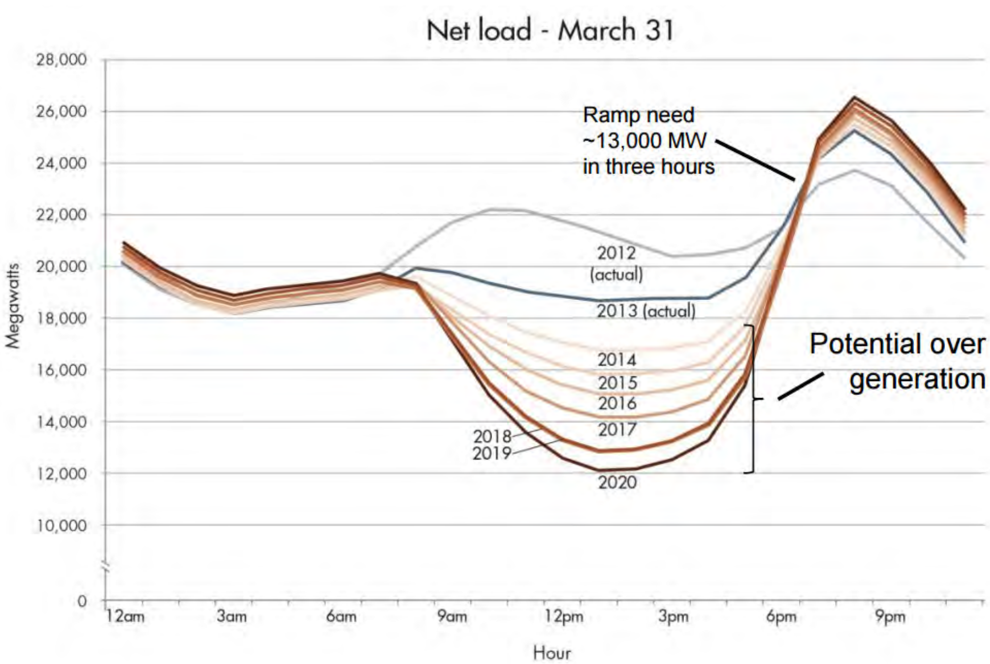
As ZNE buildings increase as a percentage of the whole building stock year-by-year, this *Duck Curve* changes as shown in the figure below. (The "duck" gets a bigger belly in each successive year.) The problem gradually gets worse because so much power is being generated in the sunny California midday, while in the evening, when solar production wanes, there is a need to bring "peaker plants" (usually gas-fired power plants) online to meet the peaking power demand. And these peaker plants must fire up very quickly, as the *rate* of increase of demand during those evening hours grows steeper each year.

The solution to this conundrum lies in *energy storage*, both on the part of the public utility and,

[2] P. Denholm, R. Margolis, J. Mitford, "Production Cost Modeling for High Levels of Photovoltaics Penetration", NREL/TP-581-42305, (Feb., 2008).
[3] CAISO, or "Cal ISO", is the "non-profit public benefit corporation", *California Independent System Operator*, which is charged by the California Public Utilities Commission to oversee and operate the electric power grid in California.




*(Above)* Caricature of the source of the descriptive name for the shape of this demand profile, *The Duck Curve*. (Courtesy of *Inside Energy*)




*(Left)* The shape of the power demand on the statewide electric grid that would be met by conventional power plants, as it varies each year by the increasing penetration of solar PV systems into the grid. (Courtesy of CAISO)

perhaps more economically, on the part of the individual building owner. As can be seen in the conceptual chart on the facing page, energy can be stored in the middle of the day and then accessed in the evening to eliminate the problem areas of the demand curve and synchronize the utilities' power plant operations with the solar PV component provided largely by all building owners in the state.

The exact nature and design of this necessary component of the electric energy system is now being debated and discussed. Should energy storage be mandated as an integral part of the renewable energy supply system in buildings, when such systems become required by code? Should this storage be accessible for use by the public utility providing the backup energy for the ZNE building in the same way that excess solar energy is harvested from the building?

The prototype case study buildings in this Volume 3 begin to offer answers to these questions and related larger issues posed by the large-scale development of ZNE buildings.

### Roadmaps and Mandates for ZNE Buildings - Update

In the two years since *Volume 2* was published (2016) there has been a continuing development in the various roadmaps to statewide adoption of mandated goals for ZNE, as well as the recent (2018) mandate by the California Energy Commission (CEC) to require by code in 2020 (as planned for many years) the installation of enough solar PV on new low-rise residential construction so that such dwellings are capable of performing at ZNE. (These actions, and the unexpected affordability of solar PV systems, have accelerated the phenomenon of the *Duck Curve*, described in the section above.)

As noted in the Preface, since the publication of Volume 2, the California Public Utilities Commission (CPUC) has released the *Commercial Buildings ZNE Action Plan*, aiming at 2030 for its adoption just as the CEC has recently enacted for 2020 the *Residential ZNE Action Plan* for low-rise buildings. Given the time required for building projects from design through occupancy, the opportunity of the shared experiences rendered by these case studies of ZNE buildings is vital.

### Smart Building Technologies - Update

There has also been a continuing improvement in the past two years in building technologies available for adapting ZNE design strategies more seamlessly. Volume 2 revealed the prevalence of a common problem affecting the performance of ZNE buildings: the sub-optimal—even dysfunctional—operation caused by the absence of the proper integration of control systems in these "smart" buildings. (See *Introduction* and *Observations* in Volume 2.) While still an issue, there has been improvement due in part to various studies[4] and actions by the control systems industry.

Related to this, the proper collection of performance data from installed metering systems continues to be a challenge. While not essential to ZNE building design, these systems provide verification of the effectiveness of various design strategies and the ability to troubleshoot any irregular performance.

The case study buildings of this Volume 3 show advances with both issues, but still with the possibility of improvement.

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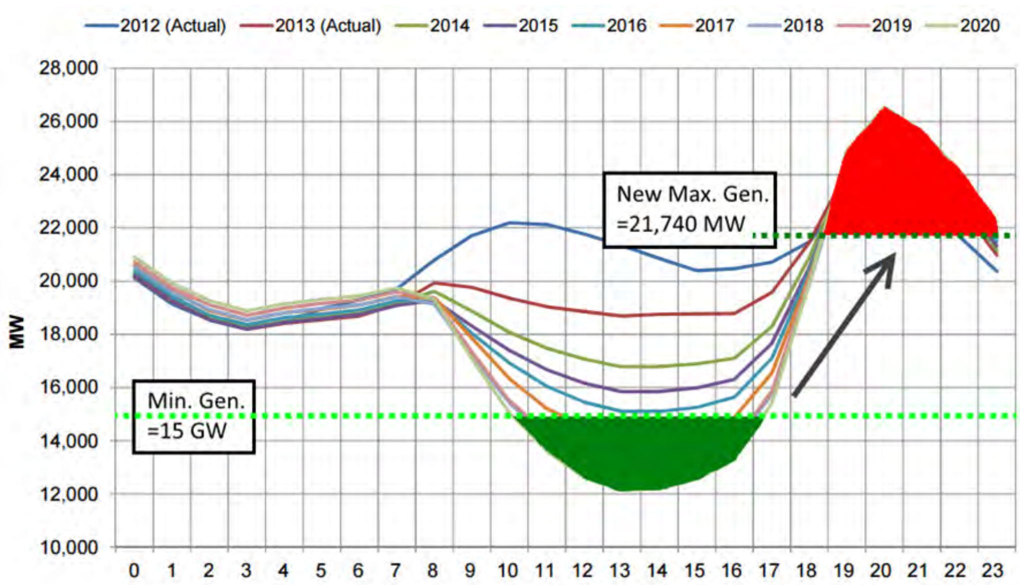
[4] *Zero Net Energy Building Controls—Characteristics, Energy Impacts and Lessons*, New Buildings Institute (NBI), Research Report for Continental Automated Buildings Association (CABA), 2015.




*(Left)* Illustration of energy storage applied to the *Duck Curve*. Energy stored during the afternoon hours from excess solar energy and discharged during the evening to prevent the sharp peak load that would occur at that time. (Courtesy of Michael Burnett[1])

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[1] Burnett, M., "Energy Storage and the California *Duck Curve*", Stanford University (2015).

# Case Study Projects ▷

CASE STUDY NO. 12

# The J. Craig Venter Institute Laboratory

PHOTO: NICK MERRICK, HALL MERRICK PHOTOGRAPHERS

# The J. Craig Venter Institute Laboratory

## *Case Study No. 12*

**Data Summary**

**Building Type:** Research Laboratory/Office (B Occupancy)

**Location:** La Jolla, CA

**Gross Floor Area:** 44,607 sf

**Occupied:** November 2013

**Energy Modeling Software:** eQuest 3.64

**Modeled EUI (Site):**
53.3 kBtu/sq.ft. per year

**Measured EUI (Site):**
73.7 kBtu/sq.ft. per year (2015)

**On-Site Renewable Energy System Installed:**
500 kW (DC) Solar PV

**Measured On-Site Energy Production:**
850 MWh per year (2015)
65.0 kBtu/sq.ft. per year (2015)

**Owner/Client**
J. Craig Venter Institute

**Design Team**

*Architect:* ZGF Architects, Los Angeles, CA

*Structural Engineer: KPFF*, Los Angeles, CA

*Mechanical/Electrical/Plumbing Engineer:* Integral Group / Peter Rumsey, Oakland, CA

*Laboratory Planning:* Jacobs Consultancy, Inc., Los Angeles

*Lighting Design:* David Nelson & Associates, Littleton, CO

*Daylighting Analysis:* IDeAs, San Jose, CA (now part of Integral Group)

*Commissioning Agent:* Integral Group, Oakland, CA

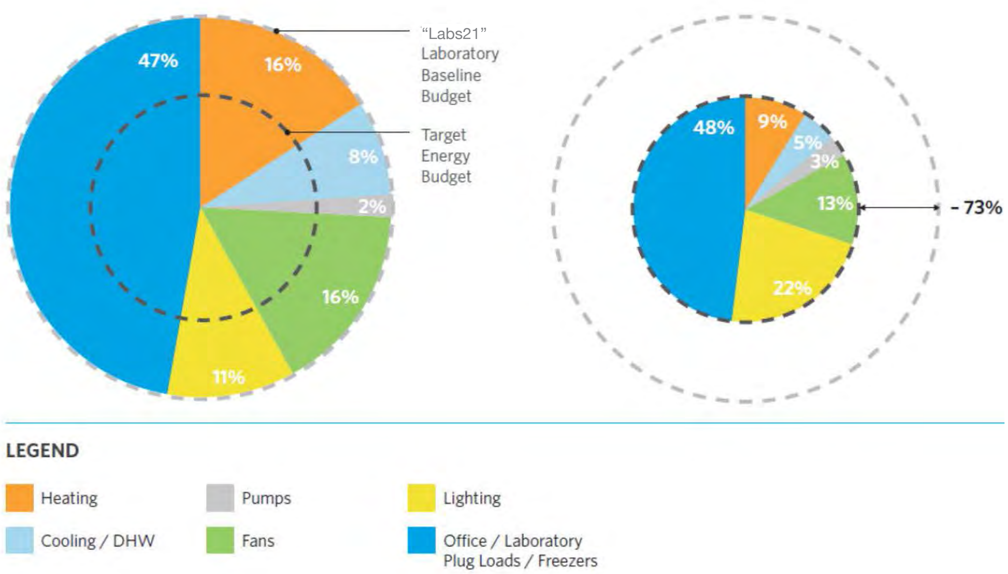
*Landscape Architect:* Andropogon, Philadelphia, PA; David Reed Landscape Architects, San Diego, CA

**General Contractor**
McCarthy Building Companies

Laboratories in general present special challenges to achieving zero-net-energy (ZNE) performance. They are a building type that is highly energy intensive, requiring roughly five times as much energy per sq. ft. as a typical office building. Even for a standard one-story laboratory, the implication for the size of the solar photovoltaic array often exceeds what can be physically accommodated on the building and the site.

Applying the best practices for laboratory design as described for the national program in energy-efficient laboratories[1], "Labs21", can reduce the energy demand substantially, but there remain significant design challenges to balance the energy use with the renewable energy supply on the project site. Case Study No. 12, the *J. Craig Venter Institute Laboratory*, is the first research laboratory facility to address these challenges in totality and to achieve *near-ZNE* performance in its initial two years of operation, with a planned program of performance improvement measures to reach the final objective of full ZNE performance.

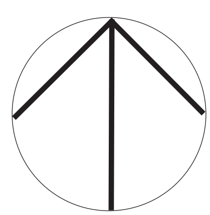
This case study is significant because it points the way to a performance goal that has been considered impractical, if not virtually impossible to achieve. It required the project team to take a Labs21 design for this site and program, with an estimated EUI = 270 kBtu/sq.ft., and to develop practical design strategies to obtain a performance at EUI = 70 kBtu/sq.ft., about 25% of the annual energy use of the Labs21 building. Such a reduction in EUI is required so that the solar photovoltaic system for ZNE performance can be physically accommodated on the building site.




Some of these successful design strategies were cutting edge but proven concepts at the time that they were developed by the project team, but have been rapidly gaining wide use because they have been demonstrated to be cost-competitive with conventional design approaches in addition to using much less energy.

[1] See "Laboratories for the 21st Century: Best Practice Guide", U.S. Environmental Protection Agency and U.S. Department of Energy

The J. Craig Venter Institute: General Vicinity Plan



## Background

The J. Craig Venter Institute (JCVI) is a non-profit institute engaged in research in genomics and related fields of molecular biology. The research mission of the Institute includes continued work on the analyzing the human genome, sequencing the human microbiome, microbial and viral genomics, understanding the genetic basis of life in the world's oceans and advancing the new field of synthetic genomics. Current research topics include ocean health, disease diagnosis, vaccine development, sustainable waste treatment and climate change.

The Institute was originally based in Rockville, MD, and in 2005 the director, Dr. Venter, was invited by U.C. San Diego (his alma mater) to build a West Coast research laboratory in La Jolla, CA, on land owned by the university and to be leased to the Institute. After several years, the commitment was made and early goal-setting and visioning sessions were begun. The idea was to build a facility that would embody the attitude and approach to the research at JCVI—innovative, pioneering and committed to contribute to the solutions of contemporary environmental and sustainability issues.

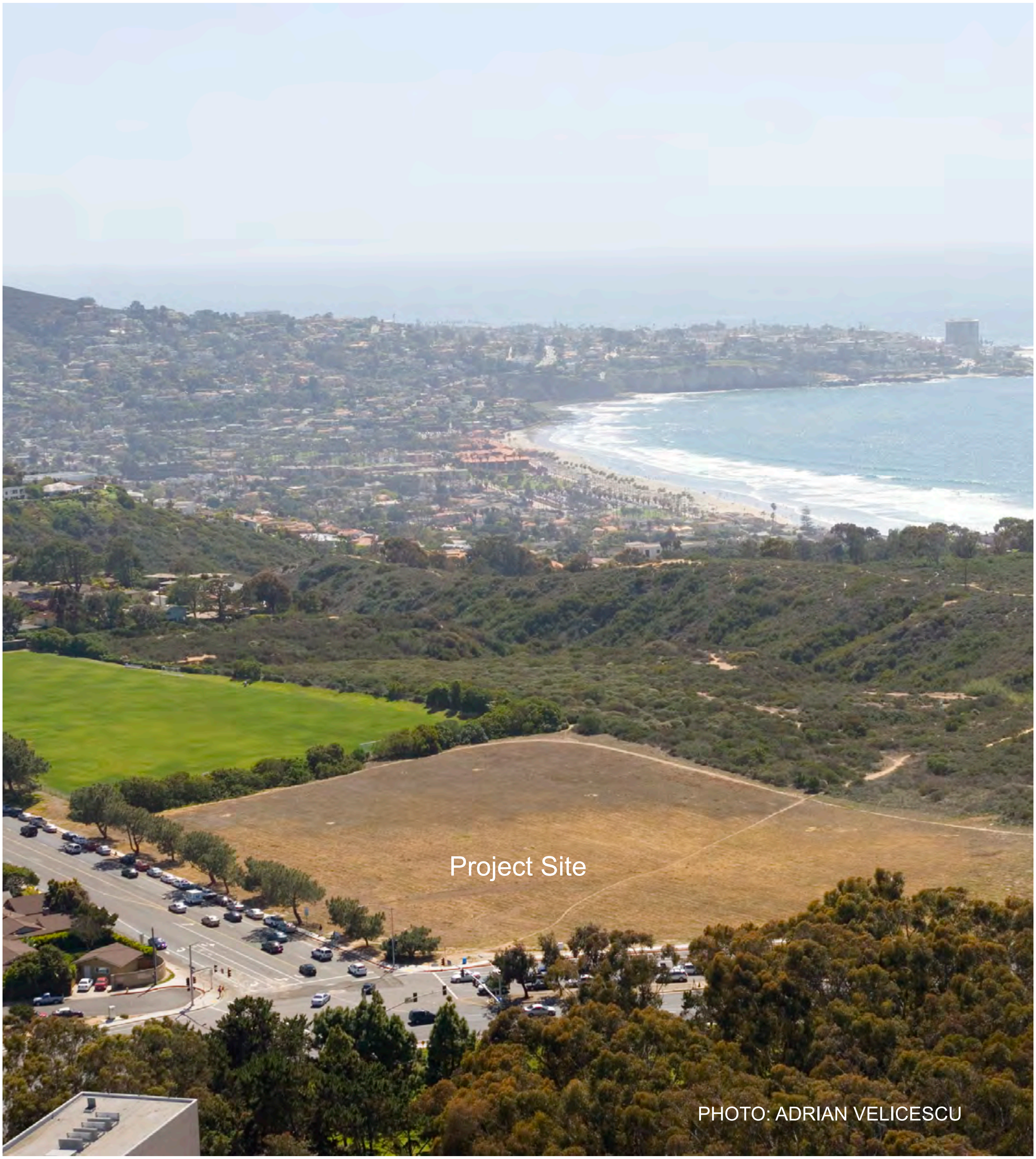
In this spirit, the design goal would be inspired by the Salk Institute, the iconic laboratory complex first occupied in 1963 nearby in La Jolla, CA. Namely, just as the Salk Institute is considered by many as the model laboratory building of the 20th century, so the JCVI laboratory, according to its director and the project team, was to be "The Laboratory of the 21st Century" in all aspects of its design. New ideas for laboratory planning, design features and systems would be tried and proven so that the building could specifically serve as a model for future laboratories to follow.

To accomplish this, Dr. Venter began by hand-picking the design professionals seen as among the most visionary in the country, particularly in the areas of sustainability and research laboratory design, who would embrace such a directive. After selecting ZGF Architects (Los Angeles) based on their innovative work in laboratory design and sustainability, Dr. Venter selected Peter Rumsey (then of Rumsey Engineers, Oakland) for the energy systems design and Andropogon (Philadelphia) for ecological landscape, for their strong emphasis on sustainable design.

It was in the early visioning sessions that this project team first discussed the "reach" goal of a ZNE laboratory design, something that had not been done before. The JCVI client had a deliberately exploratory research culture—a research scientist's adage was quoted during the ZNE discussions: "don't talk yourself out of doing the experiment!"—and the assembled design team embraced the challenge of a ZNE design goal.

Intensive work sessions explored design options for planning concepts, system concepts and performance criteria. What emerged from the work sessions and ultimately from the follow-up conceptual design studies was a conviction that a ZNE laboratory could theoretically be done—it remained to carry out "the experiment".

First came two years of fundraising for the project, final agreement with U.C. San Diego and approval by the California Coastal Commission. By the time the design team was reconvened to begin the full design and construction phase, some experience with the systems and technologies had been obtained with positive results. The team therefore was able to proceed with the original design with added confidence.


Project Site
PHOTO: ADRIAN VELICESCU

## Design Process and Low Energy Design Strategies

The organization of the principal elements of the building program of office and laboratory space on the limited site was the principal consideration in the building's planning. The intersection of classic lab planning with the site constraints and the energy systems design resulted in the basic building form. Additional program elements for on-site parking requirements and mechanical space were accommodated within this basic form.

*Planning Concept and General Design Considerations*

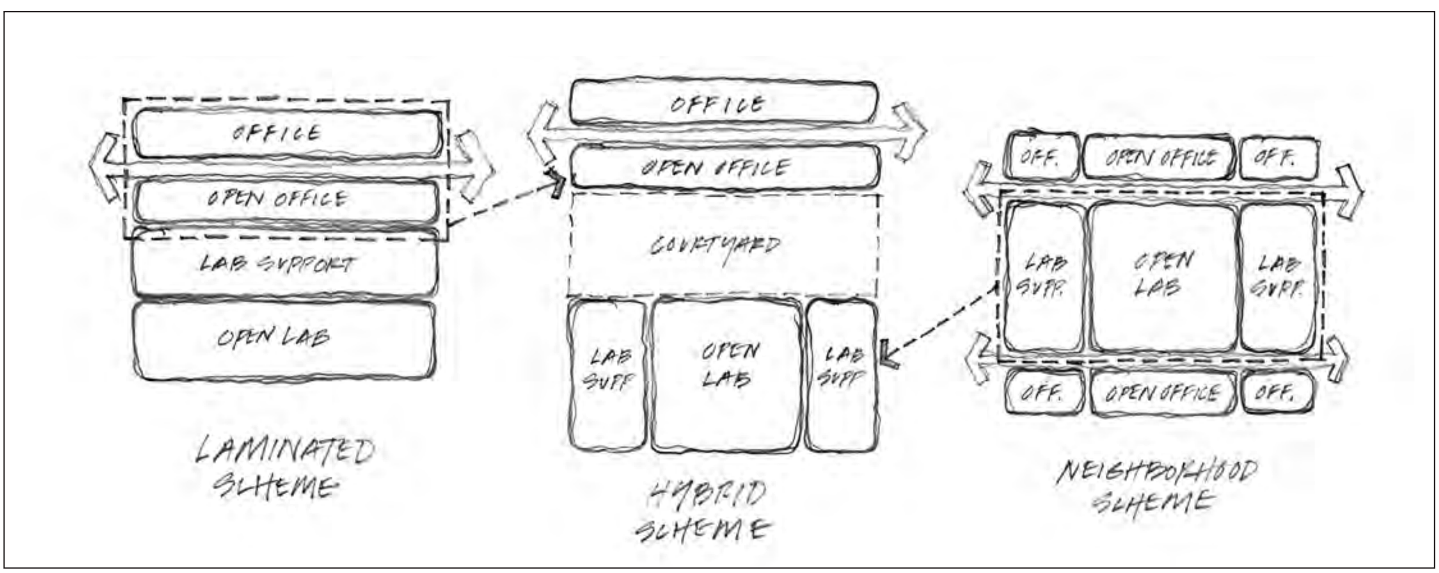
Inevitably, to achieve ZNE the building would be required to have a very large solar array maximized for the number of panels. A concept was developed where the array would be a separate structure floating above the roof of the building and with the best possible tilt and azimuth for high production. This would allow flexibility in organizing the building's mechanical equipment space under the array, and with the general lab planning as well. The implication of this scheme was that the building would be organized along an east-west axis on the predominantly north-south site geometry, with the large array tilted toward the south.

The lab planning was therefore free to take on the preferred organization of the three basic components of lab space: lab bench space, lab support and lab office space (open and closed offices). Again, the design team considered the implications for energy use to choose the basic lab planning scheme.

The traditional lab planning diagram, known as the "laminated scheme", places each of the three space components in layers. (See the diagram below for the most common layer order.) Then the lab building is created by extruding this diagram to any length at 10'6" increments for each lab planning block. Different size research groups are easily accommodated. The drawback to this diagram is that it generates a wide building with little opportunity for daylighting or natural ventilation in the office space.

The "neighborhood scheme" places the lab support inboard with the lab bench space and the open office outboard with the private lab offices. Less flexible for varying size of research groups,

*(Below left and right)* Typical laboratory planning diagrams. *(Below center)* Hybrid diagram selected for JCVI.
(Courtesy of ZGF Architects and Jacobs Laboratory Planning)



this diagram is good for daylighting all office space and provides the opportunity for natural ventilation from one side. It also provides ready accessibility to the lab space from the office space.

The design team realized that energy use could be significantly reduced by treating the office space to optimize daylighting and natural ventilation, implying a thin building, and separating the lab spaces so that their mechanical ventilation requirements could be more efficiently applied. The resulting diagram could be structured like the “hybrid scheme” in the figure on the opposite page—separating the office space from the laboratory space by a courtyard. Because of the benign climate of La Jolla, there is virtually a very easy connection between office and lab “wings”. In fact, aside from the clear advantages for low energy demand, the courtyard space would also have the benefit of increasing the opportunity for casual interaction among research groups and provide a collective work space (on nice days) for the entire JCVI community.

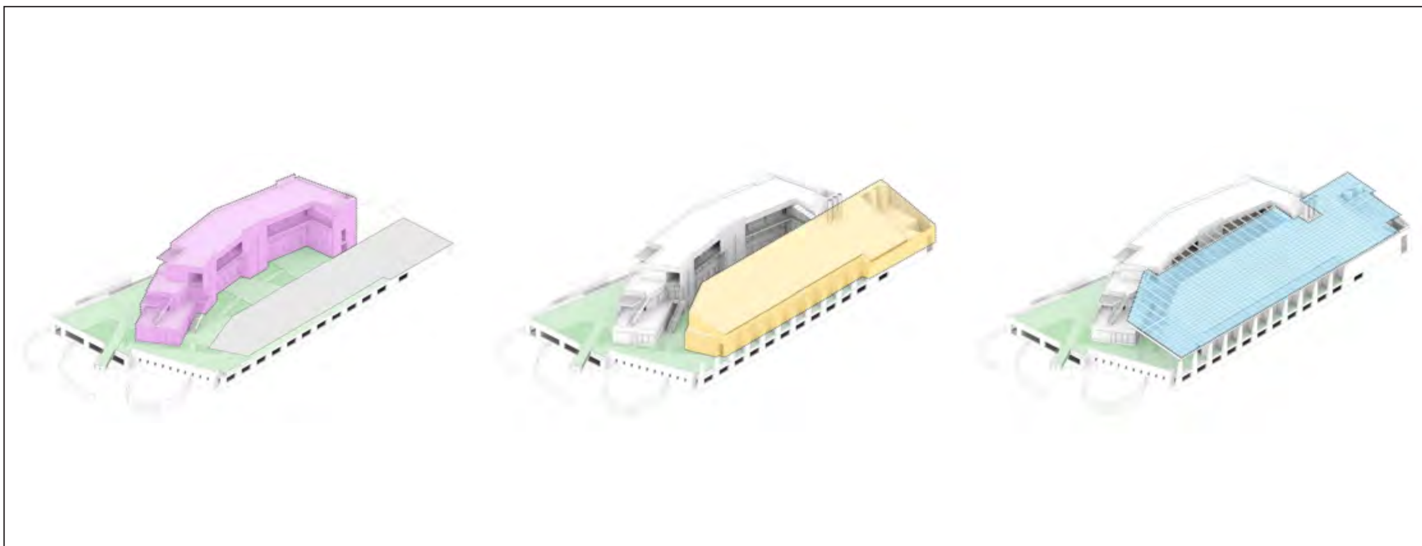
With the adoption of this lab planning approach, the basic parti became a three-story office wing (there was general office administration space in addition to lab office space) separated from a one-story laboratory wing (with a one story mechanical equipment space above) by an exterior courtyard—all topped with a sloped structure spanning from the lower laboratory wing to the higher office wing, which supported the required number of solar photovoltaic panels necessary to achieve the ZNE performance targeted.

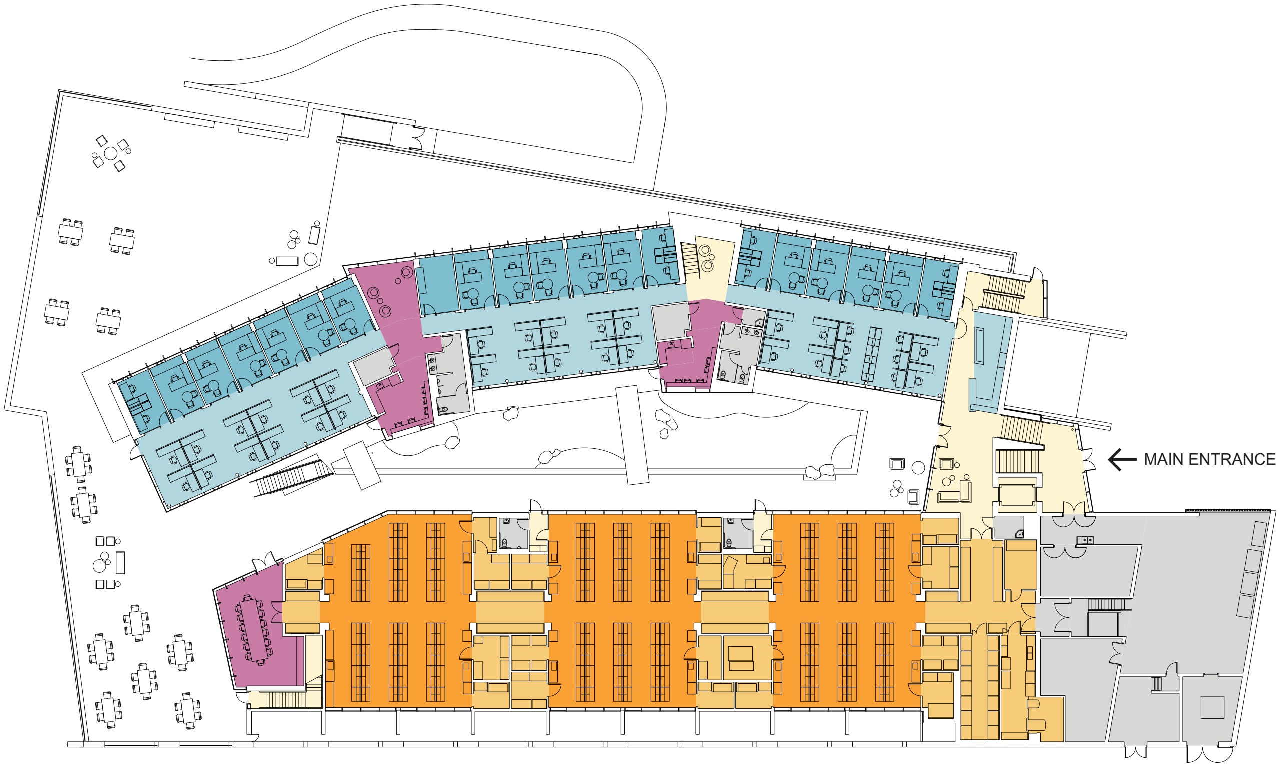
This parti would have greater overall exterior wall area but the office wing could have a much lower floor-to-floor height since it was separate from the laboratory, which requires a relatively high floor-to-floor height. The difference in cost was found to roughly balance out when all the tradeoffs of the hybrid scheme were accounted for.

The on-site parking requirement necessitated the insertion of a parking level below the building. But rather than having it fully below grade as a basement level, which would need to be mechanically ventilated, the parking level is raised up partially above grade. This provides the possibility of natural ventilation and avoids the fan energy load.

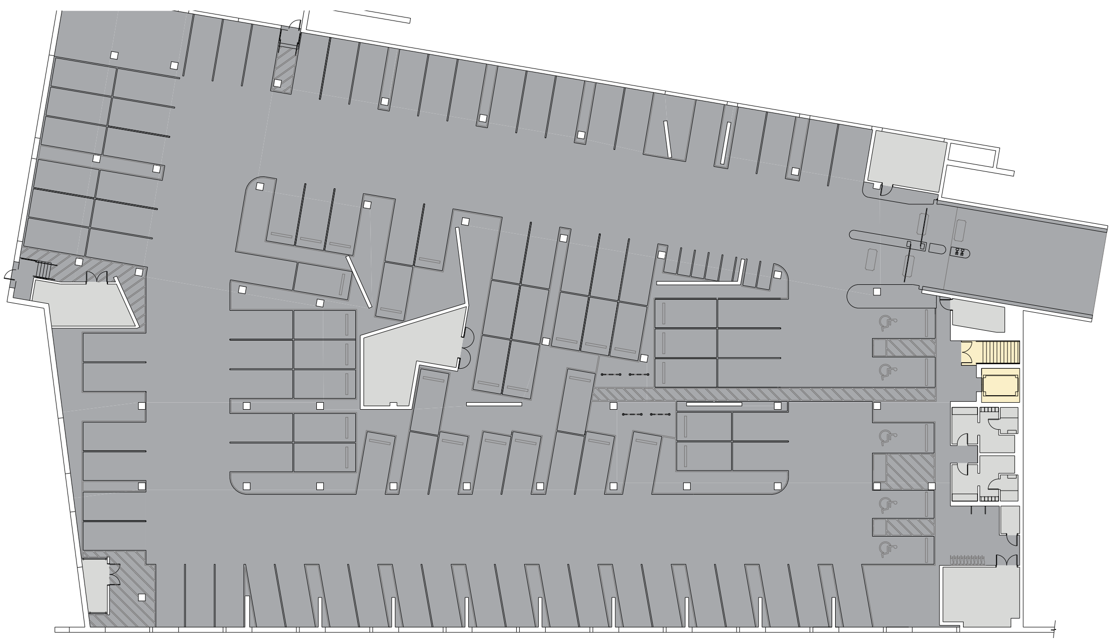
The resulting floor plans appear on the next page.

*(Below)* Basic building massing based on the hybrid lab planning diagram:
Office wing (left); Laboratory wing (center); sloped structure supporting solar photovoltaic panels (right)
(Courtesy of ZGF Architects)



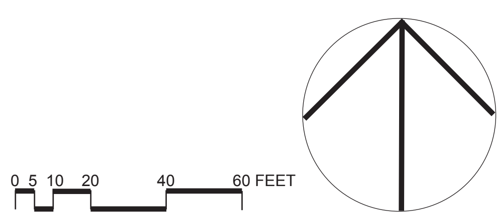


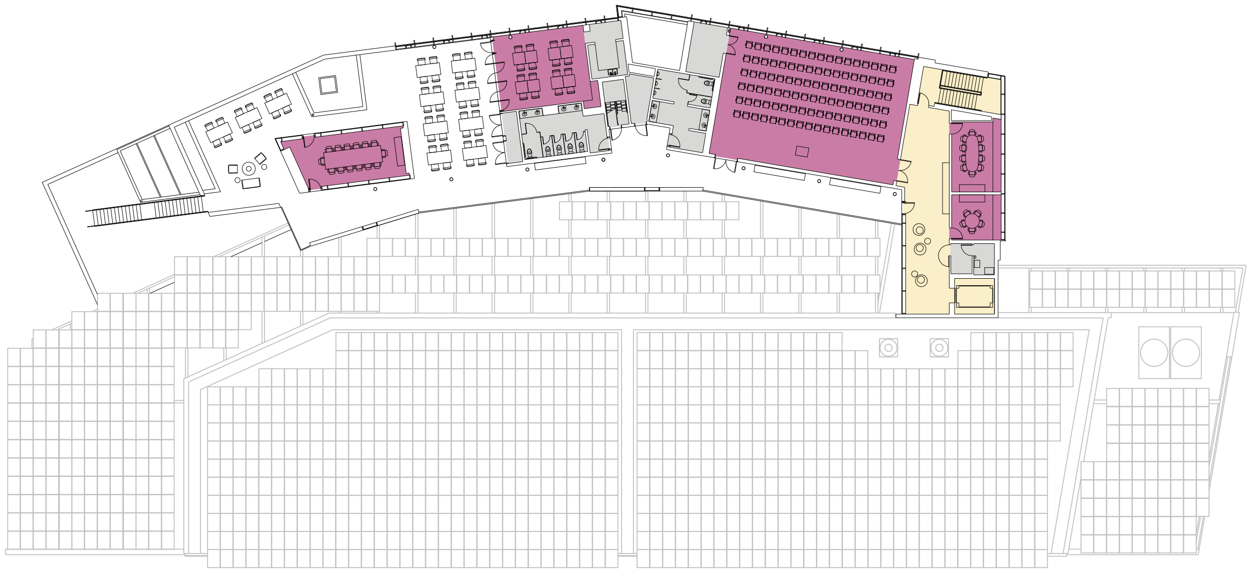

LEVEL ONE PLAN



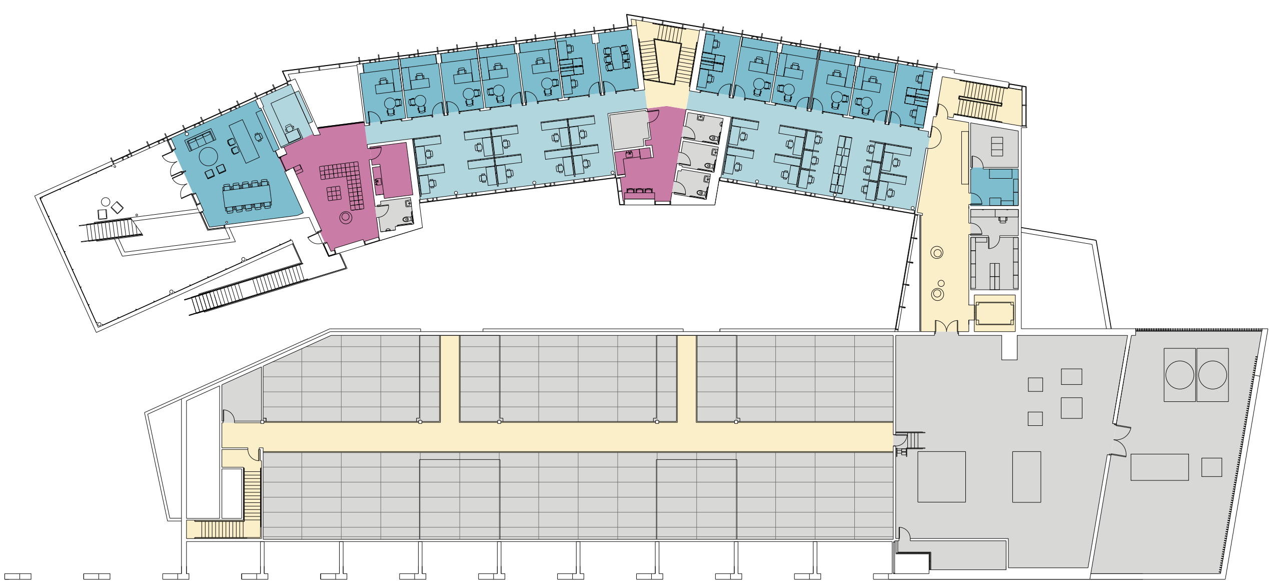
PARKING LEVEL PLAN

The J. Craig Venter Institute: Floor Plans





**LEVEL THREE PLAN**



**LEVEL TWO PLAN**

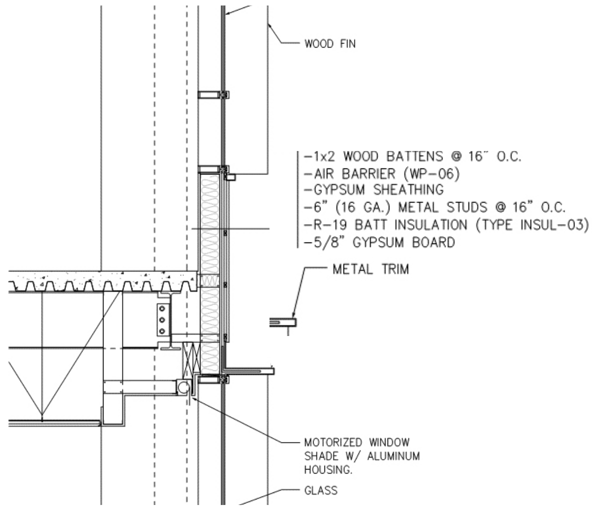
PHOTO: NICK MERRICK, HALL MERRICK PHOTOGRAPHERS

*(Previous page)* View of main entrance. (Courtesy of ZGF Architects)

*(Opposite page)* View of courtyard with Office wing on the right and Laboratory wing on the left, with solar photovoltaic support structure above. (Courtesy of ZGF Architects)

*Building Envelope*

The exterior walls and roofs conform to California energy standards in effect in 2010, which required R-19 walls and R-30 roof construction. Standard tapered roof insulation under a single-ply membrane and fiberglass batts in the walls were used. The walls were framed with 6" metal studs, but no continuous layer of rigid insulation was used to prevent thermal bridging because it was determined not to be cost effective given the mild climate year-round.




*Daylighting and Electric Lighting*

By locating all the office space in a separate wing of the building, its design could be optimized for daylighting. The narrow width of the floor plate and the maximum height of the windows allowed for deep penetration of daylight in the entire space.

The placement of the solar photovoltaic panels on the supporting structure over the courtyard was carefully designed to permit ample daylight to enter the south-facing windows, which were recessed to prevent direct glare from the sun. This was analyzed for several spacing options using daylighting software. (See image below.) This eliminated several rows of panels but was deemed necessary for the energy savings that would result from good daylighting plus the obvious preference to have the courtyard be daylight-filled and not cavernous. The structure was extended further to the west to make up the difference.

The electric lighting system was designed with T5HO lamps throughout. LED products were not cost effective at the time of design, only a few years ago. At the appropriate time in the future, the electric lighting will be replaced by the much more efficient LED technology.

The laboratory wing is also open to daylight on both sides. With higher than normal ceilings made possible by the elimination of the typically large air ventilation ducts (see the HVAC discussion below), daylight zones in the lab bench space are possible.

*(Below)* Daylighting analysis of office wing and laboratory wing for study of opening geometry of solar photovoltaic panel array over the central courtyard. (Courtesy of Integral Group)

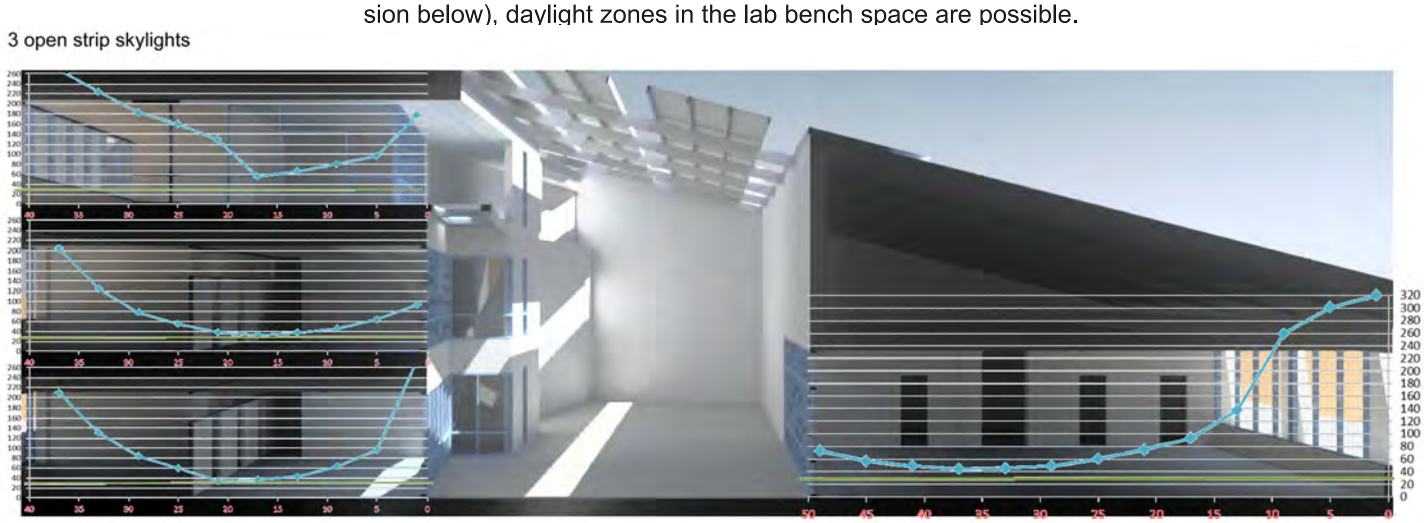


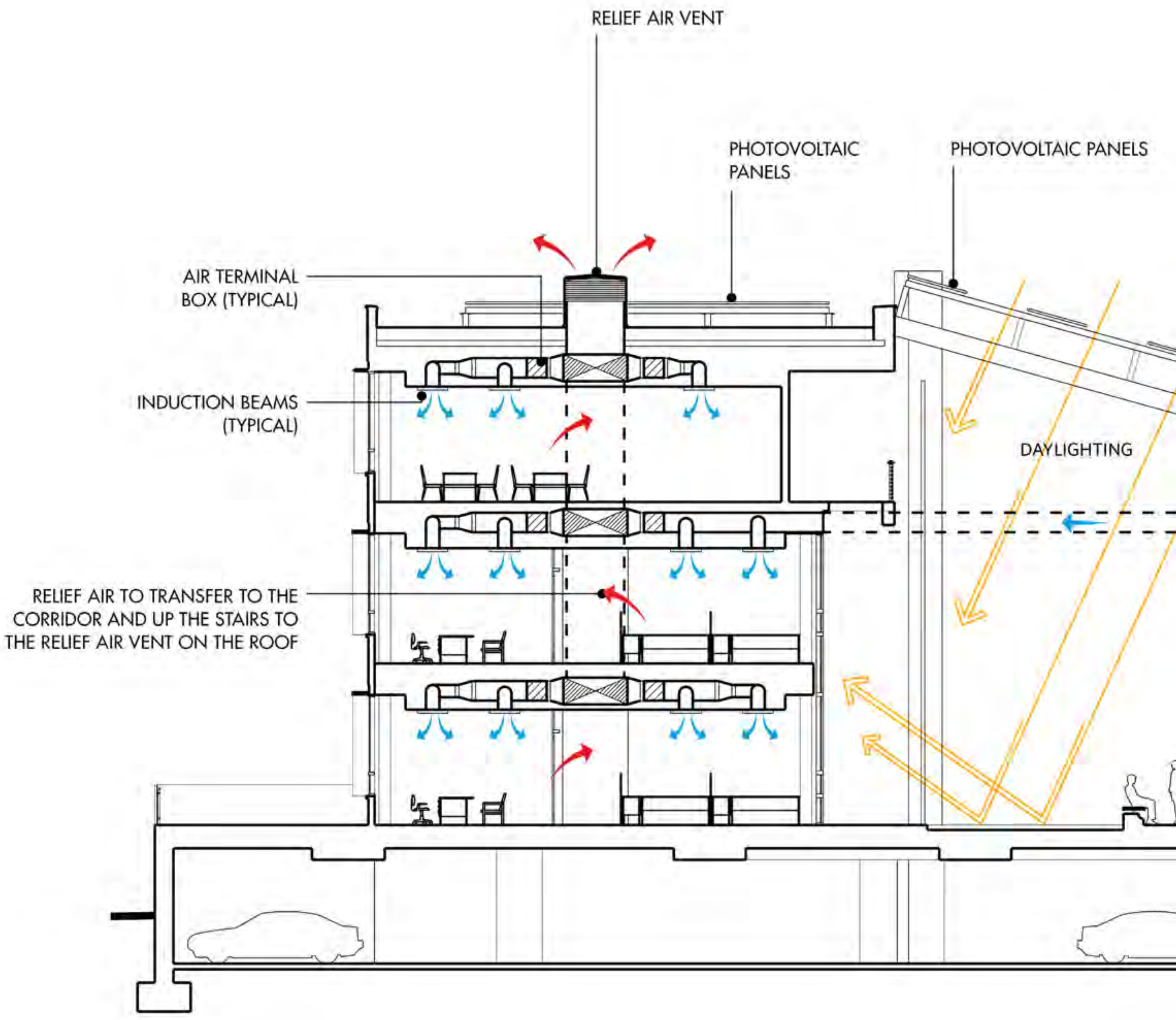
PHOTO: NICK MERRICK, HALL MERRICK PHOTOGRAPHERS

*Natural Ventilation*

Natural ventilation of the office wing is available only by user-operated openable windows, both in the private offices and in the open office space. When the outside air temperature permits, the DOAS air-handling units ("direct outside air supply") shut off and green lights in the office areas switch on, indicating that occupants can open the windows for fresh air supply. When the outside air temperature is less than or greater than comfortable temperatures, the DOAS units turn on and red indicator lights in the office areas switch on to signal to occupants that windows should be closed.

This method of controlling natural ventilation was chosen to give occupants some control of their environment. The system was not optimized by giving control of window operation to the BMS, which would also allow the operation of a night purging mode to pre-cool the building in advance of warm days. Some energy efficiency was sacrificed in favor of total occupant-control.

*(Below)* Building section with basic energy system diagram. (Courtesy of Integral Group)

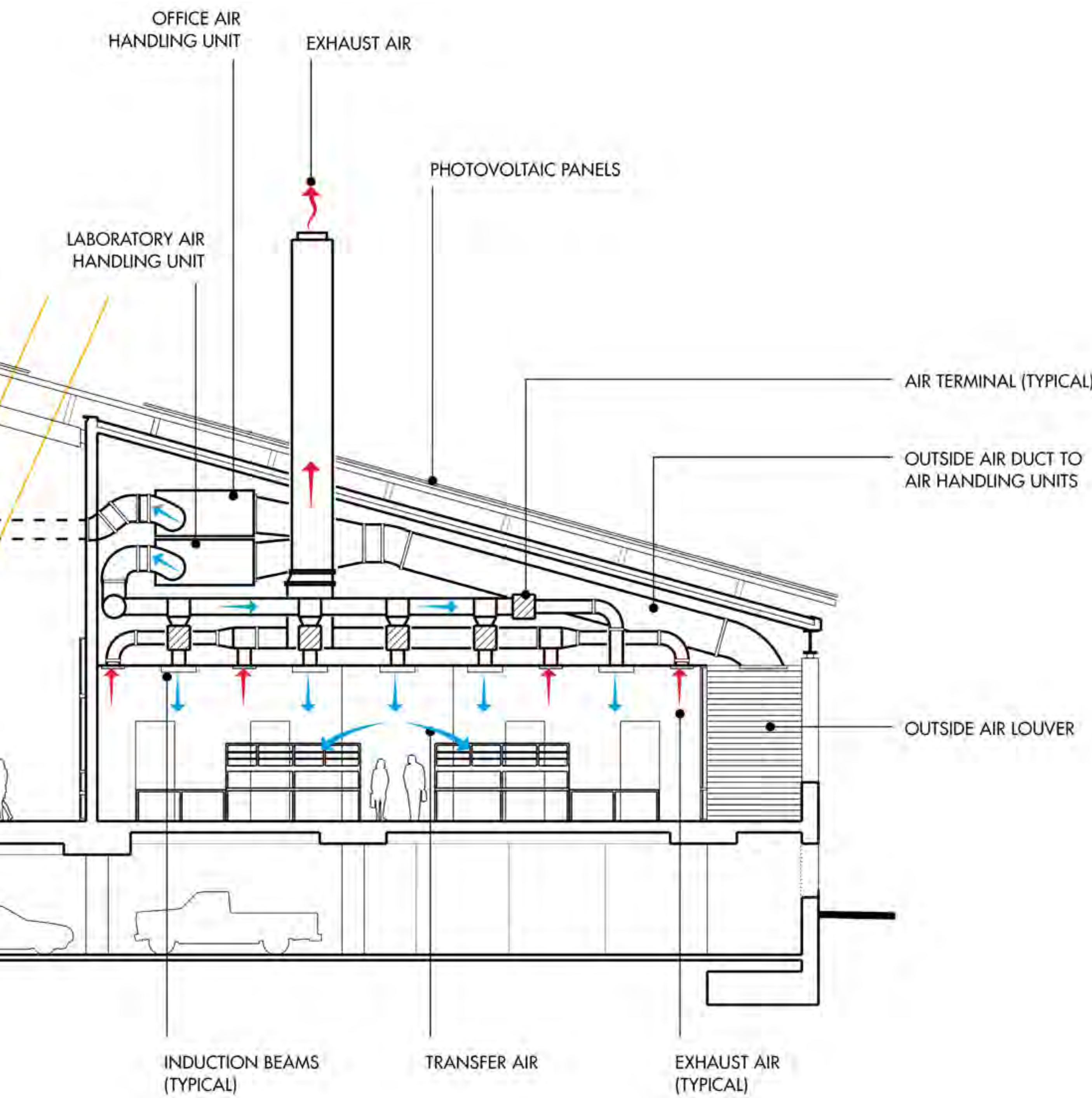


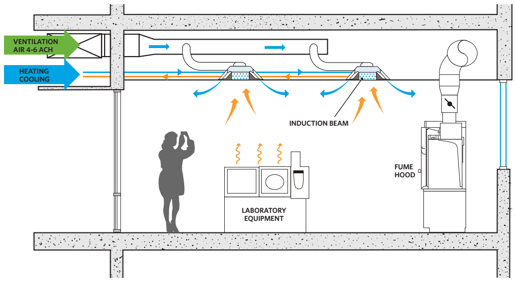
*Heating, Ventilating and Cooling Systems*

The key strategy to the reduction of energy use in laboratories is to set the number of air changes per hour (ACH) designed into the operation of the mechanical systems at the level that provides the best health outcomes and no more than is needed. The designers of JCVI call this approach “right sizing”.

By separating the offices from the laboratory spaces, the design team already reduced the amount of air changes that would be required for the office space from what it would have been if they were joined together in the same building. The second part of the strategy was to address the total number of ACH for the laboratory itself.

When the JCVI design process was begun, typical design standards for laboratories called for a constant minimum of 10-12 ACH. This also allowed for a certain flexibility when reconfiguring






*(Right)* Basic operation and view of *induction diffuser*: chilled water (blue arrow) piping and fresh air (green arrow) in small duct. (Courtesy of ZGF Architects and Integral Group)

spaces. Now, due to considerations of energy efficiency, reliable control systems have been developed that permit lower air change rates under normal conditions, usually 4 ACH when a lab is unoccupied and 6 ACH when occupied, increasing to 12 ACH when a spill or similar toxicity is detected. Since fan energy accounts for such large fraction of energy use and therefore operating cost in a laboratory, this advance in systems technology is increasingly becoming standard practice.

At JCVI, the design team specified an advanced type of system[2] for this demand control ventilation (DCV), which allowed these air change rates to be set at 2 ACH (unoccupied) and 4 ACH (occupied), reducing the fan energy consumption by half again. Safety is provided by the system with a "purge" mode (12 ACH) if sensors detect a spill or if triggered by a manual override switch located in a prominent location in the lab space. This actually provides a higher level of safety than typical laboratories that don't use sensing systems.

As a final feature of this air exchange rate reduction strategy, a control algorithm for the laboratory exhaust fans would reduce mechanical air exhaust from the maximum setting based on detected wind speed and wind direction at the moment, relying on the natural draft created by the prevailing breeze to make up the difference. This saves energy by not requiring bypass air at the exhaust fan when the supply air is at a minimum. This works particularly well at the JCVI site in La Jolla where a steady on-shore ocean breeze is prevalent.

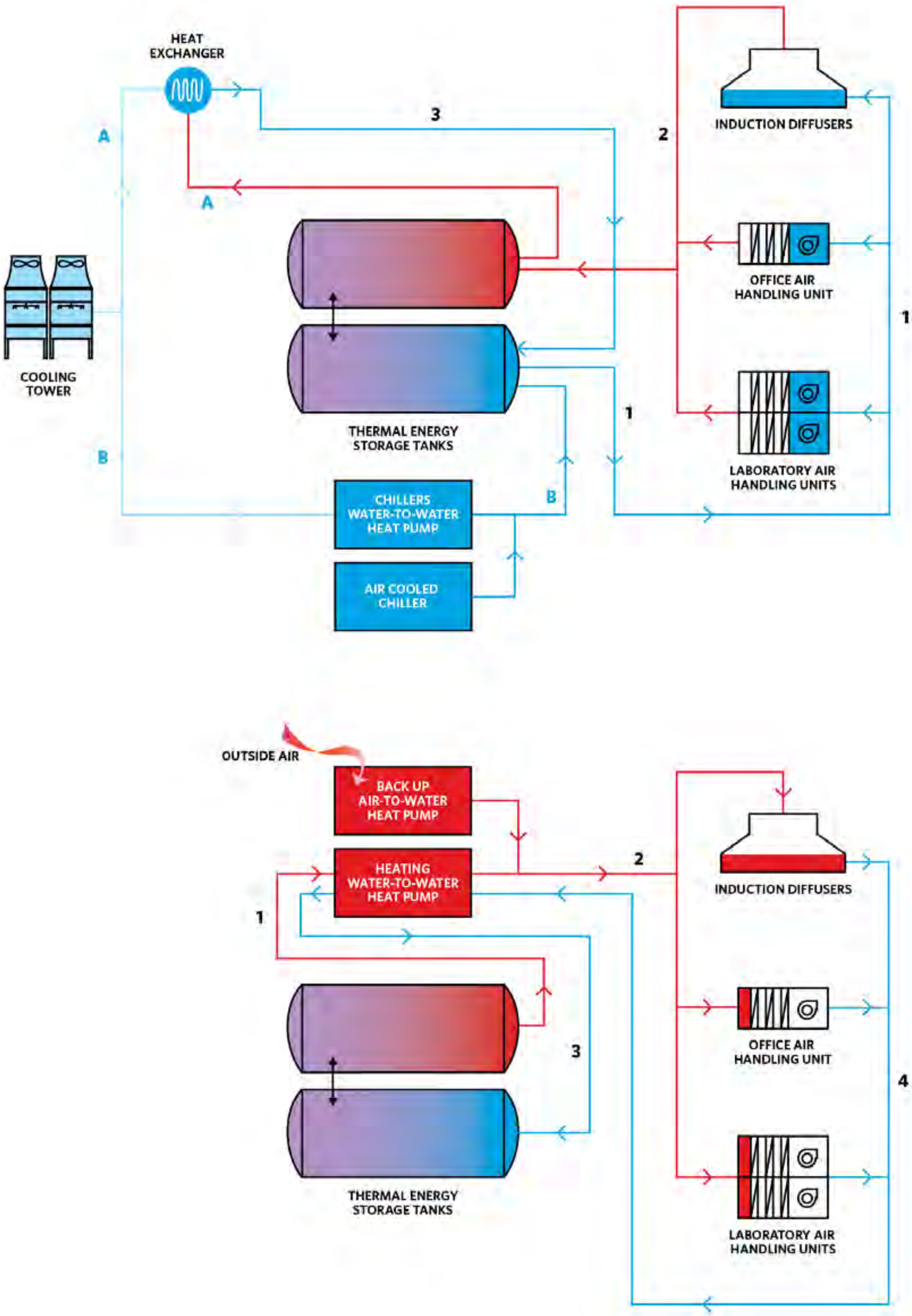
The heating and cooling system design was another opportunity to significantly reduce energy use. The engineers chose to use water to transport heat and "coolth" to both the office and lab spaces rather than air. Water is a more efficient heat transfer medium than air and it would not be necessary to duct the air from a central location. Hot or chilled water is delivered to induction diffusers (often called "chilled beams" when used for cooling alone) where fresh air from nearby local DOAS units enters the space after passing over the heat transfer coils, providing either warm or cool air to the space.

The overall reduction in duct requirements is one of the important side benefits of this design approach for the total mechanical system, saving additional cost by also reducing the vertical height required overall, particularly for the laboratory space. Another side benefit of the induction system as opposed to the forced air approach is the acoustical quality of the spaces. They are noticeably quieter than typical research laboratory spaces.

The final innovative design feature of the HVAC system is the thermal energy storage tanks, which are used as heat recovery and are combined with a water-to-water heat pump to produce the required hot or chilled water called for by the spaces. There may be simultaneous heating and cooling required in the building's many zones. Ancillary equipment in the form of a cooling tower, heat exchanger and air-cooled chiller (for cooling) and a back-up air-to-water heat pump (for heating) provide adjustments to the system operationally. (See the diagram on the opposite page.)

The design of the system around the thermal storage tanks works well in the La Jolla climate because of the relative balance of the heating and cooling loads on a daily basis.

[2] *Aircuity*®, http://www.aircuity.com/technology/optinet-applications/lab-demand-control-ventilation/




*(Below)* Diagram of HVAC system operation in JCVI offices and laboratory space. (Courtesy of ZGF Architects and Integral Group)

## COOLING

**Ideal Cooling A** Hot water from the thermal energy storage tanks and the cooling tower send water to a heat exchanger.

**Alternate Cooling B** The chillers cool the thermal energy storage tanks and reject heat into the atmosphere via the cooling tower.

**1** The cold water gets piped to air handling units and induction diffusers.

**2** Warm water by-product returns to the warm end of the thermal energy storage tanks.

**3** Excess cold water from heat exchanger goes to the cold end of the thermal energy storage tanks.

## HEATING

**1** Warm water from the thermal energy storage tank goes to the heat pump to provide heating.

**2** Heated hot water goes to the air handling units and the induction diffusers.

**3** Cold water by-product from the heat pump goes back to the cold side of the thermal energy storage tank.

**4** Cold water by-product from the induction diffusers and the air handling units go back to the heat pump to be reheated.

Hot Water
Warm Water
Cool Water
Cold Water


PHOTO: NICK MERRICK, HALL MERRICK PHOTOGRAPHERS

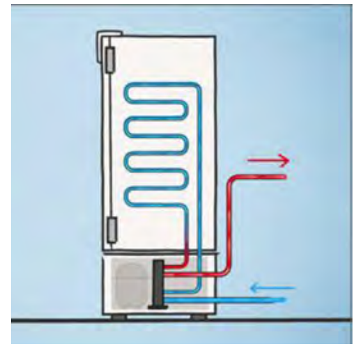
*Plug Loads and Equipment*

Since plug loads generally account for the largest amount of energy consumed in ZNE buildings, the design team wanted to understand what the energy consumption profiles were for typical laboratory equipment. These profiles typically do not correlate with the equipment rating, so the they had to measure the individual items in existing lab conditions and create an inventory with the measured energy profiles. This was important in order to model the building sufficiently well to estimate the size of the solar array.

Still, the equipment load could only be an estimate in a research laboratory, where the research projects are not well known in advance and where purchase is often based on cost.

A special effort was made with the laboratory [-80°C]-freezers[2], which typically are located in the lab support space of each researcher and are electric-powered. As a result, heat put out by the freezers contributes to the cooling load of the space. The design team proposed an idea that would significantly reduce the energy demand of this method of providing freezer space in the lab: use water-cooled freezers, which are much more efficient, and put them all in one room. As such, researchers could share space in the freezers, thereby reducing the number of freezers that would be used. Sharing freezers that were centrally located required a change in the research culture, but the scientists accepted the idea, and the equipment energy use was sizably reduced.

A system of color-coded electric outlets in the laboratories identified those that would shut off at night, so non-critical equipment could be plugged into them. (See photo below.)



*(Above)* Water-cooled [-80°C]-freezers are more energy efficient and are shared by researchers in a centrally located Freezer Room. (Courtesy of ZGF Architects)

[2] The laboratory uses both [-80°C]-freezers and [-20°C]-freezers, but since the [-80°C]-freezers use the most energy, they were specified as water-cooled and centralized in the lab.

*Master System Integration and Control Systems*

Understanding how vital were the control systems to the performance of all the energy-consuming systems of the building, the client selected an independent master system integrator to coordinate the control system communication protocols and ensure that the correct sequence of operations for all systems would be correct.

The *building interface system* that was created, the so-called "front end", allowed ready checking on the status of each system in the building. (See the system component diagram below.) Note the Building Monitoring system, which has all the energy metering systems. There is also Building Dashboard, which displays building performance on an "information kiosk" in the lobby.

*Commissioning*

Commissioning was carried out according to a basic commissioning plan that satisfied the LEED requirements.

*(Below)* Diagram of Building Interface System. (Courtesy of ZGF Architects and Integral Group)

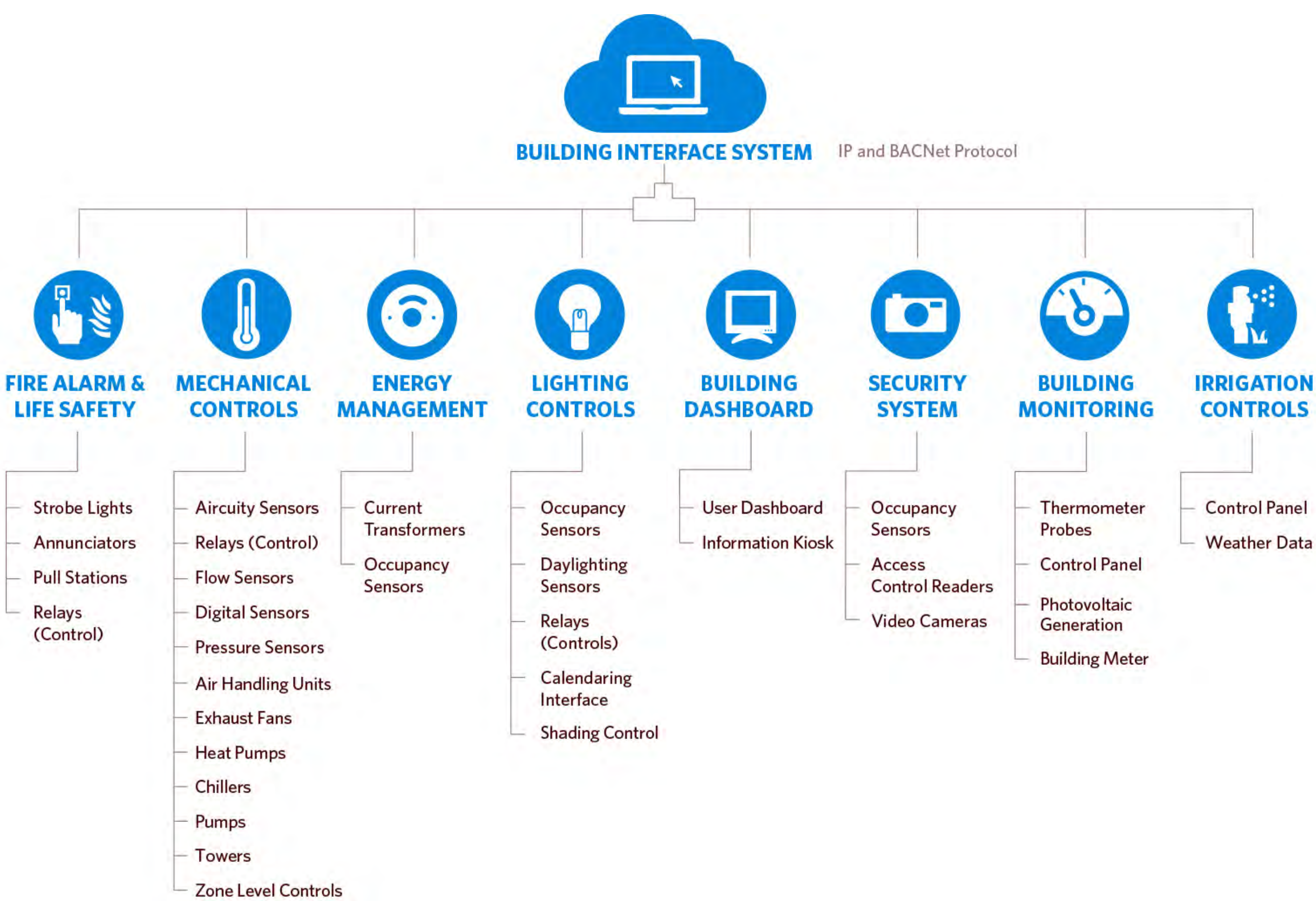


PHOTO: NICK MERRICK, HALL MERRICK PHOTOGRAPHERS

PHOTO: NICK MERRICK, HALL MERRICK PHOTOGRAPHERS

PHOTO: EDWARD DEAN

## Renewable On-Site Energy Supply

The solar photovoltaic array spanning the building's roof and the courtyard space is 500 kW using 1,488 Sunpower E20/327 panels. In 2015, the array produced 800,000 kWh of energy, which is 15% more than the modeled energy consumption for the building. So, the PV system was right-sized for ZNE performance according to the modeled energy consumption, under the assumptions and estimates made for plug load and occupant behavior.

The number of panels is close to the maximum possible on the restricted site. To render the courtyard as pleasant as possible, the number above that outdoor space is reduced to 50% of what would be possible. The daylight studies of the office space determined the spacing of PV panel rows adjacent to the office wing.

The fire marshal effectively determined the number of PV panels above the courtyard space by requiring 50% of the structure be open to prevent the courtyard from being treated as an atrium. The requirement also eliminated the idea of installing clear plastic panels in the openings between PV panels to provide daylighting and rain protection.

## Energy Design Analysis and Energy Performance
***Modeling versus Post-Occupancy Measurement***

*Energy Modeling*

Energy modeling was carried out continuously during the design phases using eQuest version 3.64. Many of the input parameters, particularly the laboratory equipment load profiles, had to be estimated or researched since no information was available. The heating and cooling system was unusual in its design, and the interaction with the user-operated natural ventilation, prevalent in this climate, had to be approximated. The result was a reasonable model for the building, which determined an annual modeled energy use of the building to be 700,000 kWh.

The good news for the project team was that this result proved the feasibility of the ZNE goal. Charts showing the modeled annual and monthly energy use by category of load (heating, cooling, lighting and equipment) are shown on the following pages.

*Energy Use—Actual Measurement and Comparison to Modeling Results*

Both the building and solar PV array are separately metered to collect detailed data on the actual energy use and energy production, both as a facilities management tool and to verify ZNE performance. The public utility, San Diego Gas & Electric® (SDG&E®), in this case provides a net meter for the building, which measures the net electric energy flow; namely, the energy used minus the energy produced by the solar photovoltaic (PV) system. The PV array typically has a separate meter that measures just the energy production by the PV system. Therefore, the building owner can check the accuracy of building's installed metering system by adding the measured production data to the SDG&E net meter data—the result should equal the building's total metered data for energy use for that period of measurement.

JCVI performed such a check on its metered data system and discovered that it was in error by approximately 20%—the meters were apparently missing some energy-use items. A study of the system identified some building equipment that was not on a metering circuit, accounting for some of the unrecorded energy use, but there remains a significant unexplained load. As of the publication date of this case study, this "unaccounted load" remains unidentified.

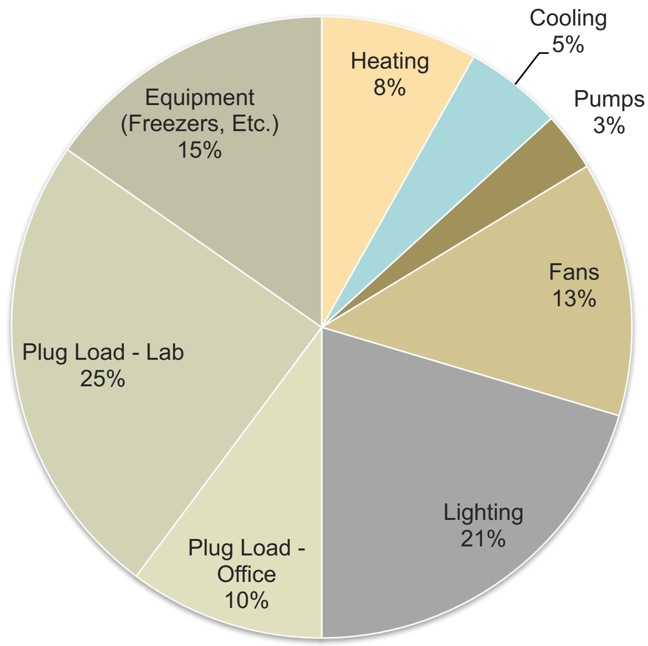
Charts showing the measured annual and monthly energy use for the year 2015 are also shown on the following pages. The total energy use is reported based on the SDG&E net meter data (adding the measured PV production to get total energy used). The difference between this amount and that measured by the building's incomplete metering system is shown as a separate category, "Unaccounted Loads".

The measured results can be compared with the modeled results to see how the different categories of energy use differ from that in the model. For example, the energy consumed for heating, cooling and pumps is significantly higher than the model indicates.

See the following sub-section, *Post-Occupancy: Observations and Conclusions*, for further discussion of these issues.

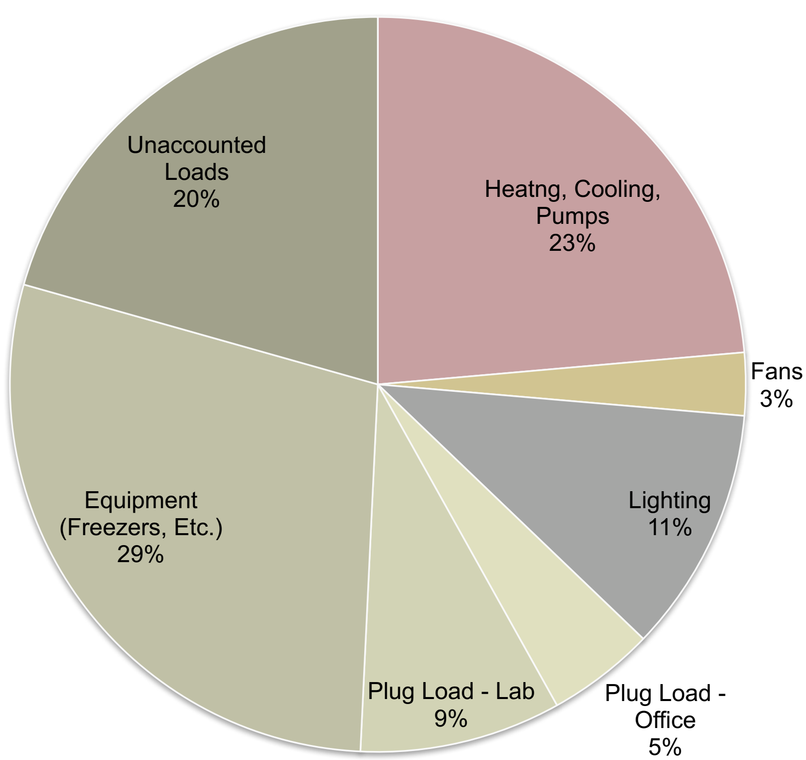
**Modeled Energy Use**
**(Annual)**

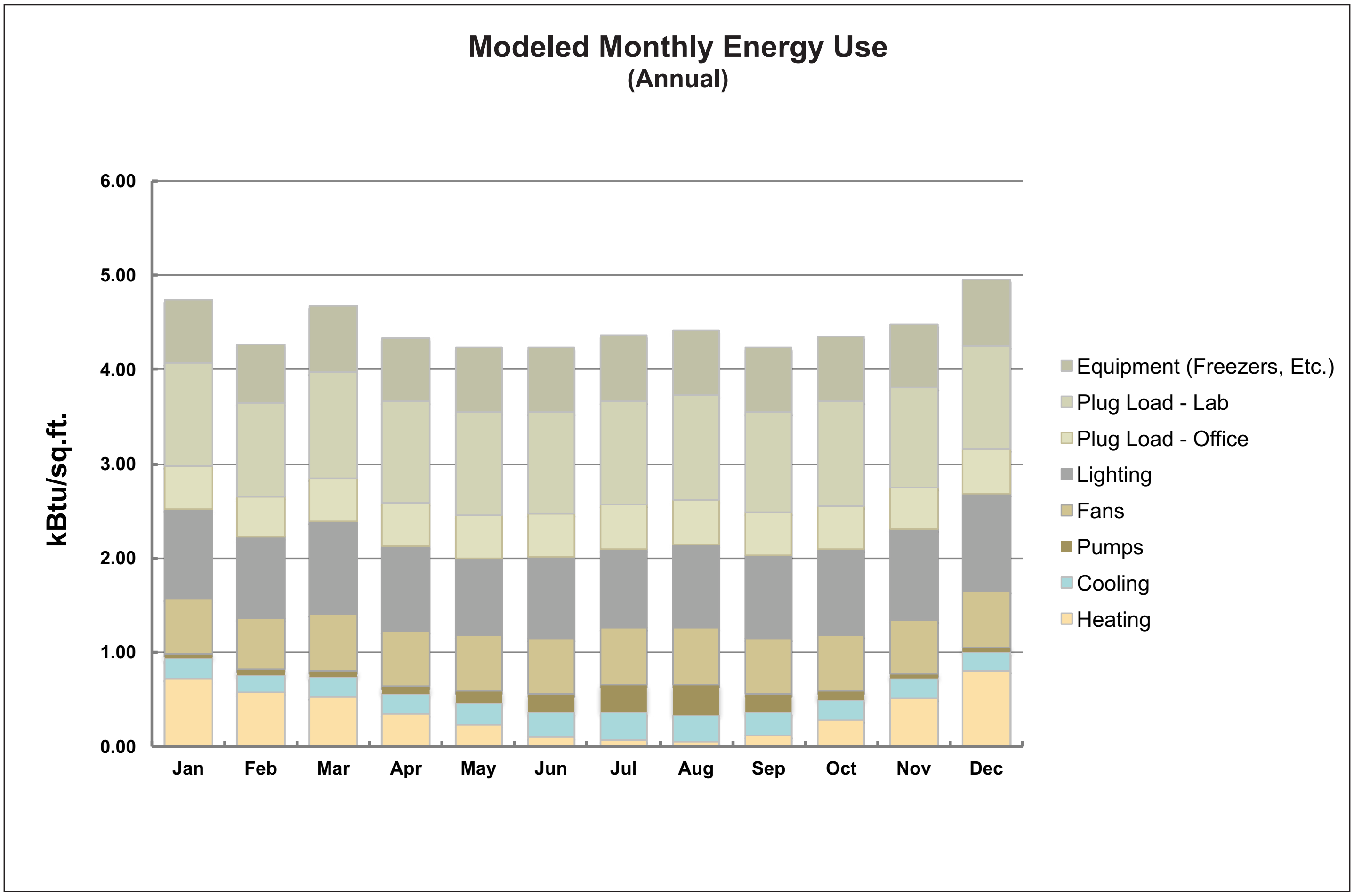
696,000 kWh/year
Modeled EUI = 53.3

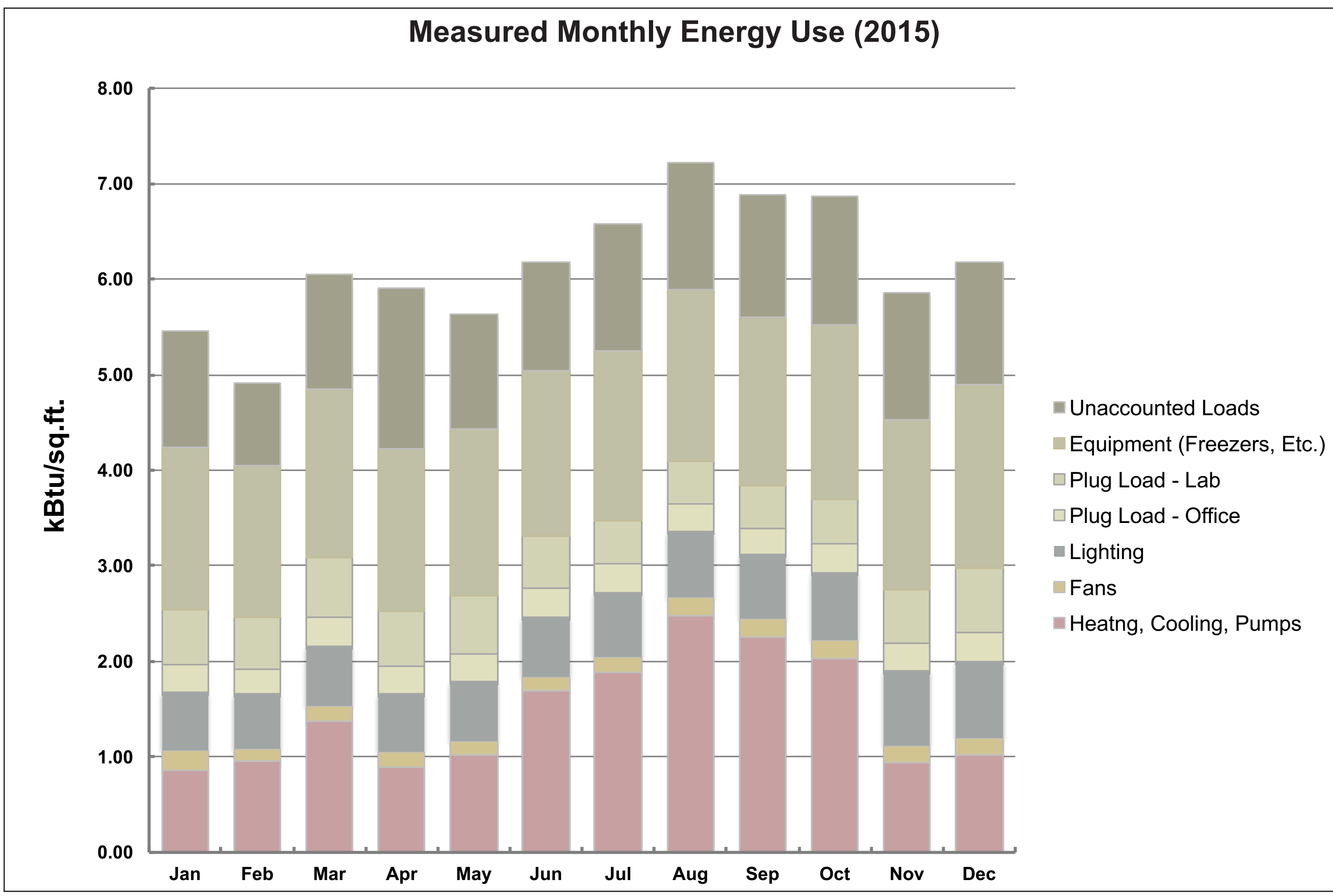


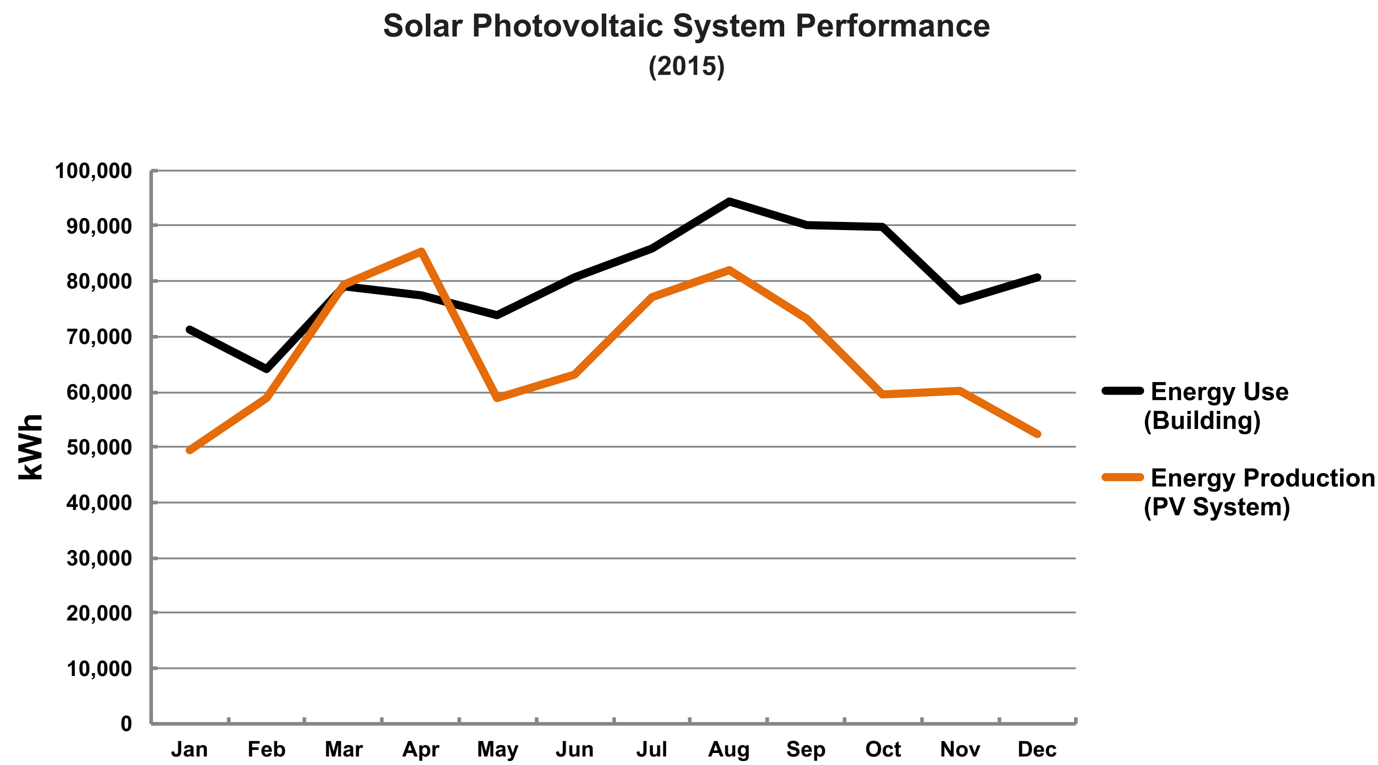

**Measured Energy Use**
**(2015)**

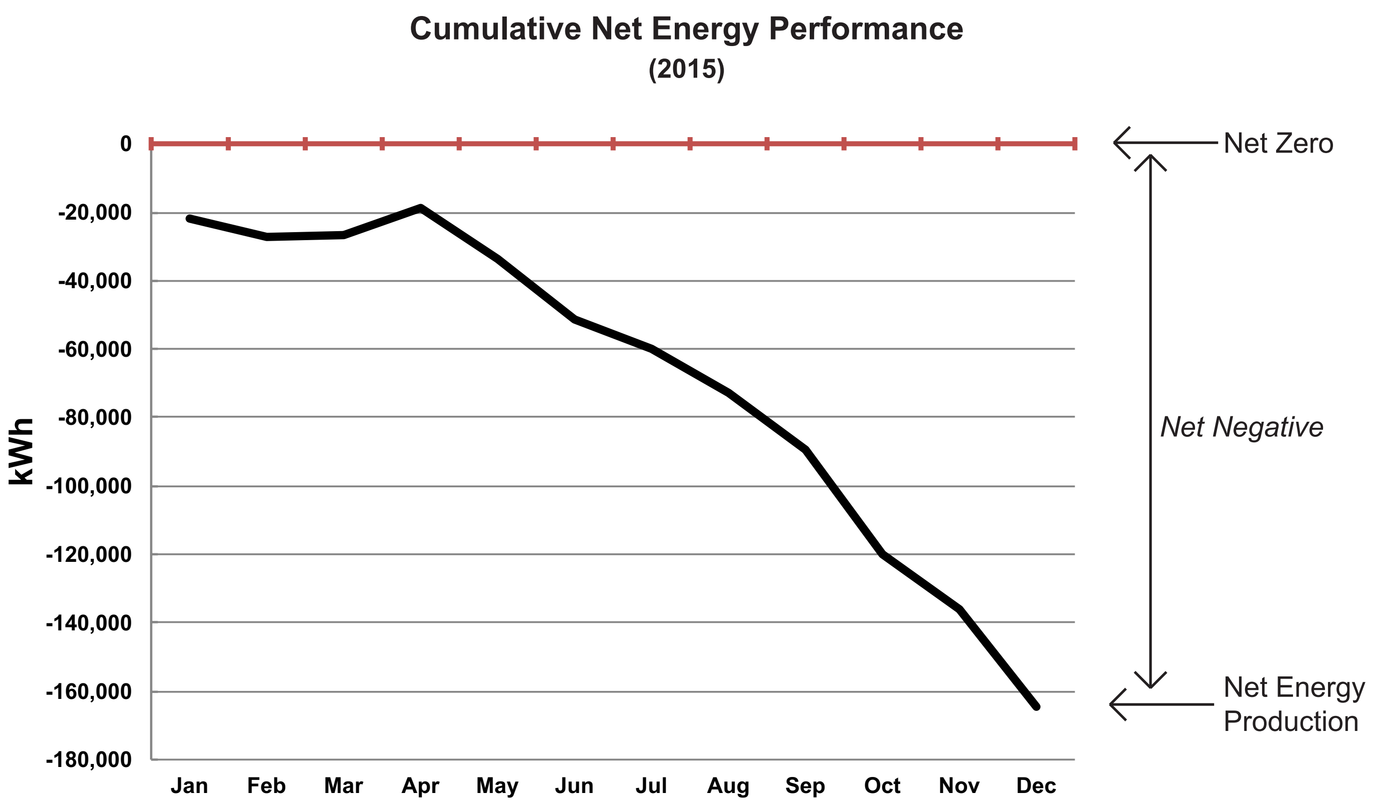
964,000 kWh/year
Measured EUI = 73.8




Modeled Monthly Energy Use
(Annual)
kBtu/sq.ft.
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Equipment (Freezers, Etc.)
Plug Load - Lab
Plug Load - Office
Lighting
Fans
Pumps
Cooling
Heating


Measured Monthly Energy Use (2015)
kBtu/sq.ft.
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Unaccounted Loads
Equipment (Freezers, Etc.)
Plug Load - Lab
Plug Load - Office
Lighting
Fans
Heatng, Cooling, Pumps


Solar Photovoltaic System Performance
(2015)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
kWh
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Energy Use (Building)
Energy Production (PV System)


Cumulative Net Energy Performance
(2015)
0
-20,000
-40,000
-60,000
-80,000
-100,000
-120,000
-140,000
-160,000
-180,000
kWh
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Net Zero
Net Negative
Net Energy Production

*Energy Production versus Energy Use: Zero Net Energy Performance*

2015 was the second full calendar year of operation and the resulting performance data shows that the building is short of ZNE by about 20%: 964 MWh used compared to 800 MWh produced on-site. The solar photovoltaic system performed as expected. It was the energy use, which was higher than modeled by nearly 30%, that caused the building to perform less than ZNE. (See the final subsection, "Post Occupancy—Observations and Conclusions", for a discussion of the possible causes of the higher energy use than anticipated.)

As the solar PV performance chart on the facing page indicates, a dip in production during the second quarter prevented the building from getting close to ZNE performance. Even without this behavior in the following year, 2016 data showed a similar general pattern with a second year of net-negative performance.

The consistent pattern of energy use exceeding energy production by the same relative fraction means that the cumulative difference grows more negative, as reflected in the chart on the previous page.

**Post-Occupancy: Observations and Conclusions**

The intent of this project was to "do the experiment" and determine if it is possible to design and build a ZNE laboratory, something that had never been done. At the end of two years, given an analysis of the design and performance of the JCVI facility, the answer appears to be affirmative given possible corrective actions, but the data has not yet proved it conclusively.

Certainly, as a great advance in laboratory design, the goal of establishing the model for *The Laboratory of the 21st Century* is met. The original target for the ZNE design was EUI = 70, compared to an energy-efficient *Labs21* design of EUI = 270. The actual measured performance for 2015 is EUI = 73.8, close to the target. Falling just short of ZNE soon after occupancy is not surprising, given the adjustments and tuning of the building systems that normally are necessary.

Also, the initial "stretch goal" of EUI = 70 was essentially achieved, but given the size of the solar array that was eventually installed (producing 800 MWh in 2015), the EUI would have to be lower by another 10 units (kBtu/sq.ft.) to reach the ZNE objective. This is certainly achievable in the next few years, given some of the issues discussed below. The "experiment" proved to be successful by one measure—the initial target EUI was essentially achieved, the path to ZNE with this building is now known and all of the design innovations can serve as a good model for the design of future research laboratories.

*Post-Occupancy: Equipment*

The most innovative strategy to reduce equipment energy consumption is the use of shared [-80°C]-freezers in a dedicated room for that equipment. This enabled the use of water-cooled [-80°C]-freezers, a much more energy-efficient type, as well as a general reduction in the number of freezers required. This programmatic change required the support of the research scientists, which was given during the planning stages.

The [-20°C]-freezers, though not water-cooled, were also intended to be purchased new as energy-efficient models. When the building opened, some scientists did not secure the purchase of the new [-20°C]-freezers for budgetary reasons and simply moved their existing freezers into the new location. The expected reduction in energy use for equipment was therefore only partially achieved initially, but will likely be fully realized in the future as this particular equipment if replaced..

PHOTO: NICK MERRICK, HALL MERRICK PHOTOGRAPHERS

*Post-Occupancy: Natural Ventilation*

Perhaps the most significant “lesson learned” in the design and operation of this building pertains to the natural ventilation design strategy. Correctly recognized as potentially one of the most effective methods of reducing energy use for cooling and fresh air in the office and conference spaces—more than half the conditioned space in the building—natural ventilation was planned by the design team to take advantage of the optimal climate for such a strategy. This strategy ordinarily includes use of the outside air for cooling both during the day and also during even warmer weather cycles to pre-cool the building with cooler night air.

However, the strategy was not entirely successful for a number of reasons. First, the decision was taken to make the natural ventilation only user-operated—no system control was included. That effectively eliminated the night cooling operation strategy. Secondly, even with a green light signal to the occupants that the windows could be opened, not all of them are operated. This is because either the occupants are not acting on this information or they are simply not there. Quite often they are in the laboratory wing.

Another factor is that the chilled beams in the office space limit the time when the natural ventilation mode can be used. The high relative humidity of the ocean fog conditions, which is prevalent in the morning hours, would create condensation when switching from natural ventilation to the chilled beams for cooling in the system as designed. Thus, use of natural ventilation during these morning hours was technically not possible without creating a condensation problem.

And finally, the natural ventilation openings in the office wing are apparently not large enough operationally at the inlet or outlet, so not enough air flow develops to provide the necessary cooling effect for the occupants. The design approach taken was to utilize the stairwells at the “knuckles” in the plan of the office wing as “thermal chimneys”, where the top of the stair shaft would have the air outlet, thus creating the drafting effect. The air inlet would be the occupant-controlled windows in the office space.

But the inlet size (controlled by the occupants), outlet size and possibly the height of the shafts themselves apparently were not adequate to create the necessary air flow. No low-power backup fans at the air outlet were included in the design, so the only alternative was to use mechanical cooling by the HVAC system even when outside air conditions would have allowed free cooling via natural ventilation.

The natural ventilation design feature could not be designed as simple cross ventilation of the narrow floor plate of the office wing because all of the private offices fill one side. For cross ventilation to work, the office doors would have to be left open (or a vent system would have to open), which would eliminate acoustic privacy. This led to the decision to add the “thermal chimney” design strategy as back-up.

Lessons learned with regard to the design of natural ventilation for spaces like the JCVI office wing in marine climates similar to La Jolla, then, are as follows:

1. Do not rely only on occupant control for natural ventilation to operate successfully as a significant design strategy to save energy. A limited amount of occupant control is desirable for psychological reasons and to enhance the sense of personal comfort, but invest real control with an automatic system tied to the BMS to ensure proper performance.

2. Be sure to employ the “night purge” operation to pre-cool the building when the weather conditions warrant—again, an automatic control system with smart inputs is required. At JCVI, this would mean incorporating forecasts of temperature and humidity into the Building Management System (BMS) control sequence to avoid unwanted condensation due to humid night air or,

alternatively, provide for a more enhanced ability of the system to dehumidify when going from natural ventilation to cooling.

3. Analyze the physical design using natural ventilation software to verify proper size and location of openings to achieve the correct air flow patterns and quantities to ensure comfort conditions.

4. Include low-wattage backup fans if using a "thermal chimney" approach to natural ventilation, to ensure good air movement under less-then ideal conditions.

*Post-Occupancy: Metering Systems*

As described above in the section on measured performance of the building, a comparison of the metering system of the building with the SDG&E electric meter revealed that the data as reported by the metering system was not complete. (This was also found to be the case in at least one other case study building in this book.)

This seems to be the result of several possible factors. The meter specified should be appropriate to quantities being measured and should be checked for proper calibration. More significantly, the single line diagram for the system should be coordinated by the electrical and mechanical engineers to make sure that all loads are being included (or not double-counted).

But more important, perhaps, is that the metering system should be designed to provide ready information both to the maintenance staff—identifying where loads are increasing unusually or other indications of malfunction—and to the occupants by providing useful information about their behavior. An example at JCVI was a missed opportunity to provide feedback to lab personnel by separately metering the steam generator for the autoclaves or the dishwashers, which is a large energy-using equipment item and whose use is very amenable to behavioral change.

Another useful design feature of the metering system could be to make sure that the data being recorded on each circuit is in the same category (that is, lighting, pumps, fans, heating, cooling, etc.). This would ensure that performance data can be easily compared to the energy modeling results. While this is interesting to the energy modeling engineer, it also can often give an indication of a system or behavioral problem.

The commissioning plan should include verification that the metering system is in fact operating correctly and, if possible, checked against the public utility's site meter to verify consistency.

*Post-Occupancy: HVAC System*

The use of chilled beams was a new idea for laboratories, but with some training the subcontractors accepted the new technology and provided lower competitive bids. This idea of training the subcontractors prior to bid essentially overcame the natural conservatism of the building industry, which tends to be risk-averse and opts for well-known technologies.

*Post-Occupancy: Electric Lighting*

At an appropriate time in the future, the fluorescent light fixtures can be gradually replaced by LED fixtures, which are now cost-competitive will result in a further reduction in the building EUI.


PHOTO: NICK MERRICK, HALL MERRICK PHOTOGRAPHERS

CASE STUDY NO. 13

# La Escuelita Education Center


PHOTO: DALE LANG

# La Escuelita Education Center

## *Case Study No. 13*

**Data Summary**

**Building Type:** K-12 Education

**Location:** Oakland, CA

**Gross Floor Area:**

| | |
|---|---|
| Phase 1 (ZNE) | 58,498 gsf |
| Phase 1 (Non-ZNE) | 13,070 gsf |
| Phase 2 | 46,934 gsf |
| Total Project | 118,502 gsf |

**Occupied:**

Phase 1 - 2012
Phase 2 - 2014

**Energy Modeling Software:**
(See discussion)

**On-Site Renewable Energy System Installed:**

Phase 1 - 196 kW (DC)
Phase 2 - 189 kW (DC)

**Measured On-Site Energy Production:**

Phase 1 - 257 MWh/year
Phase 2 - 203 MWh/year

**Owner/Client**

Oakland Unified School District

*HPS Program Manager / Sustainability Consultant:*
Greenbank Assoc, Piedmont, CA

**Design Team**

*Architect:*
SVA Architects, Oakland, CA

*Structural Engineer:* OLMM, Oakland, CA

*Mechanical/Plumbing Design Engineer:*
Taylor Engineering, Alameda, CA

*Electrical Engineering / Lighting Consultant*
IDeAs (now part of Integral Group), Oakland, CA

*Landscape Architect:*
PGA Design, Oakland, CA

**General Contractor**

Phase 1: Turner Construction Co. / ADCO Construction (Joint Venture), Oakland, CA

Phase 2: McCarthy / Turner Group Construction (Joint Venture), Oakland, CA

Primary and secondary school education facilities (known in short as "K-12 schools") make up a common building type with similar building program elements, and therefore constitute an informative case study with general application. Public K-12 schools are also highly regulated and have design standards for systems and environmental characteristics that have widespread acceptance and application. This case study illustrates not only possible transferable design strategies for other K-12 projects but also the particular constraints on the design process that affect the choices of those strategies.

**Background**

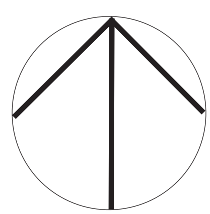
In 2006, the voters of Oakland passed a local bond measure that included $75 million in project cost for the replacement of a collection of K-12 school buildings that were seriously deficient and in need of modernization. Located near downtown Oakland and adjacent to Laney Community College, the site included an existing elementary school, a high school and two child developments centers. (See the aerial photo of the existing site conditions, below.)

In addition to the elementary school ("La Escuelita Elementary School"), the secondary school ("Metwest High School") that were already on the site, the program for the new campus was expanded to include a large multipurpose room ("The Great Room"), a health clinic, a combined child development center ("CDC"), a data center and a TV studio ("KDOL") for the District.

To accommodate such a varied program of almost 120,000 sq. ft., and to minimize disruption as well as cost, the program called for two phases of construction. Phase 1 would be built on the north half of the site and would include principally the elementary school, the Great Room, the health clinic, the data center and TV Studio. Phase 2 would follow on the south half of the site, comprised of the high school and the child development center.

*(Below)* Aerial photo of the site (pre-construction) with the existing elementary school (La Escuelita) and high school (Metwest)


La Escuelita Education Center: General Vicinity Plan



Since 2007 Oakland Unified School District (OUSD) had a policy committed to the design and construction of sustainable facilities based on the principles of the Collaborative for High Performance Schools[1] (CHPS). The District hired a sustainability consultant to assist in the development of their "green schools" program, which prioritized "low energy design" with a gradually increasing energy performance goal aimed at zero-net-energy. The LEEC project was one of the largest projects in OUSD's ongoing bond program and the District was able to secure matching state funds for this project's energy-related high performance goals.

## Design Process and Low Energy Design Strategies

OUSD first selected the architectural firm through the usual evaluation procedure, who as part of this process developed a concept design for the entire program to be placed on the site. This master plan reflected primarily programmatic accommodation, including required outdoor space and parking. (See figure on the facing page.)

At the same time, OUSD leaders and the sustainability consultant advanced a "stretch goal" for the project, namely to design the first zero-net-energy K-12 campus. To that end, OUSD and the architect filled out the design team for the next design phases by selecting engineering consultants who had a record of successful work with the design of zero-net-energy (ZNE) buildings.

With the new, ZNE-experienced consultant team in place, the design team set about integrating energy-efficient design strategies into the planning of the site and buildings per the program requirements and phasing concept. In addition, the project team was required to meet all of the requirements of CHPS, which included factors such as thermal comfort, indoor air quality and commissioning.

In general, the OUSD project leaders supported the idea of "experimental design strategies" to be explored rather than conventional systems that maintenance staff might accept as a more comfortable approach, as a means of gaining experience with systems that might be applied to future projects. The design team was charged with proving that any new approach to the design would provide deep energy savings and would work within the established project budget.

*Planning Concept and General Design Considerations*

Reviewing the originally proposed concept design of the building program components on the site (facing page, *top*), and taking note of the site orientation relative to the sun, the design team reorganized the site plan so that the buildings would face primarily south to provide better daylighting, more effective solar control and solar PV system optimization. The phasing requirements were considered as well, allowing the Metwest High School campus to continue operation while Phase 1 was built. The resulting building plans and campus organization (shown on the facing page, *bottom*, and the two following pages) were as a result dramatically different than the original concept where energy use and on-site PV production were not considered in an integrated way.

An initial analysis of the expected energy use for the campus was done using CBECS data[2] as a benchmark for comparable space types and assuming realistic energy-efficiency improvements to lower these benchmark numbers. Even assuming the most optimistic reduction by design in the energy demand of the programmed spaces, the required on-site installation of the solar PV to offset this expected demand was several times the space available on building roofs and possible parking lot canopy structures.

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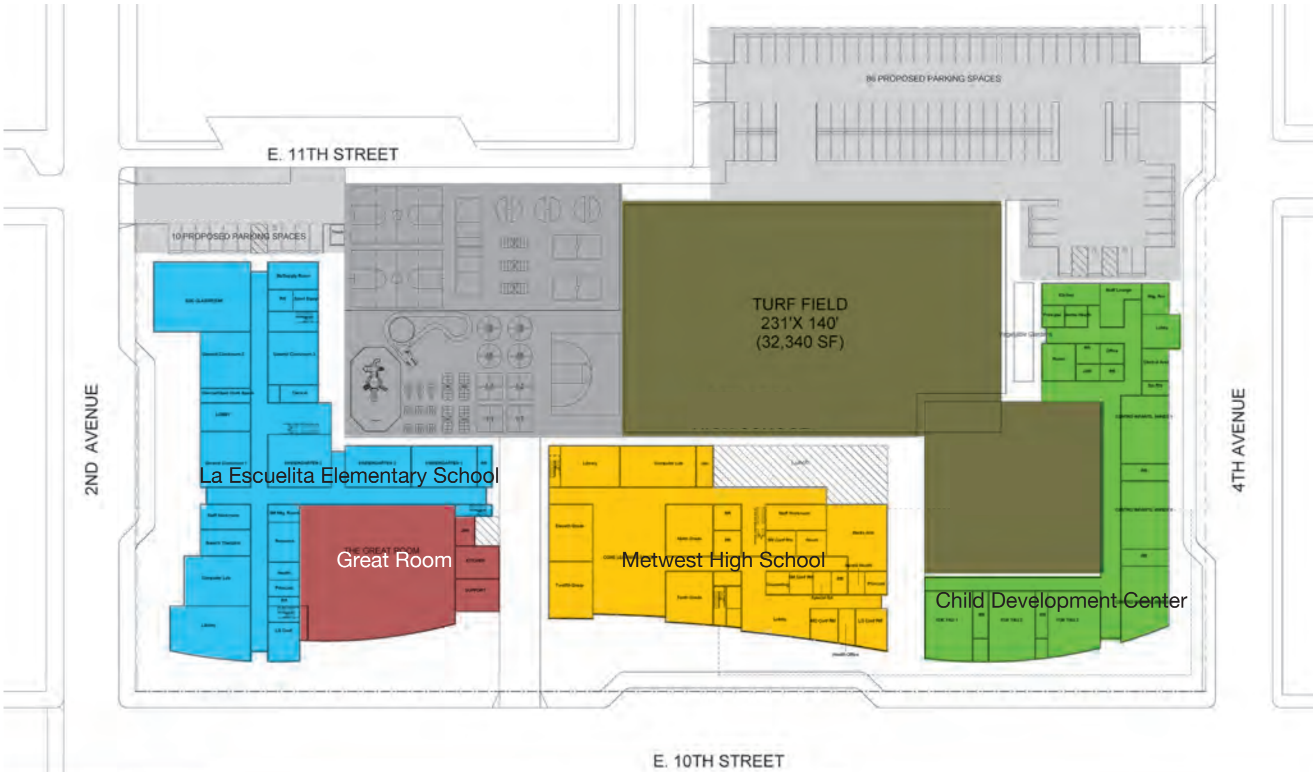
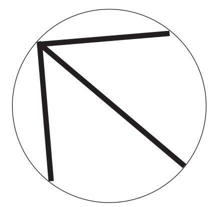
1 See http://www.chps.net/

2 *Commercial Buildings Energy Consumption Survey,* https://www.eia.gov/consumption/commercial/




Initial Concept Site Master Plan




Final Site Master Plan — Optimized solar orientation and phasing. (Courtesy of SVA Architects.)

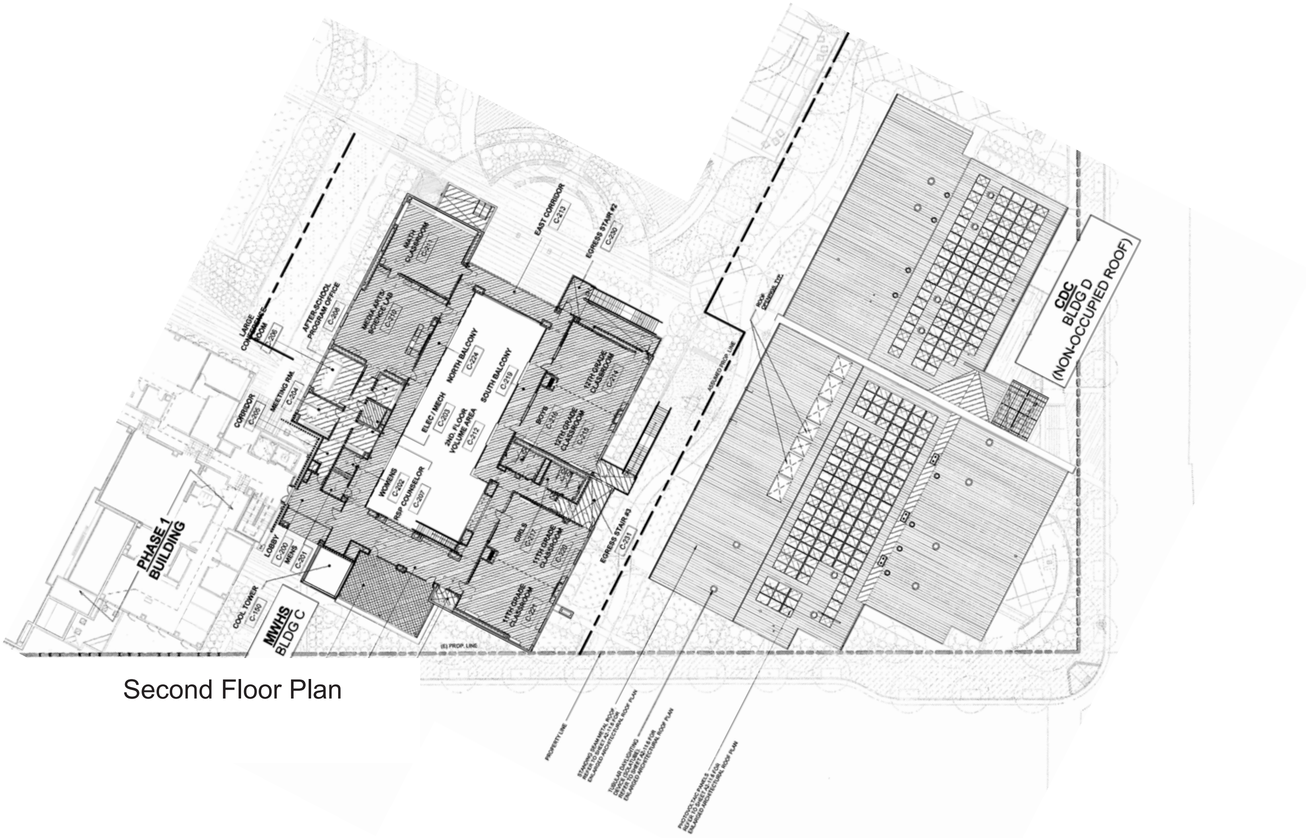

Second Floor Plan


First Floor Plan
PHASE 1

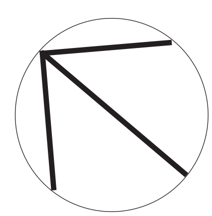
ZNE Group =

La Escuelita Education Center
Final Floor Plans

The “ZNE Group”, the collection of spaces shown enclosed with the red dashed line, is the portion of the project that was designed to achieve zero-net-energy (ZNE) performance.




Second Floor Plan

First Floor Plan
PHASE 2

This was partially the result of energy-intensive program uses such as the Data Center and the TV studio, but also the relatively high occupant load in the collection of spaces. The conclusion by the design team was that it was *not* feasible to have the entire campus achieve a ZNE performance with on-site renewable energy sources alone. OUSD leaders indicated that it was preferable to set an achievable objective of some sort so that a ZNE benchmark would be established for the District's future building projects.

The design team therefore proposed a subset of the Phase 1 building program that might collectively achieve ZNE performance through the application of aggressive energy-efficiency design

strategies. OUSD leaders agreed with the approach as consistent with the intent of the project goals. The La Escuelita ZNE project was therefore changed from both phases of the entire campus to the “ZNE Group” of Phase 1, which consisted of the La Escuelita Elementary School (LEES), the large multipurpose room (The Great Room) and related support spaces.

The rest of the discussion of this Case Study No. 13 will then refer to the collection of program spaces known as the “ZNE Group” as shown in the plan diagrams of the previous page. The total gross floor area of Phase 1 is 71,568 sq. ft. while the gross floor area of the “ZNE Group” 58,498 sq. ft., or 82% of Phase 1. Phase 2 has a total gross floor area of 46,934 sq. ft., so the “ZNE Group” is 49% of the total project area (or roughly half of the project space).

PHOTO: DALE LANG

*Building Envelope*

The building enclosure is designed to maximize daylighting and to minimize solar gain. As a baseline design, the insulating characteristics of the opaque parts of the envelope were established as R-19 for the walls and R-30 for the roofs, which meets the requirements of the California energy code. The buildings use standard metal stud framing but because of the relatively mild climate and extra cost required, a layer of continuous insulation over the exterior metal stud wall construction to prevent thermal bridging was omitted. The result was a reduction in the effective R-value of the wall to approximately R-6, a contributing factor to the relatively high heating load measured in the winter months. (See the chart on the bottom of p. 55 and the discussion on p. 60.)

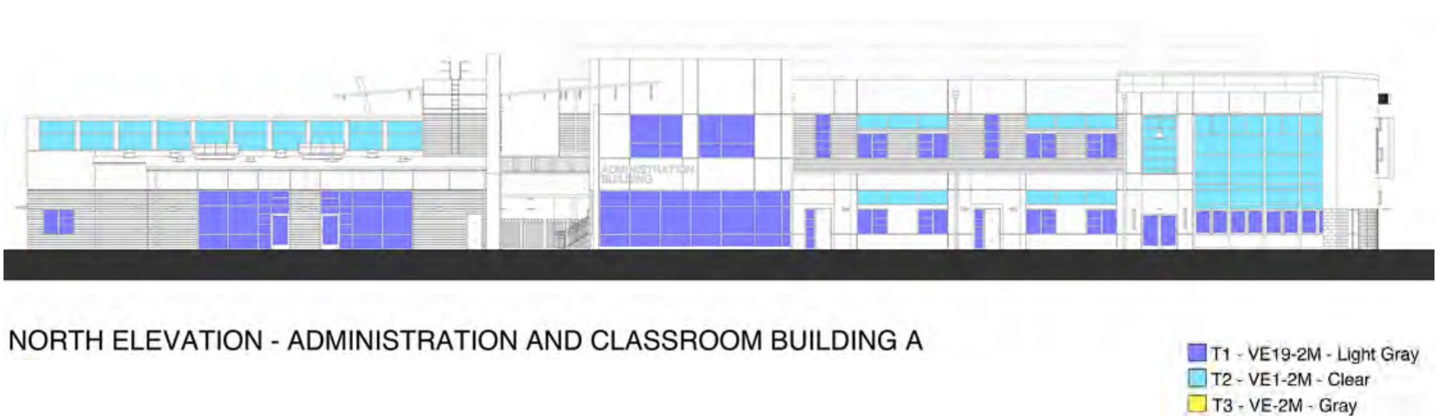
The innovative design feature of the building envelope, however, was the introduction of a technique of increasing the thermal mass of the walls beyond normal construction. This was a necessary development because of the District's policy of no mechanical cooling and the clear need for comfort cooling at certain times of the year. The CHPS criteria also required that ASHRAE Standard 55 (thermal comfort) be met. Thermal mass would provide a damping effect to this peak cooling load and allow as well a night ventilation strategy to precool the building during those sequences of weather events. (This operational strategy is discussed further below in *Heating, Ventilating and Cooling Systems.*)

The technique was to introduce two layers of cementitious board on the inside surface of the walls, covered with 1" of plaster to form 2" of a thermal mass material. (See the figure on the facing page.) To provide both acoustic treatment for the room and to allow tackable surfaces for students and teacher without covering the heat transfer surface of the thermal mass, tackboard was designed to be installed at certain locations using "standoff" hardware from the wall surfaces. This acoustic treatment was necessary as well to meet a CHPS criterion for acoustic quality. (Due to a construction error, this standoff hardware was not actually installed.)

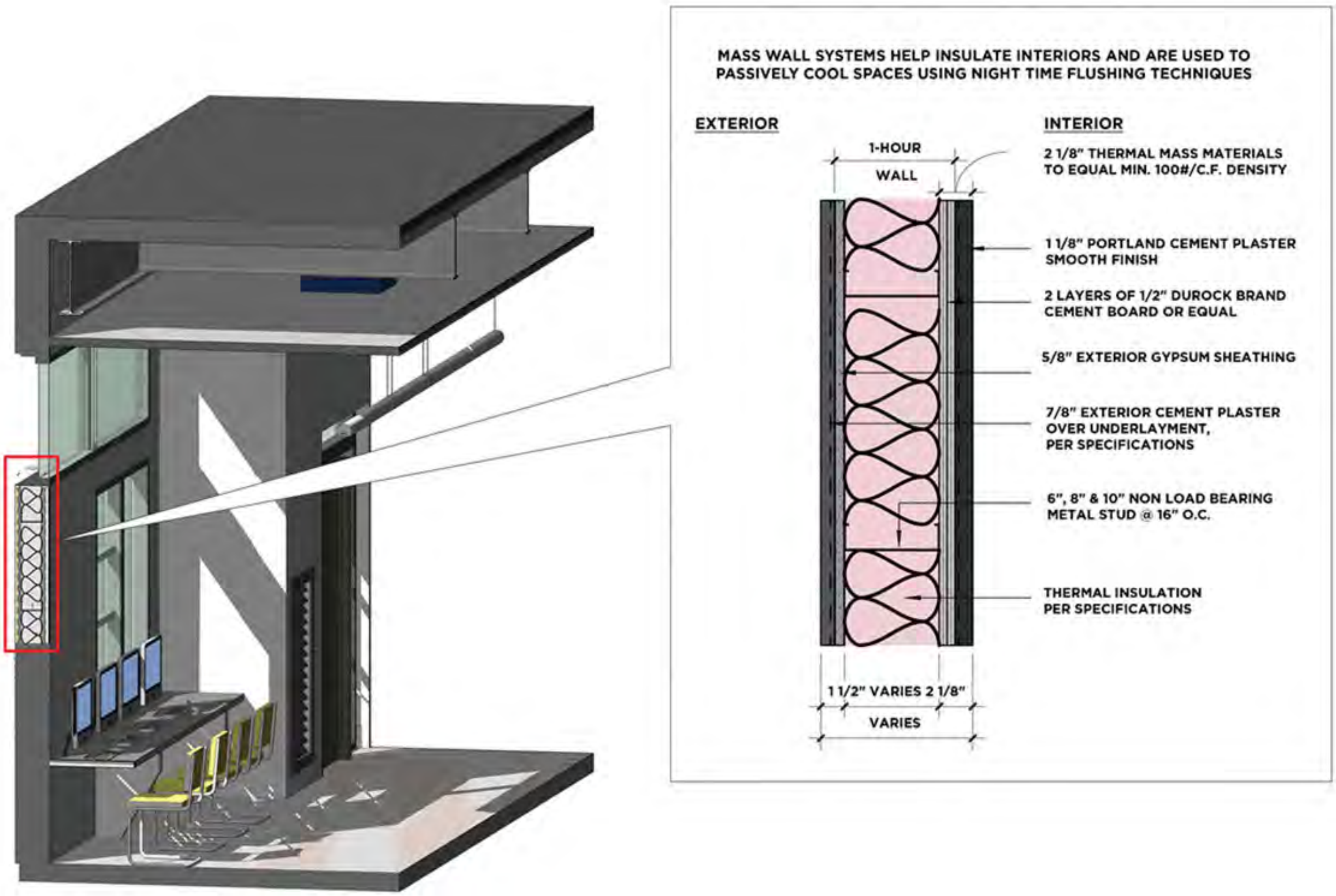
Another design feature of the building envelope was the selection of three different types of glazing for the windows, depending on the location and function of the openings in the specific location. The partial elevations of the classroom building shown on the facing page illustrate the locations of these three glazing types.

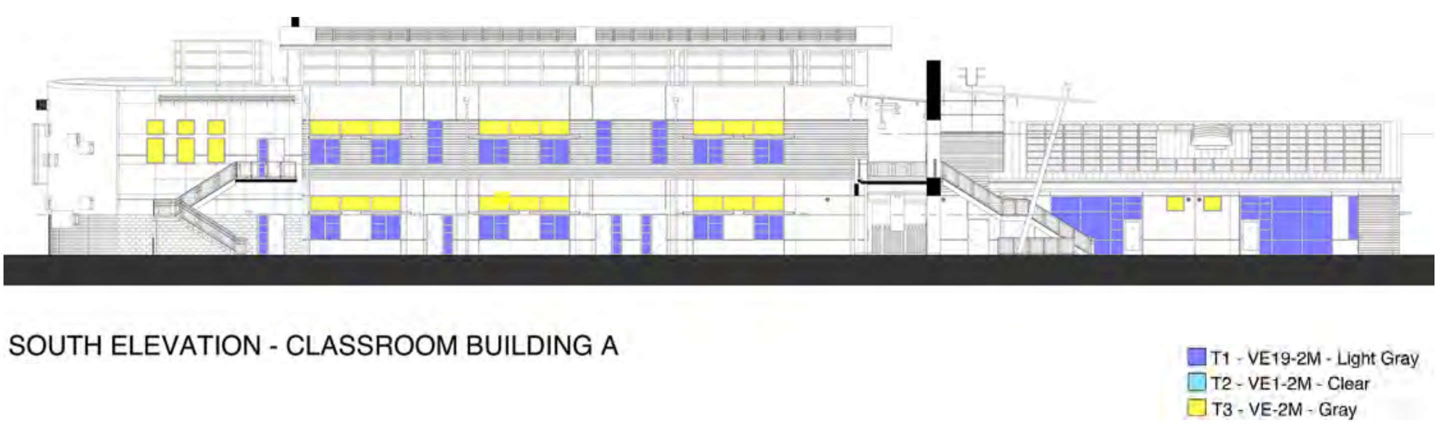
Glazing intended to maximize daylighting has a high visible light transmission (70% for glass type T2) and was used on the south-facing high windows and north-facing windows generally. Glazing in south-facing view windows has a low solar heat gain coefficient (SHGC = 0.30 for glass type T1). An even lower SHGC was specified in relatively unprotected south facade locations (SHGC = .24 for glass type T3). The low SHGC was specified because of concerns about solar heat gain overwhelming the thermal mass cooling strategy.

*(Below and Bottom of opposite page)* Glazing types used in the Classroom Building to maximize daylighting or to minimize solar heat gain, depending on location. (Courtesy SVA Architects)



*(Below)* Thermal mass is added to the classroom walls on the inside surface to pre-cool the space using night ventilation with cool night air. (Courtesy SVA Architects)




SOUTH ELEVATION - CLASSROOM BUILDING A

*(Right)* Images from the extensive daylight modeling studies. (Courtesy of David Kaneda of Integral Group and Zack Rogers of Daylighting Innovations, LLC.)

Great Room daylighting design - skylight option

Great Room daylighting design - north clerestory option

Classroom wing daylighting design - exterior view of fixed sunshades with light shelf

Classroom wing daylighting design - section showing day-lit common space connecting the classrooms

Classroom wing daylighting design - interior view, with sunshade wall (image right) and borrowed light from daylit common space (image left)

*Daylighting and Electric Lighting*

Daylighting has traditionally been a design feature of classroom facilities because of the perceived health and learning productivity benefits. Modern daylighting design adds sophisticated daylight controls and computer modeling to the design methodology. The design team utilized this approach through daylight modeling and technical specification, particularly in the classrooms and large multi-purpose room (the “Great Room”).

The daylighting design in the classroom spaces is strongly integrated with the cooling system design (displacement ventilation in the classrooms and the “Cool Towers” in the Great Room—see the discussion below under *Heating, Ventilating and Cooling Systems*) as well as the building envelope design (glazing specifications, as discussed in the previous section).

But first the designers attended to good light levels and glare control by utilizing tall windows and fixed shading devices in the classrooms. The fixed sun shades are structural overhangs and were designed also to act as a “Light Shelf”, reflecting sunlight to the interior of the room. Secondary light from the large daylit common space adjacent to the classrooms was provided via additional windows on the opposite side of the classroom, also creating light balance in the space and visual comfort conditions. Daylight models confirmed these space characteristics and that good classroom light levels would be provided under most daily conditions. (See images from the daylighting studies on facing page.)

For the large Great Room, daylight modeling was used to evaluate several architectural approaches to daylighting the large space, including skylights and a north-facing clerestory. The clerestory scheme resulted in a tilted roof, slightly sloping to the south, which had a slight advantage in PV performance. The skylight scheme produced more uniform daylight across the space. (Daylight modeling images rendering the appearance of these two schemes at top of facing page.) The clerestory scheme was selected and ultimately integrated with relief louvers for the operation of the Cool Tower. (See discussion below.)

For electric lighting when daylight is not ample, T-8 lamps are used in the overhead light fixtures because LED sources were not cost effective at the time of design and construction.

*(Below)* North clerestory of the Great Room as built, with one of the Cool Towers. (Photo courtesy of SVA Architects)

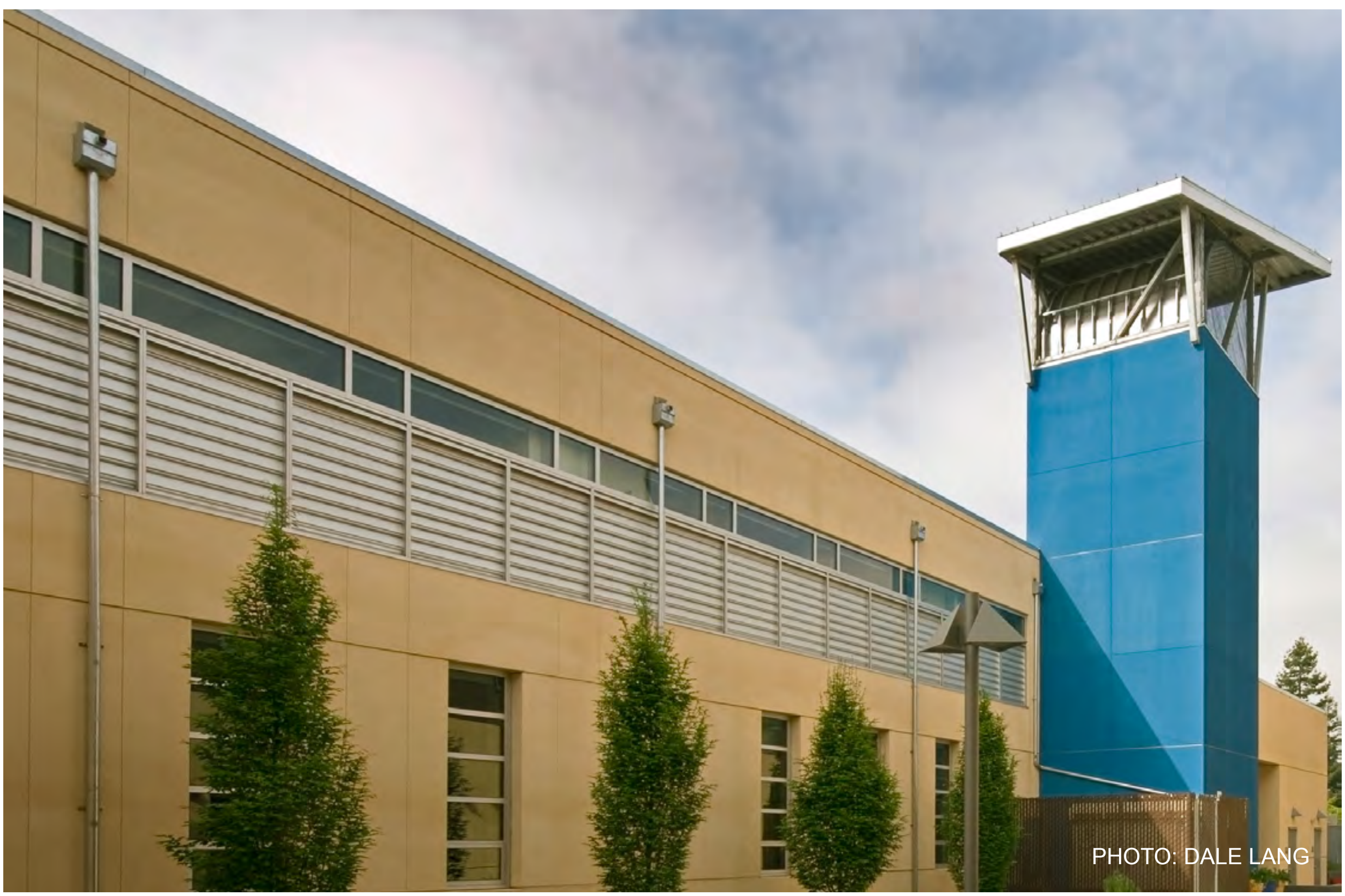



PHOTO: DALE LANG

*Natural Ventilation*

A form of natural ventilation is used for fresh air and cooling in place of standard air conditioning for the Great Room, namely the “Cool Tower” feature described below. The classrooms utilize openable windows controlled by the occupants, but the primary system for providing ventilation air is *displacement ventilation*[1].

*Heating, Ventilating and Cooling Systems*

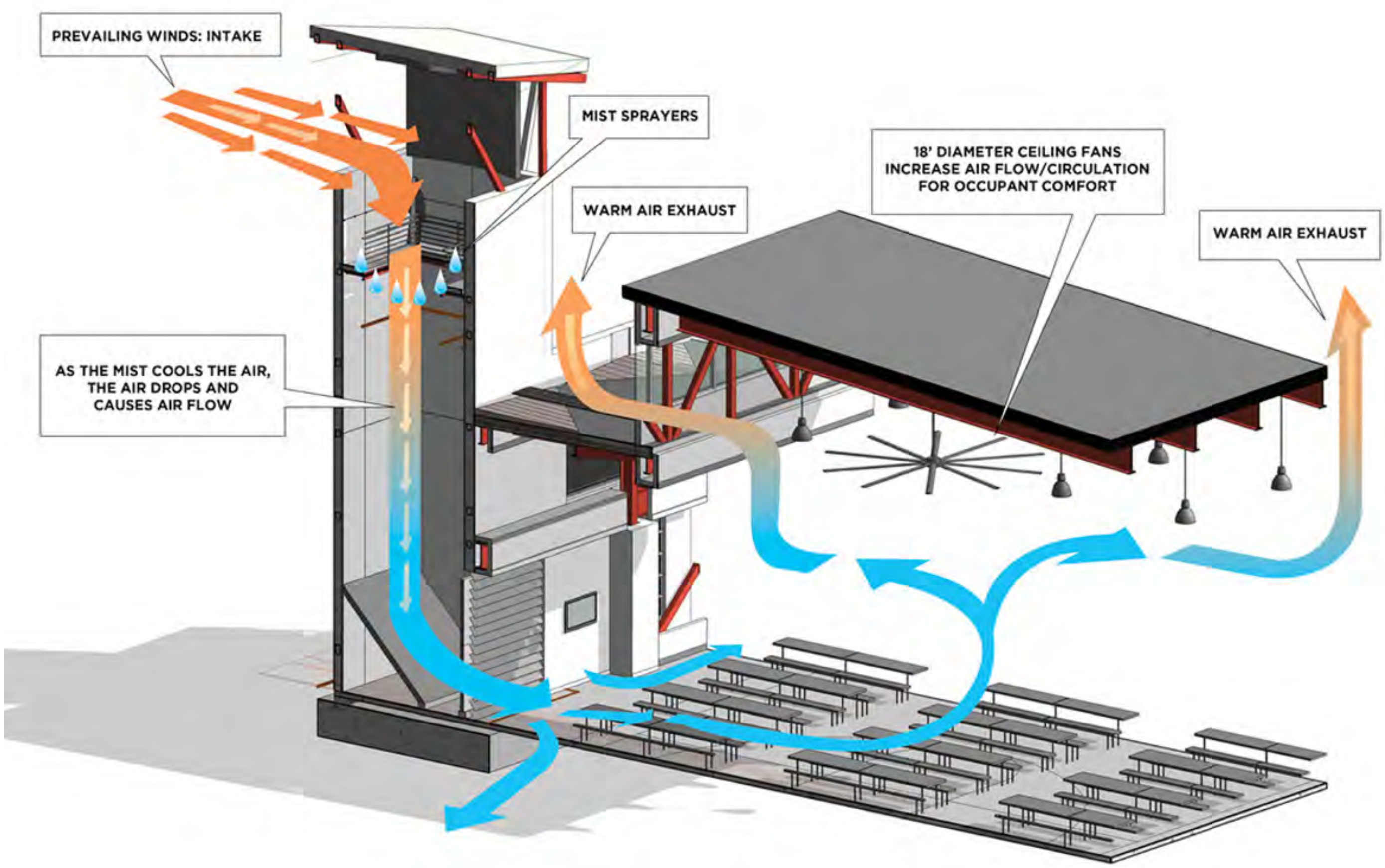
The “ZNE Group” utilizes two innovative heating and cooling systems that avoid the use of conventional compressors in mechanical air conditioning systems, as required by District policy, and make use of the natural properties of air to minimize the use of fans. The first system, applicable to larger spaces, was named the “Cool Tower” by the design team and is used to provide cooling air to the Great Room. (The “Cool Tower” is not to be confused with conventional cooling towers in air-conditioned buildings.) Without the use of any fans whatsoever, the Cool Tower initiates the designed movement of air through the space to ensure comfortable thermal conditions at all times of the year and for varying number of occupants in the room.

Two Cool Towers located on alternate sides of the west end of the Great Room act like “air scoops” for the consistent prevailing breeze off San Francisco Bay. (See cutaway diagram below.) For added cooling, fine mist sprays inside the Cool Towers create an evaporative cooling effect and lower the temperature of the incoming air to the level required. Within the space, displacement ventilation causes the air to rise due to the natural buoyancy of the air entering the space and the heat from the occupants in the room. The air is ultimately exhausted through the pressure relief louvers in the upper walls at the north clerestory windows. When the temperature in the space rises past the cooling setpoint, additional cooling effect is created by higher air velocity through the space by several large-diameter (18’) room fans.

The design works well in this California coastal marine climate, which is somewhat dry (allowing evaporative cooling to be effective) and moderate in temperature. Extensive calculations were

[1] Displacement Ventilation is a room air distribution strategy where conditioned outdoor air is supplied at a low velocity from an air supply located near floor level and extracted above the occupied zone, usually at high ceiling height.

*(Below)* Cutaway diagram of Cool Tower in the Great Room. Intake air is cooled by a water mist spray *(above)* and drawn into the room by natural air buoyancy and rising heat of the occupants. (Courtesy of SVA Architects)



done to estimate the effectiveness of the design, both in the parameters of the air flow and in the comfort conditions for the occupants. Computer models for this system were not available that would be reliably predictive as the basis of the design.

*(Facing page)* Diagrams of three modes of operation of the classroom system. (Courtesy SVA Architects)

The second innovative system was a displacement ventilation system that was used in the classrooms to provide fresh air, heating and cooling with a minimum use of fan energy, utilizing air properties in a similar way to the Great Room in the individual classroom spaces. In this case, fresh air is delivered to the classroom by a local fan unit (essentially a "dedicated outside air system" or DOAS unit that provides 100% outside air). Like the air supply in the Great Room, natural air properties are used in conjunction with a large diameter room fan to create thermal comfort conditions and appropriate air movement through the space. Heating and cooling are accomplished through three modes of operation. (Refer to the operation diagrams on the next page.)

- Heating Mode (Cold Season)
  The outside air from the DOAS unit is heated via hot water coils in the parallel fan-powered VAV boxes with blended return air. The hot water is piped from the gas-fired boilers. When the air enters the classroom near the floor, the air naturally rises toward the ceiling. The large, slowly-moving room fan (approximately 20% of full speed) mixes the warm air in the room. The DOAS air is exhausted locally through the relief air louvers as newly warmed outside air continues to enter the room.

- Cooling Mode (Swing Season)
  When space cooling is needed in the classroom and outside air is cool enough, such as during the swing seasons of fall and spring, the DOAS unit simply supplies 100% cool outside air. The air rises due to natural buoyancy and the heat of the occupants via the process known as "displacement ventilation". The large room fan remains off during this mode of operation to allow displacement ventilation to occur naturally. (For the same reason, if an occupant opens a window for natural ventilation, the large room fan automatically shuts off.)

- Cooling Mode (Warm Season)
  The DOAS unit supplies 100% outside air, which is at warm temperatures that normally require mechanical space cooling. However, in the marine climate of Oakland, adequate thermal comfort conditions can be provided by the large room fan operating at a fairly high speed.

Some user "training" is required since the operation of the large room fan can be counter-intuitive: fan *on* (though low-speed) during the winter and fan *off* when bringing in outside air for cooling during the swing seasons.

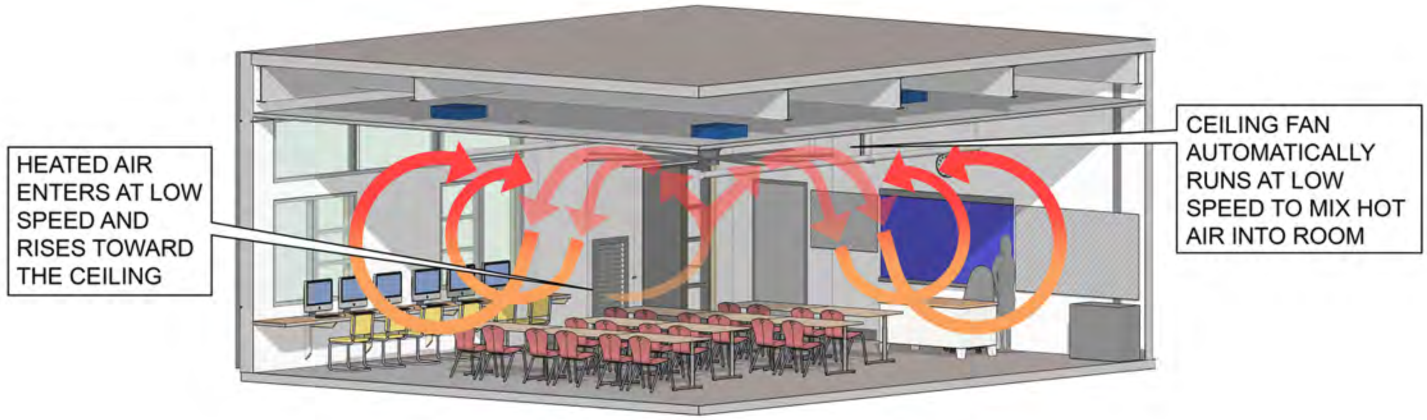
The Administration space has a system similar to the classroom spaces, except that the large room fans are manually controlled and there is no displacement ventilation (the outside air is supplied at the ceiling level).

In addition to these modes of operation during occupied hours, the system also operates in "Swing Season" mode (DOAS unit on, large room fan off) at night during the entire cooling season to pre-cool the building in advance of the cooling demand on the following day. This night ventilation operating strategy is an integral part of the cooling system, with the added thermal mass in the walls as discussed above in the section, *Building Envelope*. Sensors located in the concrete mass of the floors permit good control of the amount of night ventilation so that the building is not over-cooled by morning, requiring heating in the early hours for occupant comfort.

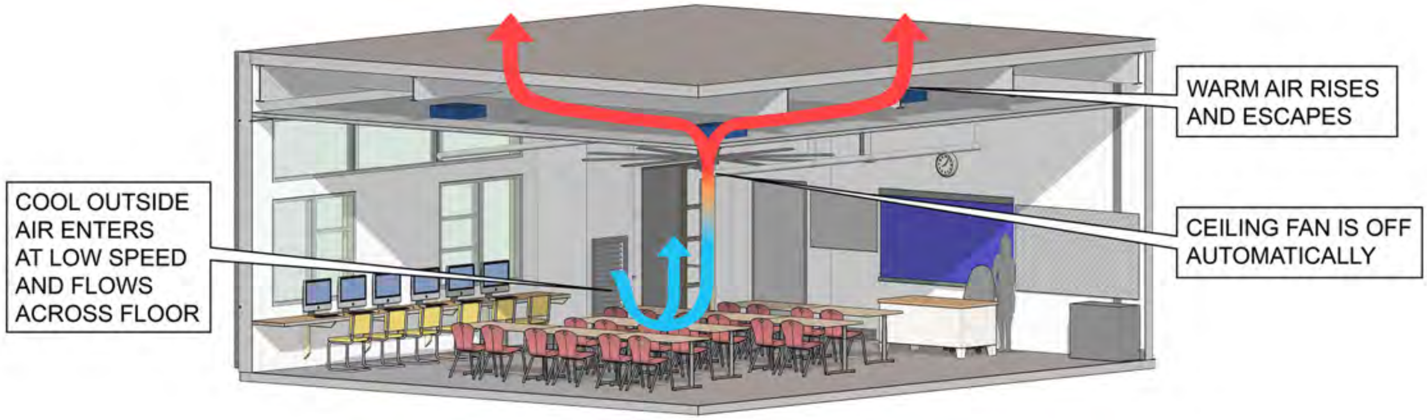
Heating is provided to the Great Room by a separate air handling unit with economizer for minimum outdoor air control that is interlocked with the Cool Tower so that the latter is closed when the heating air handling unit is operating.

The heating, cooling and ventilation systems for all spaces are designed with the large room-sized fans as an integral component of each. The design team worked with the manufacturer of the large fans to develop fan designs that were larger and delivered more uniform air movement. They built a full-scale mockup in a classroom-sized space to optimize the design, changing the dimension of the fan blade, its curvature and height above the floor, until the air motion in any direction was essentially uniform. The optimum location of the fan was found to be ten feet above the floor and two feet below the ceiling. These dimensions also proved to be good vertical distances for the desired daylight penetration.

Heating Mode (Cold Season)




Cooling Mode (Swing Season)




Cooling Mode (Warm Season)

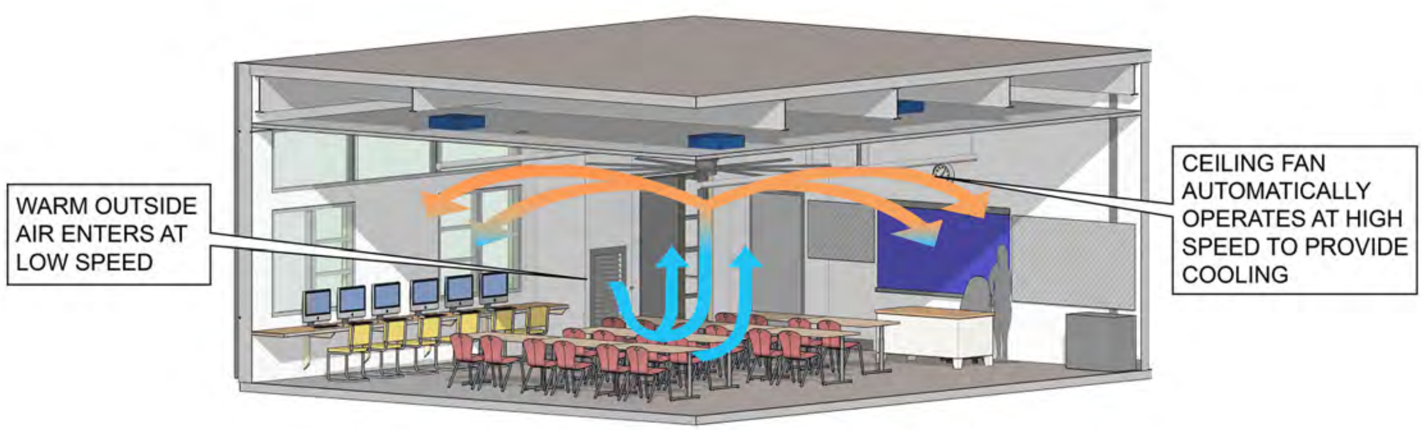


PHOTO: DALE LANG
*(Above)* Gas-fired boiler plant.

*Domestic Hot Water*

A gas-fired boiler plant provides the hot water for heating and the domestic hot water supply, with some solar thermal providing additional hot water.

*Plug Loads*

New energy-efficient computer monitors, equipment and kitchen appliances were selected for purchase as required. Existing equipment was utilized only when essential. Occupancy sensors and daylight sensors for control of electric lights are used as appropriate.

*Master System Integration and Control Systems*

The control systems for these buildings are fairly complex because of the nature of the unusual systems for heating and cooling and the number of environmental sensors involved. The District required that the controls be sole-sourced to a designated vendor for the sake of continuity across all District facilities. This vendor was responsible for integrating all energy-related control systems according to the required communication protocols, including the energy metering system. The circuiting of the latter was then communicated to the provider of the energy dashboard (Lucid) that is used to report the metered data to the District for general use and to the building users for educational use.

The design team specified that each electric load type be installed on a separate panel, which can be separately metered and then provide data about energy use by category of use (lights, fans, etc.). Such categorization of energy use can be very useful during operation and occupancy of the building.

## Renewable On-Site Energy Supply

In the mid-design phase, when the goal of the project was to achieve ZNE performance for the entire project, the initial proposal was to install solar photovoltaic (PV) panels on building roofs and on canopies above the parking lots. That amounted to 385 kW on the buildings and 190 kW on the canopy structures. Later in the project, the District determined that there was interest in expansion of the educational facilities at the site. The canopy structures were seen as not compatible with that possibility, so that PV array was removed from the scope of the project.

Eventually, the PV system was built in conjunction with the two phases and consists of 385 kW total installed on the roofs of the buildings. The installation consists of 1,200 Sunpower E19 panels (rated at 318 watts DC per panel). Total production for a one-year period during 2016-17 was 460,000 kWh or 460 MWh.

*(Left)* Layout of the PV arrays (shown in green for Phases 1 and 2).
*(Below)* PV array on the classroom wing (Phase 1)

PHOTO: DALE LANG

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

*Energy Use — Modeling*

Because of the uniqueness of the heating and cooling features developed for this project, conventional energy modeling software available at the time of the design could not effectively model their performance in any meaningful way. A labor-intensive, simple calculation using spreadsheets was instead used to calculate pressure drops under different conditions, then to apply conservative factors to the results. The engineers were confident that the results proved the concepts, albeit conservative in the amount of thermal mass and pressure relief louvers required. (Measured results showed that there was indeed a certain amount of over-sizing, but also verified that the basic concept was effective and the system performed extremely well.)

The engineers note for this case study that the energy modeling tool, *IES Virtual Environment*, now in extensive use in the U. S., includes a "bulk flow" Computational Fluid Dynamics (CFD) model that is accurate enough to model a unique system of air flow such as the one used.

The upshot is that there are no whole building energy modeling results for "The ZNE Group" to compare with the actual measured performance data. Given that the installation of solar PV panels would be sized to fill all available roof areas and would still likely not align with the energy load of the entire project, it would be pointless to match the size of system to just the energy demand of "The ZNE Group". The District would still obtain good value for the entire project with the maximum build-out of solar PV system.

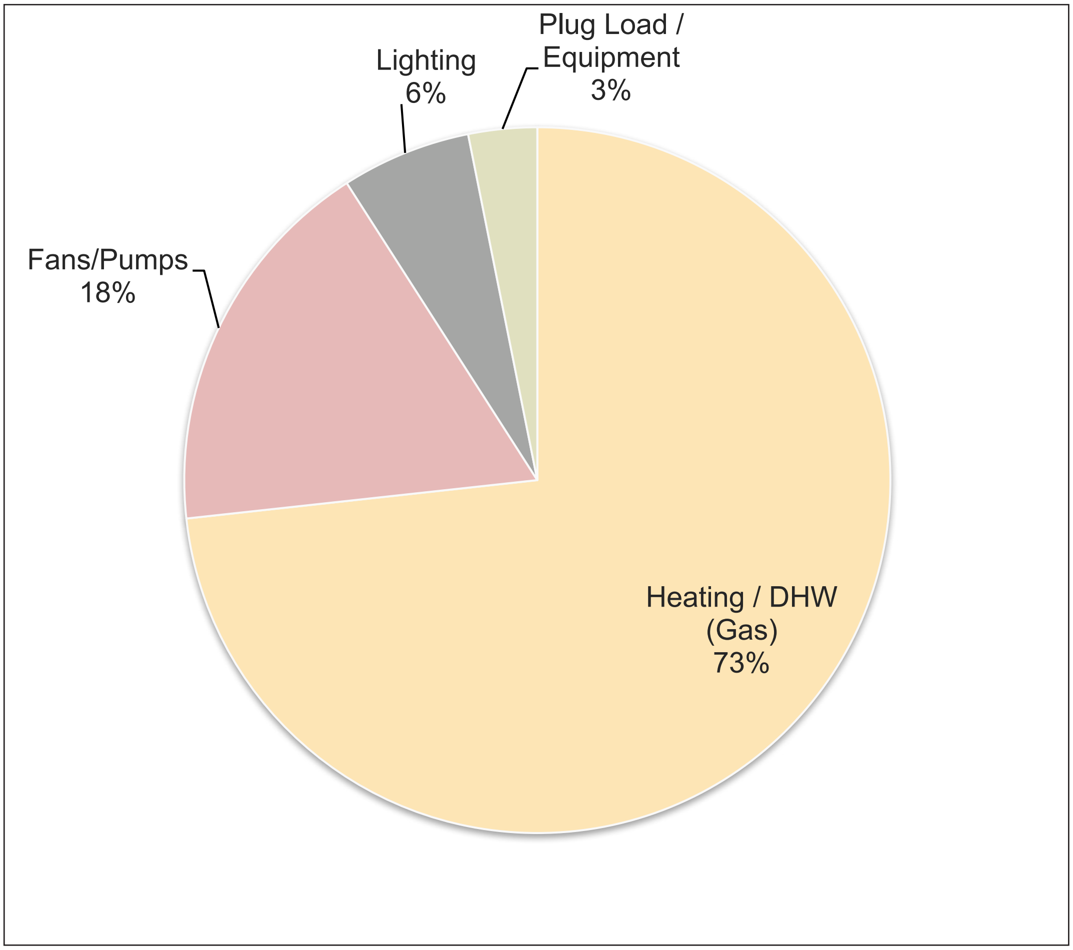
Still, to "check the box" for ZNE performance of "The ZNE Group", it is useful to create some performance comparisons as a basis for making a statement that the project achieved its Zero Net Energy goal, albeit for a pre-established subset of the project. See the section, *Energy Production versus Energy Use: Zero Net Energy*, for the discussion.

*Energy Use — Actual Measurement of Performance Results*

In this section, the measurement of energy use of "The ZNE Group" is charted and discussed. The data was obtained primarily from the District's dashboard system that was set up by Lucid, based on the metering system installed by the control systems contractor. However, the natural gas data was found to be obviously flawed due to reporting errors in the metering system, so the gas data reported in this case study is that recorded by the utility gas meter dedicated to the site boiler plant, which provides heating and the domestic hot water (DHW) to the entire site. The gas consumption data is then assigned to "The ZNE Group" based on the fraction of its gross floor area compared to the entire project's gross floor area, namely 49%.

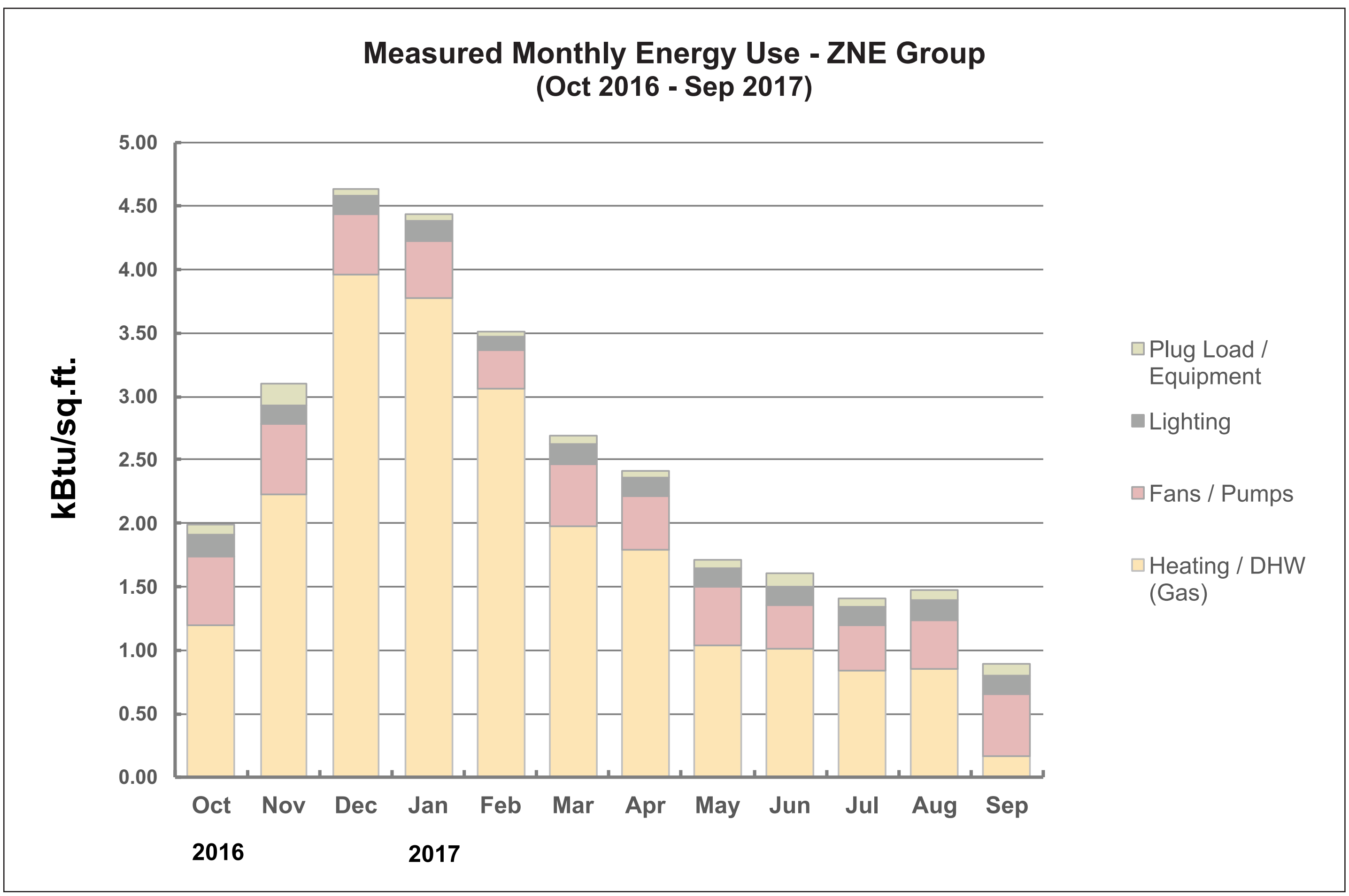
Even though this is an indirect way of establishing gas consumption data for the building under study, it is nevertheless a good measure of the heating and DHW energy use since the building envelope characteristics and general building use are uniform to a reasonable approximation. The total gas energy consumption numbers are certainly accurate since they are recorded by the utility meter, so the only inaccuracy would be the result of the assumption that heating energy use is the same on a floor area basis.

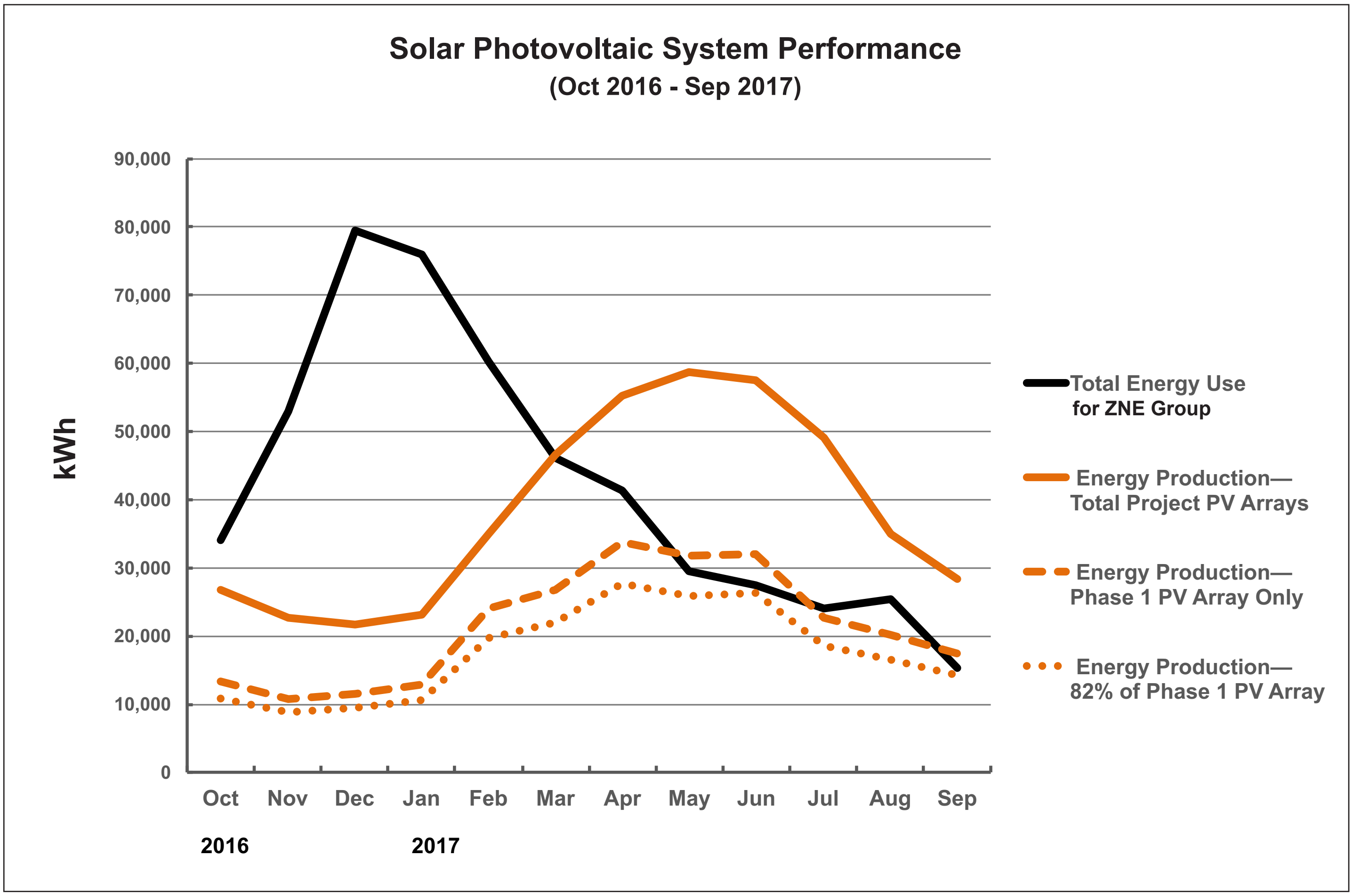
It is unfortunate that the metering system is not reliable for the gas consumption of each building in the complex, but the accurate utility meter can be used for total site consumption. The electric metering system was found to be functioning correctly and the data from the Lucid dashboard for electric energy use can be taken as accurate.

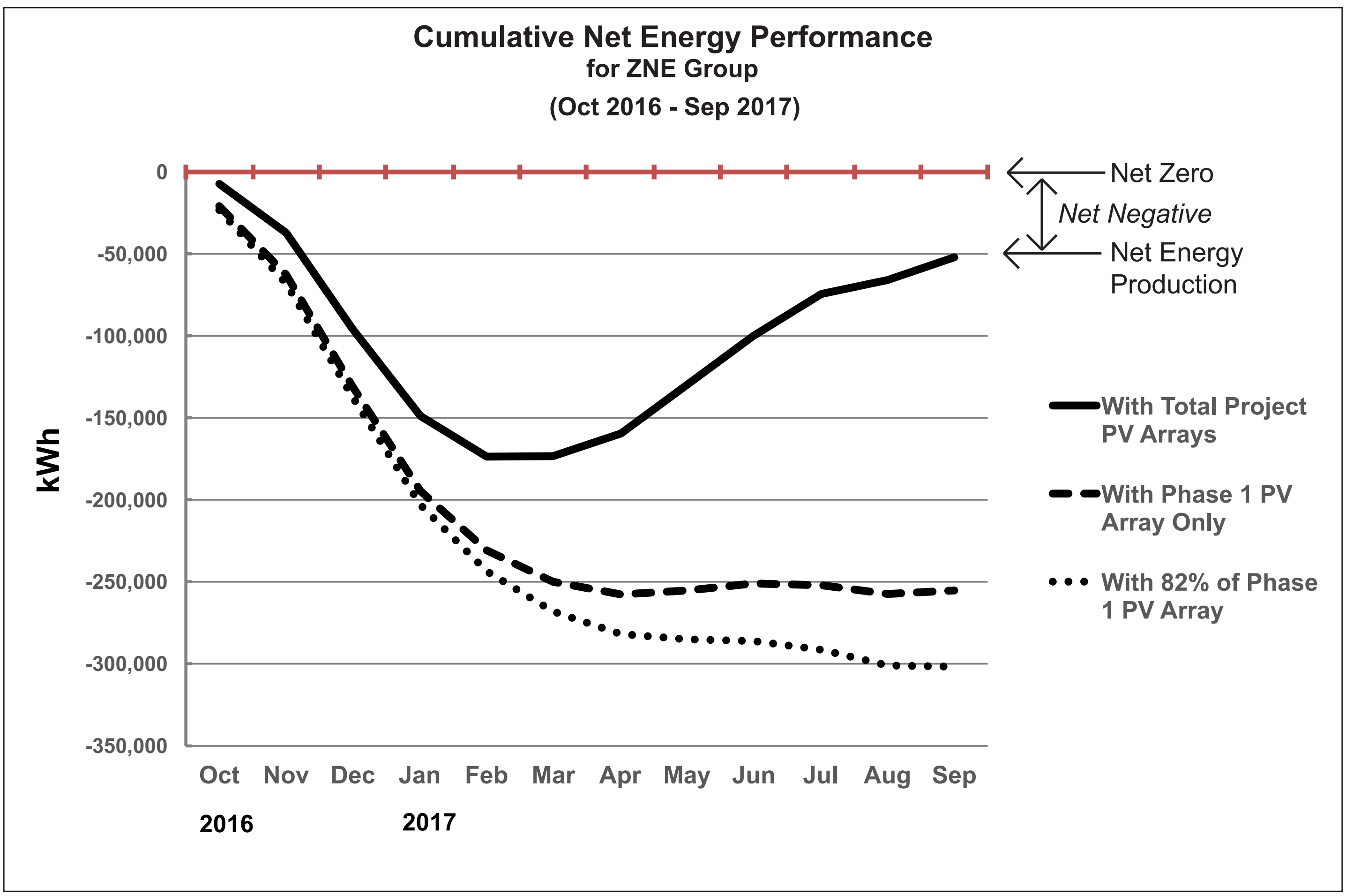



**Measured Energy Use for ZNE Group**
**Annual Total**
**(2016 -2017)**

512 MWh/year
Measured EUI = 29.9




Solar Photovoltaic System Performance
(Oct 2016 - Sep 2017)
kWh
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
2016
2017
Total Energy Use for ZNE Group
Energy Production—Total Project PV Arrays
Energy Production—Phase 1 PV Array Only
Energy Production—82% of Phase 1 PV Array


Cumulative Net Energy Performance
for ZNE Group
(Oct 2016 - Sep 2017)
kWh
0
-50,000
-100,000
-150,000
-200,000
-250,000
-300,000
-350,000
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
2016
2017
Net Zero
Net Negative
Net Energy Production
With Total Project PV Arrays
With Phase 1 PV Array Only
With 82% of Phase 1 PV Array

It is obvious from the charts of the energy consumption that heating using a conventional gas boiler plant is the largest energy demand of the building—approximately 75% of the total. This dominance by heating energy is partially the result that the other forms of energy use are so efficient and received the greatest attention in the innovative design approaches. It is easy to surmise that cooling energy demand would be much larger with a more conventional approach to the design of the building features and systems. There are additional explanations for the large proportion of heating in the overall energy use; these are discussed below.

Refer to the section, *Post-Occupancy: Observations and Conclusions*, for further discussion of the metering and data reliability issue, as well as more thoughts on the dominance of the energy use for heating.

*Energy Production versus Energy Use: Zero Net Energy*

This case study of an ostensibly zero-net-energy building project involves only a part of the two-phase total project that could be designed with an on-site renewable energy system and achieve ZNE performance, namely "The ZNE Group", as defined in the floor plan diagrams on page 38. This collection of structures was carefully designed with atypical (for this K-12 building type) and innovative systems, which helped the case study "building" reach an energy consumption benchmark of EUI = 29.9. (The national range for this building type reported by the Energy Star benchmarking tool, *Portfolio Manager*, averages EUI = 123, with EUI = 30 being in the top 3% of energy performance.) The energy use of this collection of structures is therefore comparatively very low and within the range that is characteristic of zero-net-energy performance.

On the energy production side, the solar PV system was built in the two phases of construction, two years between the completion of each part of the installation. Since "The ZNE Group" was completed in the first phase, it is not clear how much of the total PV system's energy generation can be assigned to "The ZNE Group" for assessing ZNE performance. In reality this is a semantic distinction only, whether the whole PV system or only an appropriate fraction thereof is assigned to "The ZNE Group".

For that reason, the charts on the facing page show the results for three different sizes of the installed PV system: (1) the entire PV array installed at the end of both phases of construction; (2) the PV array installed at the end of Phase 1; (3) 82% of the PV array installed at the end of Phase 1, corresponding to the fraction of Phase 1 floor area that constitutes "The ZNE Group". Clearly, use of the first method of accounting for on-site energy production provides the most favorable metric to satisfy the definition of "ZNE performance". The charts present the energy production data for all three methods so that the relative differences can be seen.

The chart on the top of the facing page shows the energy consumed versus the energy produced over the course of a recent year. The relative impact of the large amount of energy consumed for heating during two winter months is apparent, compared to the energy produced by the PV system over the course of the year.

The chart on the bottom of the facing page shows the *cumulative* amount of net energy (production minus use) over the course of the year. The curve would return to the zero axis at the end of the year if the performance were exactly ZNE. (Above the zero axis after one year would signify a *net positive* performance.) As can be seen, "The ZNE Group" is performing at *net negative*, even using the full project PV array.

The reason for this performance of the case study building is again primarily because of the high heating energy demand during two winter months, which creates a deficit that cannot be overcome even by good performance of the solar PV system. This is discussed further in the following section.

PHOTO: DALE LANG

## Post Occupancy: Observations and Conclusions

This large and complex K-12 project is ambitious in its energy performance goals and "cutting edge" in some of the design strategies employed. The project succeeded in achieving a very low energy use, as evidenced by its EUI, and installed a sizable solar PV system on available rooftops. It also effectively created a model for the District of a design approach for energy performance that can be emulated in other District projects.

Like all new design approaches, there are inevitably degrees of success for different systems and impacts on the customary patterns of use and building maintenance. A candid assessment of these permits improved design in future projects and some of these are discussed below.

*Post Occupancy: Controls and Monitoring*

Control systems and metering of actual energy use continue to be a source of problems for many high-performance buildings. In this case, problems occurred with the metering system and the handoff to the data display company (Lucid) that was developing the on-site dashboard for reporting on energy use and energy production.

At the time that the system was initially commissioned, some of the metering circuit may have been incorrectly wired and this was not detected. In addition, some of the circuits were given unclear name assignments that were not descriptively clear about the energy loads being monitored. (The dashboard programmers could only use the information provided by the control system vendor and these were not vetted by District facilities staff.)

There were additional post-occupancy factors affecting the reporting of energy data on the part of the District. The on-site energy dashboard screen that displayed the metered performance was removed because the young students did not understand its purpose and used it as a media toy. The online dashboard remained, intended as a method of regularly reporting the energy performance to District facilities staff. But due to personnel turnover, the District staff did not check the accuracy of the data being reported nor did they regularly monitor the performance of the different systems. The current District staff only became aware of the original issue of the metering system structure when asked to provide the energy use data for this case study. After considerable discussion among District staff, the dashboard technician and the project design engineers, the problems were identified and "work-arounds" were devised, as described in the section, *Energy Use — Actual Measurement of Performance Results.*

For future data reporting and monitoring, the District plans to investigate the metering system and correct any errors, effectively re-commissioning the system. An action plan will then be put in place for regular reporting on the energy performance of all features of the complex. This will enable the District to be aware of any anomalies in system functions and to investigate them.

*Post Occupancy: HVAC*

The "Cool Tower" represents a unique feature of the HVAC that is used in lieu of conventional mechanical cooling systems typically employed in K-12 projects. Its prototype design and performance was obviously not well known before construction, but as the data shows, the performance during the initial occupancy period has been good. Initially, the only operational issue was with the large damper banks common in evaporative coolers, which had to be engineered carefully so that they all closed at the same time.

The classrooms also functioned well with the displacement ventilation system and the thermal mass added to the classroom walls. Temperature sensors that were located in the floors showed that the night ventilation mode of operation was very effective. In fact, measurements indicate that the thermal mass provides more radiant cooling effect than estimated during design. (Fans ceased night operation sooner than expected.)

The biggest issue concerns the large heating loads in midwinter that are offset by the conventional boiler plant. As the energy performance charts indicate, these account for 75% of the energy consumed by “The ZNE Group” of buildings and essentially cause it to fall short of ZNE performance. The building is still energy-efficient, as evidenced by its EUI = 29.9, so perhaps the large heating component is the result of the other systems being extraordinarily low by comparison.

There are other possible explanations, however, which the District may investigate. The first is a control system or component malfunction that operates the boiler at a level that is inefficient or wasteful. Another is that the users (students, teachers or maintenance personnel) are operating the controls or spaces incorrectly, generating the use of more heating during the winter months. These causes of use of extra heating energy are correctable.

There may also be a contributing factor of the structure of the building walls, which are basic 2X6 metal stud framing. There is a significant thermal bridging effect in such walls that do not have an added layer of continuous insulation to prevent heat transfer through the metal stud. It is estimated that the R-value of the wall assembly in such cases can be reduced by about 60% from the nominal value of the insulation. The decision to omit the layer of continuous insulation was based on cost, but nevertheless it resulted in a higher expenditure of energy for heating.

*Post Occupancy: Occupant Behavior*

The efficient operation of the unconventional systems in this project, particularly in the classrooms, requires some understanding of the design features and how they work. This effectively involves two groups of users: the teachers and the maintenance staff. When the building first opened, the maintenance staff received some training in system operations and the features of the controls.

One of the trained staff persons was assigned as liaison with the teachers, explaining the operation and controls as part of a teacher orientation at the start of the school year. However, this person was transferred and the replacement was not trained in the use of building. As a result, the teacher orientation was dropped, then discontinued. The only information available to a teacher is an instruction card posted on the classroom wall.

The result is a tendency for teachers to use the building like conventional one, often making operational errors. For example, as described in the section, *Heating, Cooling and Ventilation*, when the outside air is cool enough in the Swing Season to provide cooling with just fresh air from the package unit, the large room fan is automatically off. Yet teachers often override the fan’s controls and turn it on, not understanding that it is unnecessary. Similarly, when the outside air is warm and the large room fan is operating at full power (but not disrupting the classroom environment with noise or air “flutter”), teachers often open the classroom door or windows, which automatically shuts off the large room fan. This system behavior is counter-intuitive to the untrained teacher.

Lack of training or orientation to the operation of this building also resulted in observed behaviors such as overriding dimming controls when entering the classroom when light levels are sufficient for visual acuity, simply because the eyes have not immediately adjusted to the light difference with the exterior environment.

The building is currently close to ZNE operation and performance. Re-institution of a thorough orientation program for the teachers and training for the new maintenance staff may help close the gap and bring the building to *Zero*.

PHOTO: DALE LANG

CASE STUDY NO. 14

# California DMV Field Office

PHOTO: PAUL MULLINS

# California DMV Field Office

## *Case Study No. 14*

**Data Summary**

**Building Type:** Government Service Office

**Location:** Fresno, CA

**Gross Floor Area**: 19,080 gsf

**Occupied:** 2014

**Energy Modeling Software:** Post-design only eQuest v. 3.65

**Modeled EUI (Site):** 52.5 kBtu/sf-year

**Measured EUI (Site):** 38.6 kBtu/sf-year (2015-16)

**On-Site Renewable Energy System Installed:** 304 kW (DC) Solar PV

**Measured On-Site Energy Production:** 252,000 kWh/year (2015-16) 43.4 kBtu/sf-year (2015-16)

**Owner/Client**

State of California

Department of Motor Vehicles - Client/User

Department of General Services (DGS) - Project Management

**Design Team**

*Architect:* SIM-PBK, Fresno, CA

*Structural Engineer:* Advanced Structural Design Incorporated, Fresno, CA

*Mechanical/Plumbing Engineer:* LP Consulting Engineers, Clovis, CA

*Electrical Engineer and Lighting Design:* Hardin-Davidson Engineering Group, Clovis, CA

*Landscape Architect:* Robert Boro, Fresno, CA

**General Contractor**

Durham Construction, Clovis, CA

The subject of this case study is a type of building that is repeatedly built with the same program elements and in relatively large numbers as new or replacement buildings. What differs is the climate at the site and occasionally the gross size of the facility. It is instructive to see what ZNE design strategies are common to such similar-functioning buildings and how the location and site affect the application of those strategies.

In addition, the generic type of building in this case is state-owned, dispersed throughout the state and providing public service functions that every person in the state can utilize. This exposure makes the incorporation of ZNE design features particularly noticeable and informative, signaling to users of the building a change in priorities of the State of California in how its buildings are designed and constructed.

To that end, the governor of California issued AN executive order in 2012 requiring all state-owned buildings to be ZNE according to a number of scheduled deadlines:

> "It is further ordered that all new State buildings and major renovations beginning design after 2025 be constructed as Zero Net Energy facilities with an interim target for 50% of new facilities beginning design after 2020 to be Zero Net Energy. State agencies shall also take measures toward achieving Zero Net Energy for 50% of the square footage of existing state-owned building area by 2025." [1]

As a result of the schedule milestones of this executive order, various state agencies immediately developed plans to implement the requirements. This case study describes the first steps taken by the California Department of Motor Vehicles (DMV).

### Background

The DMV annually revises its five-year plan for replacing or renovating current facilities. In 2013, the agency responded to the governor's executive order about planning for ZNE buildings in the near future, in particular to address the goal that 50% of the square footage of existing building area be ZNE by 2025. To get a head start on the latter, considering the large number of existing DMV buildings across the state, the DMV decided to convert an in-progress replacement project, then a few months into construction in the City of Fresno, to a ZNE facility. Other DMV projects that had not yet begun design or construction—all programmatically similar field offices—were designated to be ZNE, but none was quite as affected by the change to the requirements as the Fresno project.

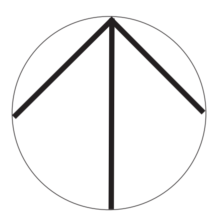
### Design Process and Low Energy Design Strategies

Originally designated as an on-site replacement building that would be nearly twice the size of the original 11,000 sq. ft., 46-year old facility, the new building began design in 2008-9. The design was mandated to be LEED-Silver certified, which enabled the design team to adopt strategies that maximized energy efficiency if life-cycle cost analysis showed that such strategies were cost effective. First-cost was not the only basis for design decisions. The final design, completed before the ZNE Executive Order B-18-12, therefore incorporated the correct basic design strategies to minimize energy use needed for ZNE performance with an on-site renewable energy source.

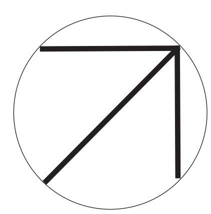
The project design and construction was managed at the state level by the Department of General Services (DGS), who utilized the standard design-bid-build process. After the successful bid process, the selected general contractor was awarded the contract and began construction

[1] Governor's Executive Order EO B-18-12. See https://www.gov.ca.gov/2012/04/25/news17508/ and http://www.climatechange.ca.gov/climate_action_team/documents/Green_Building_Action_Plan.pdf.

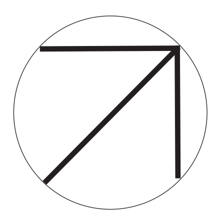
California DMV Field Office: General Vicinity Plan

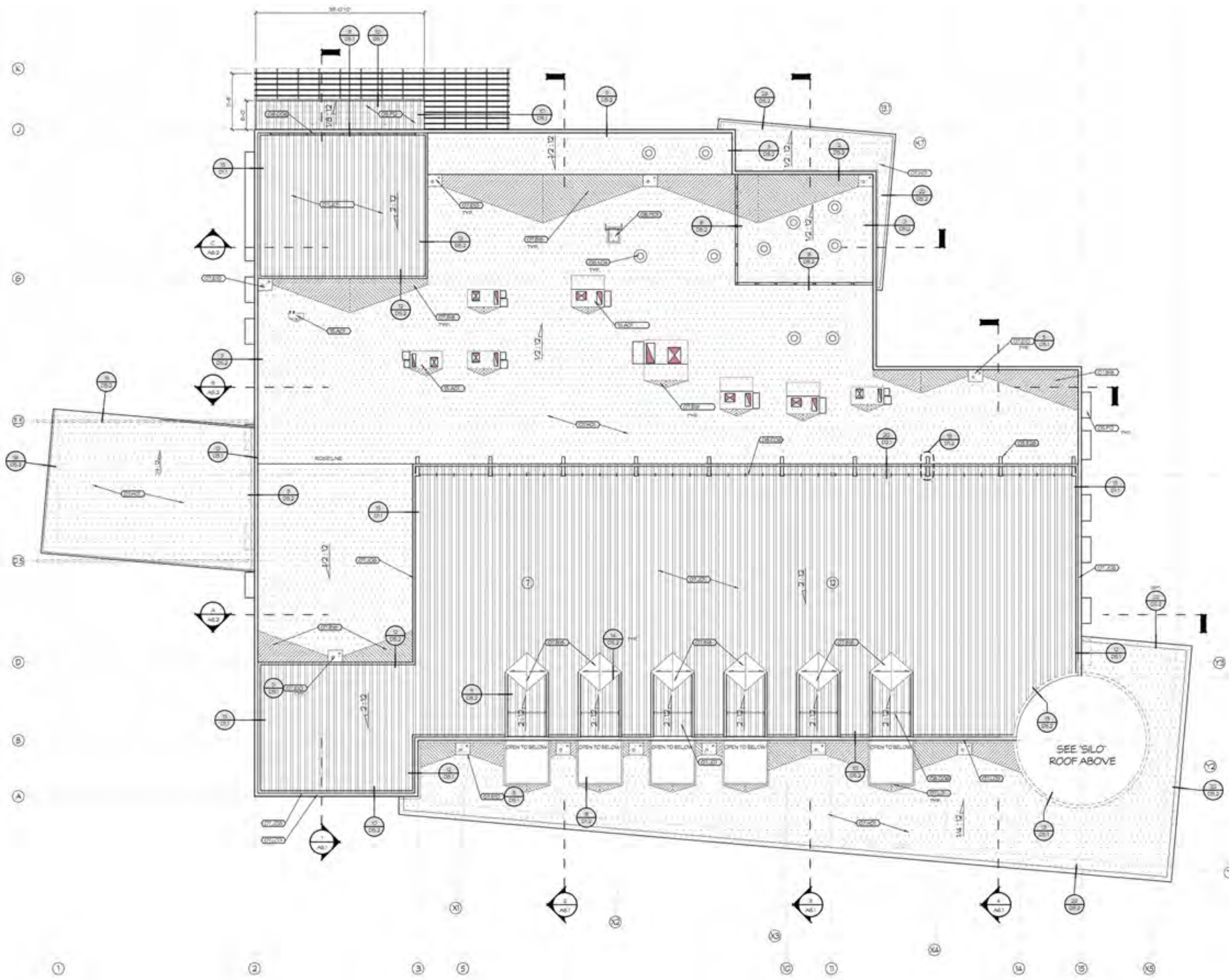



California DMV Field Office: Floor Plan




California DMV Field Office: Site Plan and Satellite View (No Scale)






*(Above)* Roof Plan. (Courtesy of SIM-PBK)

in January, 2013. Shortly after that, the executive order was issued and the DMV decided to make this Fresno field office replacement facility its first ZNE project.

Since the building was already under construction, the two state agencies decided to leave the building design unchanged and simply to add enough PV arrays to the building and the site in order to produce a ZNE performance. It was determined that the building design was essentially already optimized for low energy use and it would be less disruptive to the state contract process and the schedule to just right-size the PV system and add it to the project scope.

The new work was added via change order issued to the general contractor and additional services for the design team to design and specify the PV system and its ancillary structures.

*Planning Concept and General Design Considerations*

Programmatically, the facility provides twenty-six operating transaction windows, multiple drive test and vehicle verification lanes and usually serves 1,500 to 2,000 people per day, a large user population at any one time.

The spatial relationships and diagrams are tightly prescribed for this building type, so the shape of the floor plan is pre-determined to a large extent. The existing building also had to kept operational during construction. These constraints, combined with the site geometry and access conditions, essentially set the location at the north end of the site, with an orientation toward the southeast.

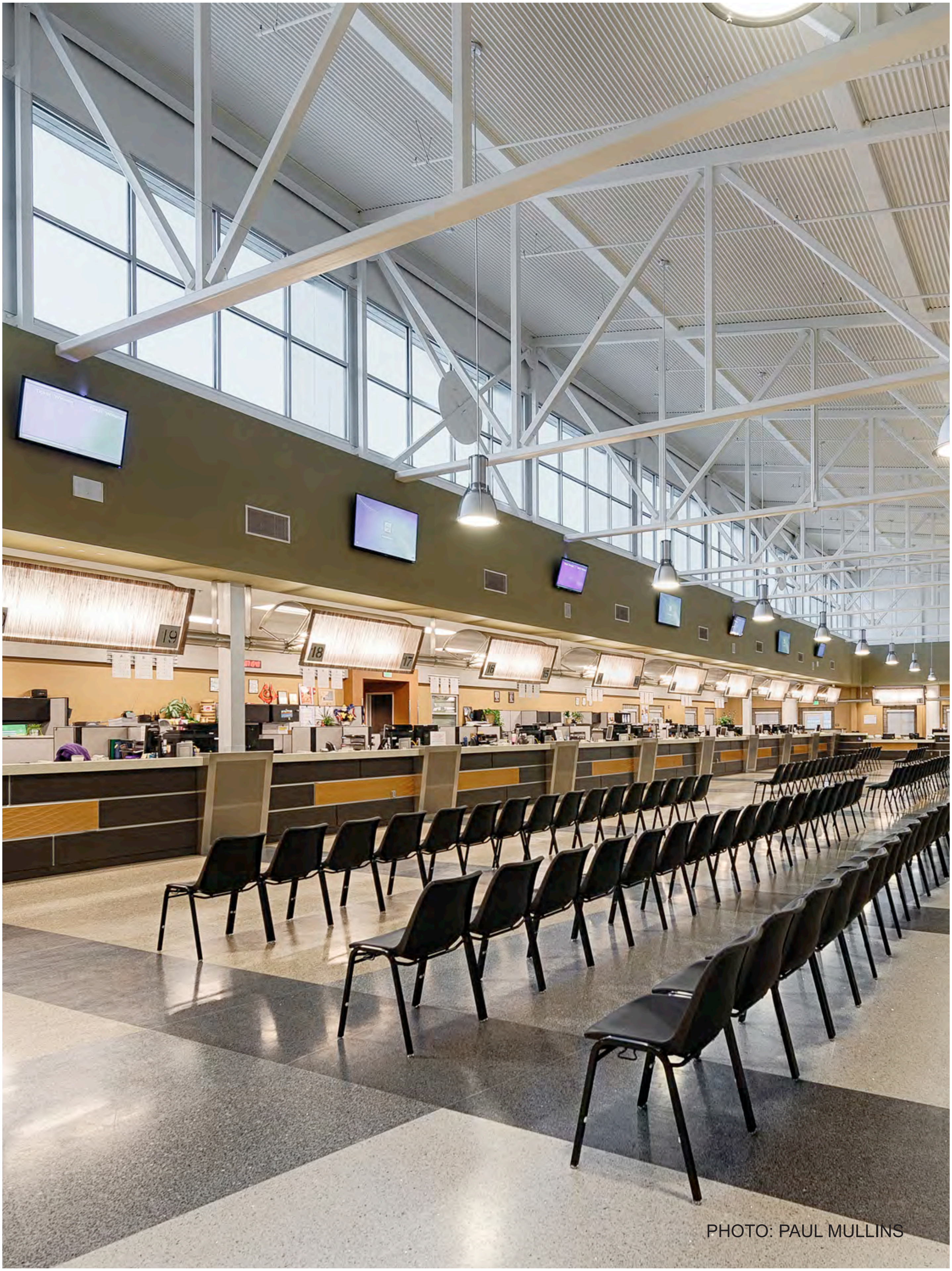
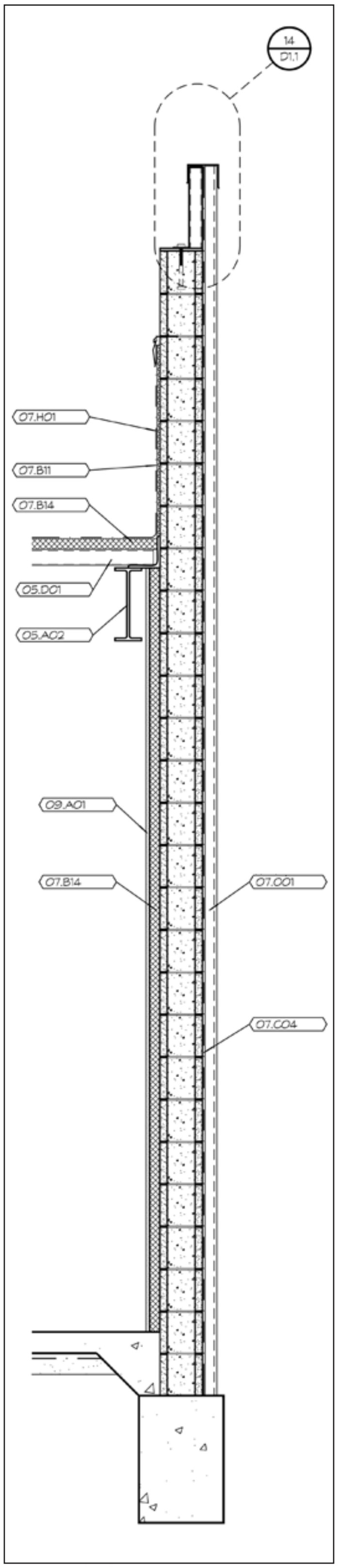


PHOTO: PAUL MULLINS

*(Below)* Typical wall section. (Courtesy of SIM-PBK)




*Building Envelope*

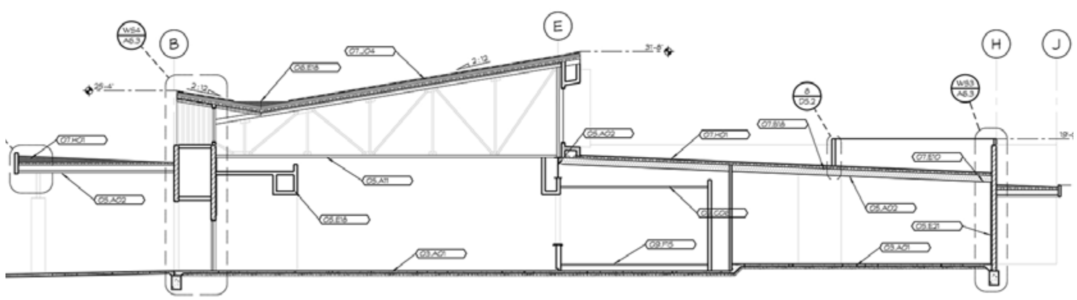
The exterior walls predominently consist of a concrete masonry unit (CMU) structure sandwiched between metal panels on the exterior and a 2” layer of continuous insulation boards and a gypsum board finish on the interior. The attachment detail of the gypsum board layer allows thermal bridging to occur, so the wall only achieves a thermal resistance value of approximately R-5. The roof structure in general, however, has a much higher average level of thermal resistance, R-38, through more aggressive use of extra layers of insulation where space allows, which is important for a roof-dominated one-story structure in this climate.

The glazing is well-protected and is specified as low-e glass.

*Daylighting and Electric Lighting*

The daylighting roof monitor provides daylight for the main central space in the building, substantially reducing electric energy demand during midday hours. The monitor actually faces northwest and, combined with the protected south clerestory windows, provides balanced and comfortable daylight distribution within that space.

Daylight and occupancy controls ensure efficient operation of the electrical lighting system, which consists entirely of LED light fixtures. Solar tubes were used for the lighting in all the corridors, restrooms and storage rooms, which were easily worked around when the PV array was added to the roof during the construction phase.



*Heating, Ventilating and Cooling Systems*

The mechanical system uses standard package DX rooftop units, but with one advanced feature: air distribution is done via a raised floor approach. This allows the use of displacement ventilation for fresh air, where cool, fresh outside air is initially filtered and introduced at the floor level, slowly rising as it becomes warmed by occupant body heat. It is then exhausted directly out of the building without the need for an energy-consuming fan.

Night operation of the HVAC units is utilized during the swing season to use outside air to pre-cool the building in anticipation of the cooling demand later in the day.

*Plug Load and Equipment*

Where applicable, all equipment is EnergyStar rated.

## Renewable On-Site Energy Supply

The change order to the project that added the solar photovoltaic arrays and the ancillary equipment and supporting structures occurred several months into construction. The DGS hired a consultant to calculate the PV system output required to meet a likely load for the building as designed. Analysis revealed that the required array size was larger than the building roof, so canopy structures were also added in the parking area to accommodate the additional panels needed. Some extra panels were added for electric vehicle charging stations that were installed for customer use as well.

The result was a 304 kW system installed on the site (600 panels) and the building (350 panels). A panel monitoring system provides information about power produced at the inverters on an hourly basis and also measures the amount of irradiation emitted from the panels to determine if the panels require cleaning or maintenance. The energy generation data is sent to a flat panel display in the Lobby as part of an informational outreach program for the public.

PHOTO: PAUL MULLINS


PHOTO: PAUL MULLINS

## Energy Design Analysis and Energy Performance
### *Modeling versus Post-Occupancy Measurement*

*Energy Modeling*

The energy modeling done as part of the PV system sizing included a comprehensive analysis of energy use by type of load for the building as designed. *eQuest v3.65* was used for this purpose and automatically provides the energy use estimates by category of use. The modeling results yielded a total annual energy use of 311,200 kWh, or an EUI of 53.5 kBtu/sf per year. Since the purpose of the modeling was not "predictive" in any way or done as an assist to the building design effort, the result was somewhat conservative to ensure that the PV system was right-sized to produce ZNE performance.

*Energy Use—Actual Measurement and Comparison to Modeling Results*

Because of the late introduction of the ZNE performance goal to the project, no plan was made to meter the various types of energy use in the building. The energy production by the PV system is monitored, however, so it is possible to obtain totals of energy use for the project by combining the energy production totals with the utility's net metered electric energy and the metered use of natural gas.

Calculating this, the total energy use for the project in the year July 2015 through June 2016 was 224,250 kWh, or an EUI equal to 38.6 kBtu/sf per year. As expected, this was a good deal less (30%) than the amount conservatively estimated in the energy modeling.

The result is the total energy use by type of energy only, electricity and gas, not by category of use. Since gas is used only for heating and domestic hot water, a rough comparison can be made of this categories with gas use. Again, the intention of the modeling was not to inform the design, so there is limited value in drawing comparisons between modeled and measured totals.

*Energy Production versus Energy Use: Zero Net Energy Performance*

The solar PV system produced 232,000 kWh in that year from mid-2015 to mid-2016, equal to 43.4 kBtu/sf per year, therefore more than adequate to provide a cushion for ZNE performance, the immediate goal of the state agencies.

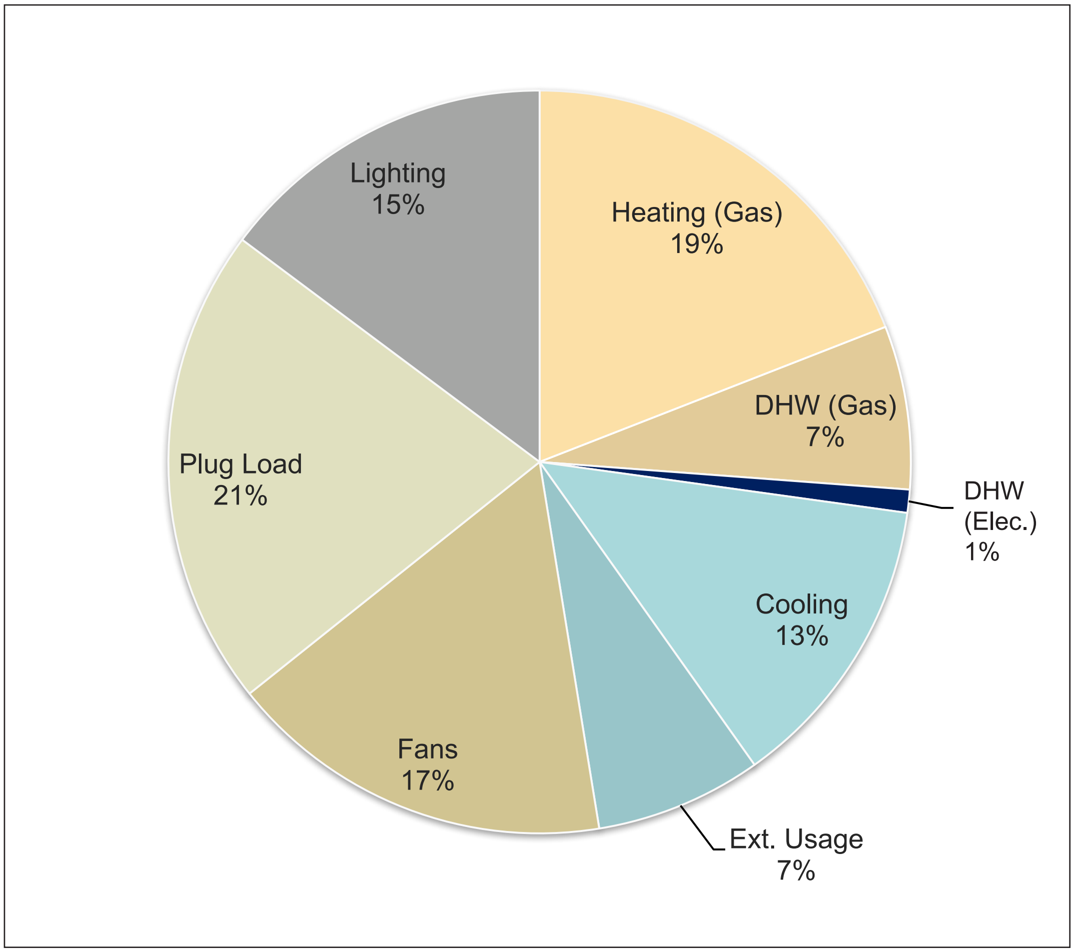
The *Cumulative Net Energy Performance* curve exhibits a near ideal representation of a well-balanced ZNE production versus use over the course of a year.

## Post Occupancy: Observations and Conclusions

This concluding section of the case study typically identifies those important aspects of the building where the ZNE design goals were not completely met, where an innovative system or building feature design failed to some extent to achieve the performance objective, or where unanticipated user behavior affected the energy use in a significant way. Because of the history of this particular project—a sufficiently large solar PV system was added to the project during construction to make it ZNE—this same type of cataloging of "lessons learned" cannot be done.

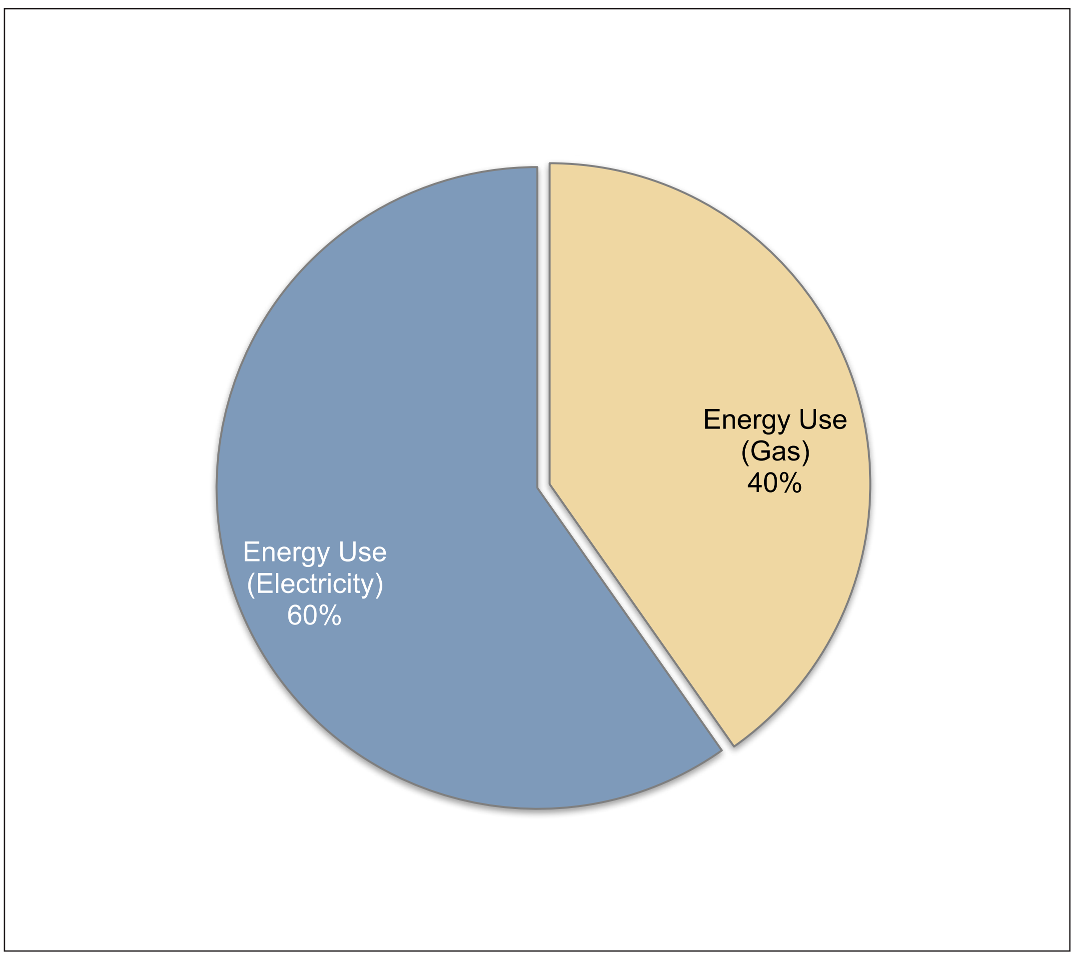
It is possible to observe generally that such "ZNE retrofits" can be done with sufficiently energy-efficient buildings and ample site area for the PV system. As the California DMV constructs similar new-building facilities with ZNE performance goals in the many types of climate zones across the state, it will be interesting to compare design features and performance results for the entire set of buildings in this programmatically prescribed typology.

Moreover, in contrast to this case study, these new facilities will be designed to achieve ZNE performance beginning at project inception and will employ integrated design strategies, features and technologies to minimize the energy use of the building to a higher standard. Such an integrated approach to the energy use and energy production building systems will necessarily result in the most cost-effective design choices.



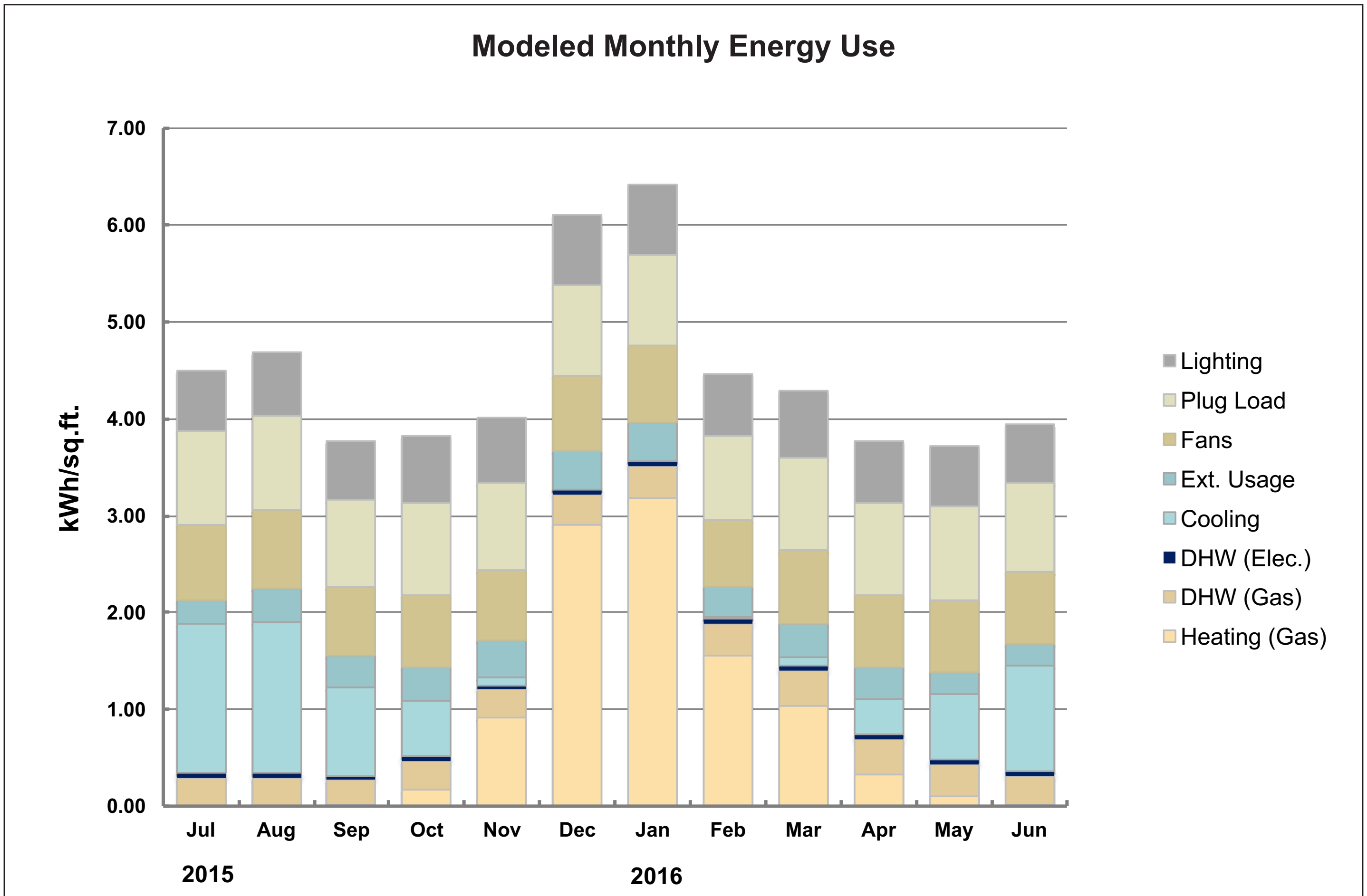

**Modeled Energy Use**
**(Annual)**

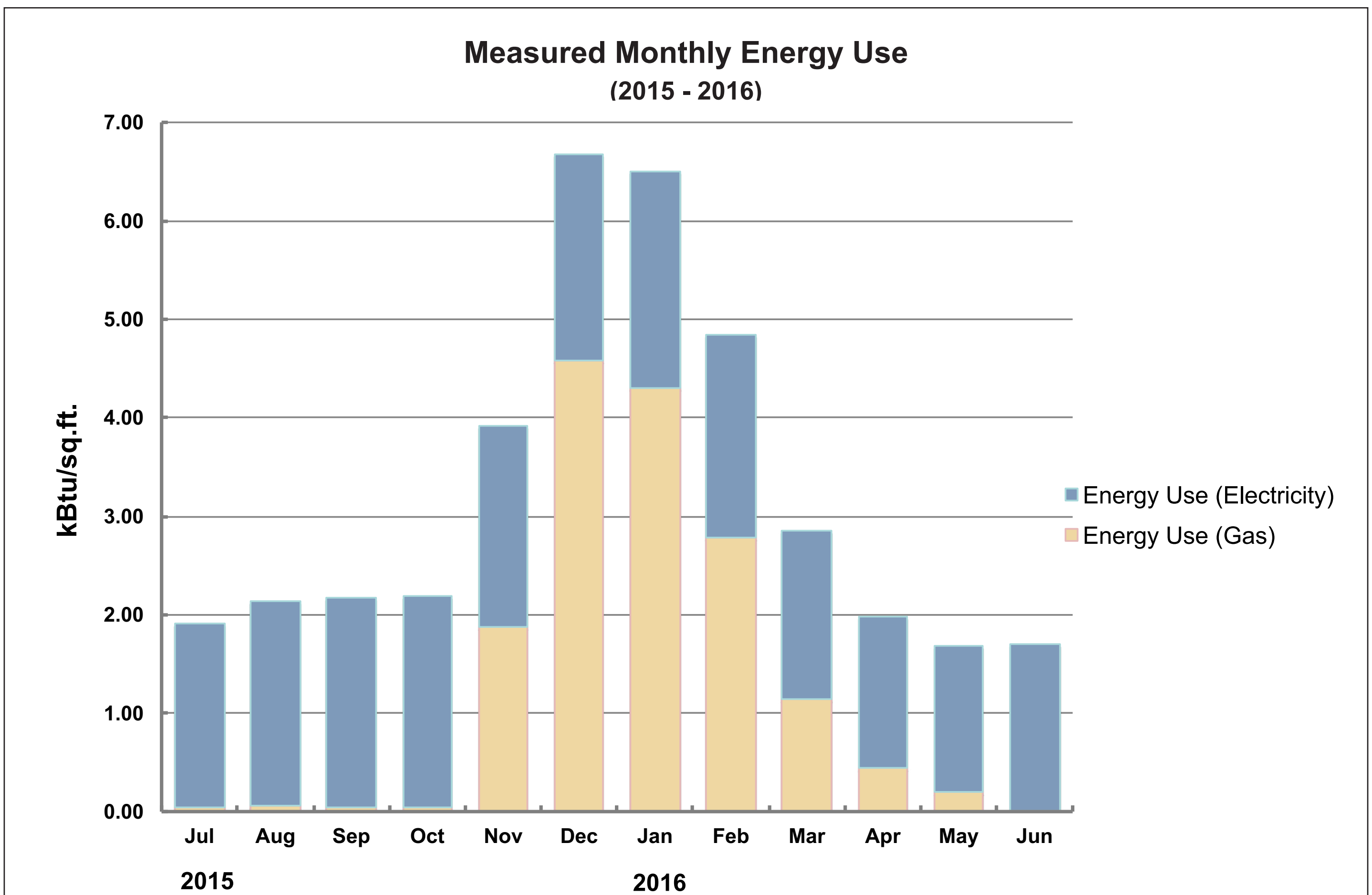
311,200 kWh/year
Modeled EUI = 53.5

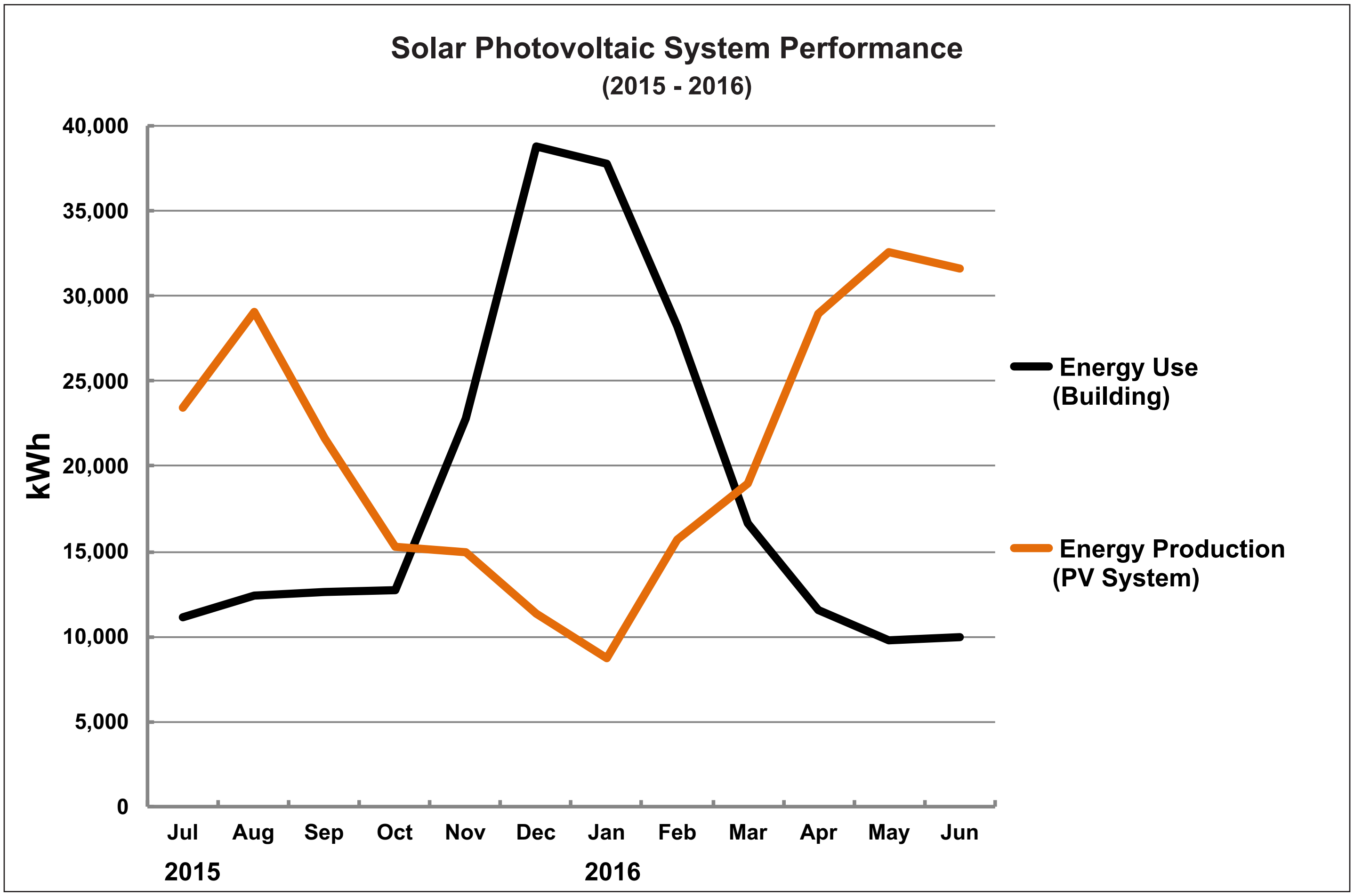


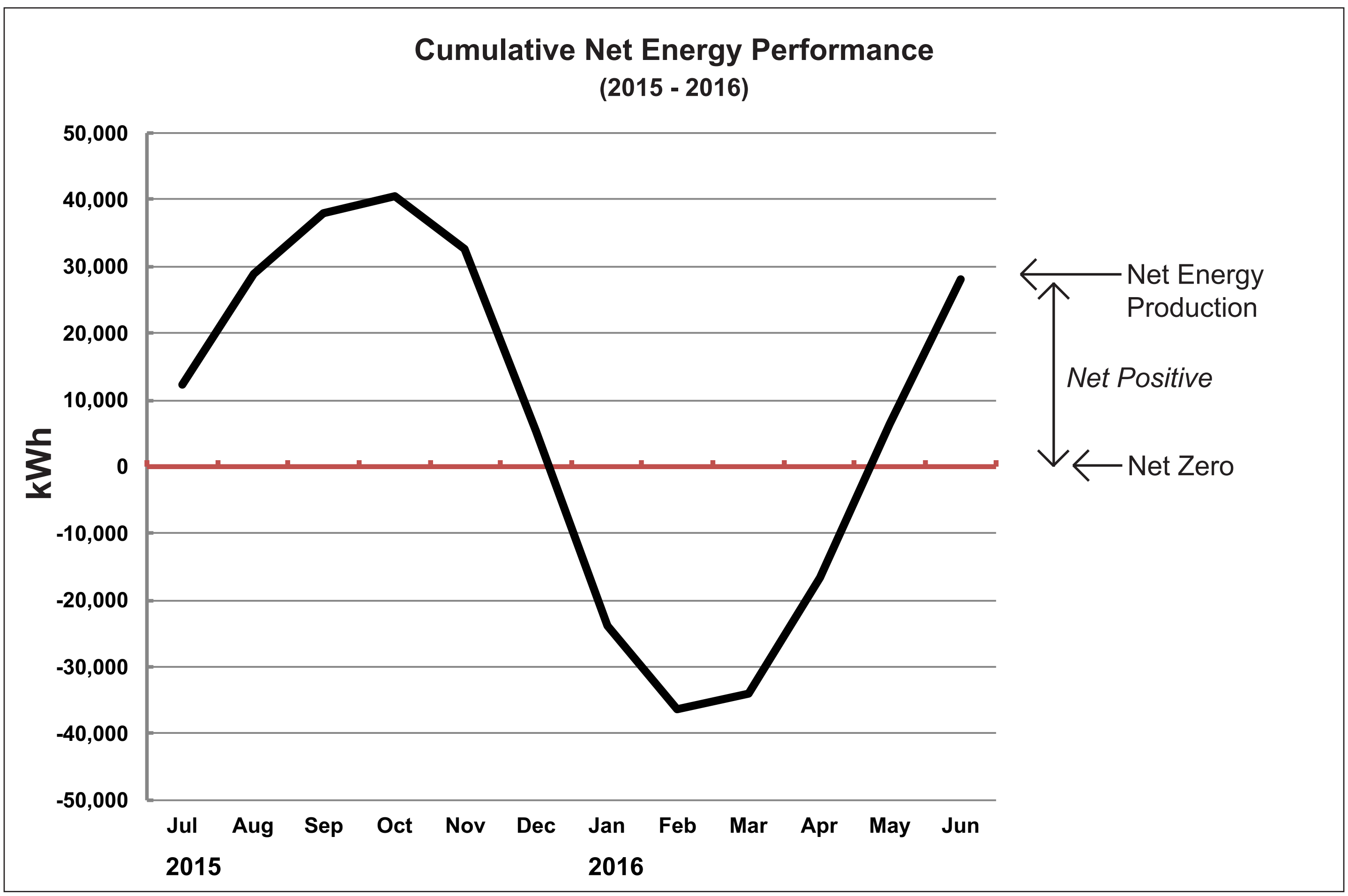

**Measured Energy Use**
**(2015 - 2016)**

224,250 kWh/year
Measured EUI = 38.6


Modeled Monthly Energy Use
kWh/sq.ft.
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2015
2016
Lighting
Plug Load
Fans
Ext. Usage
Cooling
DHW (Elec.)
DHW (Gas)
Heating (Gas)


Measured Monthly Energy Use
(2015 - 2016)
kBtu/sq.ft.
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2015
2016
Energy Use (Electricity)
Energy Use (Gas)


Solar Photovoltaic System Performance
(2015 - 2016)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
kWh
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2015
2016
Energy Use (Building)
Energy Production (PV System)


Cumulative Net Energy Performance
(2015 - 2016)
50,000
40,000
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
-40,000
-50,000
kWh
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2015
2016
Net Energy Production
Net Positive
Net Zero

PREFACE TO CASE STUDY NO. 15

# Butte College

*Toward a Bold Goal of Sustainability and Stretch to Zero Net Energy*

PHOTO: PETERSON PROVIDEO

# Butte College

## *Preface to Case Study No. 15*

The California community college system is the largest post-secondary education system in the United States, with an enrollment of 2.1 million students and a total of 72 community college districts distributed throughout the state. Of these, the Butte-Glenn Community College District located near Oroville in the northern part of the Central Valley of California, serves over 14,000 students.

Typical in many respects, Butte College is, however, a noteworthy case study because of its extraordinary commitment and successful efforts at overall sustainability and renewable energy supply for all of its campus facilities. This investment in renewable energy in the form of electric power from solar photovoltaic systems is, in fact, the unique story of Butte College. In the case of one its satellite buildings, the Chico Center (Case Study No. 15), total zero-net-energy performance has essentially been achieved.

**Zero Net Electric Energy: Bold Initiative for a Community College**

In 2004, college administrative leaders embarked on a bold sustainability program to transform existing campus facilities and to require new facilities to meet aggressive design standards that would enable the campus to reach the design goal of grid-positive performance. The challenge was not only technical but also very much one of funding such an investment in solar power for a public community college.

A comprehensive initial study examined the feasibility of facility retrofits for energy efficiency as well as design requirements for the first wave of new buildings, both of which would be funded through a local bond measure and state capital funds. With the passage of the bond measure, one side of the equation was able to be estimated, namely the total electric power demand of the campus over the course of a typical year. The corresponding annual solar PV production and overall size of the system required was then estimated. The practical issues could then be addressed: where to locate the PV panels, how to phase the installation of the total system and how to finance the entire collection of system components.

The estimated total size of the solar PV system required was approximately 4.5 MW (DC). This entire campus solar PV system was built in three separate phases from 2005 until 2011; the total rating of the final installed system is 4.55 MW (DC). The first two phases consisted of 10,000 solar PV panels, meeting less than 40% of the campus electric demand. The third phase then was the largest installation, consisting of 15,000 panels that generates the remainder of the power necessary to offset the majority of the District's electric demand.

Financing such a large and extensive solar PV system came from existing campus construction funds, special bonds, commercial loans and utility rebates. The campus benefited from declining prices for PV panels and the weakened economy from the Great Recession, which resulted in more competitive bids for the work. The federal economic stimulus package, passed by Congress in response to that recession, featured a bond program, the "Clean Renewable Energy

*(Opposite page)* Location of Butte College in northern California. (Satellite map courtesy of Planet Labs Inc., San Francisco.)

*(Below)* Some of the solar PV arrays on the Butte College campus.
(Photos: Peterson ProVideo)

*(Overleaf, next page)* Aerial photograph of the Oroville campus, in which the many solar PV arrays are visible across the site.

Satellite photo courtesy of Planet Labs Inc.

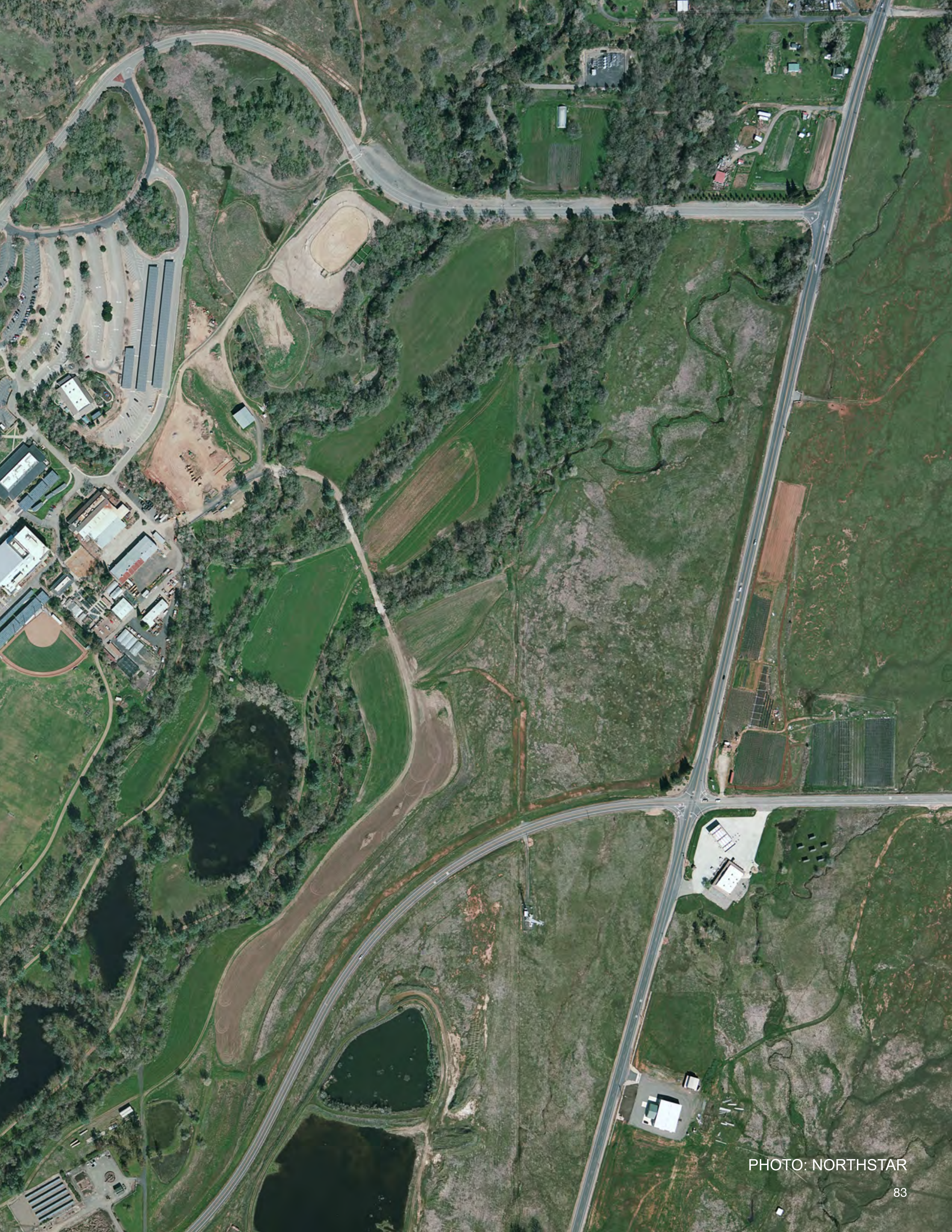


PHOTO: NORTHSTAR

*(This Page)* Various views of the installation and completed structures of the solar PV arrays on the Butte College campus.
(Photos: Peterson ProVideo)


*(Far Left)* Installation of the solar PV arrays on the canopy structures at the Chico Center. *(Near Left)* Large ground-mounted solar PV array at the Butte College campus near Oroville, CA.
(Photos: Peterson ProVideo)

Bonds (CREBS)", which Butte College used as part of its overall funding structure. All of these factors combined to reduce the cost of the entire system from the original estimate by more than 30%.

Construction of such a large on-site system had an extensive visual impact on the campus, which required some planning and design guidelines. The third phase involved 13 separate system installations that consist of simple (but large) canopy structures supporting the PV arrays. The canopy structures are located over parking areas and, more significantly, along pedestrian pathways creating shaded outdoor public areas that are welcome in the warm Central Valley climate.

An ancillary benefit of the construction of the campus solar electric system has been the experience afforded participating students in the Green Building Certificate and Clean Energy Workforce Training Program. Students enrolled in these program received hands-on training as part of the construction of Phase 3 of the system design and installation.

In November of 2017, in response to the further need to modernize the Oroville campus facilities and to support the needs of Educational Master Plan, the District proprosed and the voters approved a new bond measure to help fund construction for the next ten years. That facilities plan includes continuation of the solar energy initiatives of the previous dozen years. The RFP process for new and renovated projects includes the stipulation the solar PV systems be integrated into the design as part of the overall facility program.

*(Below)* Rendering of the new Welding Building, scheduled to be completed in 2019. Note roof covered with solar PV arrays as part of the continuing commitment to renewable energy supply for Butte College.

CASE STUDY NO. 15

# Butte College Chico Center


PHOTO: LPAS ARCHITECTURE

# Butte College Chico Center

*Case Study No. 15*

**Data Summary**

**Building Type:** Education - Community College

**Location:** Chico, CA

**Gross Floor Area**: 54,633 gsf

**Occupied:** 2004. (Solar PV System Installed 2011)

**Energy Modeling Software:** Energy Pro

**Measured EUI (Site):** 44.1 kBtu/sf-year (2016)

**On-Site Renewable Energy System Installed:** 450 kW (DC) Solar PV

**Measured On-Site Energy Production:** 656 kWh/year (2016) 41.0 kBtu/sf-year (2016)

**Owner/Client**

Butte-Glenn Community College District

**Design Team**

*Architect:* LPAS Architecture + Design, Sacramento, CA

*Structural Engineer:* Buehler & Buehler, Sacramento, CA

*Mechanical/Plumbing Engineer:* Turley & Associates, Sacramento, CA

*Electrical Engineer and Lighting Design:* The Engineering Enterprise, Auburn, CA

**Construction Management (CM-At-Risk, 2004-5)**

DPR Construction Co., Sacramento, CA

**Solar Project (2011)**

DPR Energy / Chico Electric Sacramento / Chico, CA

While Butte College embarked on its innovative program of moving to renewable energy as described in the previous Preface, it still had its Educational Master Plan to follow, which meant provision of new or renovated facilities to support that Plan. The community college system has a prescribed process for funding and approval of all new facilities, which had to be integrated with the general campus plans for the transition to the renewable energy infrastructure.

**Background**

Butte-Glenn Community College District proposed a bond measure for new and improved facilities, which was approved by the voters In 2002. This was the start of design and construction according to a facilities master plan, which ultimately included aspects of the three-phase solar PV systems installation that began in 2004. It also included funds for the construction of a much needed satellite campus building in Chico, which would serve the needs of the many students who until then had to commute the fifteen miles to the main Oroville campus.

The "Chico Center" was completed and occupied in 2005, but it was not until 2011 and Phase 3 of the campus-wide program to install solar PV systems that this building would be entirely powered by solar electric energy. In fact, the building actually achieved ZNE performance with the introduction of the solar PV systems at the Chico site, as this case study will show.

**Design Process and Low Energy Design Strategies**

At the time of its design, the Chico Center was required to meet California's energy standards, known as Title-24. The District did not require a LEED certification but nevertheless wanted to take advantage of the rebates for energy efficiency available through the *Savings By Design* program[1]. This program requires evidence of energy use performance at a minimum 10% better than that required by Title-24, using approved energy modeling software.

*Planning Concept and General Design Considerations*

The design approach was therefore to utilize conventional systems to achieve the energy efficiency required to meet *Savings By Design* criteria. The planning concept was dictated in part by the desire of the District to make the building visually prominent from the site-adjacent freeway and to provide maximum parking capacity on the remainder of the site. The result was an elongated building along the western edge of the site, overlooking the freeway.

*Building Envelope*

The walls, roof and glazing all meet Title-24 requirements of 2005. Exterior sunshades are not utilized.

*Daylighting and Electric Lighting*

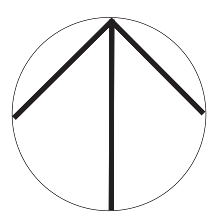
Electric lighting is basically standard for the year of design, meeting Title-24 limitations on installed power.

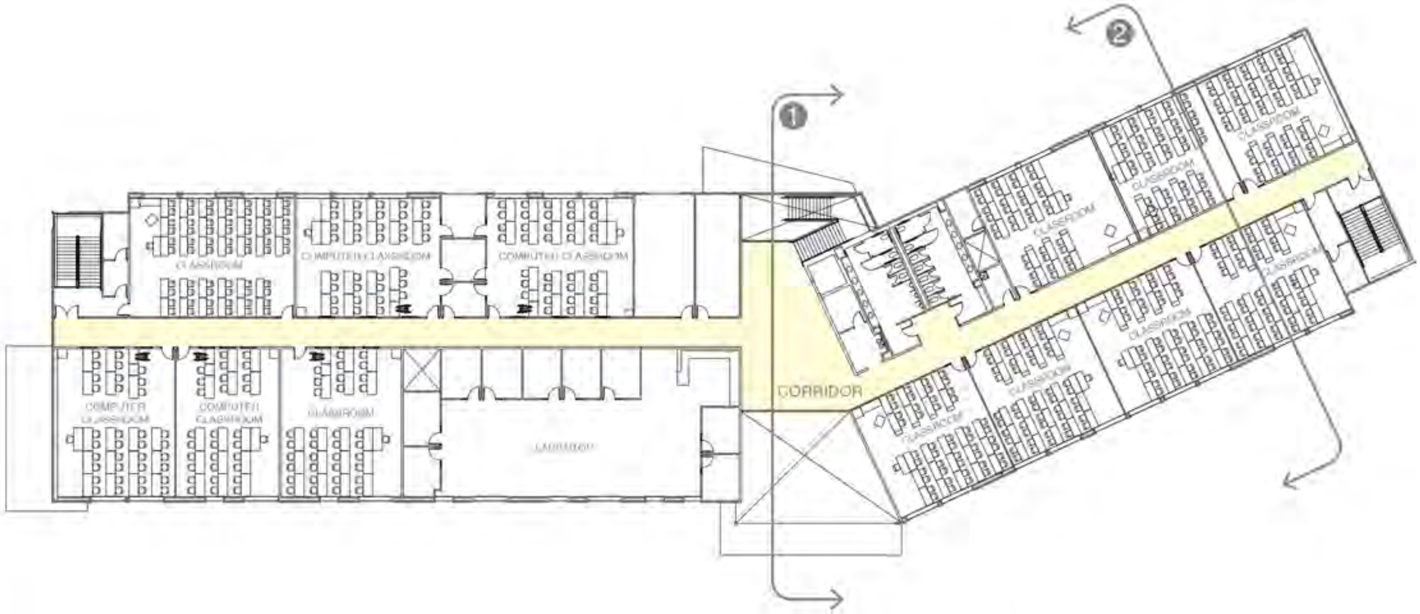
*Heating, Ventilating and Cooling Systems*

Large package HVAC units of conventional type and meeting Title-24 requirements occupy much of the roof area, limiting the possibility of the installation of solar PV panels. In 2011, as a result, when the PV panels were added to the project, they were installed on canopy structures above the south parking area.

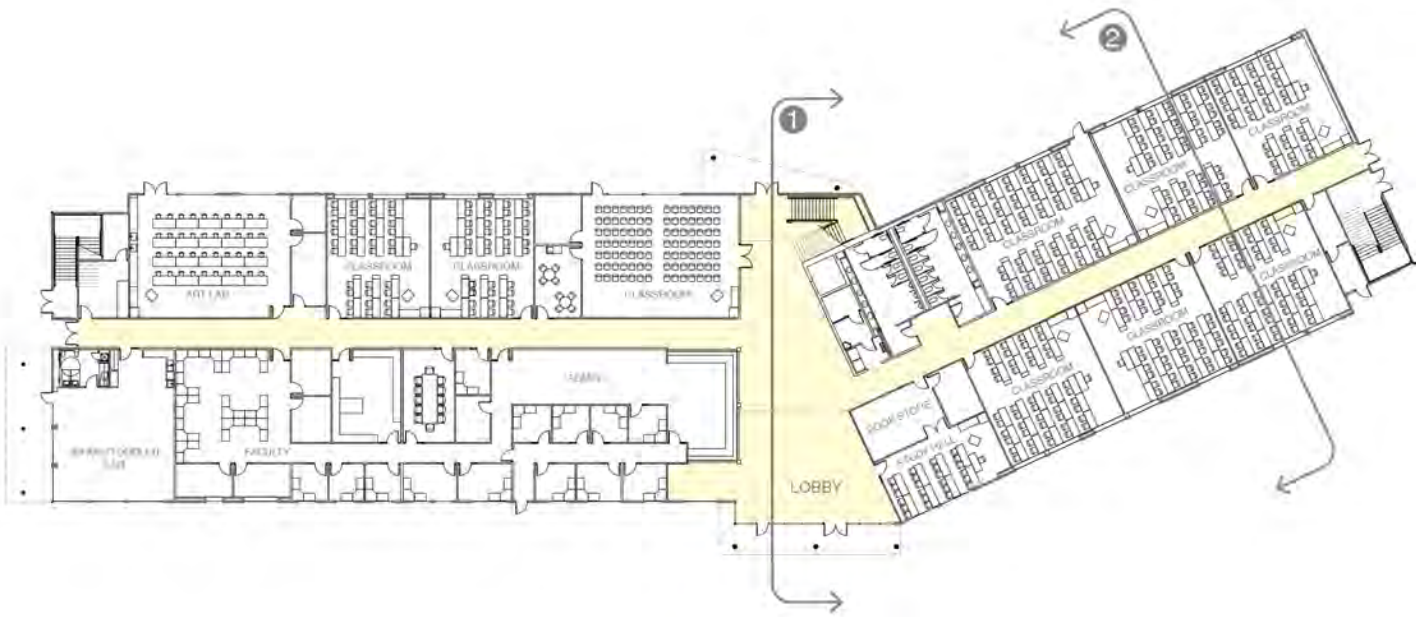
[1] PG&E Savings By Design (SBD) Program, http://www.savingsbydesign.com/

Butte College Chico Center: General Vicinity Plan



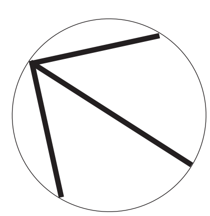


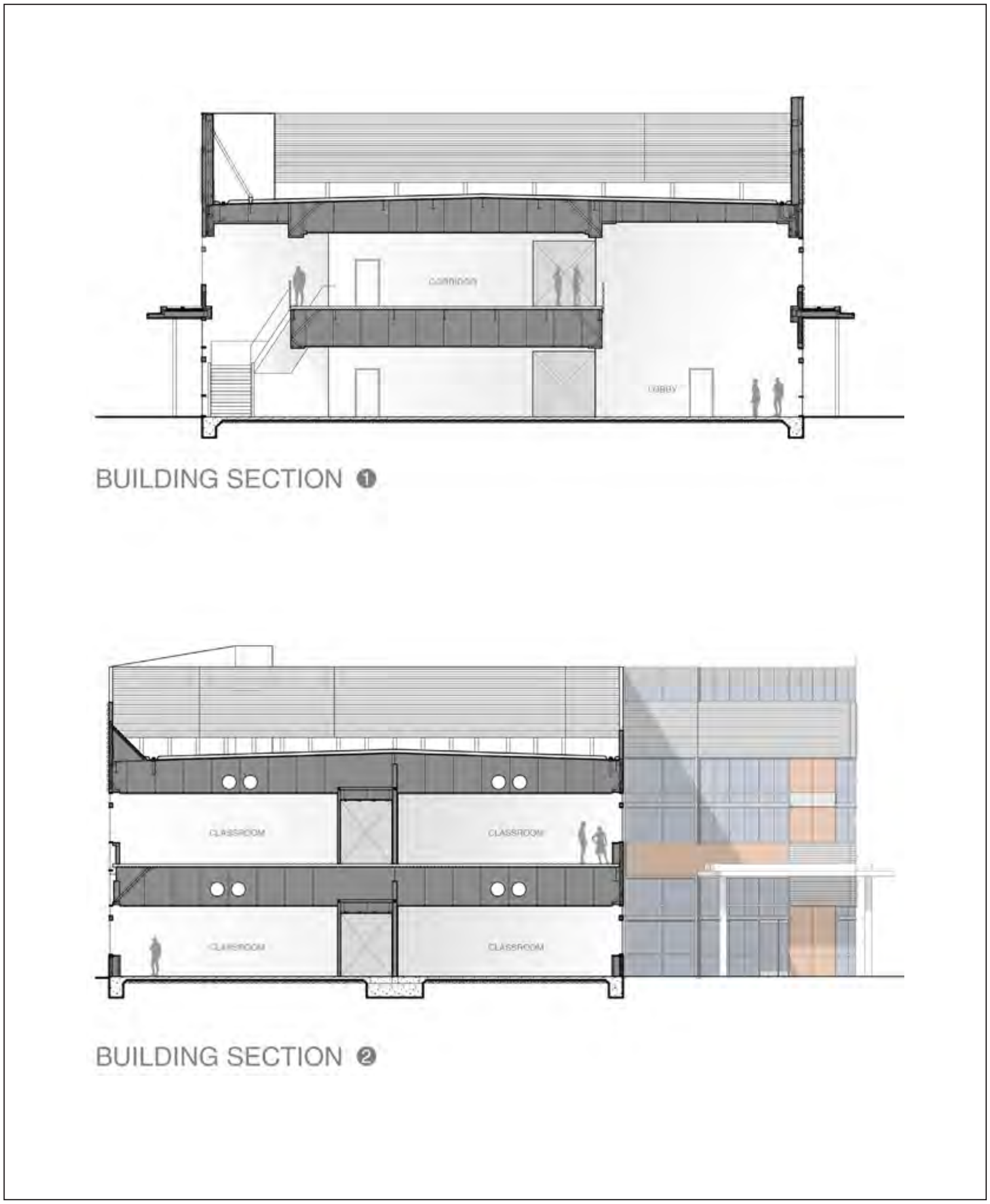

**SECOND FLOOR PLAN**




**FIRST FLOOR PLAN**

Butte College Chico Center: Floor Plan






*(Left)* Building Sections (not to scale). *(Next page)* View of Chico Center from freeway.

*Plug Load and Equipment*

Since the building was not originally designed to achieve ZNE performance and Title-24 does not regulate plug load, these parts of the energy use profile of the building were not considered.

*Master System Integration and Control Systems*

The building has separate basic control systems for HVAC and lighting as mandated by Title-24.


PHOTO: LPAS ARCHITECTURE

### Renewable On-Site Energy Supply

The initial installation of Phase 3 of the solar PV system project was at the Chico Center in 2011. By then, there was good data on the electrical energy use of the building over several years. The District wanted to include a number of electric vehicle charging stations in that canopied parking area as well.

As designed, the solar PV installation supplies energy directly to the building as required. Otherwise, the electric energy produced is fed to the electric grid. A utility net meter records the data as is conventionally done. Therefore, there is good data for solar energy production and total building use of electric energy. The electric vehicle charging stations are recorded as a building load, since they are connected back to the electrical distribution system of the building, and should be deducted from the building energy use in the ZNE calculation.

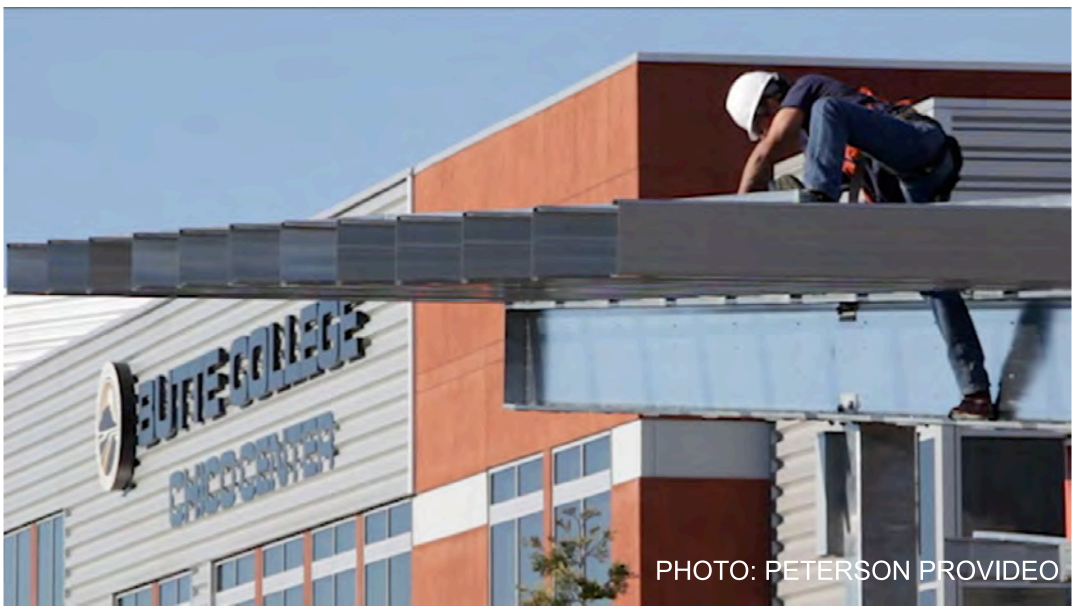


PHOTO: PETERSON PROVIDEO

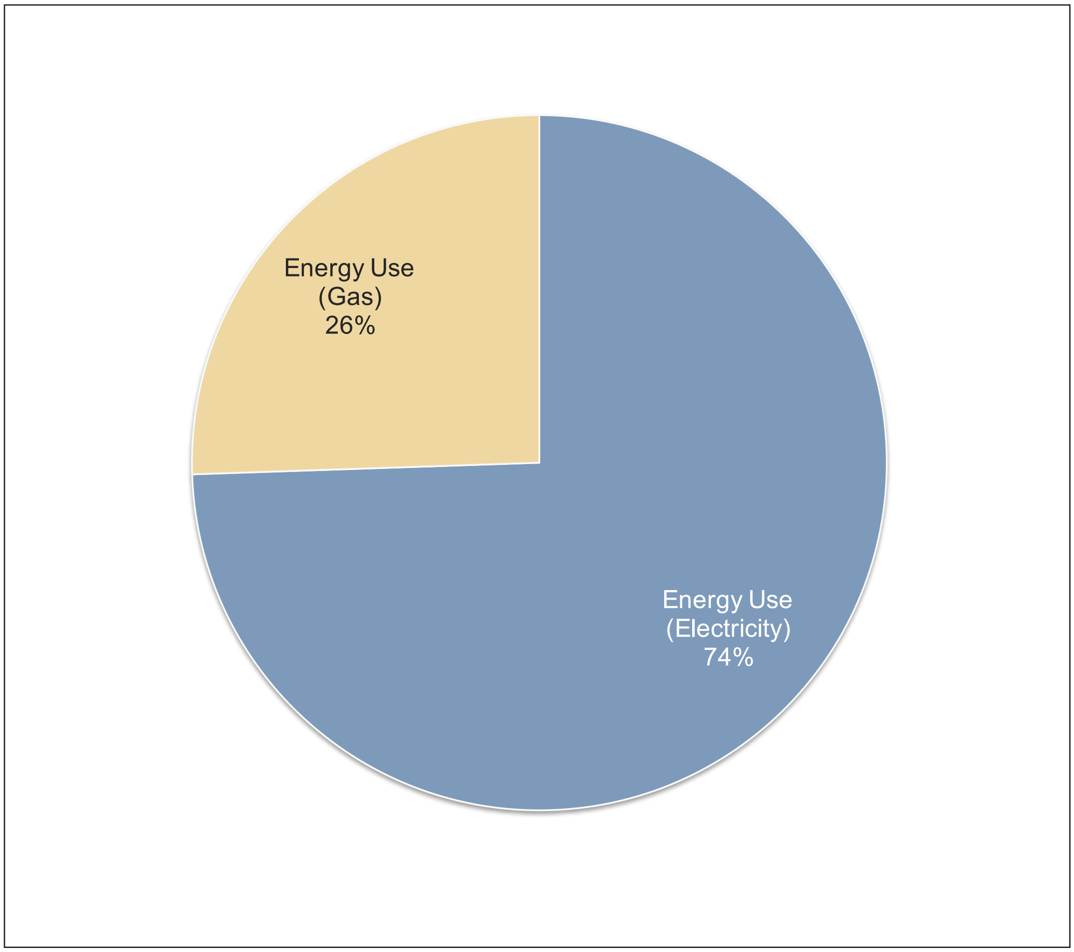
### Energy Design Analysis and Energy Performance
***Modeling versus Post-Occupancy Measurement***

*Energy Modeling*

*Energy Pro*, the certified whole building energy analysis software for use in *Savings By Design*, was used (2005 version) to verify energy use performance of at least 10% better than that required by Title-24 standards. (Results are not available.)

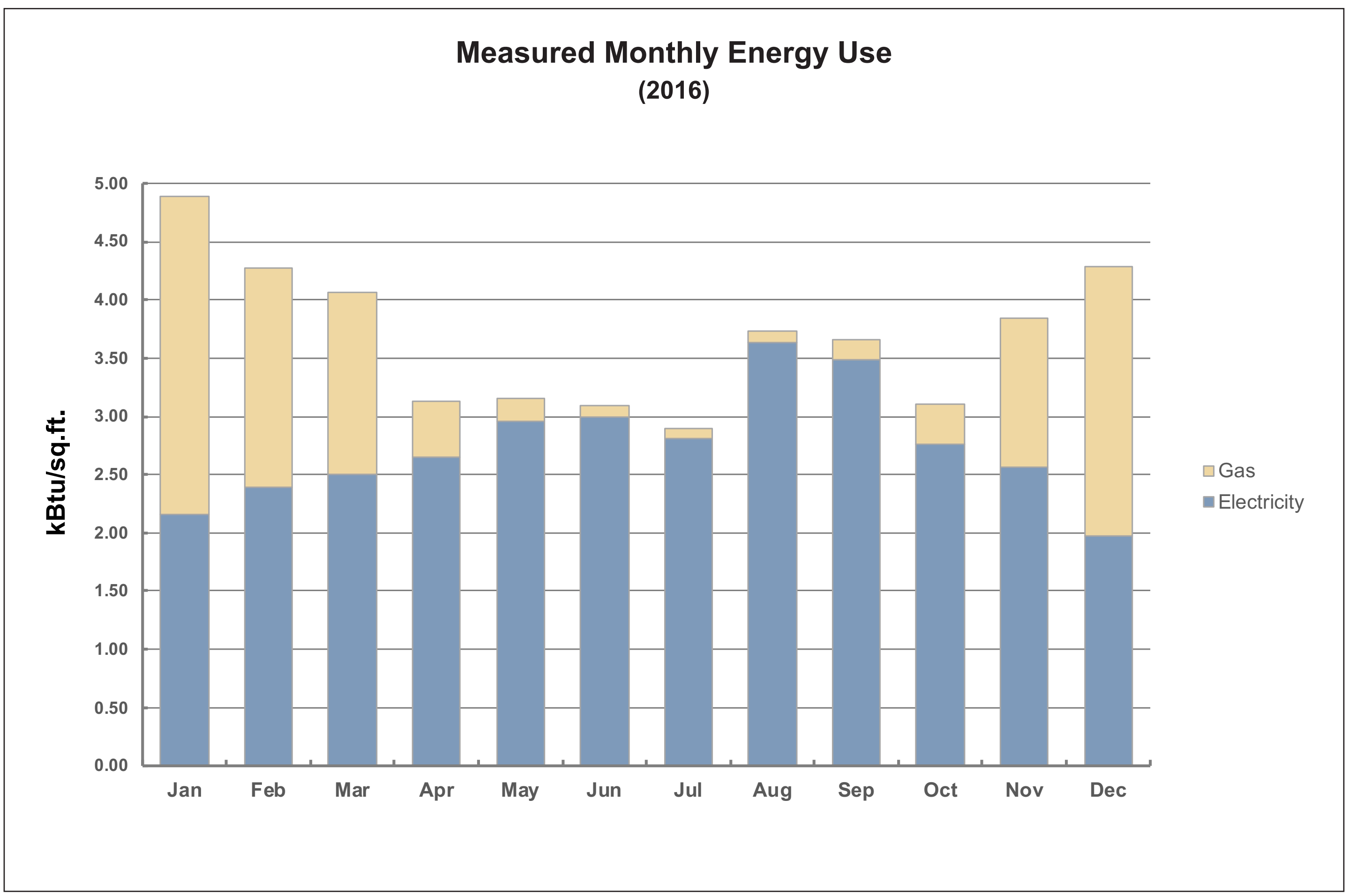
*Energy Use—Actual Measurement and Comparison to Modeling Results*

Using the building's net energy meter and the total solar electric energy production as measured by meters on the PV system, it is possible to determine the total electric energy use of the building. In addition, the utility's gas meter reading provides the other energy-use component of the building, the gas used for space heating and domestic hot water. The chart shows these performance results for the sample year 2016. The building's EUI is 44.1, rather high for a ZNE design, but good for an energy-efficient design intended to be slightly better than the California energy standards.




**Measured Energy Use**
**(2016)**

706,676 kWh/year
Measured EUI =44.1



*Energy Production versus Energy Use: Zero Net Energy Performance*

Energy production for 2016 is shown in the chart on the top of the opposite page. The chart also includes the energy used by both the building and the electrical vehicle charging stations in the same year. This annual total energy use was 50,000 kWh more than the annual energy produced by the Chico Center's solar PV arrays. (See the chart on the bottom of the opposite page, the *Cumulative Net Energy Performance,* which shows this net-negative total of 50,000 kWh at the end of the year.)

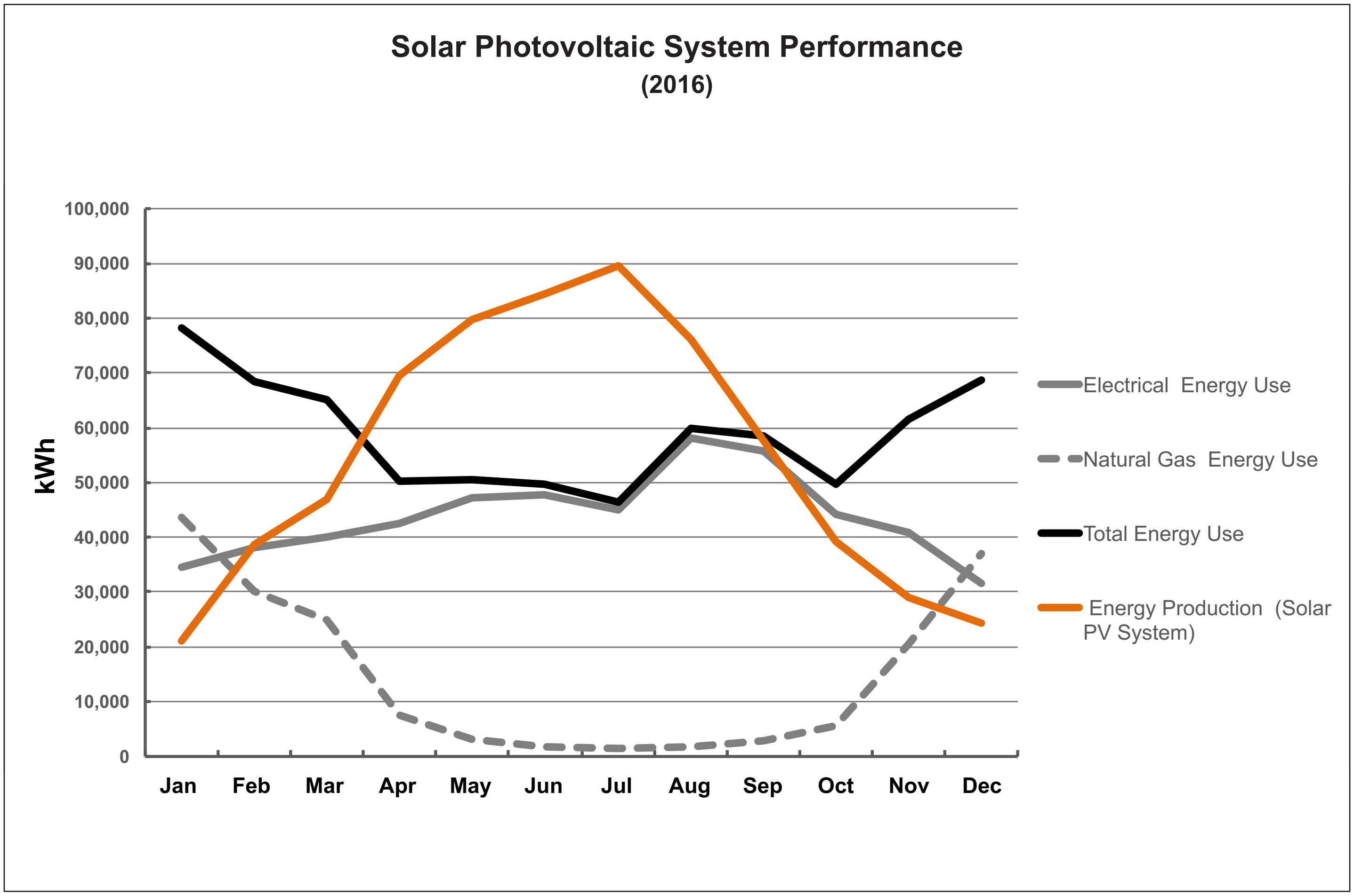
The building would be exactly ZNE if this 50,000 kWh shortfall were due entirely to the electric vehicle charging stations. The charging stations are not separately metered, but it is not unreasonable that this could be the case. The 50,000 kWh annual total translates to 190 kWh per day when the Chico Center is open. Electric vehicle batteries currently range in capacity from roughly 20 kWh to 85 kWh (Tesla Model S) and there are currently five electric charging stations at the Chico Center. Some pattern of intermittent use could therefore account for this daily total electric energy consumption. In this case, the building alone would be achieving ZNE performance.

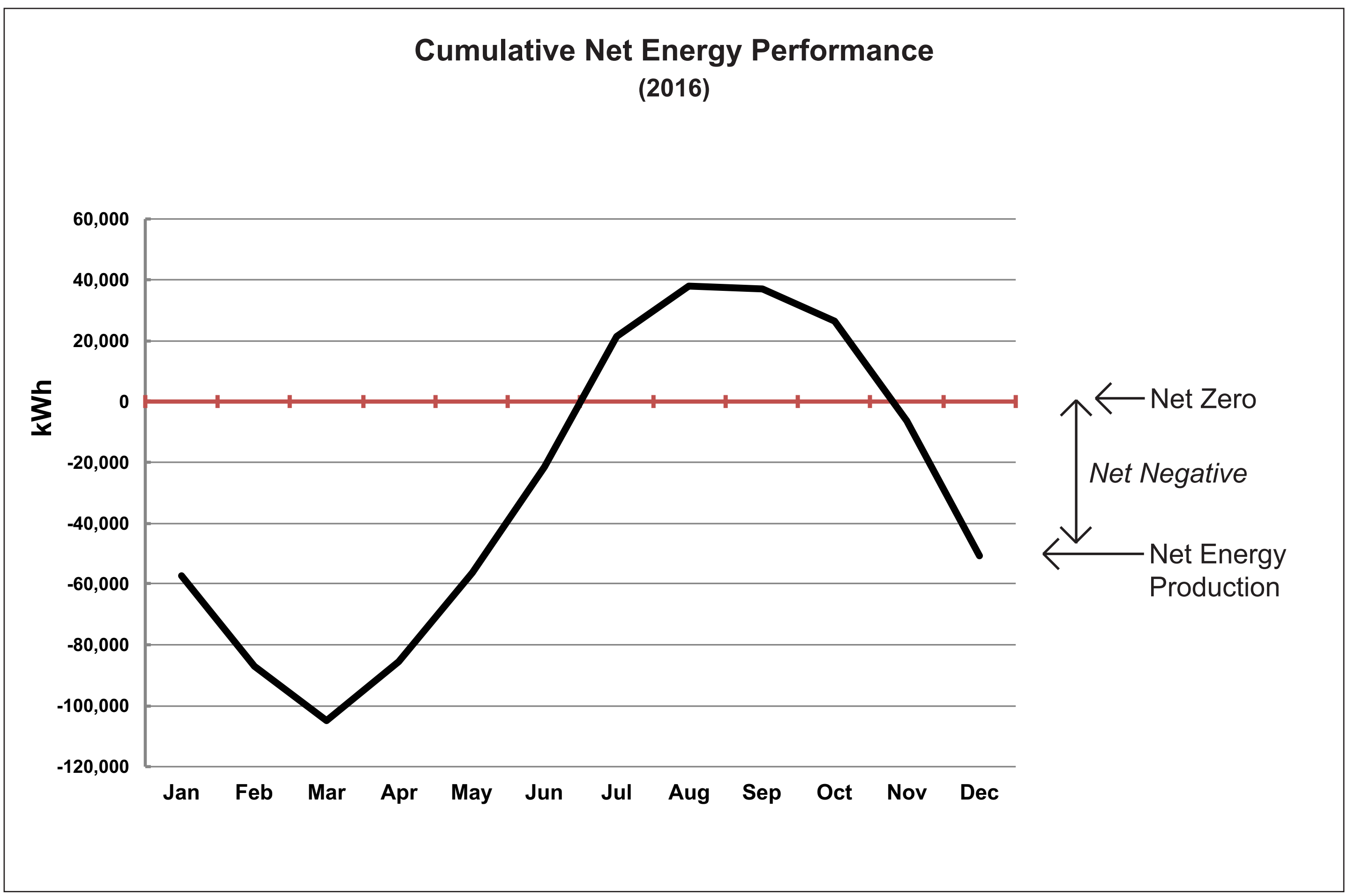
At present, Butte College is providing use of the charging stations at no charge and is not metering the electrical energy consumption due to intermittent use. It will be interesting to evaluate the metered data at a later time if conditions of use are changed and meters are installed.

**Post Occupancy: Observations and Conclusions**

This is an unusual case study since the building was not designed with a mandate or project goal of ZNE performance and the solar PV system was added six years later. In addition, the PV system is providing energy for electric vehicles in addition to the building. Therefore, observations about "lessons learned" do not apply in any but a general way.

Simply put, the basic observation is that solar PV systems can be added at a later time to an energy-efficient, conventionally-designed building and ZNE performance will still be technically possible and cost-feasible. In the case of the Chico Center, the significant decrease in cost of solar PV systems and the continuing rebates only made such a "retrofit" more attractive as an investment for the District.


Solar Photovoltaic System Performance
(2016)
kWh
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
Electrical Energy Use
Natural Gas Energy Use
Total Energy Use
Energy Production (Solar PV System)


Cumulative Net Energy Performance
(2016)
kWh
60,000
40,000
20,000
0
-20,000
-40,000
-60,000
-80,000
-100,000
-120,000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Net Zero
Net Negative
Net Energy Production

CASE STUDY NO. 16

# LACCD Harbor College Science Building

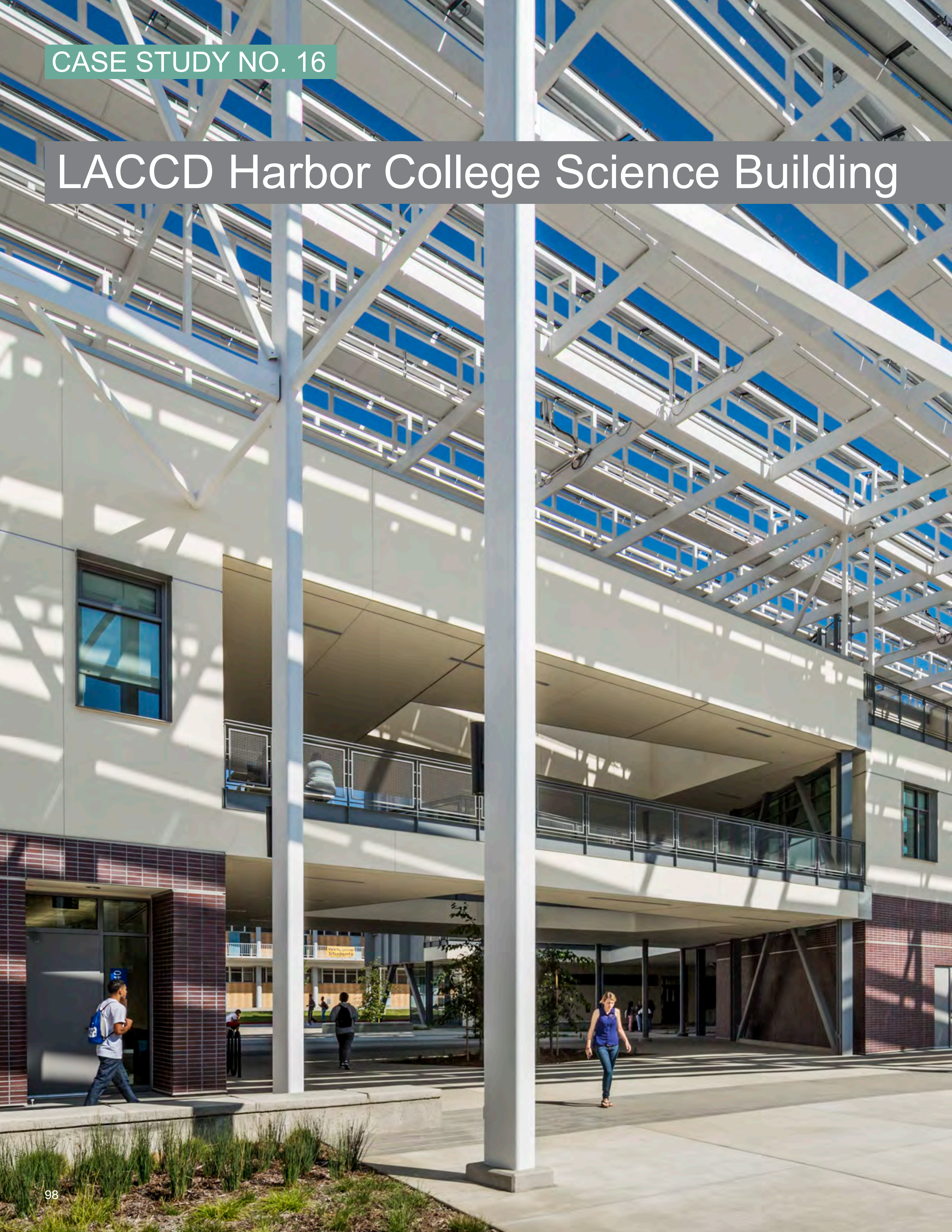



PHOTO: TIM GRIFFITH

# LACCD Harbor College Science Building

*Case Study No. 16*

**Data Summary**

**Building Type:** Education - Community College

**Location:** Wilmington (L.A.), CA

**Gross Floor Area**: 70,060 gsf

**Occupied:** 2013

**Energy Modeling Software:** IES VE (2013)

**Modeled EUI (Site):** 75.5 kBtu/sf-year

**Measured EUI (Site):** 42.7 kBtu/sf-year (2016) (See discussion)

**On-Site Renewable Energy System Installed:**
264 kW (DC) Solar PV (building)
318 kW (DC) Solar PV (campus)
(See discussion)

**Measured On-Site Energy Production (2016):**
414 MWh (Solar PV on building)
463 MWh (Solar PV-campus)
(See discussion)

**Owner/Client**

Los Angeles Community College District (LACCD)

**Design-Build Team**

*General Contractor:* Pinner Construction, Anaheim, CA

*Architect:* HGA Architect and Engineers, Santa Monica, CA

*Structural Engineer:* Saiful Bouquet, Pasadena, CA

*Mechanical/Plumbing Engineer:* Fundament & Associates, Inc. Irvine, CA

*Electrical Engineer and Lighting Design:* FBA Engineering, Newport Beach, CA

Another California community college district undertaking a significant effort in the design and construction of energy-efficient buildings and associated renewable energy supply is the Los Angeles Community College District (LACCD), which consists of nine colleges at locations around the city of Los Angeles and serves 135,000 students.

**Background**

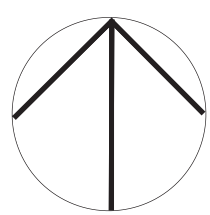
In 2008, the California legislature passed and then-governor Arnold Schwarzenegger signed SB1, known as “The Million Solar Roofs” bill. It was estimated at the time that the provisions in the bill would stimulate 3,000 MW of new solar electric power, the equivalent of approximately 6 “peak power plants”. The incentives for installing solar energy systems were soon incorporated into various facility plans, community colleges included, and sparked an interest in the construction of grid-neutral and zero-net-energy (ZNE) buildings.

Meanwhile, voters in Los Angeles had passed a series of bond measures over the previous seven years totaling $5.7 billion for improvements to community college campuses, which included energy efficiency upgrades. With the timing of the bond program, SB1 funds and the commitment of the State of California to move toward less dependence on carbon-based energy, Los Angeles Community College District (LACCD) initiated a plan to build these facilities to achieve ZNE performance.

This idea was first tried out with five building projects in early 2009, one of which was the Harbor College Science Building. The District issued an RFP to three pre-qualified design-build teams, stating in part,

> “This project shall be built in a manner that maximizes all possible sustainable attributes including, but not limited to, state-of-the-art building design, mechanical design, and material selection, and building integrated renewable energy-generation systems to achieve zero-energy consumption and a carbon-neutral profile upon completion.”

Los Angeles Harbor College Science Building: General Vicinity Plan

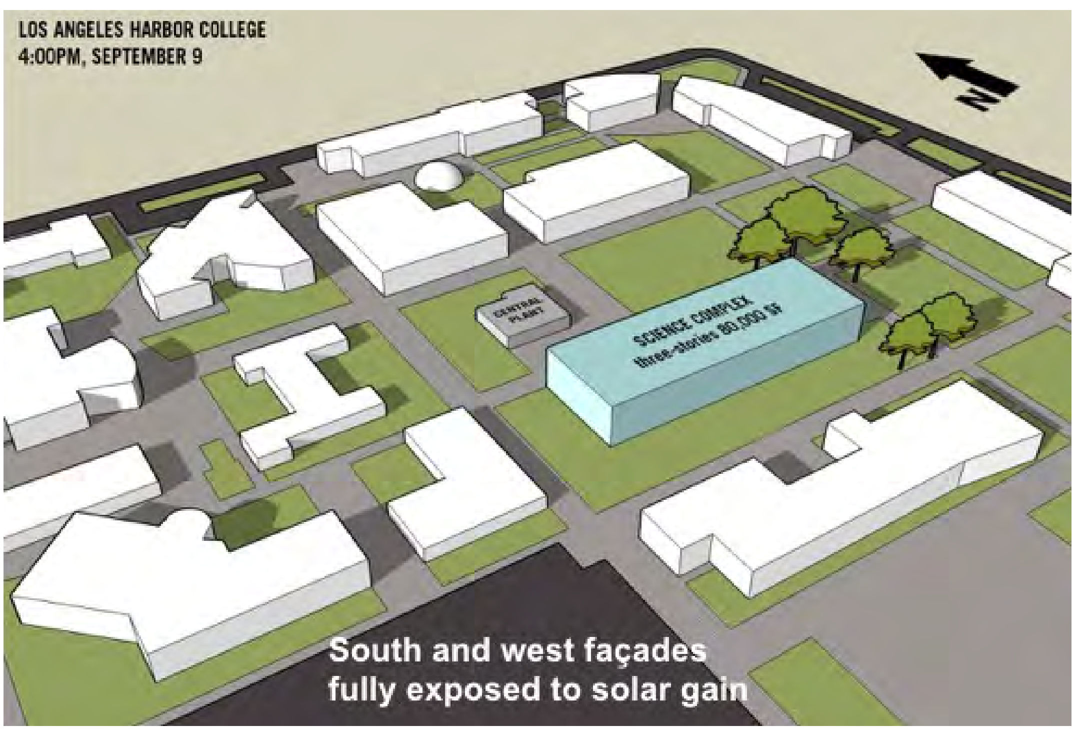


The District conducted a mandatory "eco-charrette" prior to the proposal submittals, in which the integrated design process was described to the firms invited to submit a proposal. The "eco-charette" basically described how to achieve a ZNE performance for this particular building at the Harbor College site. The three teams then developed their proposals and, after formal presentations to the District, the HGA-Pinner team was selected for the project In June, 2009.

### Design Process and Low Energy Design Strategies

Many of the design strategies were adopted during the development of the design-build proposals, which required at least a schematic level design in order to assign reliable costs to the building features and systems. This was the primary reason for providing the eco-charrette, so that appropriate design strategies for the program and site would be analyzed and the results presented to the design-build teams for their consideration.

*(Below, Left)* Slide from eco-charrette presentation provided by LACCD to pre-qualified design-build teams. This slide: site orientation factors.

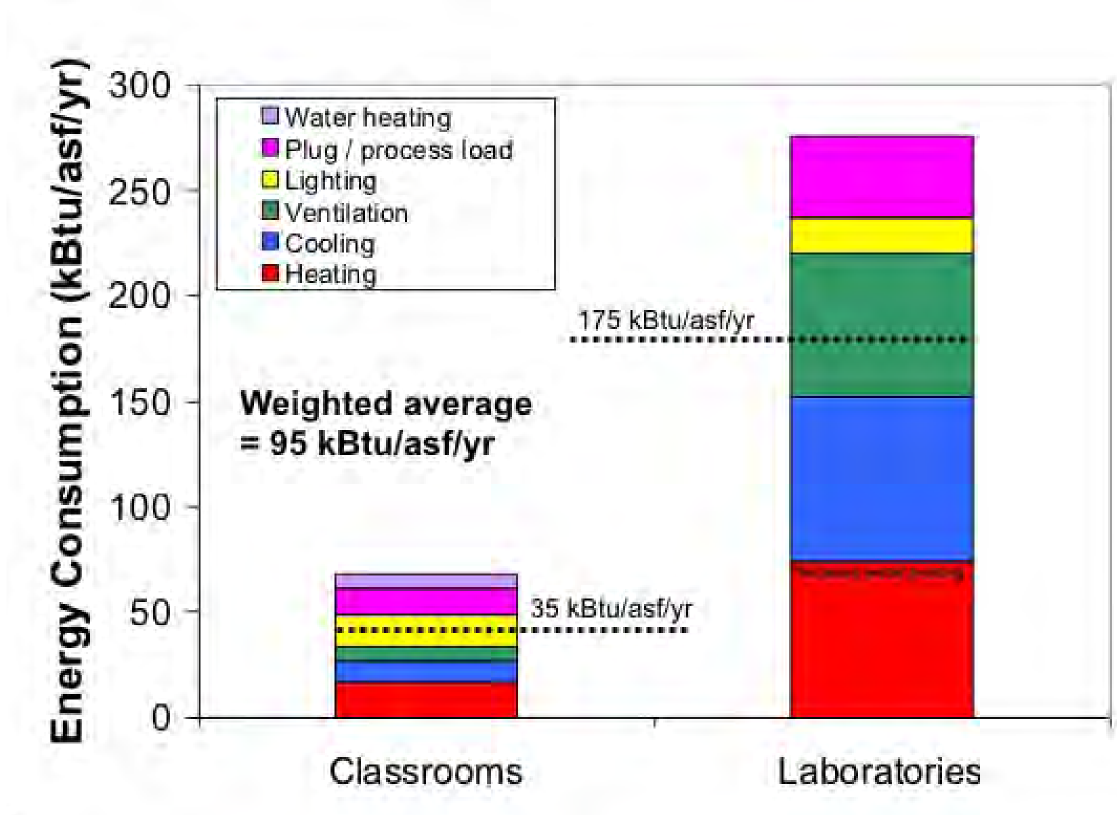


*Planning Concept and General Design Considerations*

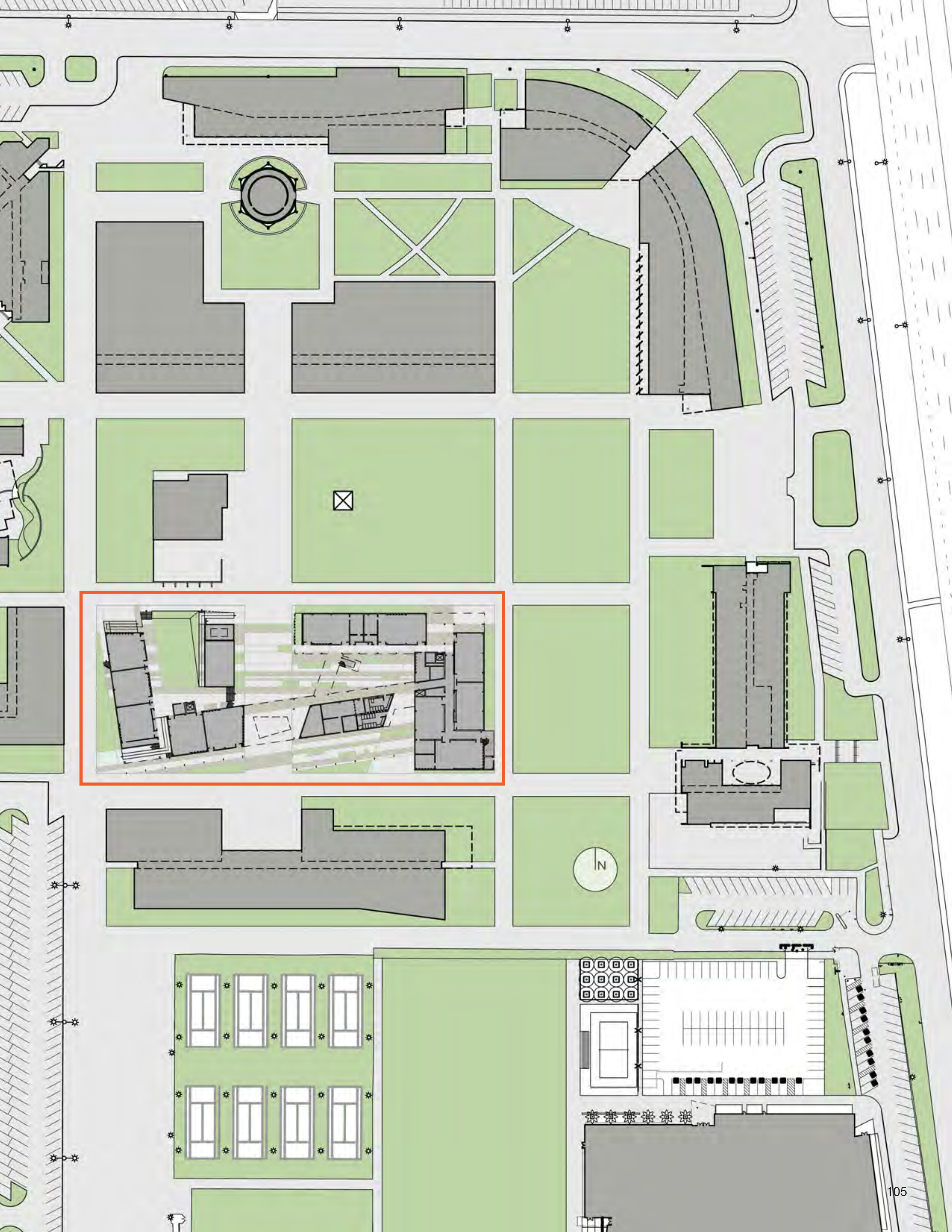
The building consists generally of both laboratory spaces and general instructional spaces, as well as office suites. As discussed in Case Study No. 12 in this Volume 3, laboratory spaces normally require an intensive use of energy and it is a particular challenge for a building with such spaces to approach ZNE performance. Even though the program is a mix a laboratory and non-laboratory space, the design team recognized that at 70,000 gross square feet of total building floor area, a cost-effective building-integrated PV system would not be adequate for ZNE performance—some site solar PV would be required in the renewable energy accounting.

Nevertheless, the design team adopted effective energy-efficiency measures to reduce significantly the energy use of the building.

*(Below, Right)* Slide from eco-charrette presentation provided by LACCD to pre-qualified design-build teams. This slide: program spaces and energy-use benchmarks.



Site Plan of Harbor College in 2013 with the Science Building as designed located in the center of campus. (Courtesy of HGA Architects)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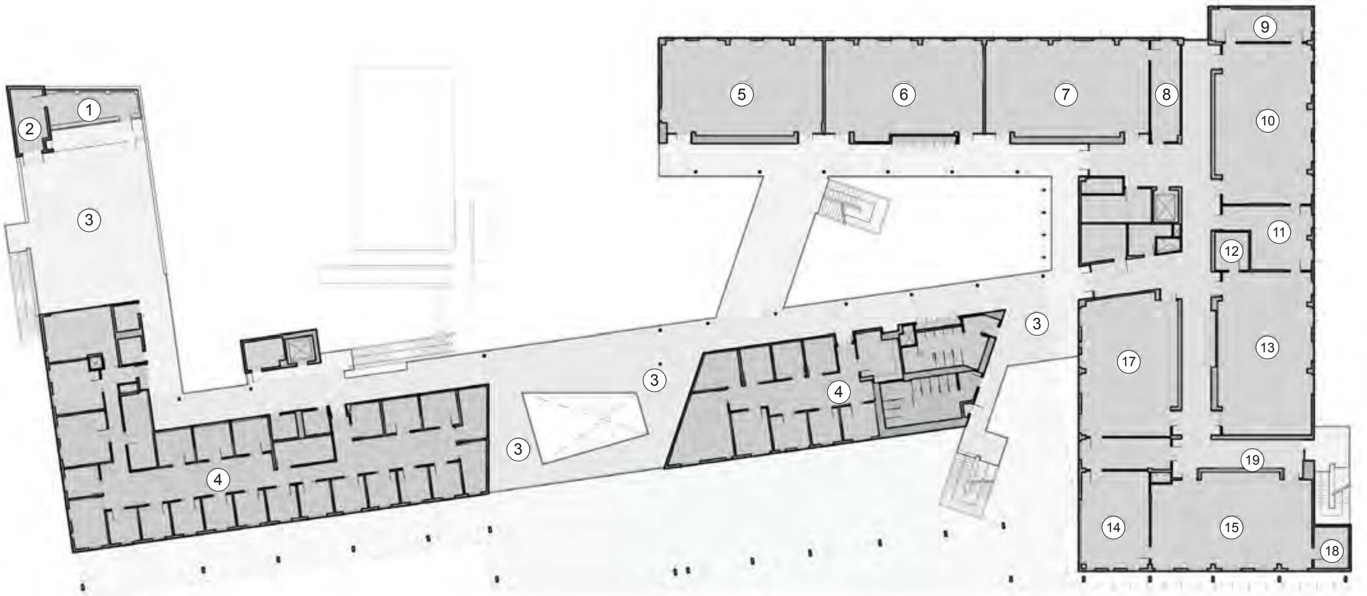
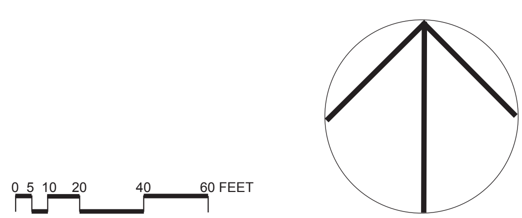
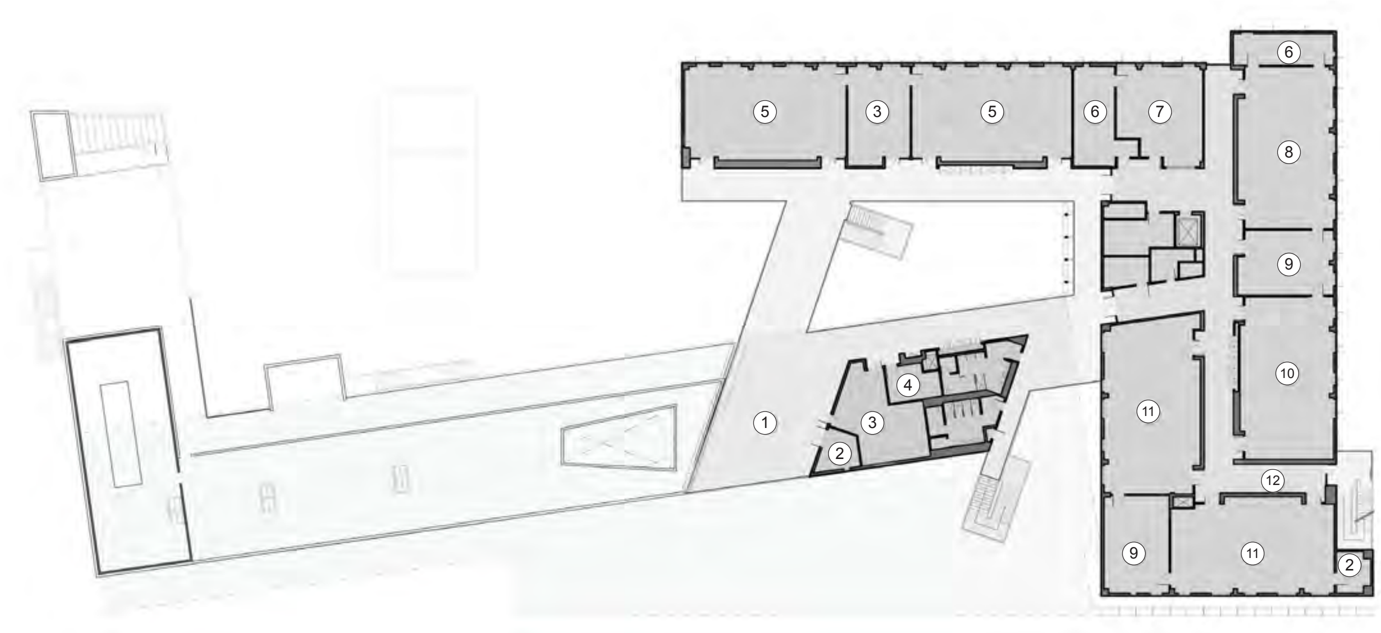


SECOND FLOOR PLAN

FIRST FLOOR PLAN

LACCD Harbor College Science Building: Floor Plans






**THIRD FLOOR PLAN**

**FIRST FLOOR**

1 LECTURE HALL
2 FLEXIBLE CLASSROOM
3 EXISTING BOILER BUILDING
4 GEOLOGY LAB
5 LAB SUPPORT
6 LOBBY
7 GEOGRAPHY LAB
8 FACULTY OFFICE
9 CHILD DEVELOPMENT CLASSROOM
10 CHILD DEVELOPMENT LAB
11 CREATIVE CURRICULUM LAB
12 KILN ROOM
13 M&O
14 COLLABORATION AREA

**SECOND FLOOR**

1 GREENHOUSE
2 GREENHOUSE SUPPORT
3 OUTDOOR COLLABORATION AREA
4 FACULTY OFFICES
5 SOLAR LAB
6 COMPUTER LAB
7 ANATOMY LAB
8 ANATOMY STORAGE
9 MICROBIOLOGY PREP
10 MICROBIOLOGY LAB
11 LIFE SCIENCE STOCKROOM
12 PHYSIOLOGY PREP
13 PHYSIOLOGY LAB
14 SPECIMEN STORAGE
15 GENERAL LAB
16 BIOTECH PREP
17 MAJORS/BIOTECH LAB
18 BIOSPECIMEN STORAGE
19 COLLABORATION AREA

**THIRD FLOOR**

1 OUTDOOR SOLAR LAB
2 LAB SUPPORT
3 PHYSICS STOCKROOM
4 SOLAR PV SERVICE ROOM
5 PHYSICS LAB
6 CHEMISTRY STORAGE
7 CHEMISTRY STOCKROOM
8 ORGANIC CHEMISTRY LAB
9 INSTRUMENT ROOM
10 ORGANIC BIOCHEMISTRY LAB
11 CHEMISTRY LAB
12 COLLABORATION AREA

PHOTO: ETHAN ROHLOFF

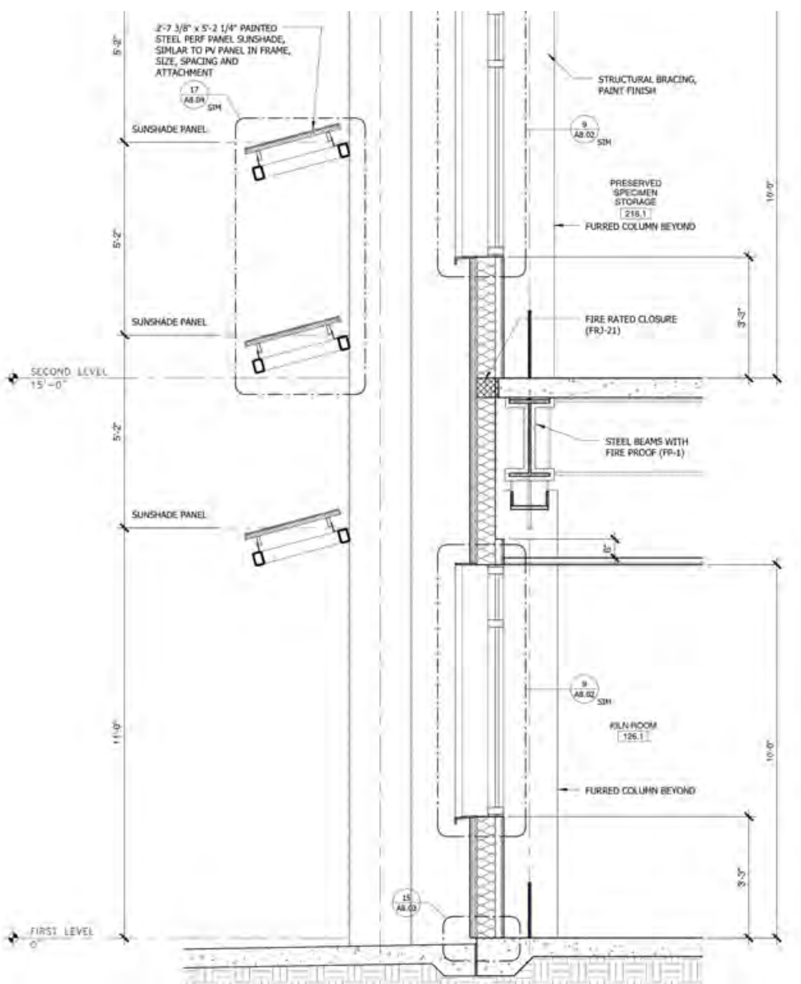
*Building Envelope*

One of the design strategies was simply to take advantage of the year-round benign climate and eliminate conditioned circulation space such as corridors and lobbies. Classrooms and laboratories open directly on to exterior circulation space. This also assists in the design of natural ventilation, which is utilized in all the non-laboratory spaces. (See photo on the following pages.)

A second principal strategy was to integrate sun-shading of the south façade with the solar PV panel installation. The support structure is the "signature" architectural design feature, encompassing both the façade and the roof as it wraps up and over the building, while providing a sizable area for the PV panels. Care was required to maintain sufficient daylight to the occupied spaces on the south side of the building.

The exterior wall consists of standard construction metal studs and R-19 insulation. No continuous insulation layer is utilized to prevent heat transfer due to "thermal bridging", primarily because of the excesive impact of first-cost. The roof has uses R-30 insulation in the roof assembly detail. See below for a typical wall section.

(Above) The structure supporting the solar PV panels provides in addition the sun-shading on the south facade while allowing daylight penetration to the spaces on that side of the building. (Photo: Tim Griffith).




2 WALL SECTION

*(Opposite Page, Top)* Aerial view of the Harbor College campus from the east in 2009. Site of the future Science Building is circled in red. Solar PV arrays are visible beyond on canopy structures above the parking areas.

*(Opposite Page, Bottom)* Aerial view of the Science Building from the north.

*(Overleaf)* View of the outdoor circulation areas, with the solar PV support structure visible above and to the right.


Welcome Students

PHOTO: TIM GRIFFITH

*Daylighting and Electric Lighting*

Daylight modeling of program spaces was carried out using RadianceIES software and the results were factored into the whole building model. Electric lights are controlled in the spaces by daylight sensors and occupancy sensors, as well as pre-programmed light level requirements.

*Natural Ventilation*

Natural ventilation can be used only in the non-laboratory spaces. The original design strategy utilized automatic window operation controlled by the BMS (Building Management System) according to a sequence of operations based on outside and inside air temperatures and data from $CO_2$ sensors in the occupied spaces. But it was decided by the facilities director that maintenance requirements for this design approach would be relatively demanding for a reduced number of staff, and therefore it would not provide dependable operation over time. The design team therefore opted for user control of the windows, with a visible “red light - green light” system mounted in a prominent location in the spaces to signal when windows can be opened (or not) to establish comfort conditions.

Such user control has drawbacks (see the discussion in the section *Post-Occupancy*), but the system operation is designed to minimize them as much as possible. The occupants get a “green light” signaling that the windows can be opened when the inside air temperature is 70°-75°F, the outside air temperature is 55°-75°F and the $CO_2$ sensor measures 900 ppm or less. The “red light” is switched on if the inside or outside air temperatures are outside that respective range, or if the $CO_2$ sensor measures 1100 ppm no matter what the temperature. In the latter case, which potentially occurs only in the large lecture rooms under special conditions, the HVAC system can operate to provide enough fresh air to reduce the $CO_2$ level once the windows are closed (presumably as directed by the instructor in the larger spaces).

The switch to user-control of the operable windows also eliminated the possibility of using a cool air “night flushing” operation of the natural ventilation system to pre-cool the building during the

*(Below)* Interior of classroom with large windows that allow natural ventilation via manual operation by the occupants.


PHOTO: TOM BONNER

spring and fall seasons. Proximity to the ocean ordinarily would allow such an energy-conserving design strategy.

*Heating, Ventilating and Cooling Systems*

The laboratory spaces require an energy-intensive type of environmental control, primarily because of the large use of fan energy to move air through those spaces. In the Science Building, these spaces are served by dedicated 100% outside air air-handling-units (AHU), which are equipped with energy recovery coils. This system is designed to maintain an air exchange rate in these spaces of 12 air-changes-per-hour (ACH) when occupied and 6 ACH when unoccupied, which is conventional practice in laboratory design. Variable air volume (VAV) boxes manage the air change rate in the spaces.

In the non-laboratory spaces, the HVAC system operates to maximize the use of natural ventilation for fresh air and space cooling when conditions permit. When air conditions require mechanical heating or cooling, the minimum required fresh air to the spaces is provided by the HVAC unit and the windows are closed. This combination of natural ventilation and mechanical heating/cooling is known as *mixed mode operation*[1].

The hot and chilled water supply to the HVAC units is piped to the building from the nearby Central Plant, which utilizes gas-fired boilers and absorption chillers. The energy use at the Central Plant for this purpose is also part of the total energy use of the building.

[1] See also Case Study No. 10, West Berkeley Branch Library, in *Zero Net Energy Case Study Buildings*, *Volume 2*, p. 88.

*(Below)* Central Plant Building is located adjacent to the Science Building and provides heated and chilled water to the HVAC units located on the roof of the Science Building.

PHOTO: ETHAN ROHLOFF

*Master System Integration and Control Systems*

The building controls system is part of a campus-wide controls system that is based on BacNet protocols. The *building automation system* (BAS) monitors all of the energy systems of the building by processing and recording data from the sub-metering network that was installed per the construction specifications. The intention was that the output from this network of meters would not only provide a means of monitoring the performance of the energy system components for the maintenance staff, but also to form the basis for the Measurement & Verification Plan, required as part of the submittal for LEED-Gold certification. (See the diagram of the sub-metering system on the opposite page.)

The design intention was that during the first year of occupancy, the actual energy use as measured by the meters could be compared with the modeled energy use. If there were a significant difference between the two in any category of energy use once the model was recalibrated for actual use conditions, the District could take corrective action. Thereafter, the District could monitor the data reported from the meters through the BAS to check on the building energy performance.

It was found at the time of the writing of this case study, however, that the data from the installed sub-meters was not being properly recorded by the central BAS. The result is that there is no data record until recently of the energy use by category of use (lighting, fans, plug load, etc.). This is discussed further below in the *Post Occupancy* section.

**Renewable On-Site Energy Supply**

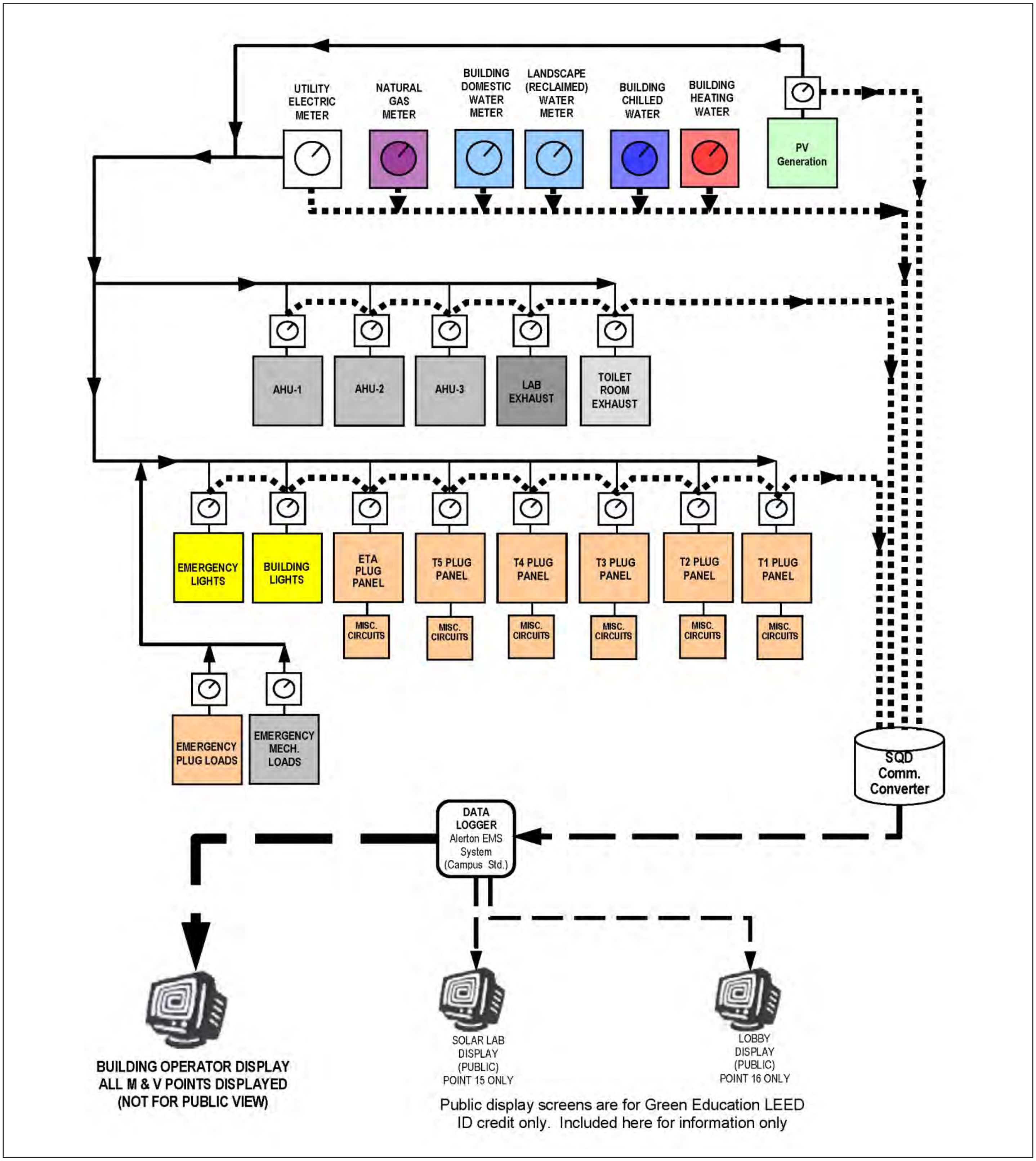
The 264 kW (DC) solar PV system that is installed on the Science Building is integrated with a structural framework to provide shading of the south façade and the roof. This building-integrated system creates the strong architectural feature that is the visual hallmark of this building.

In addition, there is a vast array of solar PV panels located on canopy structures above the three parking lots to the west of the campus and above the west parking structure, totaling 2,366 kW (DC). Together with the building-mounted solar panels on the Science Building and the Learning Resource Center (58 kW), the total installed capacity on the Harbor College campus is 2,688 kW (DC), a sizable source of renewable energy for the campus buildings as a whole.

The principal value for the Science Building is that a portion of the larger system arrays essentially can act as an "offset" of the natural gas consumed at the Central Plant for making the heated and chilled water used for heating and cooling this building. So that portion of the large parking lot arrays serves to bring the Science Building to overall ZNE performance, at least by one method of energy accounting. See *Energy Production versus Energy Use: Zero Net Energy Performance* below.

*(Right)* Photo by Tim Griffith

*(Below)* Schematic diagram for measurement and verification "points" for sub-metering system in the Science Building. (Courtesy of HGA Architects and Engineers)



## Energy Design Analysis and Energy Performance
### *Modeling versus Post-Occupancy Measurement*

*Energy Modeling*

Energy modeling was done during the design phase using IES VE software. The modeling showed a total energy use of 1,549 MWh per year or an EUI of 75.5 kBtu/sq.ft. per year. Given the number of laboratory spaces in this building, this is a reasonably low EUI that would enable ZNE performance. However, the multifloor building that is required to accommodate the full program on site does not have sufficient space for the solar PV system necessary to achieve ZNE performance, even with the innovative structure that wraps up the south façade and over the roof. Some site location for a substantial amount of additional PV panels proved necessary.

The modeled energy use for the Science Building as designed are given in the charts on the opposite page, broken out by category of energy use.

*Energy Use—Actual Measurement*

As mentioned above, until 2018 there was no data recorded for the actual energy use in the building even though the meters were operational since occupancy. This includes separate measurements of the energy used at the Central Plant for production of heated and chilled water that are piped to the Science Building for heating, cooling and DHW, as part of the building's HVAC system. The District has since begun to record all of this data.

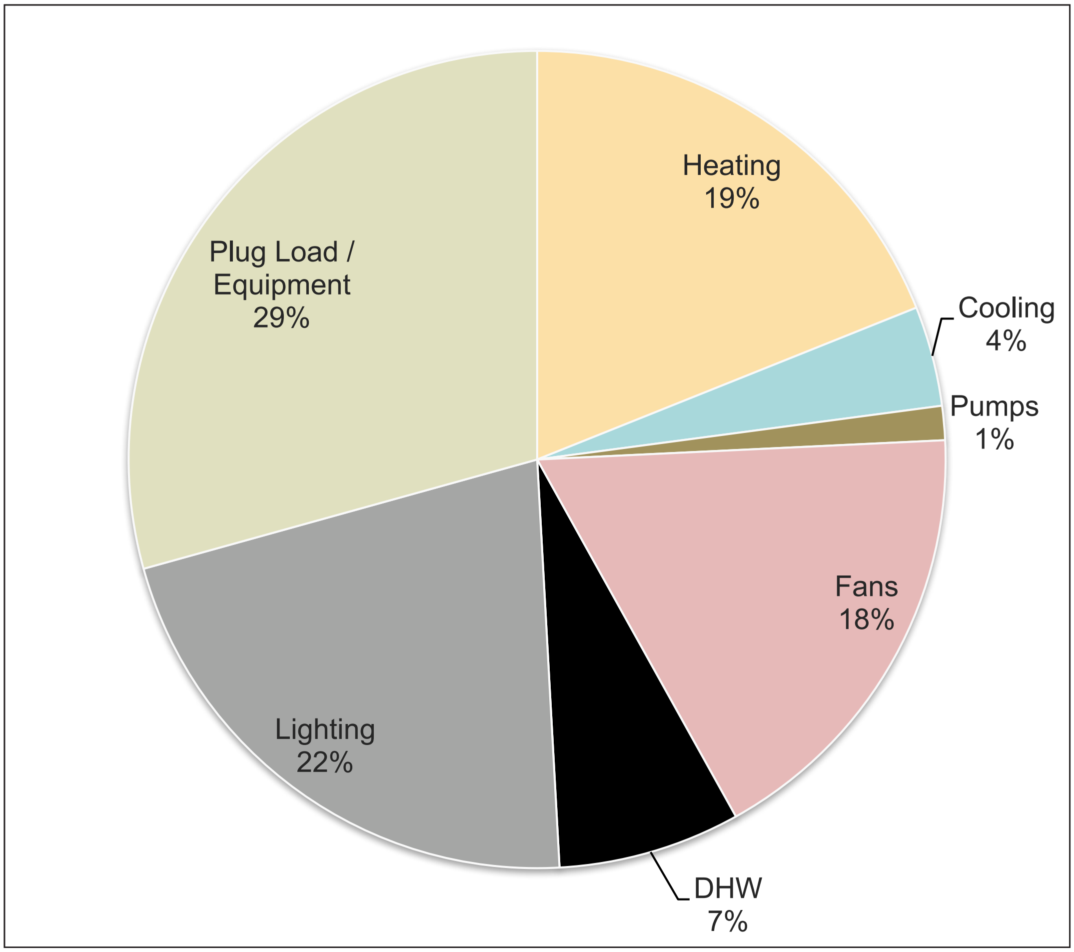
Similarly, there has been no separate metering of the energy produced by solar PV system that is part of the Science Building. However, there has been metering of the *net* electric use/production for the building, which has been recorded since the building was occupied in 2013. This case study makes use of this data to report a reasonable estimation of the ZNE performance of this building. (See the following section for further discussion of this estimation method.)

*Energy Production versus Energy Use: Zero Net Energy Performance*

As noted above, the overall size and the laboratory program of this building as designed result in an energy use that cannot be offset with a building-integrated solar PV system alone. The campus as a whole has installed a very large solar PV system above the major parking areas on canopy structures and the roof of a major parking structure. This campus system is immediately adjacent to the Science Building and some of the power generated is supplied to the Science Building via the campus power grid. Therefore, it is reasonable to "assign" a portion of the renewable energy from this campus system to the Science Building and determine that all of the building's annual energy use is effectively offset and produces ZNE performance, as follows:

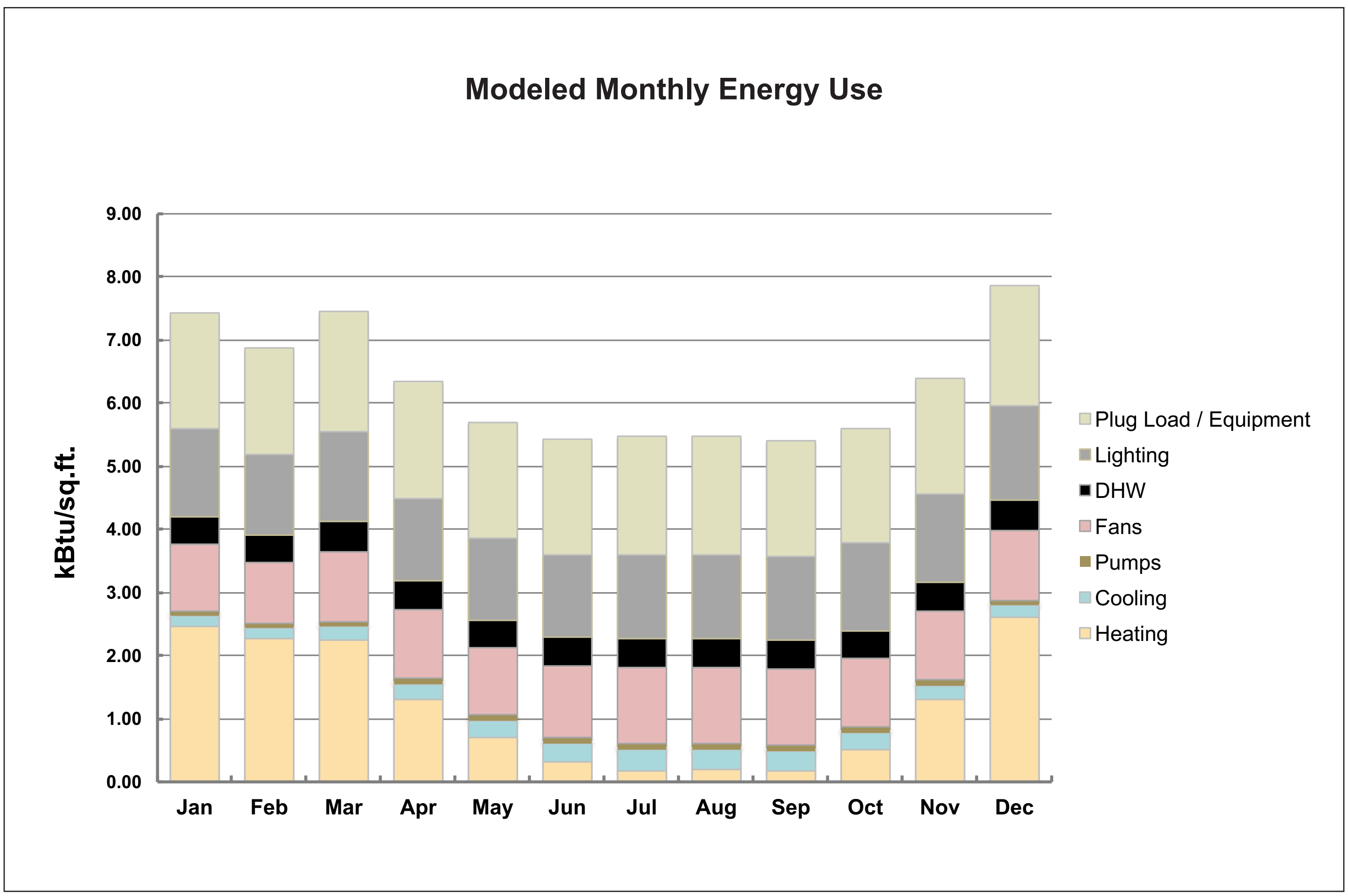
The portion of the campus system necessary for ZNE performance of the Science Building would equal the net metered annual electrical energy use at the building plus the kWh equivalent of the gas energy used for this building at the Central Plant. While the net metered annual electrical use at the building is available as recorded data, there is no separate recorded data for the gas energy figure at the current time. Therefore, for estimating purposes, the energy use *modeled* for heating, cooling and DHW energy can be used as a reasonable approximation for the actual gas energy use.

The measured net-meter electrical energy used in the building for 2016 is -3,762 kWh, making the building *ZNE-Electric*, or *grid-neutral.* This number accounts for the electric energy use of the building minus the solar PV electric energy produced by the system that is integral to the building. The *modeled* gas energy use for heating, cooling and DHW, totals 466,475 kWh (after




**Modeled Energy Use**
**(Annual)**

1,549 MWh/year
Modeled EUI =75.5



converting units to kWh). Therefore, the energy that must be provided by the campus PV system is reasonably estimated to be 462,713 kWh, or roughly 463 MW. Using the *PV-Watts* calculator[1] for Long Beach weather data and this annual solar power generation needed to offset the gas use, the size of the solar PV component campus PV system that is required is 318 kW. This compares with the 264 kW system that is installed integral with the Science Building and 2,366 kW for the entire amount of solar PV arrays above the parking areas.

Based on this calculation, the solar PV arrays needed to be "assigned" to the Science Building are 13% of the total system installed above the parking areas, or roughly 120% of the size of the system integral with the building.

In addition, using *PV-Watts*, the electric energy provided by the PV system integral to the building (264 kW) is approximately 414,000 kWh, which essentially zeroes out the electric energy use of the building. The total energy use for the building is therefore estimated to be 877,000 kWh or 877 MWh. This converts to an estimated EUI of 42.7. Although this is only an estimate based on the data recorded for the net electric energy use and an approximation using PV-Watts, it is a reasonable estimate that compares well with the modeled EUI.

Note that until the measured data for the Central Plant is recorded for one full year and the remaining data is updated accordingly, these calculations can be no more than a "reasonable estimate". However, the order of magnitude of the portion of campus solar PV system (13%) that is required suggests that it is also reasonable to conclude that the Science Building is indeed achieving ZNE performance and the future recorded data will confirm that.

## Post Occupancy: Observations and Conclusions

The Los Angeles Community College District, like many community college systems, set ambitious energy performance goals while being bound by required methods of procurement, construction contract type (design-build), first-cost price competition and limited M&O (maintenance and operation) budgets. These affected both design decisions and post-occupancy impacts, but the project nevertheless achieved most of the initial goals.

*Post Occupancy: Controls and Monitoring*

The carefully planned measurement and verification program was not continued into the post-occupancy period. Meters were installed to measure energy use in each relevant subsystem of the building but the BAS system failed to record the data properly. The District M&O staff did not detect this and a routine program of data verification had not been established. As noted above, nothing was installed at the Central Plant that would allow a separate measurement of energy used to provide heating and cooling for the Science Building.

Both of these situations have been corrected partly as a result of the inquiry for this case study publication and going forward the District plans regular data recording of all relevant system energy use.

*Post Occupancy: Natural Ventilation*

The compromise made during the design phase by changing the system from automatic control and operation to one of only occupant control has led to likely imperfect system operation. However, this has not been studied in a post-occupancy evaluation and no data has been available to do so.

*Post Occupancy: Occupant Behavior*

The basic design decision to eliminate corridors and similar connecting circulation spaces was posited on the assumption that energy use in those conditioned spaces would also be eliminated. Teaching staff reports, however, that they frequently find the doors to classrooms ajar so that conditioned air escapes directly to the outside. Maintenance staff are charged with ensuring proper operation of the doors and windows, but staff often are not viewing the central monitoring system.

The building requires some occupant involvement in the proper operation of systems and features. There were faculty complaints that some of the staff missed the training sessions that were set up to explain these aspects. As a result, knowledge of these user-controlled and user-impacted systems was not transferred to some of the occupants, so it is reported that there has been some confusion and lack of buy-in by the staff.

*(Opposite Page)* A class meets on the roof deck space to discuss the details of the solar PV system as part of the regular curriculum.

[2] http://pvwatts.nrel.gov/

PHOTO: TOM BONNER

PREFACE TO CASE STUDY NO. 17

# Stanford University

*Toward a Realistic Goal of Sustainability and Zero Net Energy*

PHOTO: STEVE PROEHL

# Stanford University

## *Preface to Case Study No. 17*

Major campuses with a large collection of existing buildings have a different kind of challenge achieving ZNE than individual new and existing buildings that have their energy supply systems incorporated as part of the building. Historically, campuses under one owner/institution that have been developed and built over an extended period of time typically utilize a shared, centralized energy supply system to maintain serviceability and occupant comfort in the buildings. This is the situation, for example, in the previous case study, LACCD Harbor College Science Building, where the heating and cooling loads are met by a gas-fired central plant and a campus distribution network for heated and chilled water.

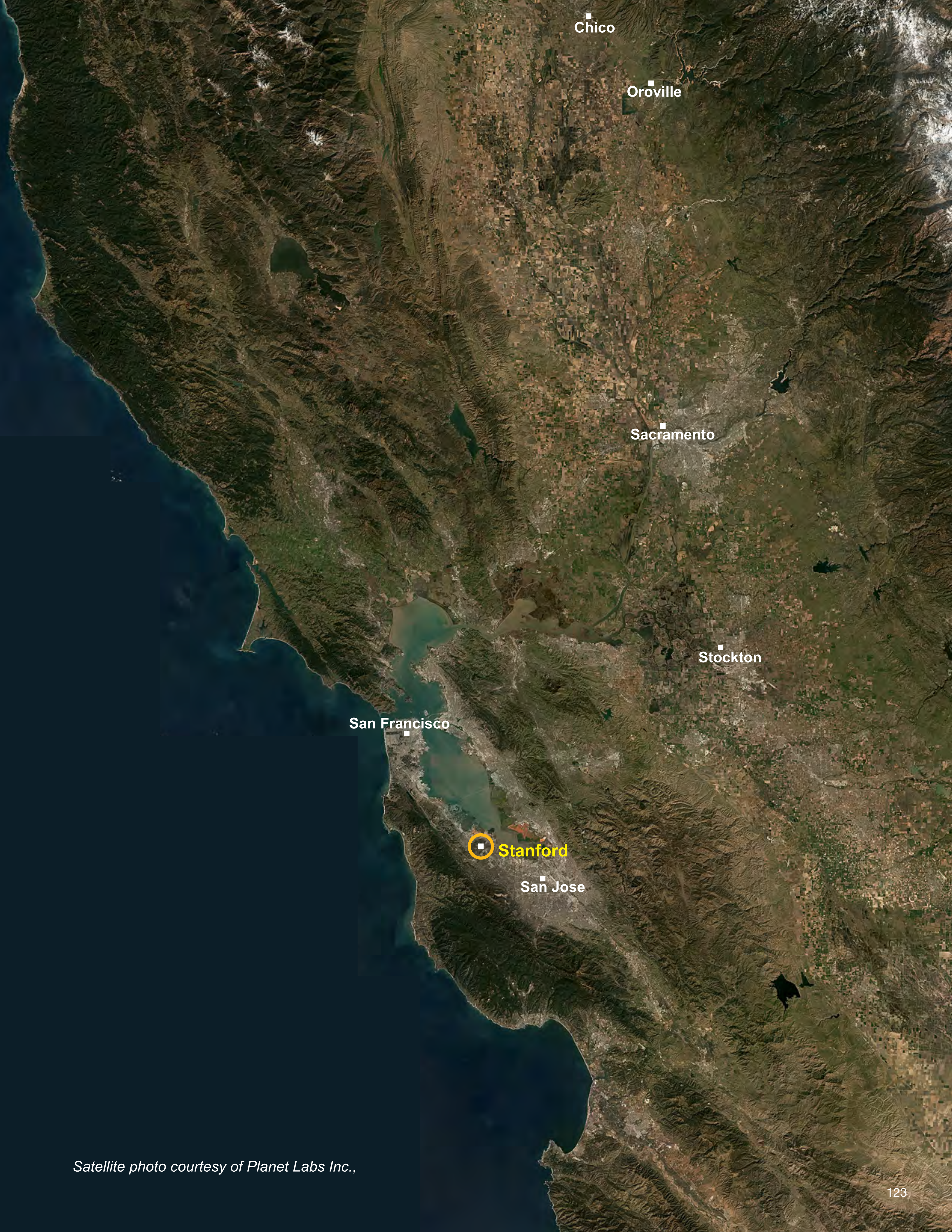
Stanford University had an even greater challenge of this type because of the sheer size and diversity of the campus, the age of its buildings and their historical context. While the university did not initially adopt a campus-wide goal of ZNE performance, the goal of substantially reducing campus-source carbon emissions combined with a timely opportunity has created a realistic path to that achievement.

**Background**

Shortly after the turn of the current century, when the sustainability movement took hold at major colleges and universities, Stanford University decided to reorganize its administrative departments in charge of campus utilities and transportation into a single department that emphasized sustainability in its overall operations. This *Department of Sustainability and Energy Management,* as the combined departments were named, was first charged with making an organizational framework with campus goals and strategies for greater campus sustainability, starting with an assessment of the existing infrastructure and administrative procedures in that regard.

*(Above and below). Photos of Stanford University campus courtesy of Stanford University.*

The next step was to devise a plan of action based on this assessment for the most effective and practical measures to achieve the greatest possible savings in energy and water, to reduce waste and to lower carbon emissions substantially. This plan, called *The Energy and Climate Plan*, was to be presented to university leaders for discussion and ultimately approval of the final plan going forward. The process of evaluation and communication with the campus was




*Satellite photo courtesy of Planet Labs Inc.,* designed to be open and participatory as well and, perhaps as a result of this process, the plan would emphasize "realistic" objectives. "Deeds not words" was the frequent reminder during these discussions that led to the development of the final plan.

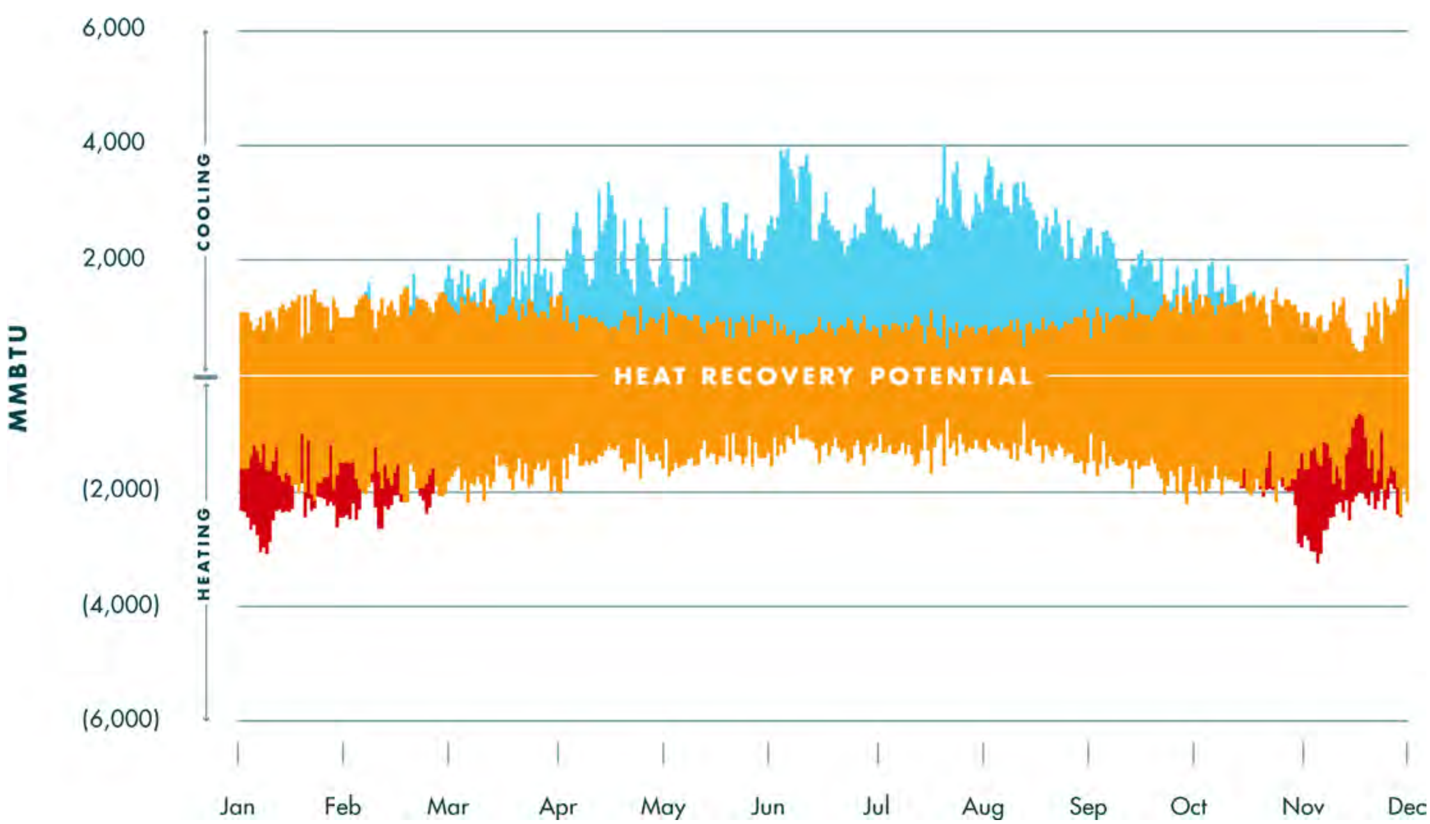
In 2007, a director was hired to lead the new department and to help finalize the plan for the broad categories of transportation, water and energy utilities. It turned out that *energy* was to provide Stanford with the greatest opportunity to improve the sustainability of the Stanford campus.

**The Central Energy Facility — A Dramatic Opportunity**

*(Below)* A data analysis of the heating and cooling demand of the Stanford campus as supplied by the existing central plant revealed that a majority of the loads could be met by *heat recovery* if the separate heating and cooling systems were combined in a new energy-efficient system design. (Diagram courtesy of AEI.)

As a first step in the assessment of the campus energy utilities, the department staff undertook a broad campus study of the amount of energy used, and in what form, to provide electricity, heating and cooling for the large collection of campus buildings. A six-month collection of detailed data was analyzed and the results indicated some strategies with potentially substantial impact on the efficiency of the energy infrastructure, though how great an impact was not obvious at first. The strategy identified for further study that would prove to have the highest impact: *heat recovery*.

This further study indeed proved the great potential for *heat recovery* to substantially increase energy efficiency and reduce carbon emissions at the campus central plant. The reason for this was a combination of factors, including the load profiles across the campus created by the mix of buildings and the regional climate characteristics.



*(Left)* The existing central plant in 2008, leased from Cardinal Cogen, located near the main part of the Stanford Universiity campus. (Photo courtesy of AEI.)

*Simultaneous Heating and Cooling — Conventional Approach vs Innovation*

Almost all large non-residential buildings in this climate require simultaneous heating and cooling at all times of the year, particularly in the case of laboratories and hospitals. To meet this type of demand, the Stanford campus at this time utilized a conventional approach for its central plant, generating steam for heating and chilled water for cooling, distributing these media throughout the campus to the various buildings using a large network of distribution pipes. When chilled water was made at the central plant, the heat removed was discarded to the environment via evaporative cooling, in the process using 25% of the entire campus demand for water.

The data collected suggested the study of *heat recovery* in some form as an adjunct for this system, with the expectation that about 10% of the time there would be sufficient excess heat from the cooling process to contribute to the simultaneous heating demand. Further study indicated, surprisingly, that excess heat could be harvested 75% of the time. In fact, analysis showed that about 90% of the heat requirement in campus buildings could be met through *heat recovery* from the central cooling system.

Stanford then focused on a truly innovative strategy to take advantage of the great potential for energy efficiency revealed by the data: heat pumps with hot and chilled water storage. There is some proven precedent of this approach: northern European countries had switched to hot water from steam for their district heating plants and experienced significant efficiencies due to reduced energy losses in the distribution network. The same principle would apply to a system based on heat pump technology.

There is also a huge cost efficiency to this approach since the electric-powered machines could be operated off-peak at lower rates using the large thermal storage. Because of this off-peak operation, the equipment does not have to be sized to meet the campus peak demand and therefore could also be significantly downsized, saving on initial system cost.

*Heat recovery* would be a major feature of such a strategy, but there would be inherently higher efficiency and potentially elimination of all carbon emissions because of the equipment employed and the energy source contemplated—solar versus fossil fuel. The introduction of the solar component would require an operational management approach that would optimize energy performance while minimizing operating cost. This would essentially require a new type of operating software—another challenge of this innovative strategy.

It was a strategy with highly desirable outcomes, but the implication was the total abandonment of the existing central energy plant. This had significant financial implications and operational risk, and would require major campus planning decisions by Stanford's leaders.

*The "Realistic" Opportunity Presents Itself*

This "out of the box" strategy became realistic only because of a coincidental opportunity with regard to the existing gas-fired central plant. This existing central plant was actually owned by a subsidiary of General Electric Company, Cardinal Cogen Inc., and leased to Stanford University. As part of the lease agreement, Cardinal Cogen operated and maintained the equipment, with Stanford paying for replacement equipment when scheduled.

The lease contract was due to end in 2015 and a renewed **30(?)**-year agreement would have to be signed at that time if Stanford were to opt for the "No Change" strategy instead of the decidedly innovative *green* strategy. Since the design, construction and start-up period for an entirely new system would require 5-7 years, Stanford knew that there was no time to lose if the new strategy were to be realistically considered—all essential studies for the new system and review by university leaders would have to be completed by 2008 for a "Go – NoGo" decision.

*(Opposite page, top)* Aerial view of the Stanford campus, with the existing central plant and new site for the CEF.

*(Opposite page, bottom)* Diagram of the distribution network from the new CEF.

(Diagrams courtesy of AEI.)

*Studies for the New Central Energy Facility*

There were a number of technical studies necessary to be completed by 2008 and there were challenges along the way. One was to determine if large-scale heat pumps with the desired heat recovery features could be obtained competitively on the market. Stanford ultimately had to write a specification for the equipment so that the university could obtain multiple bids.

With that item checked off, the next challenge was essentially to model and optimize the operation of the system based on system component performance characteristics and thereby determine the size of the various pieces of equipment. Software to model this size and type of system did not exist, so Stanford wrote its own[1]. Published as the *Central Energy Plant Optimization Model (CEPOM)*, the software calculates the most efficient hourly operational plan to meet loads based on demand, the price of energy and the equipment specification. The model analysis studied five-year increments from 2015 to 2050 to map the complete cost and replacement schedule that would be required for the system. The result was an optimization for the equipment selection and system operation that set the basis of design for the new Central Energy Facility (CEF) that was most cost-, energy- and resource-efficient.

Another pre-design planning study involved what had to be done at all campus buildings and the distribution network. The changes were able to be tabulated in a straightforward engineering study, essentially requiring all the steam-to-hot-water heat exchangers be replaced by new hot water (HW) heat exchangers. As part of this study, the future chilled water (CW) demand was estimated for 2008-2015 to make sure that there was enough capacity in the current distribution network and the existing buildings, so that no special changes had to be made to that part of the system.

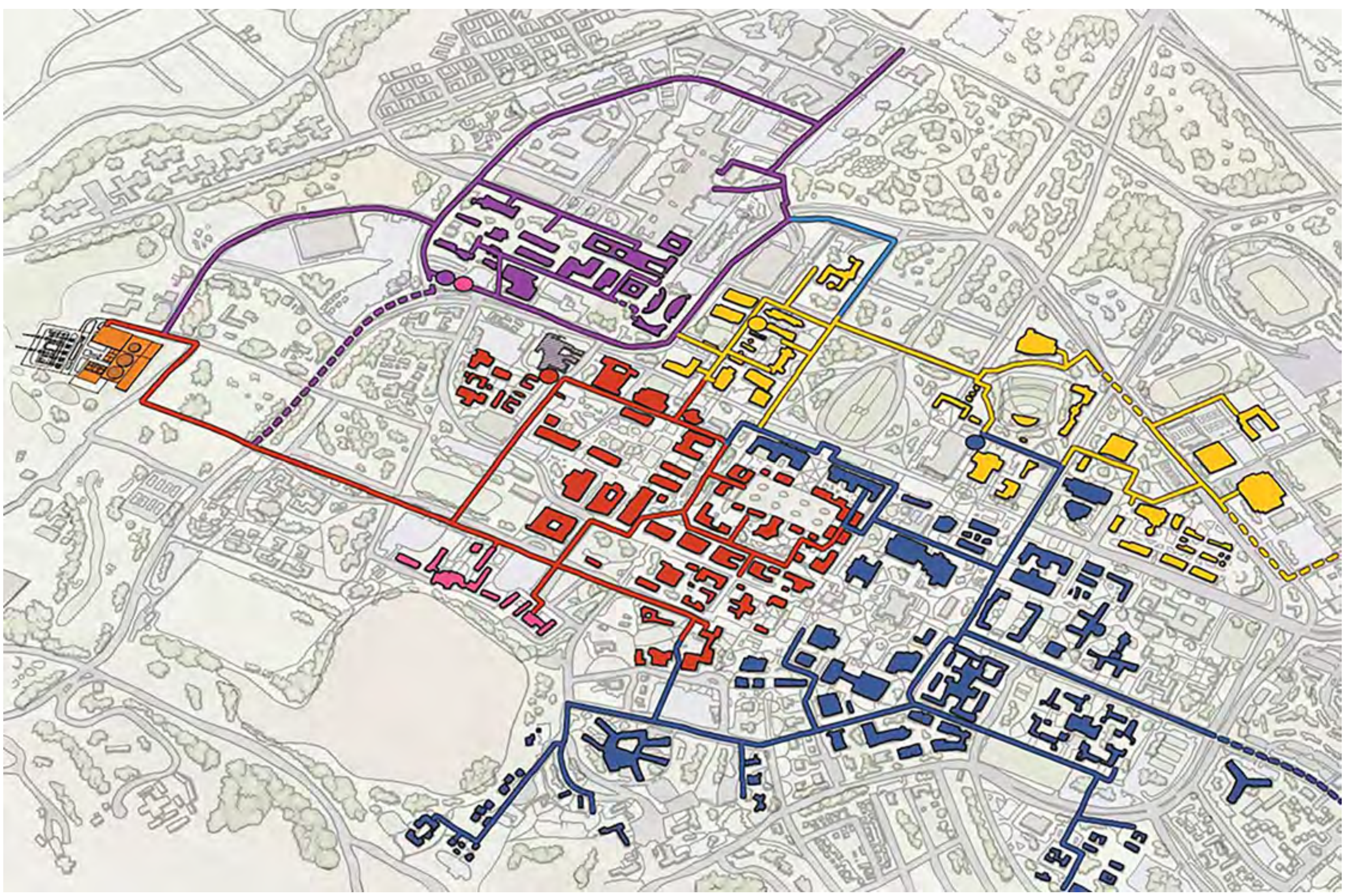
An additional study was done of the actual design of the large heat pumps, which were specified as *ground source* heat pumps. Rather than go the expense of installing a large new ground loop system connected to the heat pumps for rejecting and absorbing heat, staff studied the advantage of utilizing two existing horizontal networks of piping that circulated water: the landscape irrigation system in the turf playing fields, which used non-potable water, and the drinking water distribution system. The study showed that both could be used effectively as the ground loop components of the heat pumps. Connected to the irrigation system, the heat pump could use a heat exchanger to dump heat at night when the sport fields were being irrigated; warmer irrigation water was just as effective in keeping the turf healthy. During the day, the drinking water network was used as a "heat" source by heat exchangers, effectively chilling the drinking water before it was delivered to the buildings on campus—also a welcome outcome.

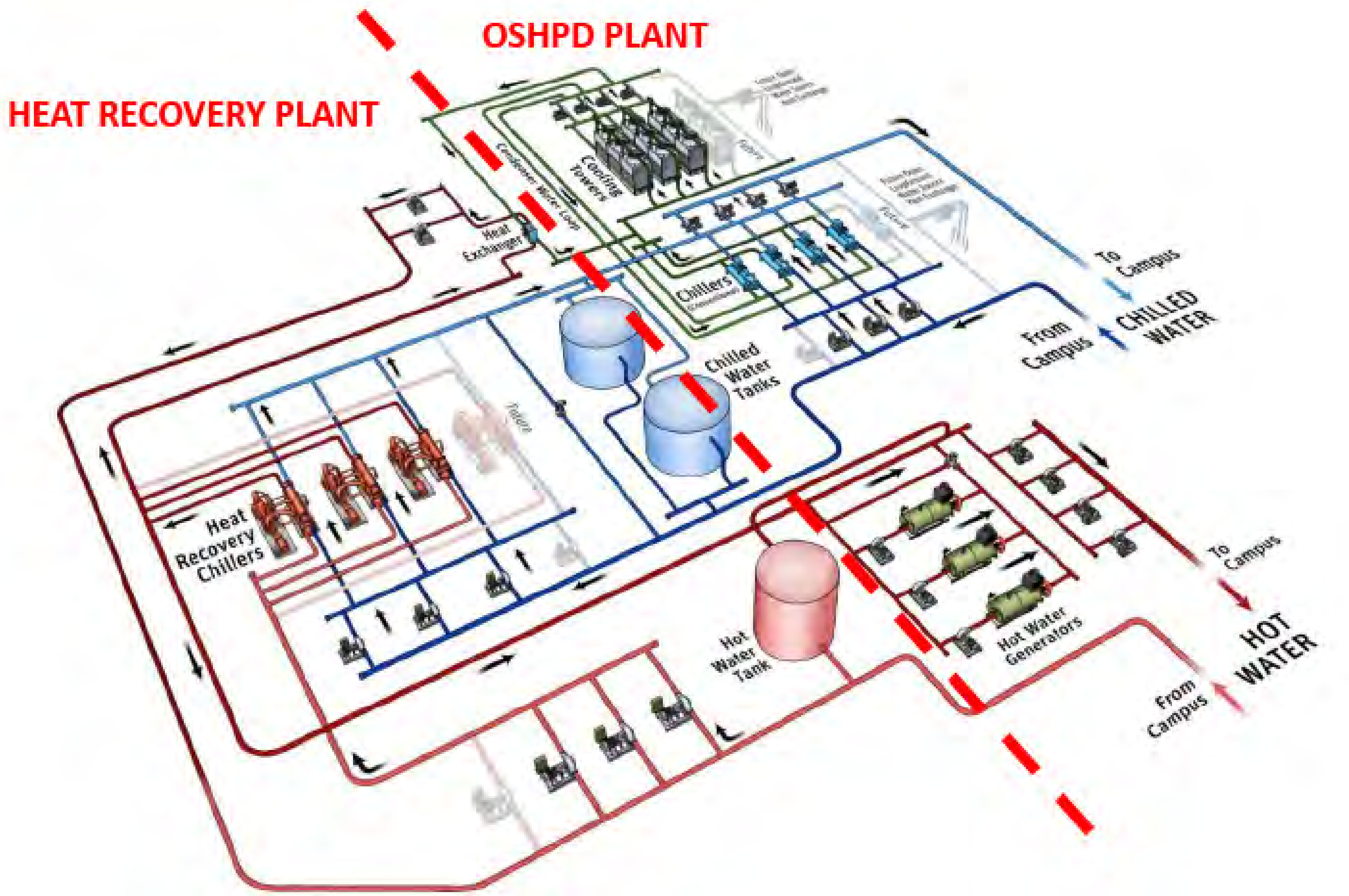
Finally, the cost of this major changeover, plus replacement and operating costs over a 30-year period were studied for the new CEF versus the no-change scenario. The cost study showed that the new CEF had a lower present-value cost than a renewed lease of the existing cogeneration plant and concluded that it was the best investment for Stanford University while meeting all the sustainability goals.

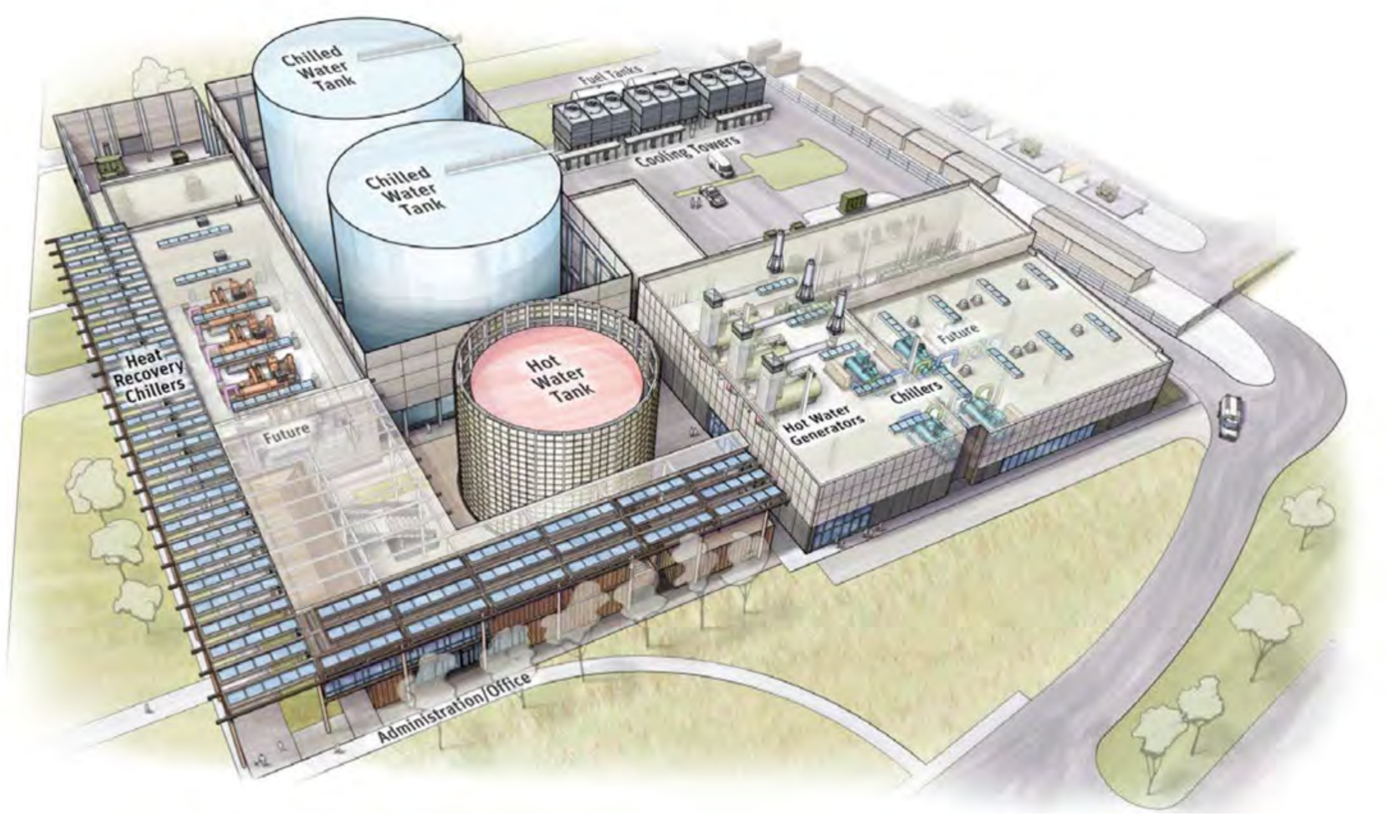
Campus peer review and Stanford's own internal review of the studies supported the conclusions. This convinced campus leadership of the merits of this bold plan and the Board of Trustees approved moving forward.

[1] Stanford University has made this patented software, *Central Energy Plant Optimization Model*, publicly available, currently through Johnson Controls. The spreadsheet version, intended for non-profit institutions of higher education, is available at no cost, though this is temporarily on hold due to licensing issues.


EXISTING
CEF &
SUBSTATION
NEW
SITE






*Diagrams courtesy of AEI*

*(Opposite page, top)* System diagram of the new CEF, with the "OSHPD Plant" separated in order to meet then-current code requirements.

*(Opposite page, bottom)* Isometric sketch of the final CEF design with all system components.

**The Central Energy Facility — Choice Made and Moving Forward**

Stanford began the process of planning the new CEF in 2011. Before that, the campus had asked Cardinal Cogen if they would be willing to extend the lease of the existing plant on a month-by-month basis if construction and start-up of the new CEF experienced any delays. The company declined, so a hard start date for operation of Stanford's new CEF was set for 2015.

The design of the facility started by using the well-studied basis of design undertaken by the campus in the previous three years. Still, some constraints appeared during the design phase that had to be accommodated. The most significant of these was a consequence of the fact that the Stanford University campus has major hospitals that are served by the CEF and are governed by the California Office of Statewide Health Planning and Development (OSHPD). This agency would not approve the new CEF since it would not fit any approved criteria and the path to approval of the new design approach would simply take too much time given the 2015 deadline.

The solution was to design a small sub-system that would serve the hospitals, which would necessarily be conventional gas-fired equipment for heating. This "OSHPD Plant", separated from the main CEF, meets all the OSHPD requirements—it's a necessary anomaly in this otherwise simple energy plant design. As a result, the CEF is not purely electric power driven, but has a small fossil fuel use. However, given that this gas-fired facility was required, Stanford could use it as a back-up source of heated and chilled water for high peak load situations or a potential unplanned shut-down of one of the heat pumps.

The non-equipment space of the CEF, namely the administrative offices, control rooms and meeting spaces of the Department of Sustainability and Energy Management, with its on-site solar PV array, has performed at ZNE and merits independent treatment as a ZNE building design. (See Case Study No. 17, *Central Energy Facility Office Building*, following this *Preface*.)

Construction began in late 2012 and by March, 2015, the CEF was started up after 22 miles of the distribution network around the campus were modified and the connections were made to the new heat exchangers in 155 campus buildings. This significant effort took more than two years, but eventually the entire campus was converted to the modified system, with heating and cooling energy supplied by the new CEF.

It remained to connect to a solar electric power supply to realize the full potential of minimizing the carbon emissions that the CEF could make possible.

*(Below, left)* Aerial view of the construction site after grading and preparation.

*(Below, right)* Aerial view of the construction site at an early stage. Note how concrete pads for large thermal storage tanks are set well below grade.

(Construction photos courtesy of Whiting-Turner Contracting Company.)

PHOTO: STEVE PROEHL

*(Overleaf, previous page)* Aerial view of the completed Central Energy Facility.

**Plan for Renewable Energy Supply**

The final piece of the plan was the connection to a solar PV energy system large enough to supply electricity at a substantial part of the entire Stanford campus demand. Since land and existing building rooftops were limited at the campus, a large-scale solution away from the campus had to be devised.

The solution was found in the *Direct Access Program*[2] passed by California legislature in 1998. (This program was suspended in 2001 and reinstated in 2010.) Stanford University was eligible to participate in the program beginning in 2012. Under this program, Stanford entered into a *power purchase agreement (PPA)* with a third party provider, the solar energy company, SunPower, to obtain electricity from a new 68 MW solar electric "plant", called the *Stanford Solar Generation Station*, consisting of 155,000 PV panels located in the Mojave desert north of Palmdale, California.

According to California law, the transmission wires from the desert to the Stanford campus are managed by the "non-profit public benefit corporation", California Independent System Operator (Cal ISO). The parties to the PPA include the public electric utility (in this case, Pacific Gas & Electric Company), which provides the equivalent amount of electricity to the Stanford campus as put into the grid by the SunPower plant. The terms of the agreement are in effect for 25 years.

The solar power plant provides 53% of the current electric power demand of the entire Stanford University campus at 20% less cost than that expected if Stanford had purchased the directly from the electric utility for the new energy-efficient CEF. There has been a campus facilities program to install solar on new and existing campus buildings and those systems contribute an additional 5 MW, which is an additional 7% of the total electric demand. This brings the total renewable energy supply for the campus to 60% of total campus electric demand.

This is a significant advance down the path to a total ZNE campus, accomplished in less than 10 years from the start of concept planning.

The combined systems of the Central Energy Facility and the Solar Generating Station constitute the *Stanford Energy System Innovations (SESI)*.

**Post Construction Performance**

In the first year of operation, the new CEF used only 5% of the natural gas total that was typical of the old cogen plant. This was due only to the operation of the OSHPD plant for the Stanford hospitals. Electrical energy use unsurprisingly increased, requiring 33% more draw from the grid, but the peak electrical demand was significantly lower because of the thermal storage—38 MW peak compared to the typical 45 MW peak of the old cogen plant.

*(Opposite page)* Views of the Stanford Solar Generation Station in the Mojave Desert of California.

(Photos courtesy of SunPower.)

[2] For more information about the Direct Access Program, see https://www.pge.com/en_US/business/services/alternatives-to-pge/electric-services/direct-access-electricity/direct-access-electricity.page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CASE STUDY NO. 17

# Central Energy Facility Operations Center

PHOTO: ROBERT CANFIELD

# Central Energy Facility Operations Center

## *Case Study No. 17*

**Data Summary**

**Building Type:** Higher Education-Administration

**Location:** Stanford, CA

**Gross Floor Area:** 9,571 sf

**Occupied:** March 2015

**Energy Modeling Software:** eQuest (2010)

**Modeled EUI (Site):** Not available - see discussion

**Measured EUI (Site):** 54.1 kBtu/sq.ft. per year (2017-2018)

**On-Site Renewable Energy System Installed:** 175 kW (DC) Solar PV

**Measured On-Site Energy Production:** 288 MWh per year (2017-18) 102.9 kBtu/sq.ft. per year (2017-18)

**Owner/Client**

Stanford University

**Design Team**

*Mechanical/Electrical/Plumbing Engineer (Prime):* Affiliated Engineers Inc. (AEI), San Francisco, CA

*Architect:* ZGF Architects, Portland, OR

*Structural Engineer:* Rutherford + Chekene, San Francisco, CA

*Lighting Design:* Affiliated Engineers Inc. (AEI), San Francisco, CA

*Landscape Architect:* Tom Leader Studio, San Francisco, CA

**General Contractor**

The Whiting-Turner Contracting Company

The *Central Energy Facility (CEF)* at Stanford University began successful operation in March, 2015, and has exceeded the initial performance targets in its first three years of operation. As radically innovative as the energy systems are in their design for the campus, the story of this project has even more aspects of design worth noting. For although 90% of the structure is functionally given over to industrial-type space and large machines, about 10% of the space is occupied like a specialized office building, where the application of advanced design ideas continues.

One of the outcomes is zero-net-energy (ZNE) performance of the office building component of the CEF, which makes it an instructive case study for this Volume 3.

### Background

As noted in the Preface, the Department of Sustainability and Energy Management had completed three years of feasibility studies leading up to the decision by Stanford University to abandon its existing central plant and build the dramatically innovative CEF beyond the current edge of campus. These many studies and related analyses essentially formed a basis of design for the CEF, but there remained much to determine through the process of actually developing the design of the physical structure and space with the help of outside professional design firms.

Because of the industrial nature of the project, Stanford awarded the contract for the design of the CEF to an engineering firm that was skilled with these types of facilities, Affiliated Engineers (AEI) of San Francisco. Concerned about the visual aspects of the facility, its relation to the original 1888 campus plan by Frederick Law Olmsted and the design of the attached office building, Stanford also met with several architectural firms and recommended ZGF Architects (Portland) to AEI, the prime contractor. The arrangement was agreed upon since the two firms had prior experience of successfully teaming together on complex projects.

### Design Process and Low Energy Design Strategies

Design studies began in earnest in 2011, using the large amount of work that had been done to that point as the point of departure. Design challenges included the relation of the CEF to the adjacent central campus and, related to this, the size and scale of the facility and the industrial appearance of the storage tanks and electrical sub-station.

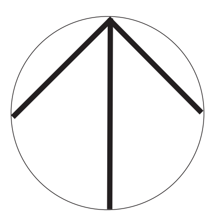
*Planning Concept and General Design Considerations*

The brief for the entire building included engagement with the campus community as a visible demonstration of sustainability and zero-net-energy at Stanford, as well as to capitalize on the educational opportunity created by the CEF and its design. The design team began with this, suggesting expansion of the building program to include public spaces, both indoor and outdoor, such as meeting spaces, a lecture room and even an outdoor amphitheater.

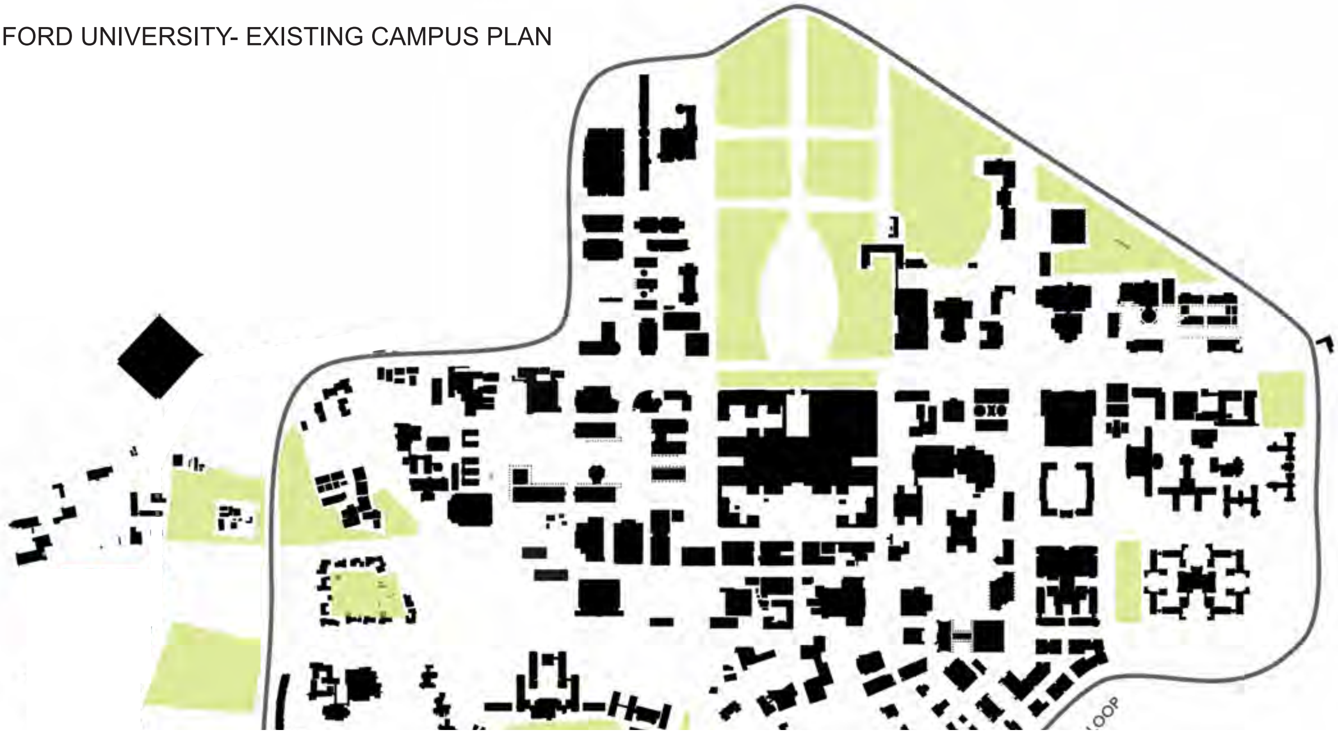
The office spaces, primarily occupied by the Department of Sustainability and Energy Management, include these meeting and lecture rooms that were programmed to accommodate small conferences for general campus use as well as the many visitors that specifically come to the CEF to learn about its advanced design features. The program for this separate office building includes the main control room of the campus energy and distribution systems.

The campus architect for Stanford University, recognizing that the campus would expand in the future in the direction of the new CEF, suggested that the new facility, specifically the office building component, be designed in relation to the long axes of Olmsted's historic campus plan. This plan features a main central axis ending at the entry to the original core of historic buildings, but also perpendicular axes from there that create long sightlines through the landscape and its

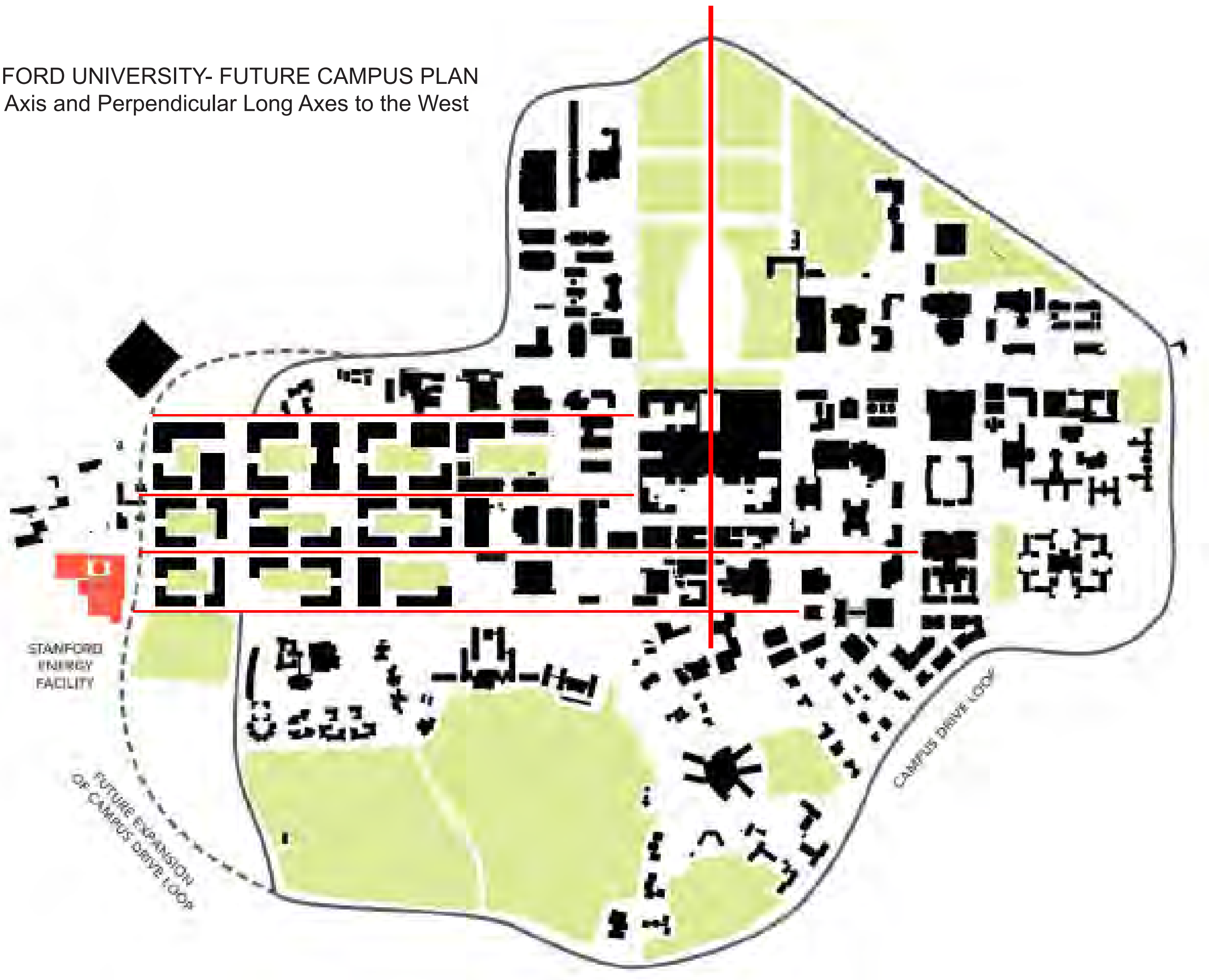
Central Energy Facility Office Building: General Vicinity Plan



STANFORD UNIVERSITY- EXISTING CAMPUS PLAN



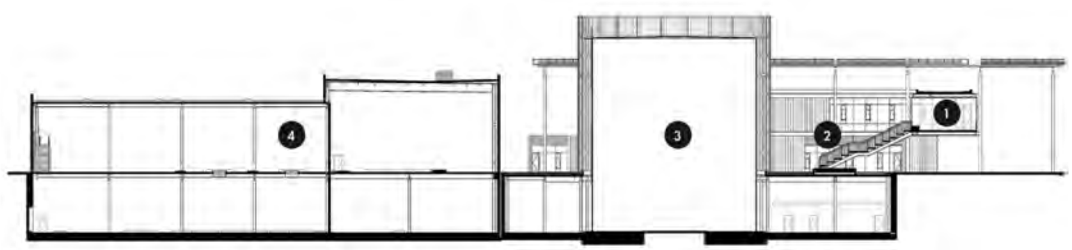
STANFORD UNIVERSITY- FUTURE CAMPUS PLAN
Major Axis and Perpendicular Long Axes to the West



structures back to the historic core. By placing the CEF at the end of one of these long axes, the structure would both terminate that axis and link it in an important way to the whole campus fabric.

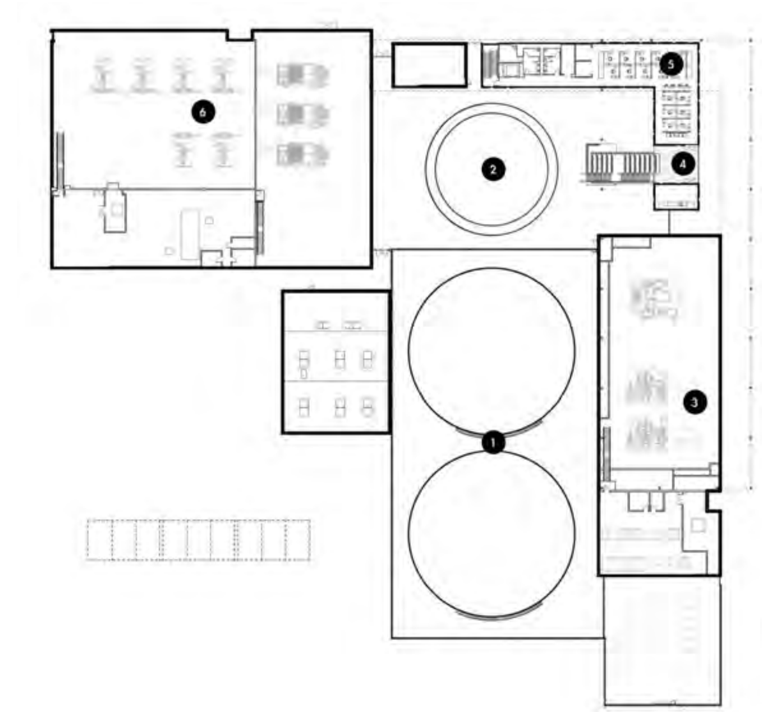
To reinforce this idea, the architects created a canopy structure over two-stories in height, floating above the office building, that created a large-scale architectonic feature to serve as an end to that axis. The canopy functionally serves as the support structure for solar PV panels that provide power directly to the office building and thus advertises its ZNE characteristic.

The axis termination with the CEF and the office building's "solar canopy" would only be visually successful if the large cold water storage tanks and electrical substation were hidden in the line of sight from the long axis. Placing the electrical substation on the back side of the CEF would be a simple solution, but the three tall cold water storage tanks would only be hidden if they were wrapped by other parts of the building and placed on a level below grade. The design team proposed this design approach and tested its effectiveness by studying the sightlines near the facility. The height of the solar canopy was determined by these sightline studies and ensured the visual screening of the cold water storage tanks. The smaller hot water storage tank became a distinguishing feature and the heart of the CEF.



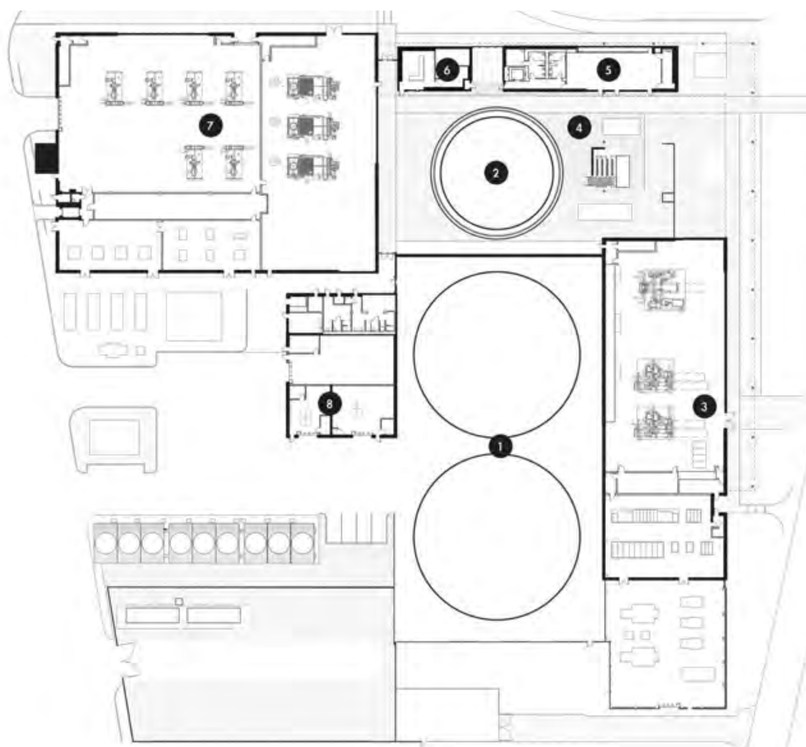

*(Left)* Diagrammatic section through the CEF showing lowering of hot water storage tank (#3) and OSHPD plant (#4) below grade and the floating solar canopy above the office building (#1 & #2).

*(Below)* East facade of the office building, visually dominated by the large solar canopy floating above the building.



**SECOND FLOOR PLAN**

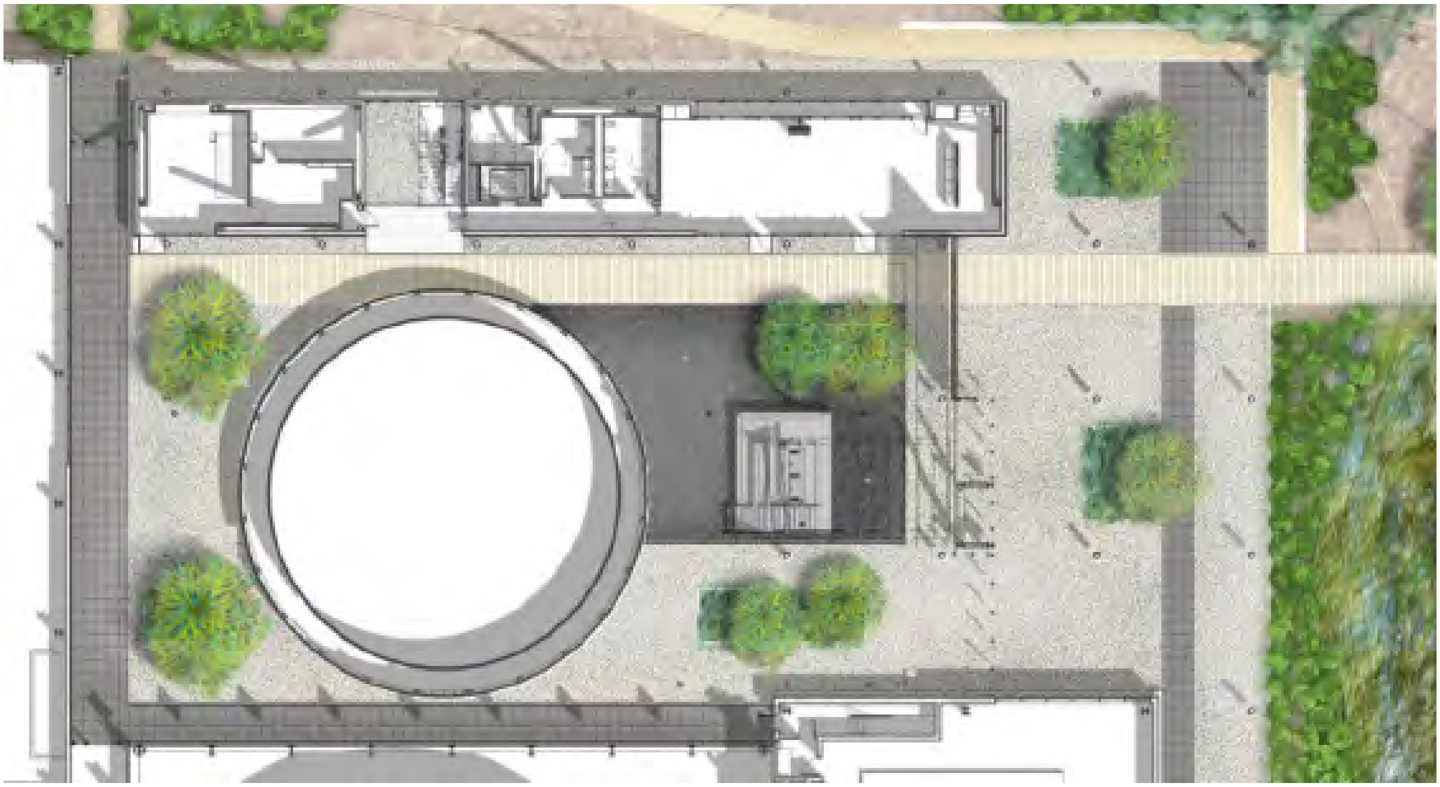
1 Chilled Water Storage Tank
2 Hot Water Storage Tank
3 Heat Recovery Chillers
4 Balcony
5 Office
6 OSHPD Plant

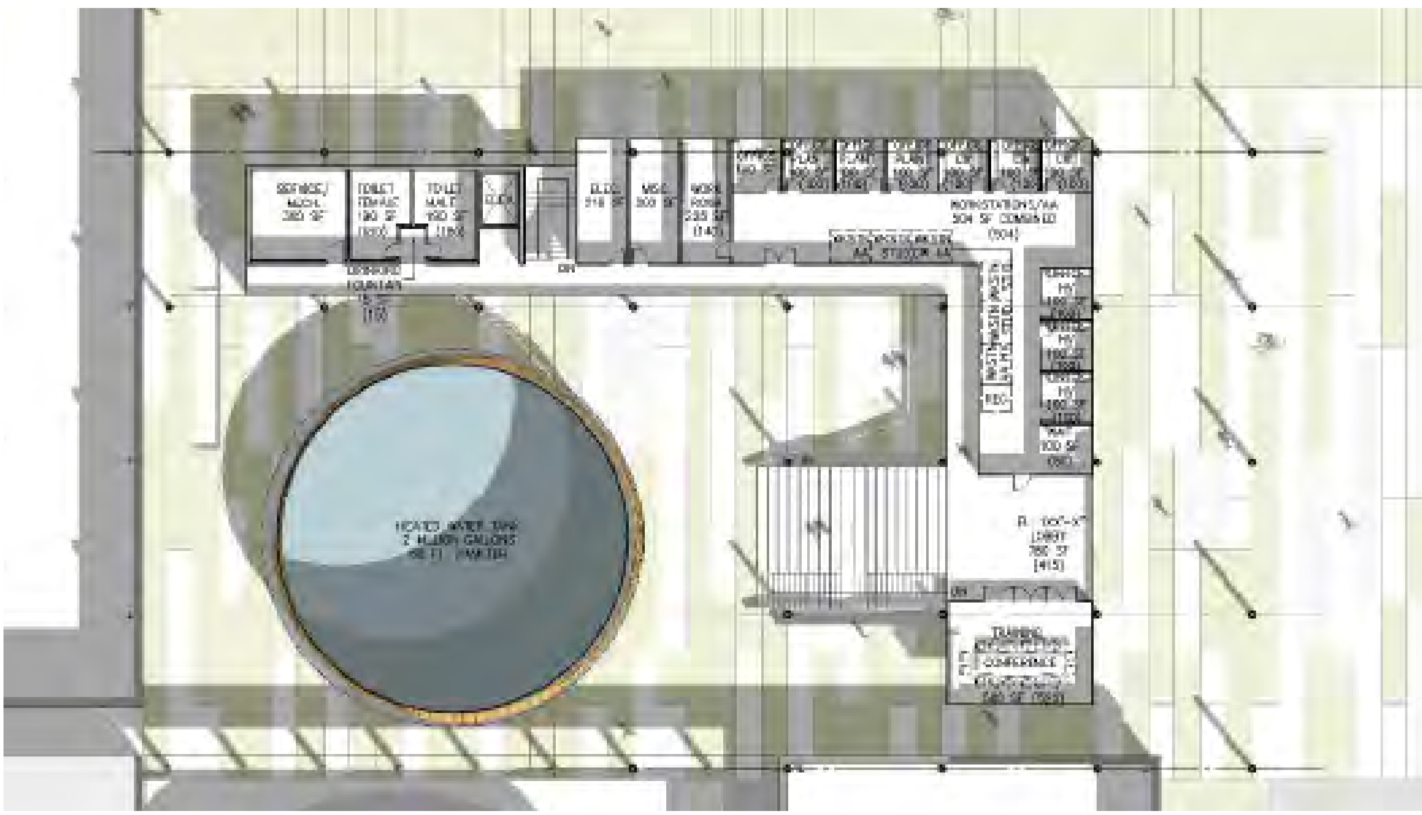


**GROUND FLOOR PLAN**

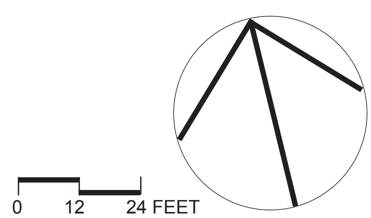
1 Chilled Water Storage Tanks
2 Hot Water Storage Tank
3 Heat Recovery Chillers
4 Entry Courtyard
5 Conference Room
6 Control Room
7 OSHPD Plant
8 Workshops

Stanford University Central Energy Facility (CEF) Floor Plans





CEF Office Building Floor Plans
(Top) Second Floor Plan
(Bottom) Ground Floor Plan

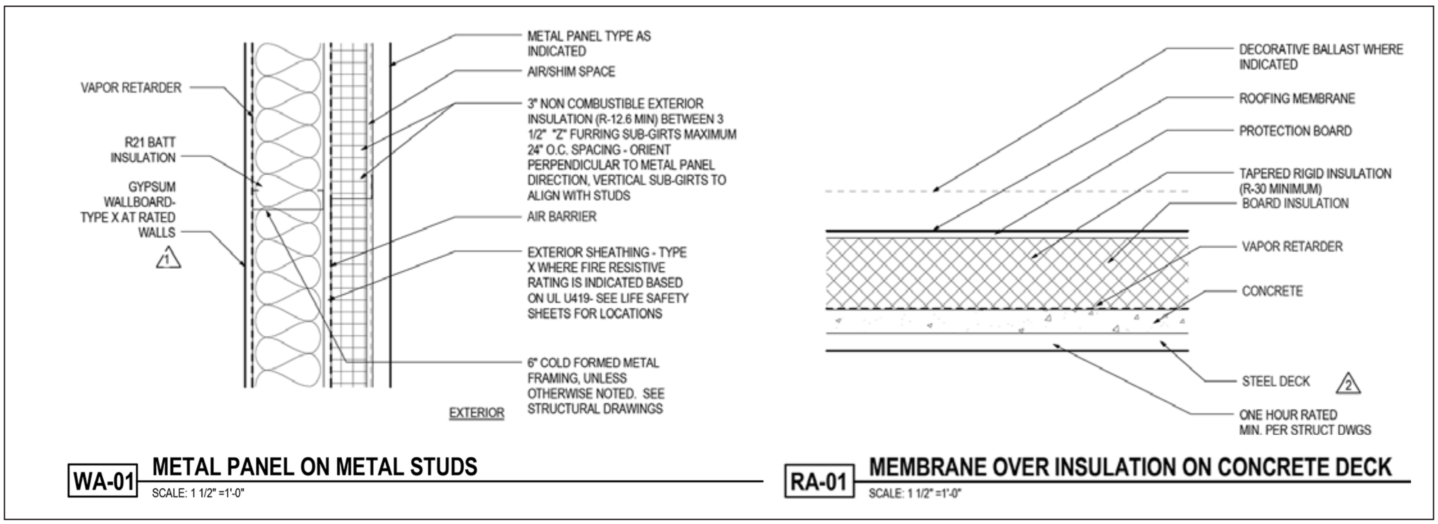


*(Opposite page, top)* Diagram of ZNE design features for the CEF Operations Center. (Courtesy of ZGF Architects.)

*(Opposite page, bottom)* Interior view, CEF Control Room for monitoring and optimizing campus systems performance.

*Building Envelope*

The exterior wall of the office building consists primarily of floor-to-ceiling glass that is well-shaded by the canopy and provides clear views to the surrounding landscape. Sun angle studies were done during design to ensure that there was no exposure that would result in excess solar gain. The envelope enclosure is heavily insulated (minimum R-34 in the walls and R-30 in the roof) and detailed to provide at least 3" of continuous insulation on the exterior of the metal studs, metal roof deck and elevated floor deck. This layer of continuous insulation prevents thermal bridging, a common issue with conventional building envelopes. See illustration below:




*Daylighting and Electric Lighting*

The office space is well-daylighted with tall glass on both sides of the narrow (30') floor plate. The shading from the extensive solar canopy prevents direct glare conditions. The optimal spacing of the opaque canopy elements for this purpose was studied during the design phase using shading mask analysis.

*Natural Ventilation*

User-controlled operable windows allow for natural ventilation when outside conditions warrant in this year-round temperate climate. Since the designers and client opted for user-control, night flushing to precool the building during peak cooling weather events is not possible.

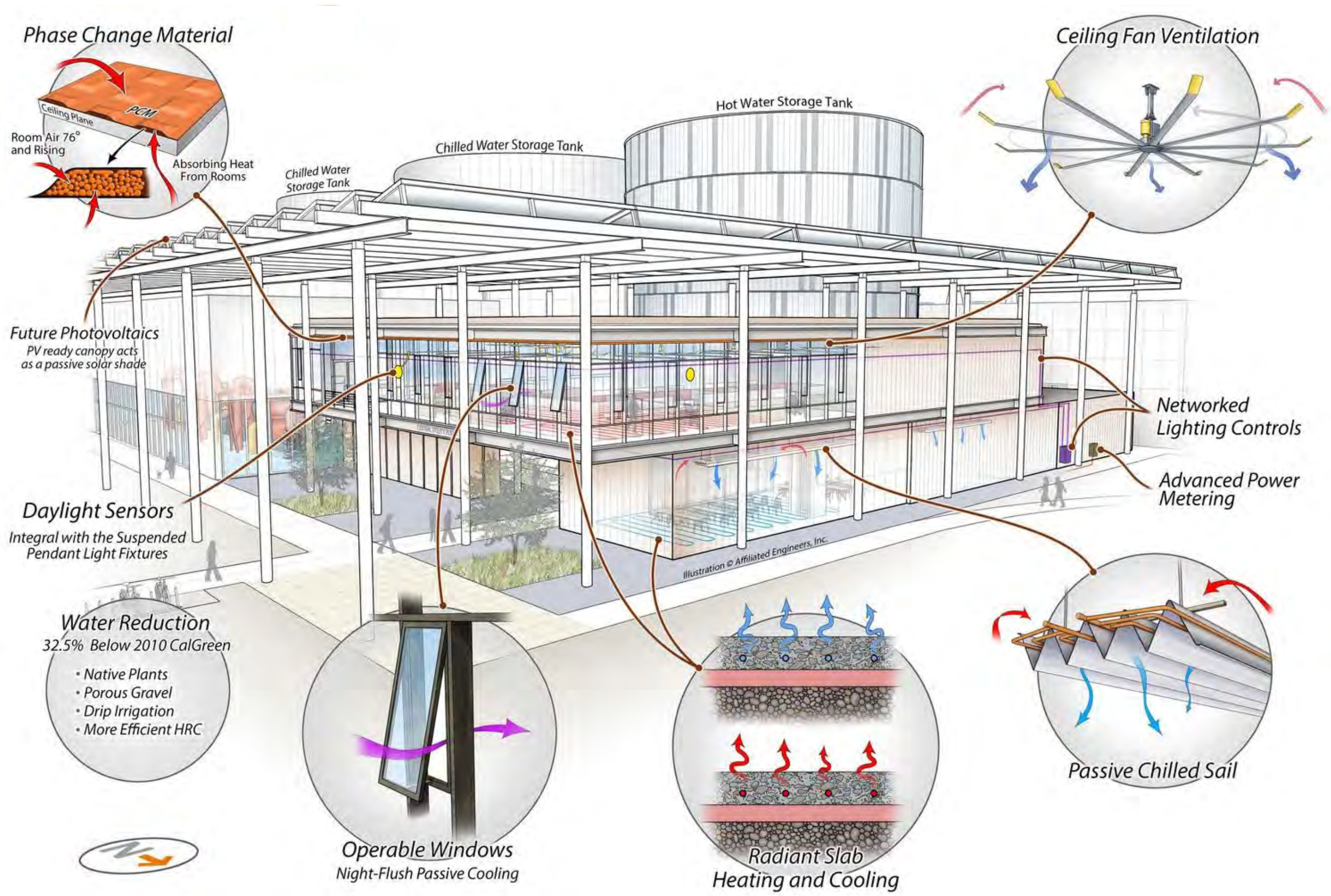
*Heating, Ventilating and Cooling Systems*

The office building utilizes a radiant floor system throughout for heating and cooling, with additional climate control provided by ancillary systems. Radiant systems generally require less energy and provide greater comfort than all-air systems and are an ideal system for office spaces.

The radiant system in this case is a "single-pipe" system, which requires a "dead band" in the operation between the heating and cooling modes. This generally occurs, for example, when foggy mornings give way to warm and sunny afternoons, an occasional event in this microclimate.

The ancillary systems were added in part at the behest of the users, who wanted to use the building as a test facility for new systems and technologies that might be considered for future buildings on the Stanford campus.

*(Following pages, overleaf)* View of interior courtyard and amphitheater designed as part of exterior stairs to the second floor level.



Phase Change Material
Ceiling Plane
PCM
Room Air 76° and Rising
Absorbing Heat From Rooms
Chilled Water Storage Tank
Chilled Water Storage Tank
Hot Water Storage Tank
Ceiling Fan Ventilation
Future Photovoltaics
PV ready canopy acts as a passive solar shade
Networked Lighting Controls
Advanced Power Metering
Daylight Sensors
Integral with the Suspended Pendant Light Fixtures
Illustration © Affiliated Engineers, Inc.
Water Reduction
32.5% Below 2010 CalGreen
• Native Plants
• Porous Gravel
• Drip Irrigation
• More Efficient HRC
Passive Chilled Sail
Operable Windows
Night-Flush Passive Cooling
Radiant Slab
Heating and Cooling

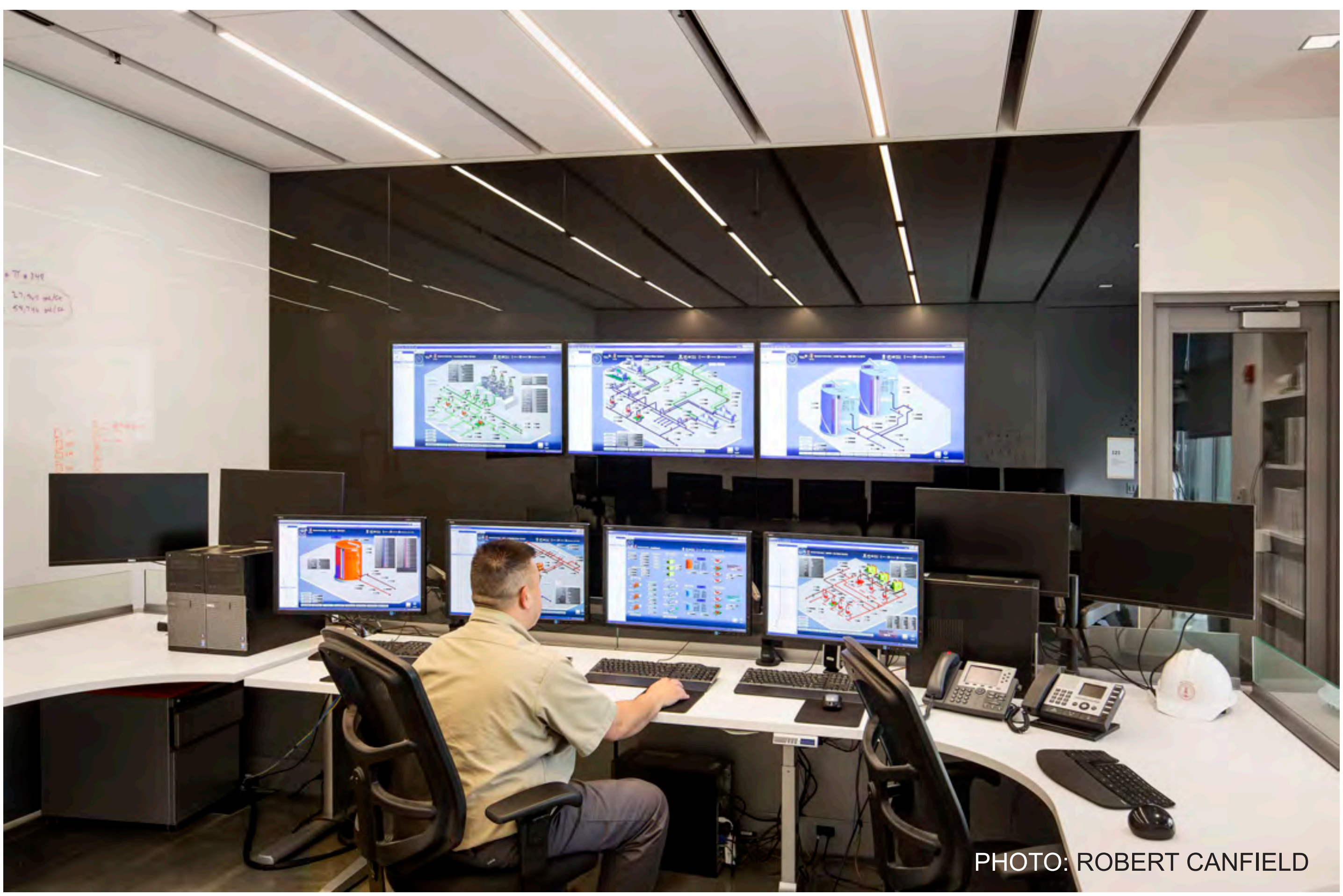



PHOTO: ROBERT CANFIELD

PHOTO: ROBERT CANFIELD


EXIT
EXIT

*(Opposite)* Interior views of the general office spaces.

(Photos: Robert Canfield.)

One of these ancillary systems was ceiling-mounted *chilled sails*, which was added in the conference spaces on the first floor to respond to the sudden increase in cooling load caused by a large increase in the number of occupants. Since the radiant floor system is located in a concrete slab, the response time would have been too long to provide comfort conditions quickly enough. Installed directly below the ceiling, the folded metal chilled sails effectively provide instant response by utilizing very effective convective heat transfer with the room air. Like chilled beams, chilled sails use chilled water and passive air movement to provide the desired thermal comfort conditions in the space. On peak cooling days, the chilled sail system is backed up by a fan-coil unit, which is used only under those more extreme conditions.

A second ancillary "system", used throughout the building, is a blanket-type phase change material (PCM) as a passive cooling technique, acting like thermal mass to absorb heat at a constant temperature rather than causing an increase in room air temperature. These PCMs are located above and on the suspended ceiling, where they can interact with the room environment.

These materials absorb heat from the space above a certain temperature (called the "Q-value") and gradually become liquified. To perform the same function on the following day, the material must be exposed to a lower temperature and returned to a solid state during the night. This is accomplished by using a small exhaust fan at night in the plenum space only, where the PCM is located, to chill down that space so that the PCM is fully re-charged for the next day. Measurements are currently being done of the effectiveness of this system to reduce the peak of the cooling load.

## Renewable On-Site Energy Supply

As described above, the large cross-laminated wood canopy structure placed above the office building supports the solar PV panels. It also provides an architectonic element intended to be reminiscent of the trellises over other campus courtyards while providing shading of the glass facades on the second floor. It was not sized to support a specific number of solar PV panels that would offset the building's annual energy consumption.

Originally, the cross-laminated panels were installed for shading purposes. It was not until March, 2017, that the solar PV system totaling 175 kW was installed on the canopy and started to produce power that could be utilized by the building. Because PV panels were installed everywhere on the canopy, the system actually has a large over-production, which is put into the general campus power grid.

## Energy Design Analysis and Energy Performance
### *Modeling versus Post-Occupancy Measurement*

*Energy Modeling*

Energy modeling was initially done using eQuest (2010) for the basic building and systems that were capable of being modeled at that time. Additional techniques of calculating the effectiveness of non-standard systems, including the use of custom spreadsheets, were utilized and added to the eQuest results to gauge the overall performance expected for the building. The high process energy requirements of the campus CEF control room and server room were only partly known the time, so a meaningful overall energy model for the building was not obtained.

Monthly results of the breakdown by category of energy use were not derived, but there was confidence by the design team and Stanford representatives based on the overall analysis that the design was highly energy efficient and met all required sustainability objectives.

*Energy Use—Actual Measurement and Comparison to Modeling Results*

Metered energy use was recorded for the basic categories of electrical use (lighting, plug load and building equipment) and the heating and cooling energy as separately measured via flow meters. The electrical energy use includes the control room for the campus energy supply, which is a substantial power draw because of its 24/7 operation.

The building used approximately 151.6 MWh during the period from 5/2016 to 4/2017, which equates to an EUI of 54.1 (kBtu/sq.ft. per year). It is important to note that the EUI includes not only the administrative office building but also the intensive process loads of the central plant control room and server room that are associated with larger campus operations.

*Energy Production versus Energy Use: Zero Net Energy Performance*

As noted above, the solar PV system installed on the canopy structure was not determined by the building energy use data, but simply fills all the available space on the canopy. The system produced almost 290 MWh of energy over the course of the year from 5/2017 to 4/2018, which is almost double the actual annual energy use measured for the building. So, even with half of the solar PV system installed on the canopy, the building easily achieves ZNE.

## Post Occupancy: Observations and Conclusions

*Post Occupancy: Natural Ventilation*

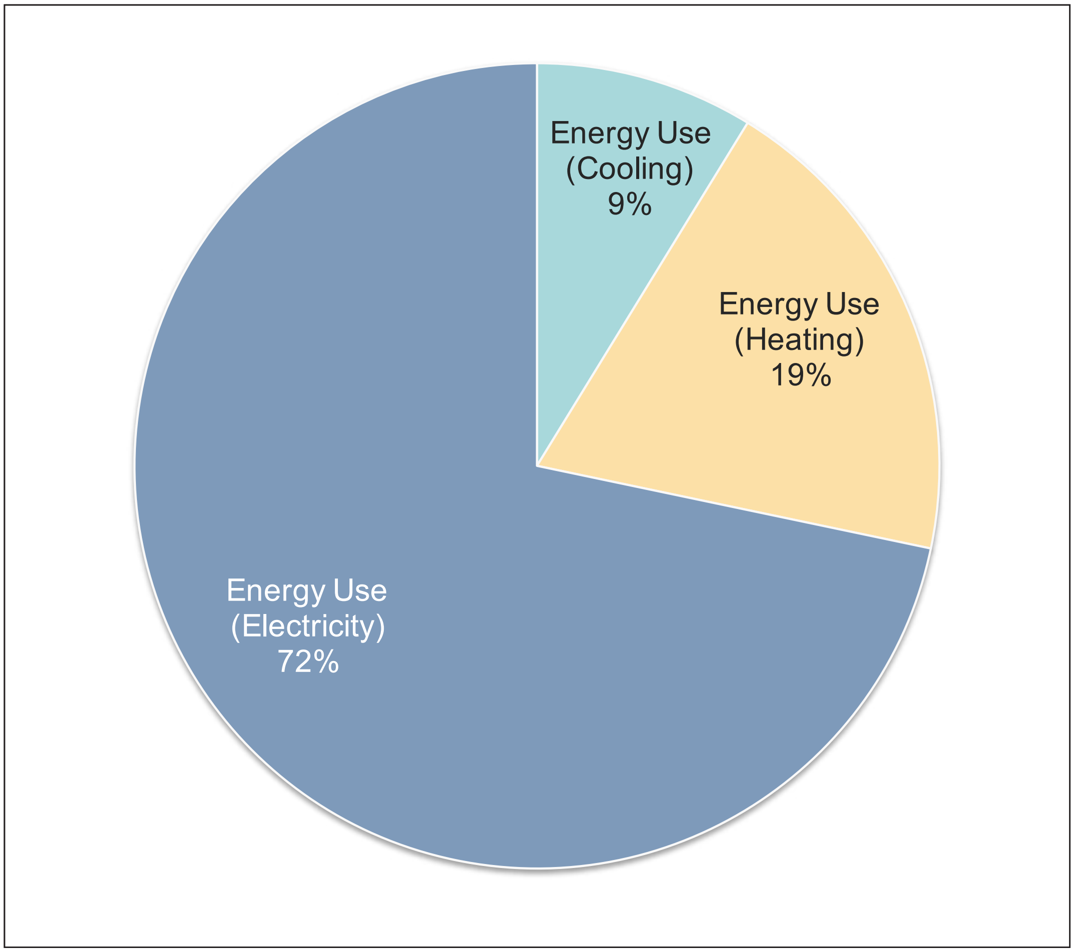
Reliance on user operation of the natural ventilation for fresh air and cooling is questionable, even with the most attentive of user groups. Finely tuned operation that is responsive to outdoor air conditions and efficiently reduces the cooling load is best accomplished through automated, continuously-operating window actuators and an integrated operating system. Deep energy savings are possible with this type of system. On the other hand, user-operation provides the occupants with a sense of control of the internal environment and comfort conditions. This is the typical discussion of pros-and-cons among designers and clients when evaluating natural ventilation as a cooling design strategy.

In the case of this building, the choice of user-operated windows was driven by the perceived extra cost of an automatically operating system and the state of that technology at the time this building was designed. The users also favored the option of manual control only since they felt invested in awareness of the energy performance of the building.

*Post Occupancy: Occupant Behavior*

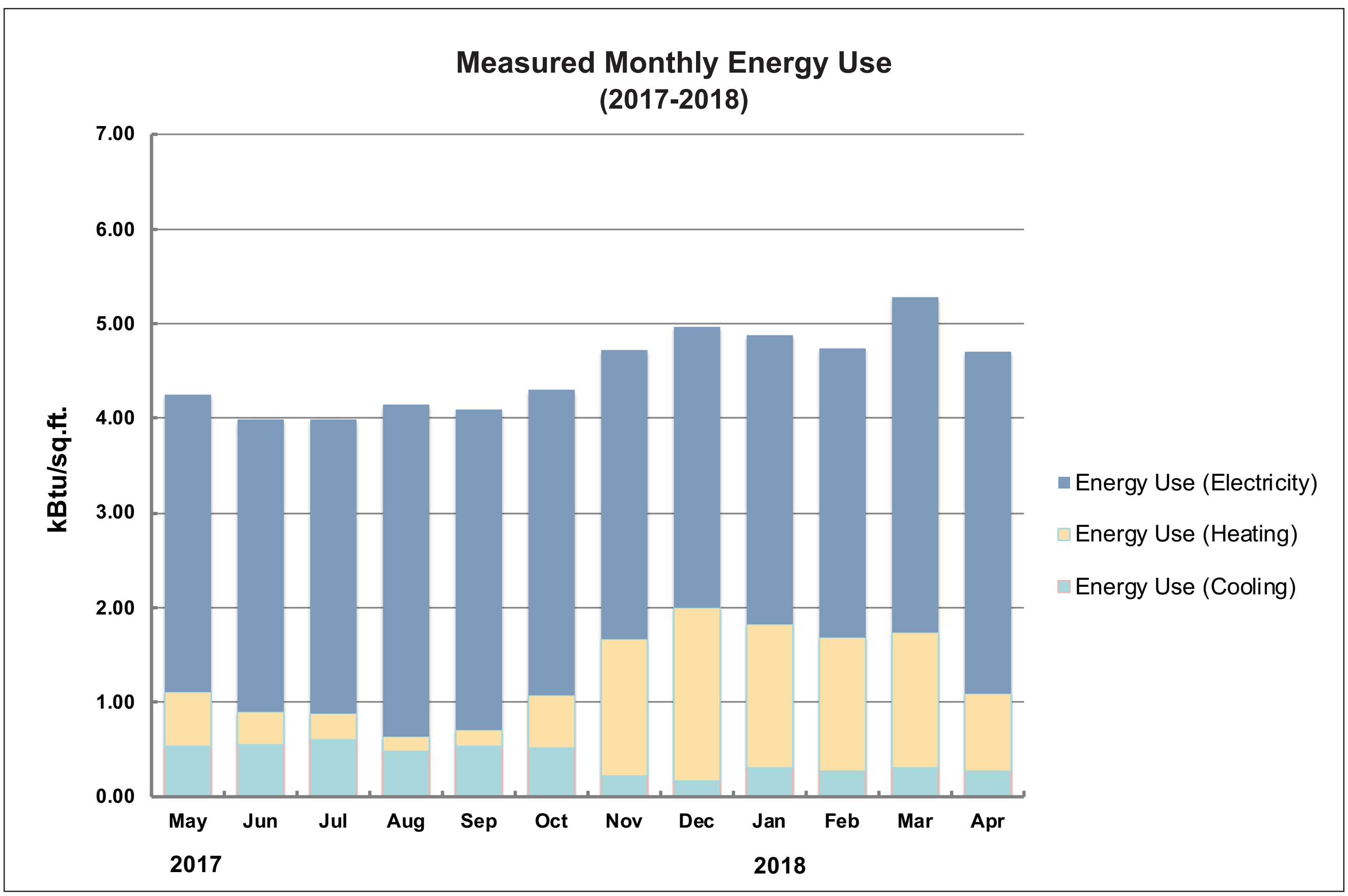
The initial campus planning design decisions—positioning the building to terminate a long axis from the center of campus and create a strong visual presence at that termination—were more successful than anticipated. The building has high numbers of visitors, both from the campus and abroad, attracted by the importance placed on the energy management and sustainability aspects of the entire CEF. The planning concepts and the design of the facility is at least partly responsible for this response. (There was even a request made to Stanford to allow a wedding to take place in the outdoor amphitheater at the office building's courtyard space, based on the mission of the CEF project and its realization.)

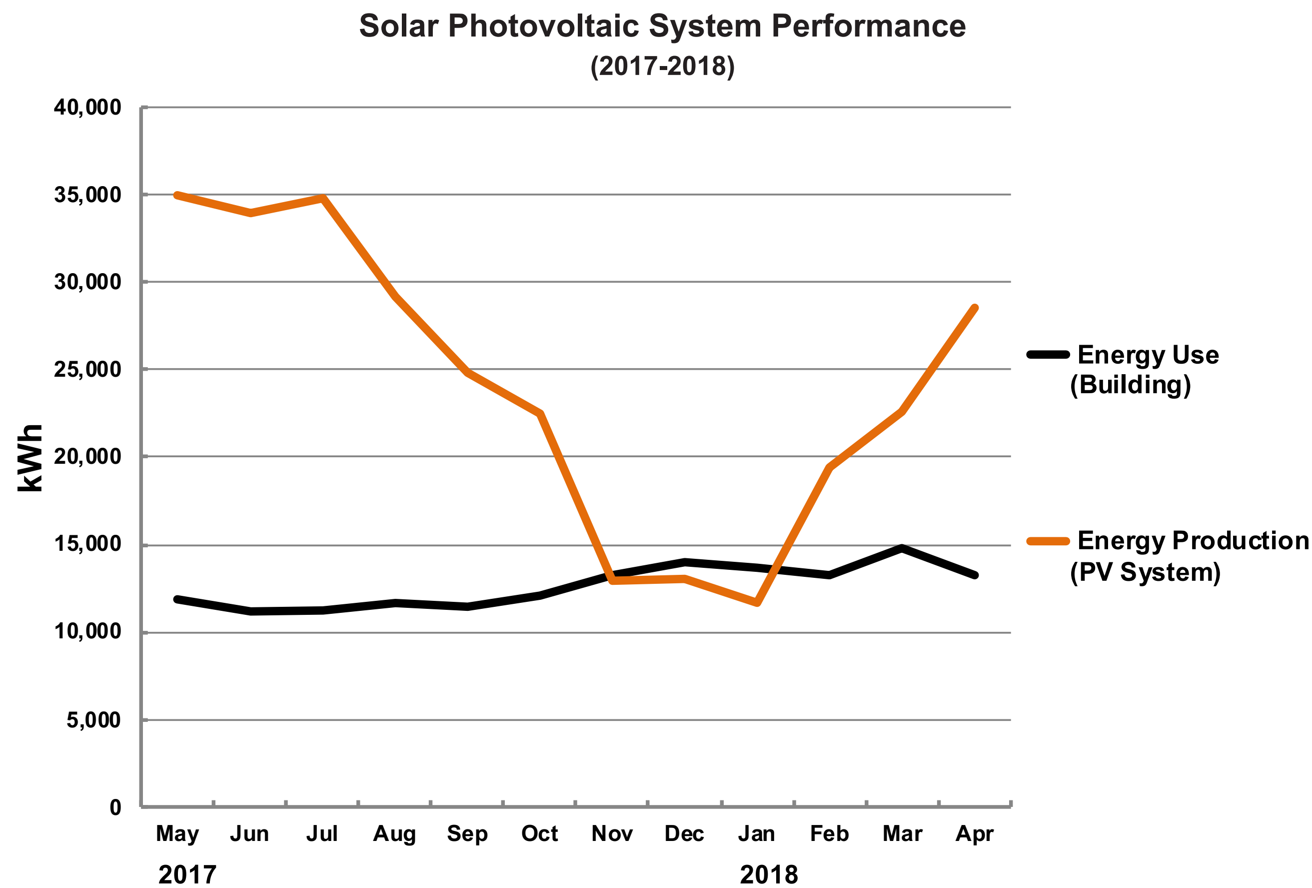
Campus classes and meetings are regularly scheduled in the office building's communal spaces as well. The importance of such interest in these ZNE buildings should not be underestimated, as they also serve as educational demonstrations of forward-thinking design principles and a "realistic" approach to ZNE building design.




**Measured Energy Use**
**(2017-2018)**
**(Annual)**

151.6 MWh/year
Measured EUI =54.1




Solar Photovoltaic System Performance
(2017-2018)
kWh
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
2017
2018
Energy Use (Building)
Energy Production (PV System)

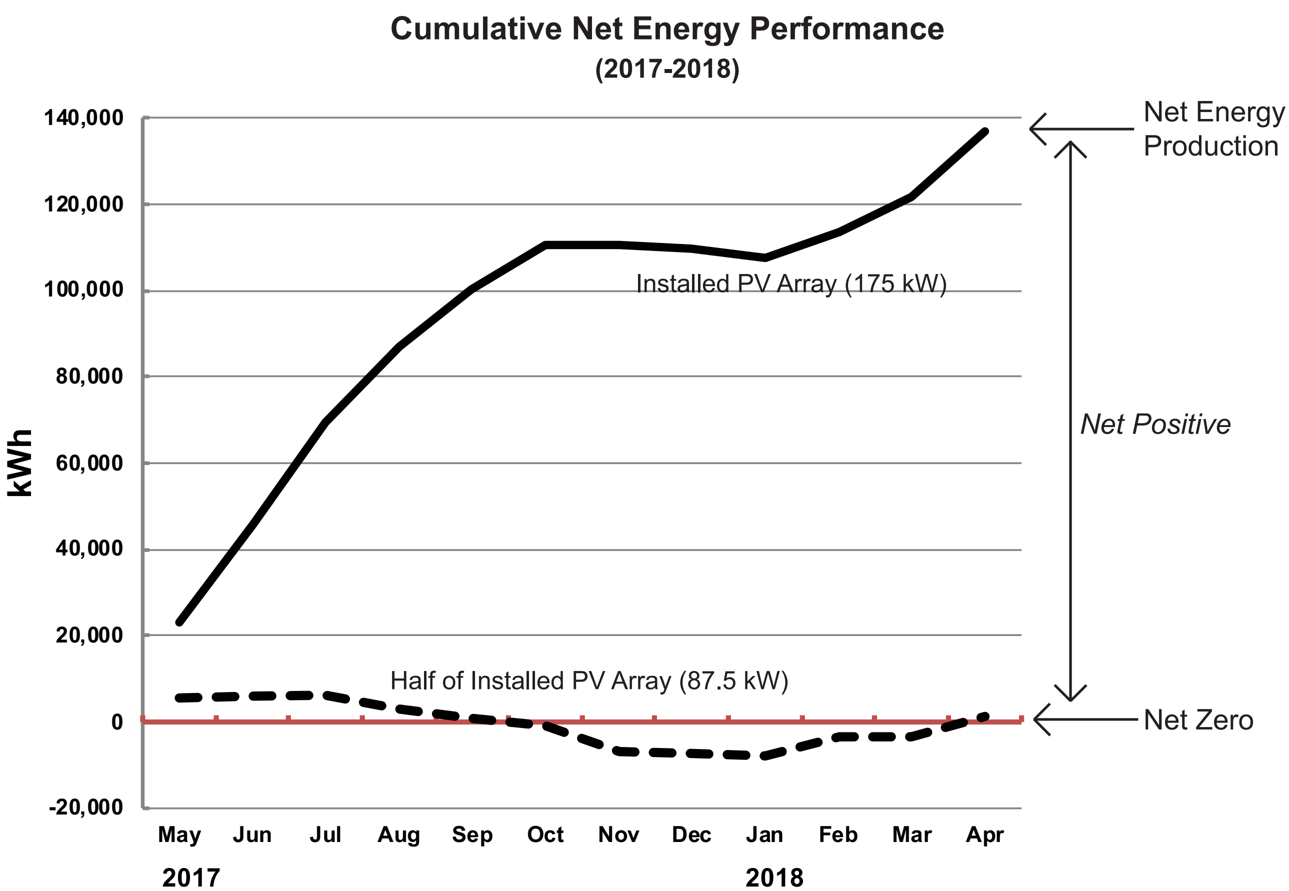

Cumulative Net Energy Performance
(2017-2018)
kWh
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
-20,000
Installed PV Array (175 kW)
Half of Installed PV Array (87.5 kW)
Net Energy Production
Net Positive
Net Zero
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
2017
2018

PHOTO: TIM GRIFFITH

# Conclusion ▷

# Observations

Volume 3 of Zero Net Energy Case Study Buildings examines the design and performance of six more major buildings located in the three principal population areas of California: the San Francisco Bay Area, the Los Angeles-San Diego metropolitan areas, and the Central Valley. The geographic expansion of the case studies reveals that ZNE design strategies can be uniformly applied in these areas, though with obvious adjustments for the duration of the heating and cooling seasons in the different climate zones.

These case studies are also, in some cases, somewhat different than those of the previous volumes—complex, large and part of a campus of buildings that are very much part of the story. They do not lead to the usual discussions of energy accounting for a single building with a separate solar PV system or, for that matter, of energy modeling versus energy performance. Nevertheless, there are a number of observations that can be made of these case study buildings that have general application.

***Building Metering and Monitoring Issues: Include in Design and Commissioning***

For all of the projects in Volume 1 and several of the projects in Volume 2, the metering and energy monitoring systems essentially had to be commissioned and required post-occupancy adjustments to function properly. Some never delivered reliable data on building performance. Unfortunately, the same failing was experienced in several of the case study projects of Volume 3. The performance of these buildings could be ascertained only from the utility's net meter alone. In one case, because the subject building was serviced for heating and cooling by an unmetered connection to a central plant, the energy consumption could only be estimated.

There is little question of the value of collecting reliable energy use and energy production data from the installed systems in a ZNE building. It allows energy monitoring and troubleshooting any observed anomalies in performance. Especially for "smart" buildings, which is the usual nature of effective ZNE designs, it is essential to have this monitoring in real time.

The issue appears to lie with the initial design of the metering system to deliver manageable, organized data as well as the thorough commissioning of these systems to ensure that the system is delivering the data as intended. After that, the building operator must have a program of regular monitoring, checking for accuracy and recording the data for evaluation. If any of these steps are missing, the data is lost and usually not retrievable.

Although proof of ZNE performance is not a requirement except for certification by the International Living Future Institute (ILFI), a building client/owner usually welcomes accurate performance monitoring for this purpose.

***Integrated Master Control Systems: Essential Design Role for "Smart" Buildings***

The case study buildings of Volume 3 demonstrate continuing advance in the design of ZNE buildings, namely, the value of the master control system and the new corresponding design team role of systems integrator. This is discussed in some detail in the Introduction to Volume 2 and remains an ongoing issue with the design, commissioning and operation of high performance buildings.

***Natural Ventilation for Fresh Air and Cooling: Maximize "Free Cooling" Potential***

It is interesting to see the different approaches in the case studies of Volume 3 to the design strategy of natural ventilation. This remains one of the under-utilized design strategies for greatly reducing the cooling energy use in buildings, particularly in the marine climate zones of California, which contain most of the major population centers of the state. The case study buildings employ the range of design approaches from simple occupant-operated windows with no integration with building management systems to more sophisticated technologies using full integration.

The case studies provide valuable comparisons of these design approaches for different building types and provide insights to the issue of maximizing the great free-cooling potential of natural ventilation (including the strategy of “night purging”) while providing the enhanced perception of thermal comfort via some occupant control.

It is clear from the case studies that a design strategy that uses solely occupant-control not only fails to take advantage of the large potential free-cooling available but can even result in counter-productive effects if not properly operated. Yet, this is the approach taken in three of the six case study buildings in this Volume 3. All three buildings are located in a marine climate zone where “night purging” could have been utilized for significant free cooling—a ZNE operation strategy not possible with only occupant-operated control of natural ventilation openings.

This is an evolving issue that will be affected by the introduction of new “smart” technologies, sophisticated control systems and reliable hardware in the next few years. Likewise, now-available advances in energy modeling software, particularly incorporating current state-of-the-art computational fluid dynamics (CFD), will build confidence among designers in predicting finely detailed air movement through buildings, making the design of automatic adjustment of openings part of the early design process.

Future ZNE case study buildings will no doubt incorporate these available technologies and demonstrate the great potential for free-cooling while at the same time providing occupants a sense of control of the thermal comfort conditions of their space. This is the ideal to strive for in these future designs.

***Non-Technical Issues: The Need for User Training and Involvement***

Early designs for ZNE buildings (see Volume 1) involved clients and users who embraced the role of “early adopters” of this then-novel approach to building design. The result was usually strong user involvement in the monitoring and operation of the building’s energy features. This active involvement in the everyday performance of the building supported the design intentions for the design features and their proper operation.

As ZNE buildings move more into the mainstream in the next few years and are operated and occupied by the “majority” of users, there is the design issue of selecting systems and features that do not require the intervention of these users to be effective. (See discussion above about the natural ventilation design strategy). There is also the intermediate condition that the selected systems, which may be non-conventional and unfamiliar to most users including maintenance staff, nevertheless require some simple training to ensure proper operation and even non-interference by users that would be counter-productive to the operation of these systems.

The latter will be a particular design concern for K-12 schools, which is a building category that is emerging as a prime candidate for ZNE design before the target date of 2030, when the ZNE code requirement will likely be set. Case Study No. 13 in this Volume 3 is an example of such a project that devised a ZNE design for a portion of the project and this issue of user training emerged as a significant “lesson learned”. For a user population, including both occupants and maintenance staff, that is at best only casually interested in the ZNE performance of the building, the appropriate training is essential.

The observation from this case study is that the informational training must be a planned periodic event because of natural changes in the user population. It is critically important that this be on-going for the maintenance staff for the same reason and that the district facilities management bureaucracy accept this responsibility.

In general, this will be a common issue in the next decade of ZNE design of most building types. The common solution involves some degree of user training, which requires owner commitment to regular programs for staff and users, as well as the design team’s continued involvement in the post-occupancy period with the owner’s staff and commissioning agent.

# Acknowledgments

Once again, for this Volume 3 of these ZNE case studies, the following individuals—clients, designers, contractors, commissioning agents and remarkably skilled technicians—are owed a great deal of thanks for giving their valuable time in lengthy interviews and sharing an amazing amount of valuable information that accurately and thoroughly describes the story of their projects. Thanks also for their patience with the many follow-up emails and phone calls about design details, their extra work confirming performance data and their time reviewing the draft case study for completeness and accuracy. Without this openness and supportive effort, the case studies would be quite incomplete and not nearly as valuable as they are proving to be.

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