Designing for Zero Carbon

Volume 1

Case Studies of All-Electric Buildings

Written by
Edward Dean, FAIA
Bernheim + Dean Inc.

Foreword by
David Hochschild, Chair
California Energy Commission

March 2022

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Foreword

California is a world leader on environmental policy, particularly energy and climate policy. In the late 70s, the Warren Alquist Act was signed into law, creating the California Energy Commission (CEC) as the state's primary energy policy and planning agency, of which I am currently the Chair. The first paragraph of the act reads:

> *"…a principal goal of electric and natural gas utilities' resource planning and investment shall be to minimize the cost to society of the reliable energy services that are provided by natural gas and electricity, and to improve the environment and to encourage the diversity of energy sources through improvements in energy efficiency and development of renewable energy resources, such as wind, solar, and geothermal energy."*

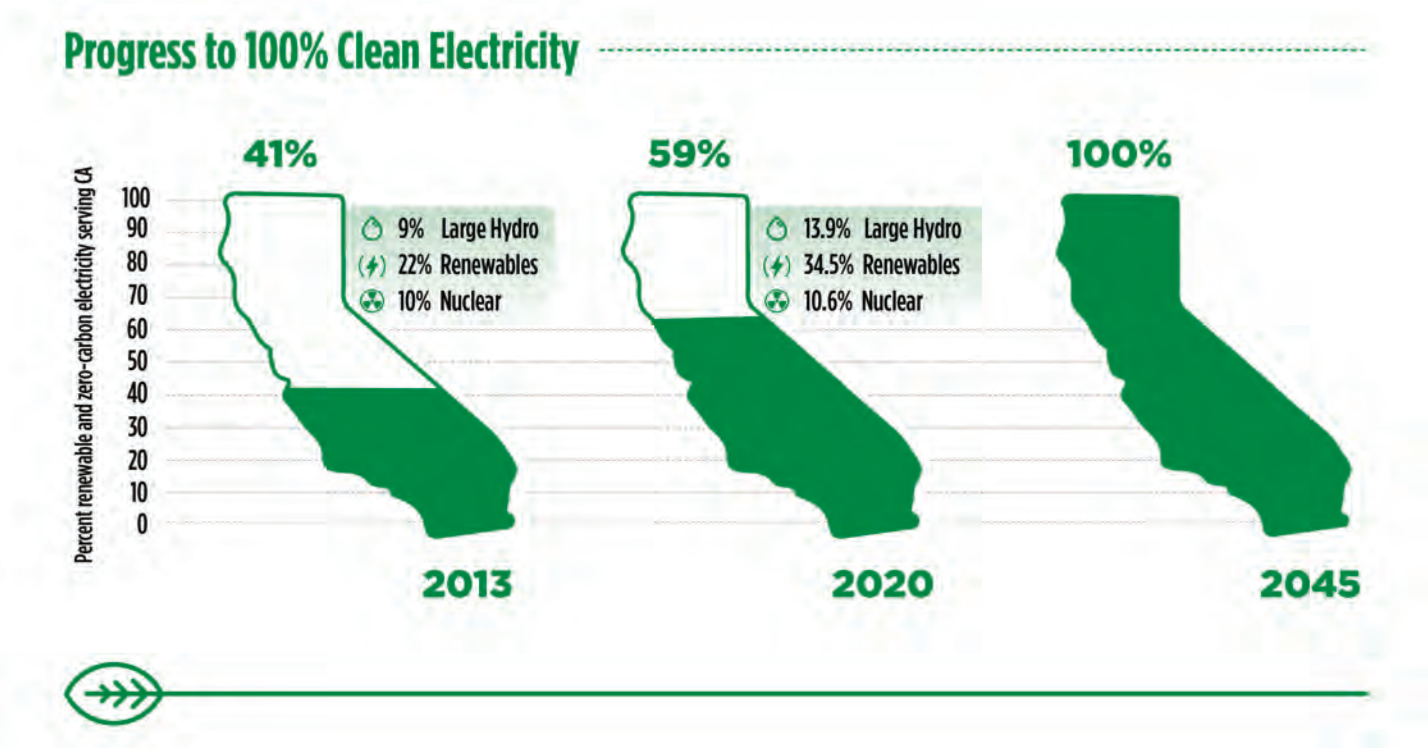
Addressing this goal not only forms the foundation of developing energy efficiency standards for the built environment, but also the rationale to address the environmental and social costs presented by the climate crisis. To reach this aspiration, buildings must be both efficient and able to access reliable and renewable energy.

In the CEC's *2018 Integrated Energy Policy Report*, electrification of building end uses emerged as a key pathway to achieving the state's goals, and subsequent reports and analyses have continued to support that pathway. The underlying strategy is to construct a reliable, affordable, carbon free electric grid and use that energy in substitution of fossil fuels. SB 100 (De León, 2018) sets a policy to achieve this grid of the future, and several statutes and policies have subsequently been passed to support building decarbonization including SB 1477 (Stern, 2018), AB 3232 (Friedman, 2018), SB 68 (Becker, 2021), and the Budget Act of 2021 (SB 170, Skinner, 2021, chapter 240).

In essence, the core strategy of building decarbonization is to reduce energy demand, increase flexibility of remaining demand, and then supply energy with carbon free resources. Electric heat pumps are a foundational technology to this approach as they can be triple the efficiency of conventional technologies while taking advantage of potentially abundant clean electricity. While heat pumps have nearly all the market share for key building cooling equipment such as refrigerators and air conditioners, they have only a fraction of the market for key heating equipment for space and water heating. Builders consequently have less experience using these technologies. Incorporation of the latest innovative technologies and techniques presents both the challenge of inexperience and an opportunity to reduce cost, improve performance, and improve the health of occupants.

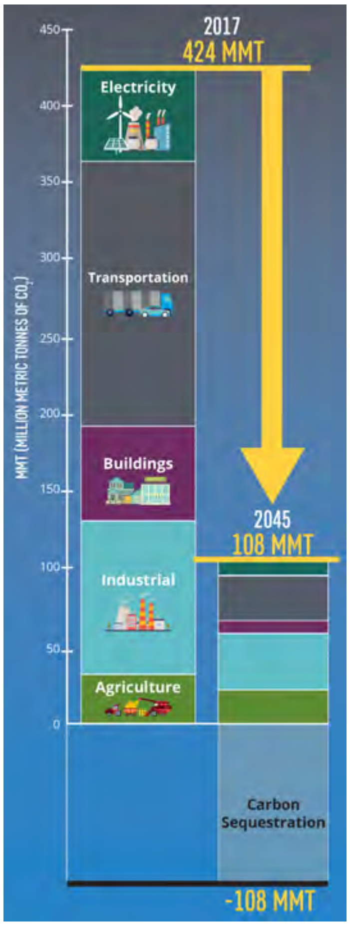
The climate crisis requires swift action and unprecedented market transformation. It is therefore critical to accelerate knowledge transfer and best practices in building design and implementation. This volume, *Designing for Zero Carbon,* is part of this important effort and showcases well those buildings and designs in the vanguard of change with trends that will ultimately become standard building practices.

—David Hochschild, Chair, California Energy Commission



Source: California Energy Commission (February, 2022)

Introduction



(Above) Greenhouse gas (GHG) emission reductions in million metric tons (MMT) required to meet California 2045 carbon neutrality targets, including decarbonization of the grid and electrification of buildings.
(From: Pathway 2045--Update to the Clean Power and Electrification Pathway, Southern California Edison, Nov., 2019)

Why This Book of Case Studies?

Climate change and its effects are more apparent in our everyday lives than ever before, motivating massive social actions to address the source of the problem: greenhouse gas (GHG) emissions, primarily carbon (CO_2) emissions. Approximately 39% of annual global CO_2 emissions are generated for our buildings. It is no wonder that the building sector has always been a focus of these transformative efforts.

A Short History of Building Design and Carbon Emissions

In the decades since the energy crisis of the 1970s, the emphasis was on increased ***energy efficiency*** of building construction, products and operation. This made sense since all of these were notoriously energy *inefficient* and the amount of renewable energy delivered by the electric grid was relatively small. So, the carbon emissions could be reduced by simply not using as much energy. Codes were enacted and strengthened, energy-use-intensity (EUI) was predicted and benchmarked, and new building technologies managed building systems more efficiently.

While inroads were made on reducing the amount of carbon emissions due to buildings, the numbers were still high. Building professionals then promoted the idea of ***zero-net-energy (ZNE) buildings***, which combined energy efficiency in building design and operation along with renewable energy production, usually on-site and usually solar energy. Over the course of one year, the building would produce as much renewable energy (no carbon) as it would consume. This produced a "clean energy" offset of any carbon-based energy used in the building for heating and cooking, further reducing the carbon emission total of the building. In California, codes were updated, building technologies improved and, in general, greatly improved performance resulted for these ZNE buildings.

But to achieve current international, national and California goals for carbon emission reduction, still more has to be done. What remains after ZNE? Providing renewable energy offsets for remaining on-site fossil fuel end uses is one step, but it does not fully decarbonize the building. There are still carbon emissions that result from the use of fossil fuels, including such common building energy uses such as gas-fired water heating, space heating and cooking. The ultimate goal is, therefore, a ***zero-carbon building***.

The concept of a *zero-carbon building* (*zero* carbon emissions!) is therefore based on "clean" electricity as the sole energy source in building operation, since other sources are inevitably fossil-fuel based with associated carbon emissions. Clean electricity means electrical energy from not only on-site solar energy systems but also that provided by the public utility.

At the present time, however, California's public utilities generally have a large portion of their electrical energy generated by gas-fired power plants—about one-third on an annual basis. That is undergoing a significant transformation in California, however, as a result of SB 100, signed into law by Governor Jerry Brown in 2018. This law requires that renewable energy and zero-carbon resources supply 100 percent of electric retail sales to end-use customers by 2045. That is, the electrical grid in California is mandated to be 100% zero-carbon after 2045.

So, a zero-carbon building designed today will not actually be zero-carbon in its operation until that milestone is achieved in 2045 in California. Until then, it will essentially be *zero-carbon-ready*. But it will also be the ultimate solution to the challenge of eliminating carbon emissions from the building sector entirely by producing buildings that use 0% of energy consumed with associated carbon emissions.

It is worth noting, however, that the grid is clean enough today to reduce emissions significantly by going to all-electric design compared to mixed renewable and fossil-fuel-based energy systems—that benefit will grow each year as the renewable energy power supply continues to progress toward the 100% goal in 2045.

The progression over the past 40 years or so therefore has been an emphasis on *energy-efficient buildings* moving to *zero-net-energy buildings* and finally to ***all-electric buildings***. The all-electric buildings become fully *zero-carbon buildings* in 2045, at least in terms of energy used in operating the buildings.

The New Paradigm—All-Electric (Zero-Carbon) Buildings

Zero-carbon buildings are therefore now the goal in the campaign against climate change caused by GHG emissions initiated by the built environment. This means all-electric new building construction and, the more difficult task, existing building renovations and retrofits to convert these structures to all-electric building operation.

Achieving this goal requires developing a pathway for the building industry, which has started being defined by a number of actions recently taken:

- Governor Brown's 2018 Executive Order B-55-18 to achieve carbon neutrality for California no later than 2045. This is in addition to SB-100, which mandates that the electrical grid in California be 100% renewable energy no later than 2045.
- Governor Newsom's 2021 announcement that the California Public Utilities Commission (CPUC) and the California Air Resources Board (CARB) are evaluating pathways to achieve statewide carbon neutrality by 2035, ten years in advance of the 2045 target date.
- President Biden's Infrastructure Plan of 2021, which aspires to achieve 100% carbon-pollution-free electricity nationwide by 2035 through a series of actions.[1]

The next two decades will therefore see a transformation of the building inventory as all-electric building design and construction becomes the norm for new and existing buildings.[2]

All-Electric Buildings: Old and New Issues

Energy-Efficiency and Zero-Net-Energy (ZNE)

The new generation of buildings will be electrified but still energy-efficient. The advancements in building energy efficiency over the past forty years are still beneficial in terms of operating cost, environmental impact and electric grid management. And if the renewable energy system and ZNE design features are feasible and cost-effective for a building owner, a ZNE all-electric building may be preferred. ZNE buildings have other advantages as well in terms of occupant satisfaction and productivity, daylighting, natural ventilation and other aspects of a healthy building environment. When paired with battery energy storage, these ZNE all-electric buildings have enhanced capabilities for peak load shifting and resilience in case of grid interruptions.

But these all-electric zero-carbon buildings can also be energy-efficient but not quite ZNE, while also achieving the same design advantages. This will be the new paradigm for building design going forward.

[1] See: https://www.whitehouse.gov/briefing-room/statements-releases/2021/11/08/fact-sheet-the-bipartisan-infrastructure-deal-boosts-clean-energy-jobs-strengthens-resilience-and-advances-environmental-justice/

[2] For a comprehensive discussion of the methodologies of this transformation, see *The Building Decarbonization Practice Guide—A Zero Carbon Future for the Built Environment,* The William J. Worthen Foundation (2021).

Embodied Carbon

Embodied carbon is a parallel consideration in the design of these buildings that is becoming an important factor. Carbon emissions result from the construction process itself, the manufacture of building materials and the transportation of those materials to the building site. At the present time, these processes result in substantial carbon emissions and are in addition to the carbon emissions produced in building operations over the life of the building. Even reuse of the salvaged materials from the building's ultimate demolition is part of this embodied carbon discussion.

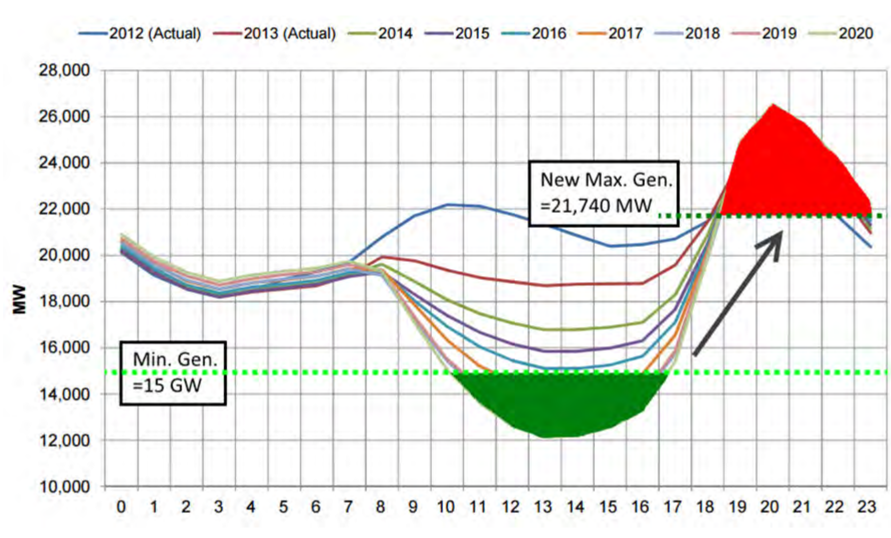
As the electric grid is gradually decarbonized and more processes in the manufacturing and transportation sectors are electrified, the embodied carbon factor will gradually diminish. Until that general economy-wide decarbonization occurs, however, any thorough analysis of energy use and carbon emissions for a project should include that of embodied carbon, especially since that general decarbonization is likely to lag behind complete decarbonization of the electrical grid in 2045.

Such an embodied carbon analysis can point the way for design decisions about alternate materials, building structural systems and even renovation versus new building. (Case Study No. 4 in this book, Robert Redford Conservancy, includes an example of such an embodied carbon analysis.)

Grid Harmonization

With the shift to all-electric buildings utilizing solar photovoltaic systems, the statewide electric grid will be facing even more of a challenge of where to put all the excess renewable energy generated by these buildings during the middle of the day and how to meet the increased peak power demand created by these buildings on overcast days and in the evening. Referred to as "The Duck Curve Conundrum", this issue is discussed at length in the Introduction to *Zero Net Energy Case Study Buildings, Volume 3.*

The solution pathway to this challenge lies primarily with *energy storage*, which would allow the growing peak demand in the evening to be reduced by shifting the midday excess energy to that time period. It lies as well with incentive structures for load shifting and demand response, which reinforce and enhance this effect. The nature and design of these necessary components of the electric energy system is now under discussion at the state and local levels.



(Right) Illustration of energy storage applied to the typical 24-hour demand profile for the California statewide electric grid (called 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)

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

What is clear is that the next generation of buildings, which will be all-electric and eventually zero-carbon, will have to be designed to achieve a certain *grid harmony*, resulting from the coordination of on-site energy generation and storage with the public electric grid, in whatever form this ultimately takes.

Previous Books in This Series

The first volume of these case study books was published in 2014 and focused on ZNE non-residential buildings.[3] This was followed by two more case study books about ZNE non-residential buildings[4,5] published in 2016 and 2018, plus a ZNE residential case study book[6] in 2018. Then, following the new awareness of the path to *zero-carbon* buildings, a case study book about all-electric grid-connected ZNE residential buildings[7] was published in 2020.

The Case Study Buildings in This Book

The five non-residential case study buildings in this sixth volume fit the now-ideal characterization described above to eliminate completely the carbon emissions from new buildings: energy-efficient using state-of-the-art building technologies, cost-effective on-site solar electric systems and all-electric building systems and equipment. In addition, they represent very common building types where the design approaches taken are likely to be readily adaptable to similar types of projects: a public school, a spec office building, a college classroom building renovation, a city services office building and a medical clinic/office. Thus, each of the case studies serves as an excellent model for many of new buildings now being planned that aspire to be zero-carbon emitters.

Only one of the projects performed an embodied carbon analysis and none includes battery storage as a resiliency feature. These are emerging design strategies being considered as the societal effort to reduce carbon emissions intensifies and the nature of the public electric grid is transformed to meet this challenge. No doubt, future editions of these case study books will examine buildings with such features.

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[3] Zero Net Energy Case Study Buildings, Volume 1. Softcover copy at Amazon: https://www.amazon.com/Zero-Energy-Case-Study-Buildings/dp/153063024X/ref=sr_1_1?. Free downloadable electronic version in PDF format:

[4] Zero Net Energy Case Study Buildings, Volume 2. Softcover copy at Amazon: https://www.amazon.com/Zero-Energy-Case-Study-Buildings/dp/1530353254/ref=sr_1_2?s=books&ie=UTF8&qid=1468961171&sr=1-2. Free downloadable electronic version in PDF format:

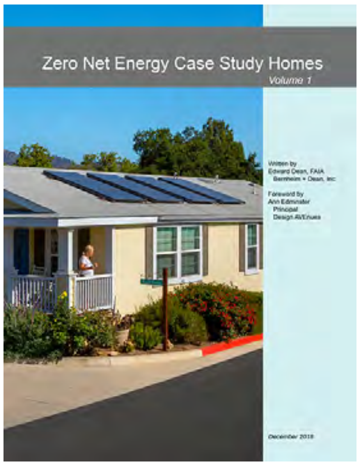
[5] Zero Net Energy Case Study Buildings, Volume 3. Softcover copy at Amazon: https://www.amazon.com/Zero-Energy-Case-Study-Buildings/dp/1724455842/ref=sr_1_4?s=books&ie=UTF8&qid=1540491487&sr=1-4&keywords=Zero+net+energy+case+study+buildings&dpID=41%252BxiBKT0tL&preST=_SX218_BO1,204,203,200_QL40_&dpSrc=srch. Free downloadable electronic version in PDF format:

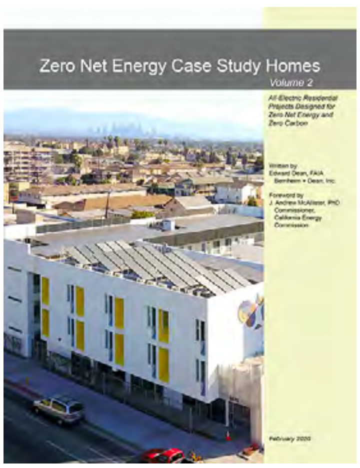
[6] Zero Net Energy Case Study Homes, Volume 1. Softcover copy at Amazon: https://www.amazon.com/Zero-Energy-Case-Study-Homes/dp/1791732437/ref=sr_1_1?crid=121618CMHX2JN&keywords=zero+net+energy+case+study+homes&qid=1562112200&s=books&sprefix=zero+net+%2Caps%2C188&sr=1-1. Free downloadable electronic version in PDF format:

[7] Zero Net Energy Case Study Homes, Volume 2. Softcover copy at Amazon: https://www.amazon.com/Zero-Energy-Case-Study-Homes/dp/B0851KJKFZ/ref=sr_1_8?dchild=1&keywords=zero+net+energy+case+study+buildings&qid=1598681002&s=books&sr=1-8. Free downloadable electronic version in PDF format:

Prologue

Previously Published ZNE All-Electric Case Study Buildings





As noted in the Introduction, this is the *sixth* book in the series of case studies[1] focusing on buildings that have been designed to be extraordinarily energy-efficient, thereby significantly reducing their impact on the overall demand for carbon-based energy sources. In fact, the previous five volumes have featured case studies of *zero-net-energy (ZNE)* buildings. As the public electric power grid is transformed within the next 25 years into a carbon-free source of energy, however, the focus will shift from ZNE buildings to *all-electric* buildings, which by definition will be *zero-carbon (ZC)* operating buildings.

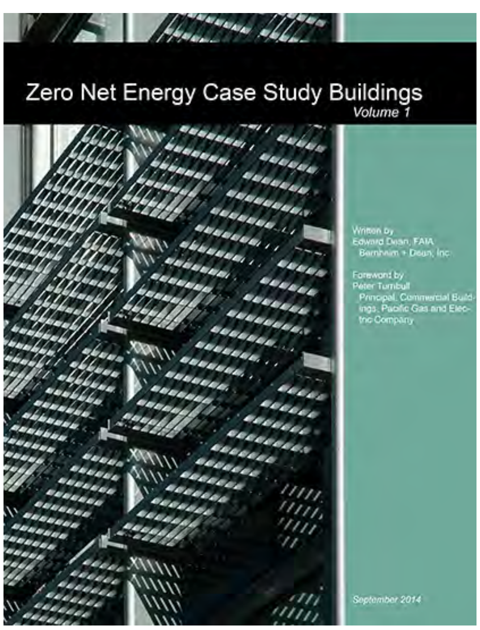
Looking forward to this shift, this sixth volume of case studies focuses on energy-efficient all-electric buildings. Looking back, however, it is noteworthy that many of the ZNE buildings in the previous case study books are also all-electric, and therefore will become zero-carbon operationally by 2045. These projects are therefore also instructive in the design of both residential and non-residential zero-carbon (operation) buildings and can be seen as valuable prototypes for the future.

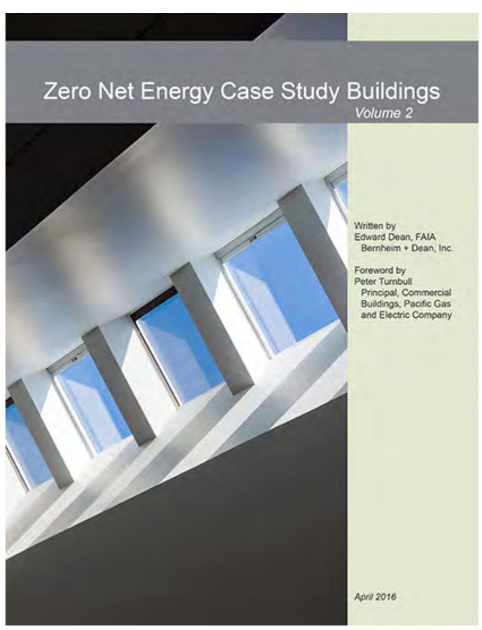
The two previous books, *Zero Net Energy Case Study Homes*, *Volumes 1 and 2*, covered several principal types of residential projects, some of which are all-electric. These exemplary residential projects can be studied in these two books. *(Left)*

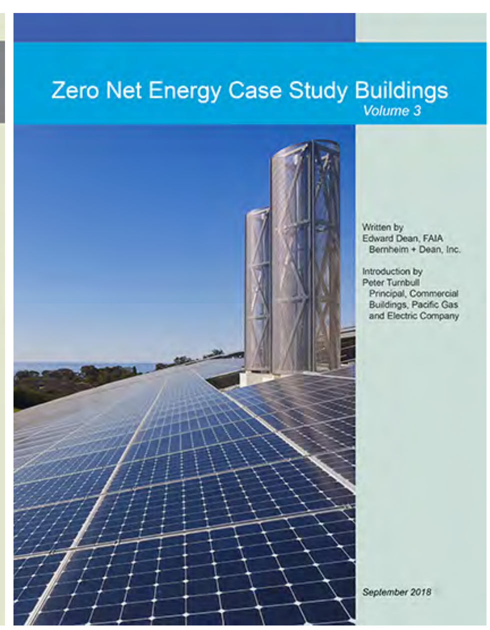
Since this sixth book focuses on non-residential buildings only, it is especially useful to note the previous case studies of ZNE all-electric buildings that are described in the three volumes, *Zero Net Energy Case Study Buildings, Volumes 1, 2 and 3. (Below)*

This Prologue exhibits some of these previously published all-electric non-residential projects with their basic facts and where the detailed case studies for each can be found. The new case studies then follow in the main section of this book.

[1] See the Introduction to this book for the complete list of book titles and where they can be found online or in softcover publication.







Zero Net Energy Case Study Buildings - Volume 1

Packard Foundation Headquarters Building

Building Type: Two-Story Office
Location: Los Altos, CA
Gross Floor Area: 49,000 gsf
Occupied: July 2012

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

On-Site Renewable Energy System Installed
285 kW (DC) Solar PV
Measured On-Site Energy Production
282,000 kWh/year (2013)
19.6 kBtu/sf-year (2013)

HVAC System
Air-Source Heat Pumps
DHW
Solar Thermal System with Electric Storage Tank

Zero Net Energy Case Study Buildings - Volume 2

Speculative Office Building at 435 Indio Way

Building Type: Office
Location: Sunnyvale, CA
Gross Floor Area: 31,759 gsf
Occupied: May 2014

Modeled EUI (Site):
21.2 kBtu/sf-year
Measured EUI (Site):
13.5 kBtu/sf-year (Oct 2014 — Sept 2015)

On-Site Renewable Energy System Installed:
113.2 kW (DC) Solar PV
Measured On-Site Energy Production:
266,000 kWh/year
28.6 kBtu/sf-year (Oct 2014 — Sept 2015)

HVAC System
Air-Source Heat Pumps
DHW
Solar Thermal System with Electric Storage Tank

Zero Net Energy Case Study Buildings - Volume 2

West Berkeley Branch Library

Building Type: Civic / Library
Location: Berkeley, CA
Gross Floor Area: 9,300 gsf
Occupied: January 2014

Modeled EUI (Site):
17.5 kBtu/sq.ft.-year
Measured EUI (Site):
23.1 kBtu/sq.ft.-year (2014)

On-Site Renewable Energy System Installed:
52.2 kW (DC) Solar PV
Measured On-Site Energy Production:
75,350 kWh per year
27.7 kBtu/sq.ft.-year (2014)

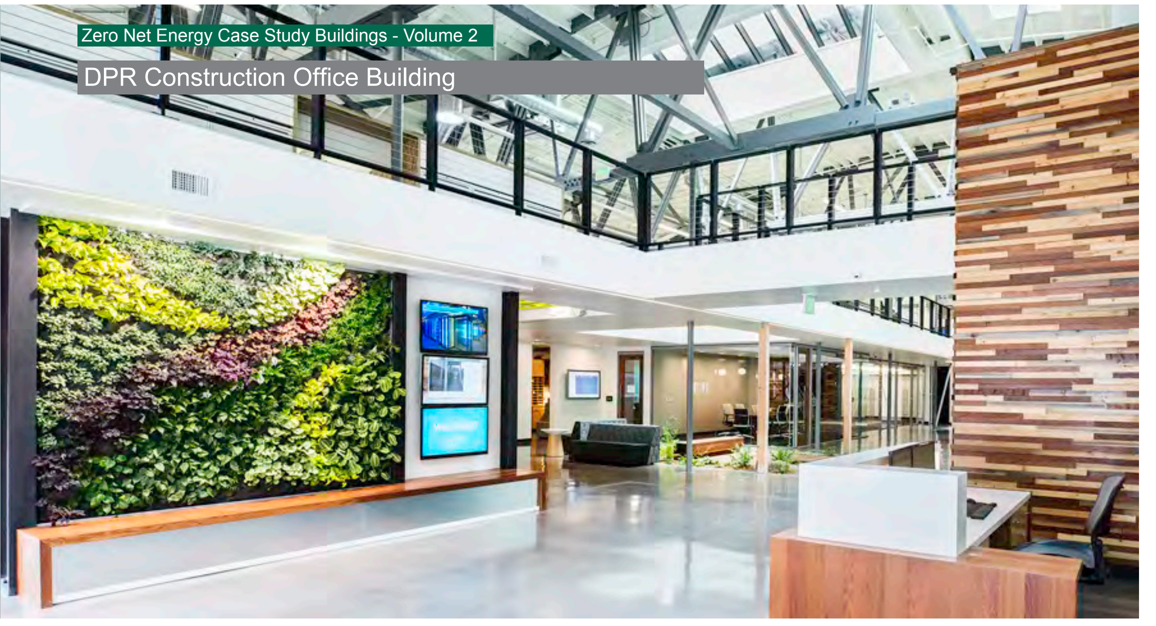
HVAC System
Air-Source Heat Pumps
DHW
Solar Thermal System with Electric Storage Tank

Building Type: Office
Location: San Francisco, CA
Gross Floor Area: 24,010 gsf (including tenant space of 4,000 gsf)
Occupied: May 2014

Modeled EUI (Site):
25.8 kBtu/sf-year
Measured EUI (Site):
22.4 kBtu/sf-year (May 2014 — June 2015)

On-Site Renewable Energy System Installed:
118 kW (DC) Solar PV
Measured On-Site Energy Production (Electric):
157,000 kWh/year
26.8 kBtu/sf-year (May 2014 — June 2015)

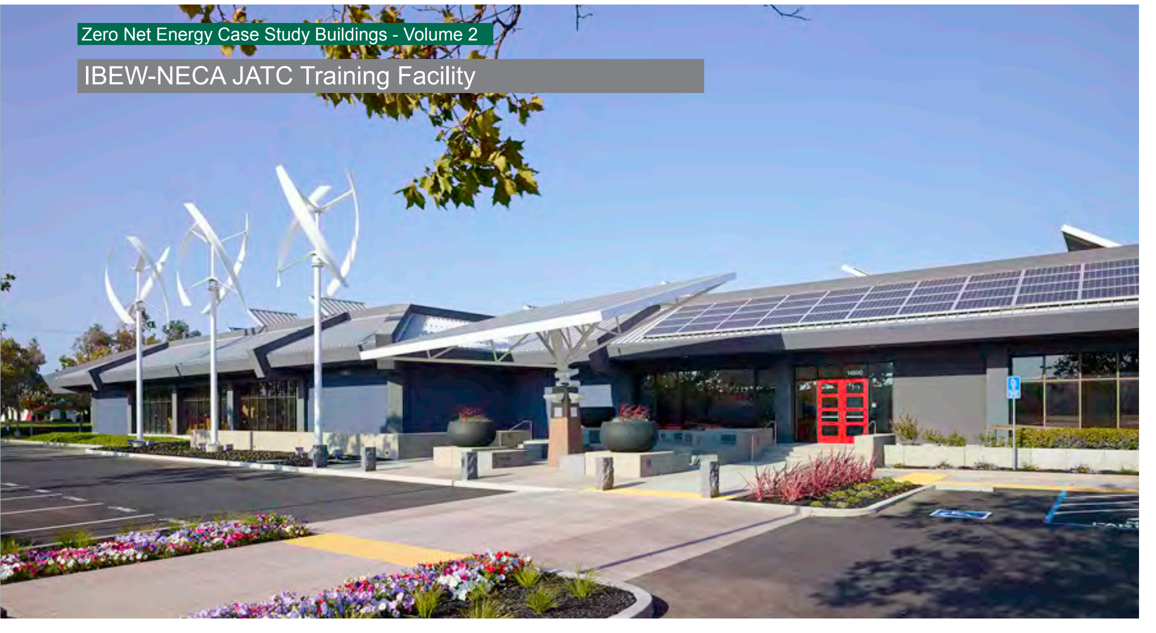
HVAC System
Air-Source Heat Pumps
DHW
Solar Thermal System with Electric Storage Tank



Building Type: Classroom / Office
Location: San Leandro, CA
Gross Floor Area: 45,000 gsf
Occupied: June 2013

Modeled EUI (Site):
18.0 kBtu/sf-year
Measured EUI (Site):
16.3 kBtu/sf-year (July 2014—June 2015)
On-Site Renewable Energy System Installed:
154 kW (DC) Solar PV-flat panel
12 kW (DC) Solar PV-tracking
12 kW (DC) Wind Turbines
Measured On-Site Energy Production:
267,500 kWh/year
20.3 kBtu/sf-year

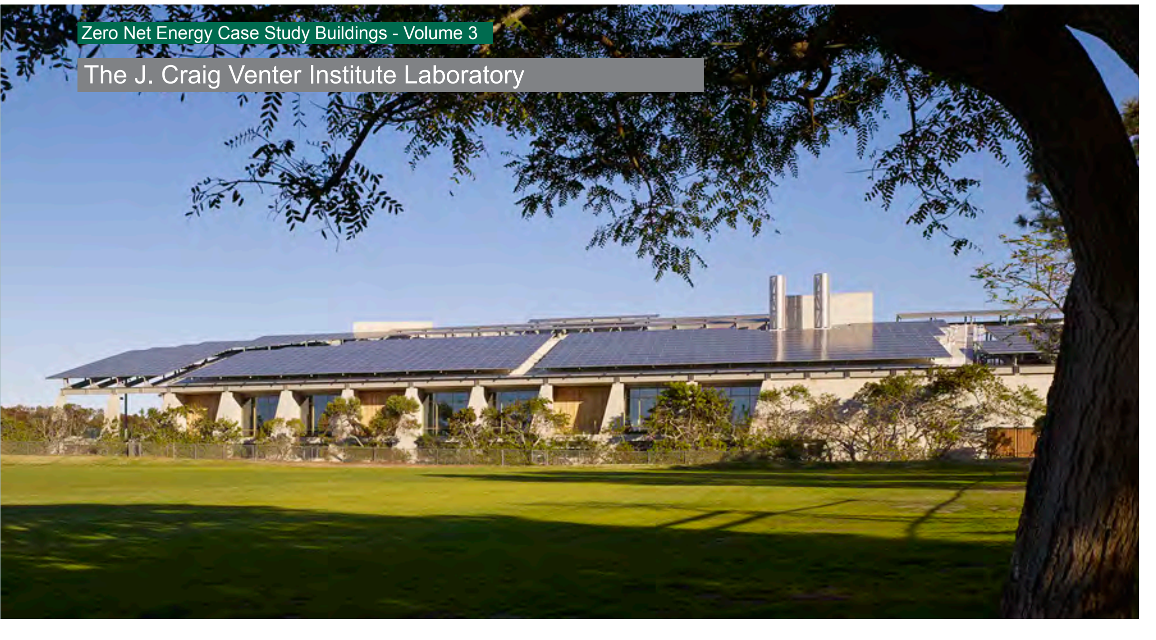
HVAC System
Solar Thermal with HW Storage and Water-Source Heat Pump
DHW
Solar Thermal with Electric Storage Tank System



Building Type: Research Laboratory/Office (B Occupancy)
Location: La Jolla, CA
Gross Floor Area: 44,607 gsf
Occupied: November 2013

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)

HVAC System
Water-Source Heat Pumps with Thermal Storage Tanks
DHW
Heat Pump



Case Study Projects ▷

CASE STUDY NO. 1

Santa Monica City Hall East

PHOTO: JEREMY BITTERMANN / JBSA

Santa Monica City Hall East

Case Study No. 1

Data Summary

Building Type: Mid-Rise Office Building (New)
Location: Santa Monica, CA
Gross Floor Area: 50,200 sq.ft.
Occupied (Partial): 3/2020

Modeled EUI (Site):
24.9 kBtu/sq.ft. per year
Measured EUI (Site):
(Data available in 2022)

On-Site Renewable Energy System Installed:
292 kW (DC) Solar PV
On-Site Storage Battery:
None
Measured On-Site Energy Production:
399,430 kWh per year
27.1 kBtu/sq.ft. per year
(Oct. 2020 through Sep. 2021 for first year of full operation)

Owner/Client
City of Santa Monica

Design Team
Architect:
Frederick Fisher Architects, Los Angeles
Structural Engineer:
John A. Martin Associates Los Angeles
Mechanical, Electrical and Plumbing Engineering:
Buro Happold Engineering, Los Angeles
Landscape Architect
AHBE Landscape Architects Los Angeles

General Contractor:
Hathaway Dinwiddie, Los Angeles
Solar Contractor:
Blue Sky Energy, Los Angeles

This first case study of a three-story municipal office building describes the process, design features and performance characteristics associated with the realization of "one of America's greenest city hall buildings".[1] The building was designed to meet the standards of the *Living Building Challenge* [2], aiming in particular at a certification for zero-net-energy performance as documented after a year of operation.

Although occupancy of this building and the performance verification was delayed by the Covid pandemic, this facility is now expected to achieve the full LBC certification in 2022.

Background

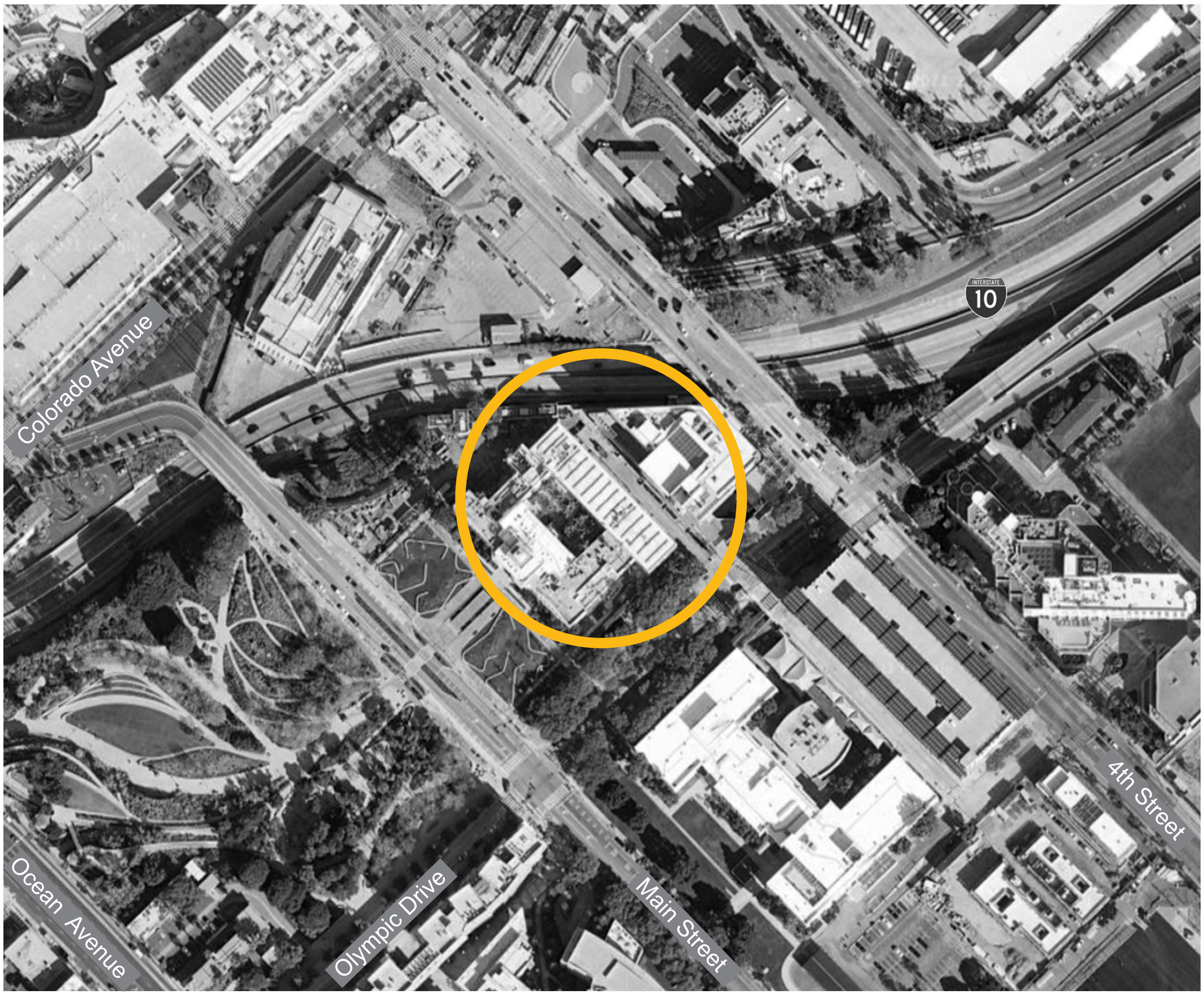
The public service functions of the City of Santa Monica had long-outgrown the original City Hall building, a 1938 historic structure designed in the WPA Moderne style located in the heart of the city along Main Street. (Photo below)

As the city and its administrative functions grew over the decades, these departments were housed in leased spaces in other parts of the city. By 2004, these leased spaces were in five separate locations and discussions began about consolidating these offices in a new building in the City Center.

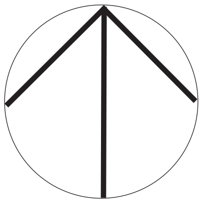
(Above) View of the western facade of Santa Monica's historic City Hall facing Main Street circa 1990.

[1] *Architectural Digest*, 27 August 2020.

[2] The *Living Building Challenge* is administered by the International Living Future Institute (ILFI) and consists of seven performance categories, including net-zero-energy, net-zero-water and net-zero-waste. For more information, see: https://living-future.org/lbc/basics4-0/.



Santa Monica City Hall East - General Vicinity Plan

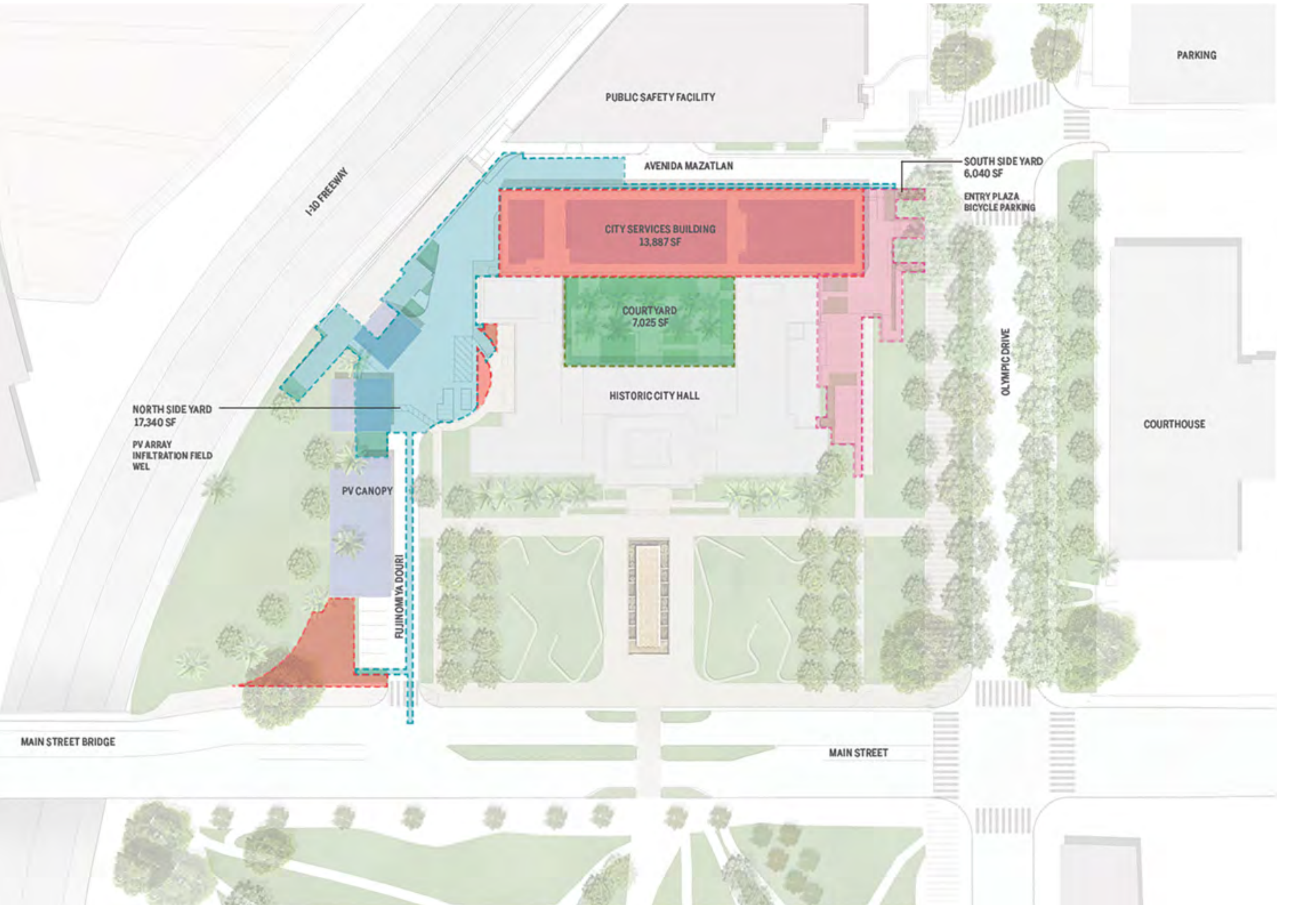


The motivation from the beginning was to eliminate the substantial cost of leasing space and to create a single location for all community services. But there was also the idea to create a project that would demonstrate the sustainability features of future buildings that the City would promote in the construction and operation of new buildings. The City had developed a comprehensive sustainability plan starting in 1994 and the idea was to roll the elements of the current version of this plan into the design of the new building as a test of the new policy and technologies.

In 2014, the City embarked on a traditional approach to the procurement of the building—a feasibility study to outline the building program, building location and placement, planning constraints and total project cost, followed by a design phase and a bond measure to fund the project. With public approval of the bond measure, construction could begin. This plan was carried out, with the grand opening of the new facility planned for Earth Day 2020.

The building was completed as planned, but due to the Covid pandemic the building was delayed in opening to the public until June 2021.

(Below) Site Plan Diagram of the City Center showing the location of the new addition to the east of the historic City Hall. *(Courtesy of Frederick Fisher Architects.)*



Design Process and Low-Energy, Zero-Carbon Design Strategies

One of the principal questions addressed in the feasibility study was: what are the appropriate levels of sustainability to be adopted as the design goal for this project? Should the building just "meet code", although Santa Monica was coincidentally planning the adoption of a reach code[3] that included a mandate for zero-net-energy (ZNE) design of new building permit applications? Or, going in a different direction, should the building be required to be certified LEED-Platinum by the USGBC, requiring additional sustainability measures but not necessarily ZNE? Or should the design goal be *stretched* to satisfy all the requirements of the Living Building Challenge administered by ILFI, which includes ZNE and a special all-electric requirement? [4]

A third-party consultant carried out an analysis of these alternatives as applied to the concept design developed during the feasibility study, in particular assessing the cost implications of each. The analysis showed that the Living Building Challenge measures would have a total payback period of approximately 16 years, justifying the added cost for the expected life of the building. The stretch goal of the Living Building Challenge was therefore adopted and incorporated into the final concept design.

The project was determined by the City to be *design-build* [5]. The consultant team that carried out the feasibility study competed successfully for the contract to execute the project as defined by that study. The bond measure was approved by the voters in 2017, funding the construction of the building with the full set of design features and strategies as defined by the Living Building Challenge.

The *net-zero-water* design incorporates rain water collection and treatment equipment to render the water potable, which is unusual enough in a public building and, in fact, first in the State of California. More unusual is the incorporation of composting public toilets in this *net-zero-water* design and its on-site treatment goals. But for the purposes of this case study, the focus is on the ZNE design features, which are described in the following sections.

Planning Concept and General Design Considerations

Since the intent of the building program is to consolidate the many city departments and public service offices within the City Center site together with the existing City Hall structure, the logical concept was to attach the programmed 50,000 gross square feet as an addition behind the prominently visible sides of the historic building. At three stories and with a receding architectural presence through the choice of materials, this design approach eased the concerns about compatibility with the historic features of the existing building.

Connecting the addition to the ends of the two wings of the existing City Hall also created an enclosed green space for use by the occupants and the public. The narrow floor plates of the addition generated bysqueezing the new building on the available site abutting the public safety building also provided the opportunity for good daylighting from the window areas.

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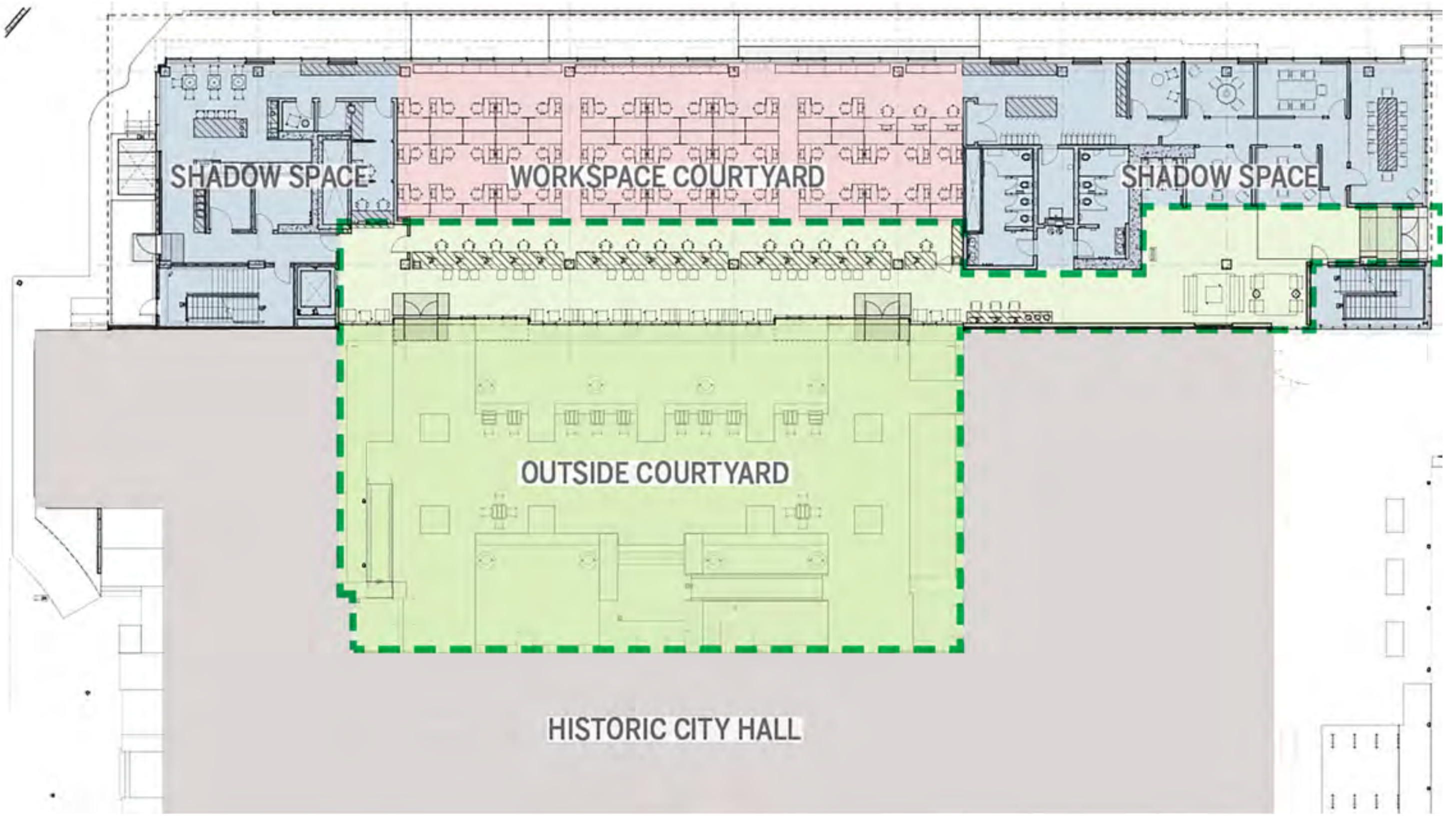
[3] A *reach code* is a local building energy code that "reaches" beyond the state minimum requirements for energy use in building design and construction, creating opportunities for local governments to lead the way on climate change solutions.

[4] A prerequisite for the ILFI certification is that the building must not use natural gas—that is, the building must be all-electric in its operational energy source. Santa Monica at the time was considering an ordinance that prohibited gas connections to new construction, so this requirement was seen as an opportunity to explore the idea.

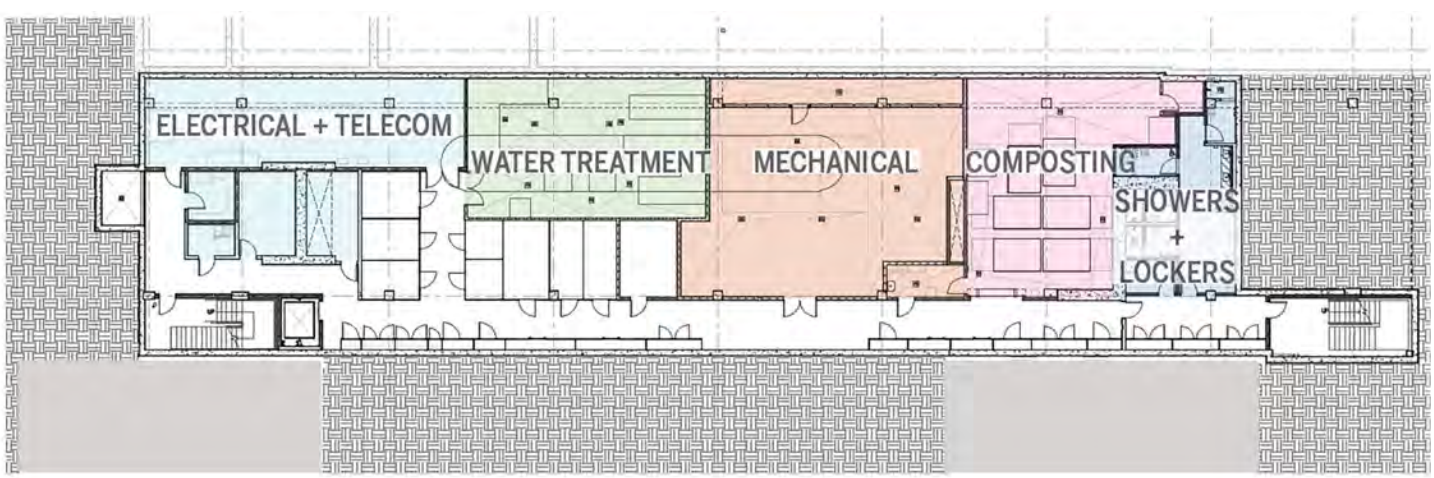
[5] Design-build project delivery is a single contract with a design team and a general contractor.

(Above) Rendered sectional perspective through the new courtyard and City Hall East addition to the historic City Hall at left. *(Courtesy of Frederick Fisher Architects.)*

(Right) Rendered bird's eye view of Santa Monica City Center with new City Hall East building. *(Courtesy of Frederick Fisher Architects.)*

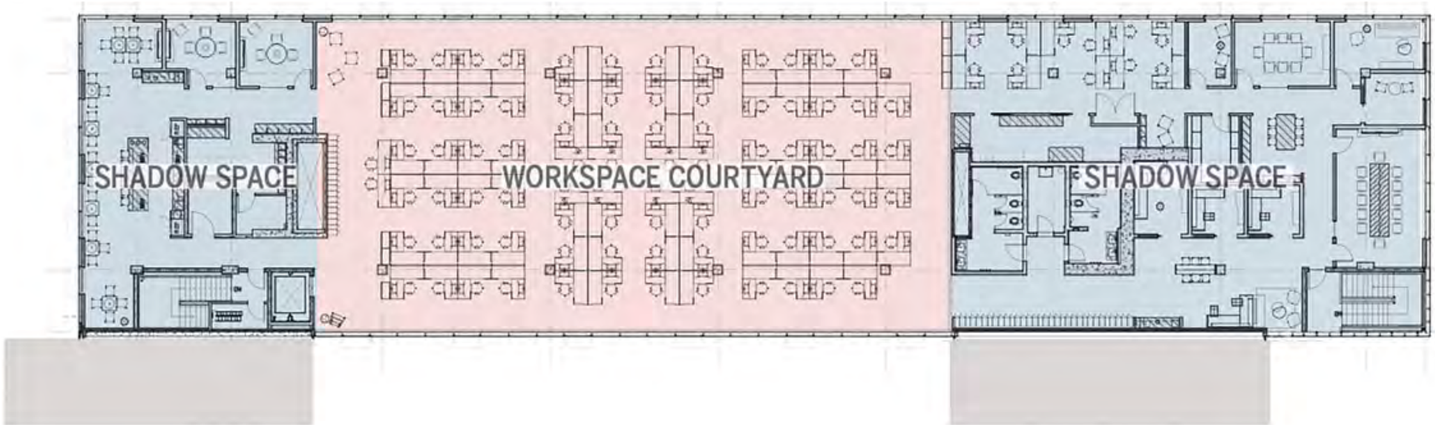


GROUND FLOOR PLAN



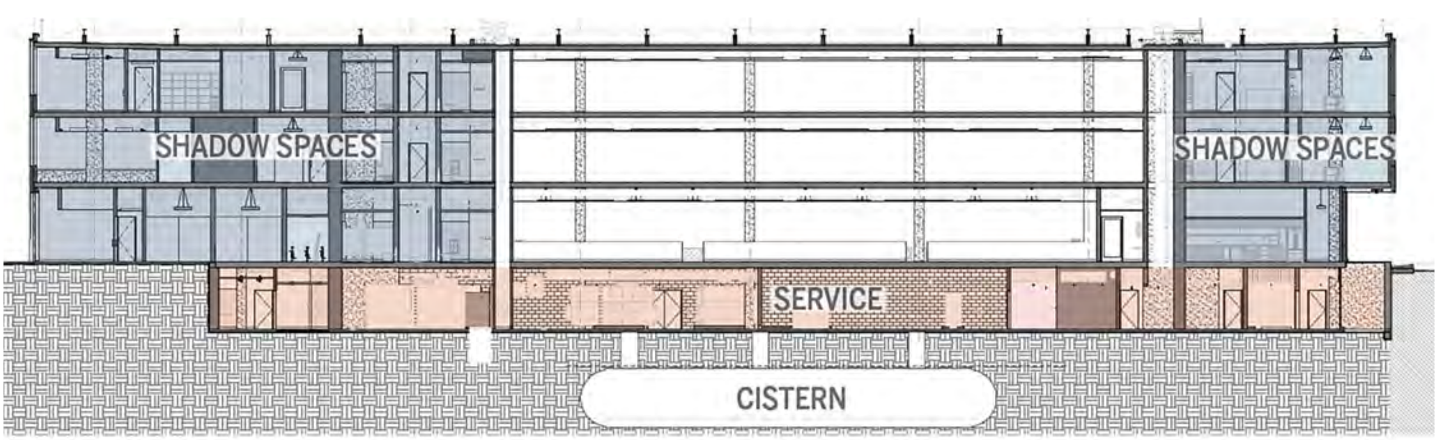
BASEMENT PLAN

SANTA MONICA CITY HALL EAST: FLOOR PLANS AND BUILDING SECTIONS



SECOND FLOOR PLAN (THIRD FLOOR PLAN SIMILAR)

TRANSVERSE (CROSS) SECTION



LONGITUDINAL SECTION

Building Envelope

The City’s Landmarks Committee had ruled that the new addition was required to be strongly differentiated from the historic City Hall through the choice of material for the building’s envelope. The Committee approved the proposal for an all-glass curtain wall, which provided both the desired strong architectural contrast as well as some reflective characteristics of the historic facades within the enclosed green space. This choice of building envelope material, however, created design issues related to energy performance. The issues are control of solar heat gain, insulating value and daylighting.

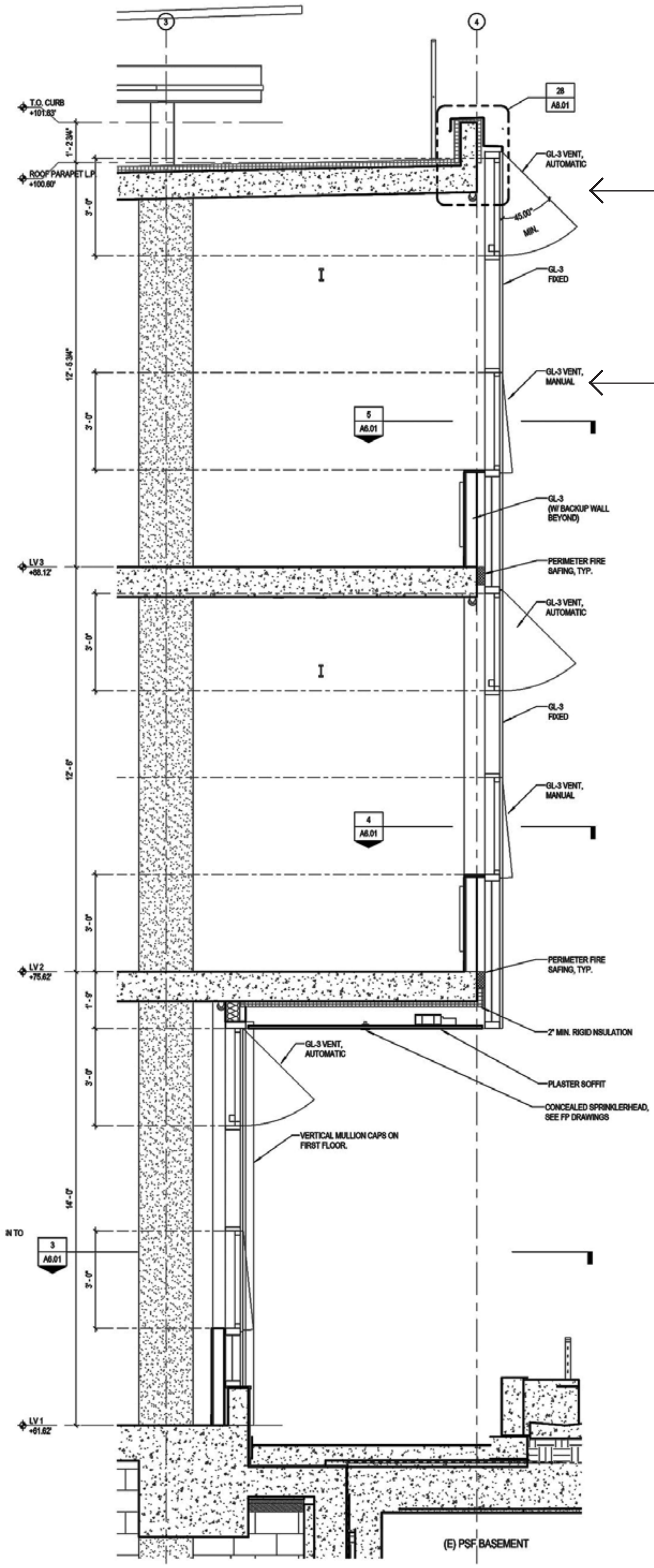
The “plain glass box” design concept required the absence of exterior sun shading devices of any kind. Given the roughly east-west orientation of the building, exterior shading design would have been challenging and expensive. The result is that these three design issues are necessarily addressed entirely by the curtain wall characteristics, which are optimized to reduce the energy loads caused by the building envelope. (See the typical wall section in the figure on the opposite page.)

The design team chose an advanced type of glass[6] with a neutral-silver appearance, incorporating it into a double-glazed curtain wall system. The modern glass coating provides high daylight transmission with a low solar heat gain factor. A variable frit pattern is applied to the glass to further reduce the solar heat gain and to eliminate the visual glare produced at the interior space by the direct sun incident on the curtain wall. The frit pattern is minimal (30%) when the glass is in the optimal location for daylighting (above desk height) and maximum density (80%) when the glass is not in a vision-outward location. (See the typical curtain wall elevation with frit patterns on page 14.)

The building envelope does not have a low U-value since it is almost entirely glass curtain wall, but the building utilizes other energy efficient design strategies as described in the following sections to achieve zero-net-energy performance.

(Right) View of new City Hall East building from the south, with the curtain wall visible on the south and east elevations *(Photo: Randall Howard)*

[6] Viracon low-iron glass with VN-53 coating for both high visible light transmission and low solar heat gain factor. The base specification is Solar Heat Gain Coefficient = 0.23, Summer U-Value = 0.25, Visible Light Transmittance (VLT) = 52%.

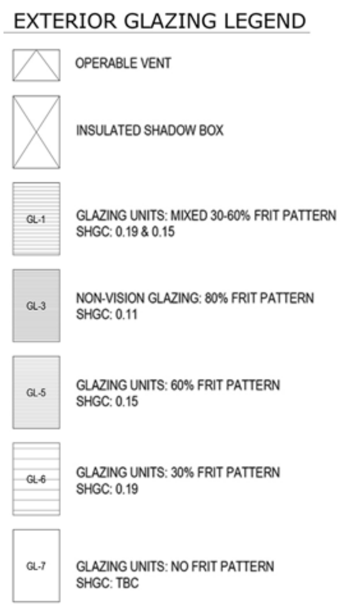


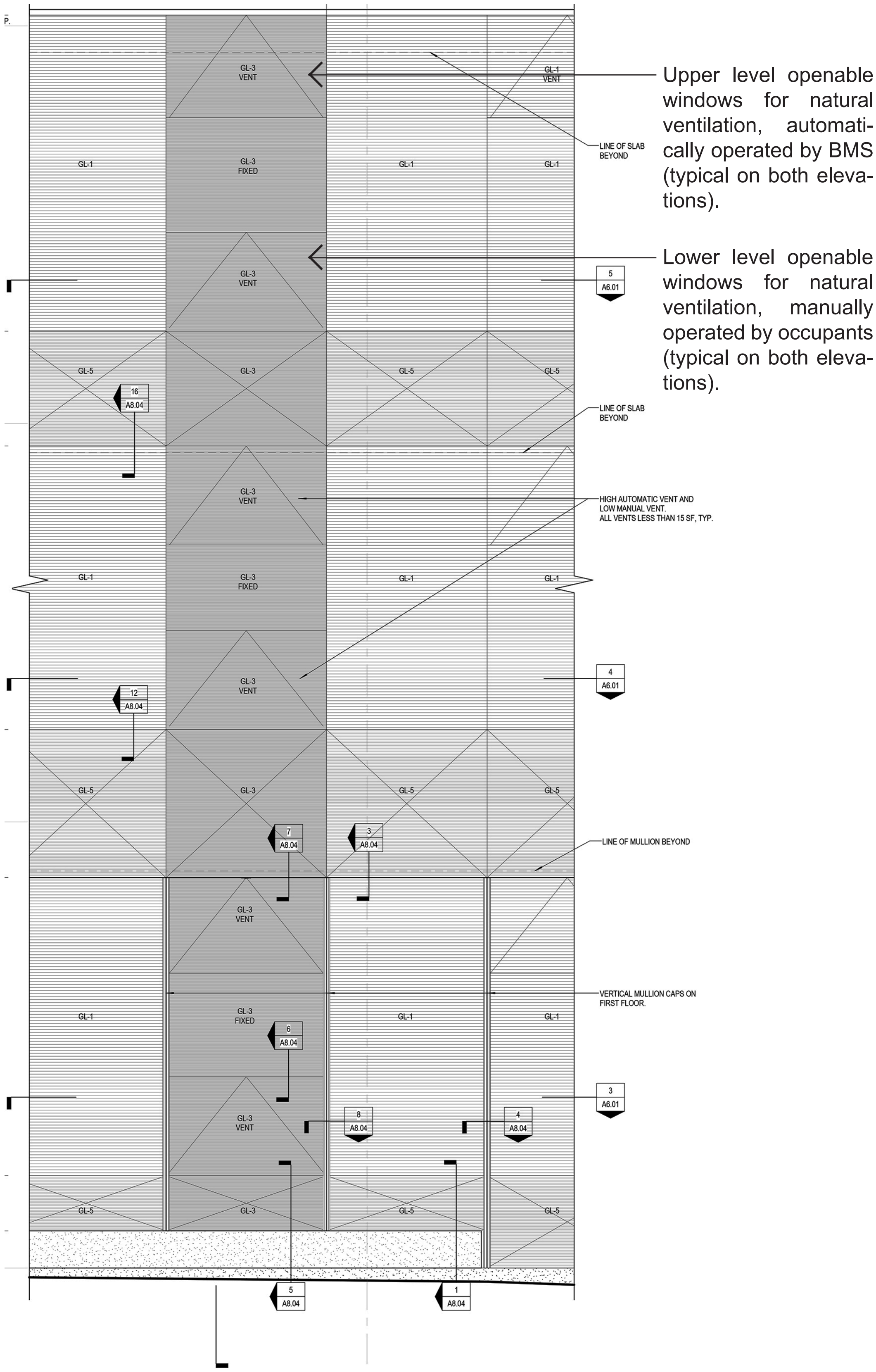
Upper level openable windows for natural ventilation, automatically operated by BMS (typical on both elevations).

Lower level openable windows for natural ventilation, manually operated by occupants (typical on both elevations).

(Left) Wall section through the east facade, showing curtain wall with openable windows at each level. *(Courtesy of Frederick Fisher Architects.)*

(Above) Detail view of frit pattern on the glass facing the courtyard. *(Courtesy of Frederick Fisher Architects.)*





(Right) Typical partial east elevation of curtain wall showing frit pattern variations that maximize sun control and daylighting. *(Courtesy of Frederick Fisher Architects.)*

Thermal Storage – Phase Change Material

In order to reduce the peak cooling load that would normally result from the instantaneous solar heat gain created by the glass curtain wall (though a smaller peak due to the glass coatings) phase change material[7] was added selectively to internal ceilings and walls, as well as to the perimeter spandrel glass areas. The phase change material essentially absorbs the heat gain and then releases it at a later time, thereby lowering the peak and smoothing out the cooling load impact. Combined with the night flush operation, some of the heat gain never appears as a load on the cooling equipment. Another effect is that it extends the operating period of natural ventilation.

(Above) Phase change material installed over insulation in selective walls. *(Courtesy of Buro Happold.)*

Daylighting and Electric Lighting

Good daylight penetration results from the narrow floor plates, approximately 56 feet wide. Reduced glare from the glass curtain wall on the east and west facades due to the frit pattern applied to the glass enhances the visual comfort level of the interior spaces.

All electric lighting is LED-sourced, with occupancy sensors and 50% dimming capability.

Natural Ventilation

As indicated in the wall-section and the typical curtain wall elevation, there are large operable windows located at two heights on each floor, one at occupant level and a second one just below the ceiling. This occurs at the long east and west elevations along the entire length of the building, producing ample fresh air flow via this optimal cross-ventilation design.

The upper windows are automatically controlled by the building management system (BMS) and the lower windows are user-operated, allowing each person to choose personal comfort conditions. If outdoor air temperature conditions warrant natural ventilation, then the BMS opens the upper windows and the cooling system is shut off. If cooling is required, then the upper windows automatically close. For the meeting rooms, the cooling system cannot operate unless the manually-operated lower windows are closed, as signaled by window contacts. However, for the open-plan office areas, the cooling system can operate if some of the manually-operated lower windows are still open; occupant training was deemed to be sufficient to create awareness of this condition and to learn to follow the action of the automatic upper windows.

When the night flush operation is engaged, the upper windows open and the operation proceeds, usually with natural air flows. The mild marine climate of Santa Monica is benign enough for the natural ventilation mode to proceed for most of the year. In the winter, a short pre-heat period is sometimes required in the mornings.

Heating, Ventilating and Cooling Systems

The HVAC system utilizes air-source heat pumps to generate heated or chilled water that circulates through radiant concrete slabs. These concrete slabs are completely exposed on the underside and partially exposed on the floor above, thus heating or cooling the spaces above and below through radiant means. During peak cooling events, the radiant slab cooling is supplemented by three separate VAV air-handling units (AHUs) for active cooling requirements in the three major zones.

A separate VRF (variable refrigerant flow) system is used only for electrical and server rooms (cooling only). Exhaust air from these rooms is circulated back into the office spaces as needed for heating in the winter months.

Domestic hot water (DHW) is provided by residential-type air source heat pumps.

(Following Page) Interior view of typical office space, with courtyard beyond the windows at right. *(Photo: Jeremy Bitterman.)*

[7] ENRG Blanket™ by Phase Change Solutions, https://phasechange.com/enrgblanket/


PHOTO: JEREMY BITTERMANN / JBSA

Plug Loads

The City decided to provide laptops for the majority of its staff in the new building rather than larger desktop computers. In addition, each workstation is limited to only three electric outlets. Power strips are not allowed.

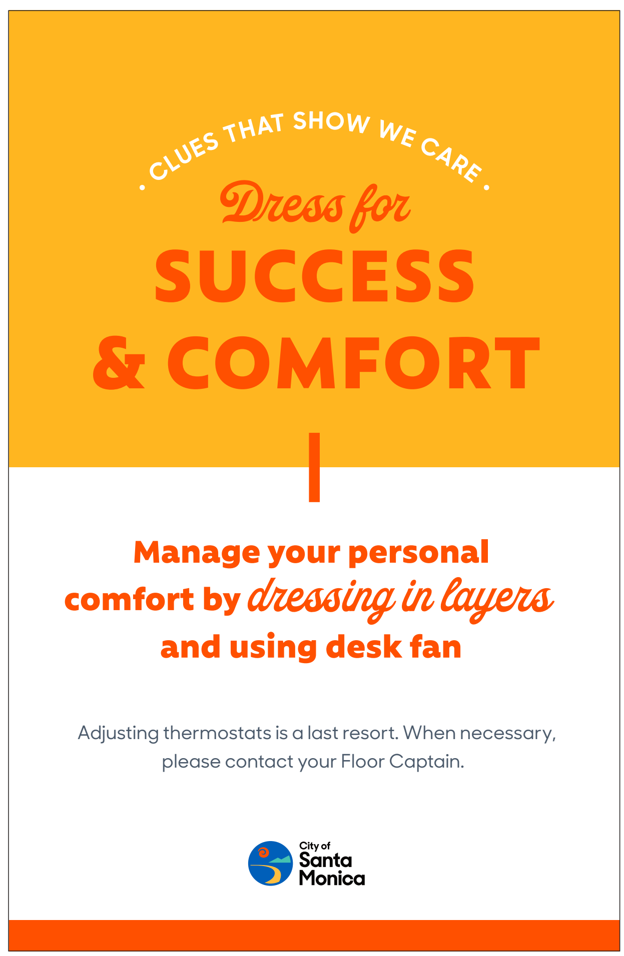
Commissioning

The building commissioning was only partly completed in early 2020 because of the Covid pandemic. It was finished after the new opening date in June 2021.

Occupant Training and Behavior

One city employee is assigned as the building technician, whose responsibility is to manage building operations and procedures. This includes reviewing and recording the various data reports produced by the BMS on the various systems. It also includes responding to occupant inquiries and advising about the use of the various building systems.

The occupants receive introduction and training on the building's energy use features, as well as the water and waste systems. Signage was developed to assist with behavior change management. (See examples below.)



Renewable On-Site Energy Supply

Solar Photovoltaic System

Based on the energy modeling done during the design phase, it was clear that there was not enough roof area to accommodate the size of the solar photovoltaic system needed for ZNE performance. The modeled annual energy use of the new building totaled 363,000 kWh and a calculation of the maximum size solar photovoltaic (PV) array that fit on the building roof, using high-output commercial grade panels, projected an annual output of 245,000 kWh. As a result, it was decided to build canopy structures above the staff parking areas on the north side of the City Hall complex and to install the remainder of the solar PV panels required to guarantee ZNE performance.

The total solar installation is comprised of 370 roof-mounted panels, 460W SunPower X21-460-COM, and 336 canopy-mounted panels, 360W SunPower X22-360. The roof-mounted panels are referred to as a "Commercial" panel, which are 20 inches longer than the canopy-mounted panels, denoted "Residential" panels. The size restrictions of the canopy structures required the use of the shorter Residential panels. The rated output of the roof-mounted system is 170.3 kW and that of the canopy-mounted system is 121.7 kW, for a total system power output of 292 kW.

The annual energy produced by this system was estimated using the online PV-Watts calculator[8]: 411,500 kWh total. The canopy-mounted system is projected to produce 167,300 kWh and the roof-mounted system is estimated at 244,200 kWh.

The Living Building Challenge certification requires that the building perform at ZNE for twelve contiguous months after occupancy. The solar PV system was slightly oversized anyway to produce enough energy to remain at or exceed ZNE performance while accounting for degraded production, inverter malfunctions, panel cleanliness and other maintenance issues over the first few years. The numbers for the modeled energy use and the projected energy production of the system indicate that there likely is sufficient extra capacity in the solar PV system to achieve the ZNE performance continuously through the next decade..

Energy Storage (Batteries)

The new building is designated an "Essential Services" building, which requires some additional features to be designed that enable the facility to remain functional in the event of an emergency such as an earthquake. For example, the structural design, as well as all the mechanical and plumbing connections, must satisfy all performance requirements for 50% higher seismic forces. A decision was made *not* to include battery energy storage in case of a power failure for cost and space reasons. A diesel-fueled emergency generator is installed to provide power to essential IT systems and other key functions.

Interestingly, the contractor used a solar PV system with battery backup for temporary power at their trailers during construction. The 20kW system was mounted on the roofs of these construction trailers with the 60 kWh of battery storage inside.

[8] See https://pvwatts.nrel.gov/

(Right) View over rooftop PV installation toward the north-west and the Pacific Ocean. *(Photo: Amy Williams.)*

PHOTO: AMY WILLIAMS

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

Energy Use — Modeling

Energy modeling was done for the parametric studies of design alternatives as well as for the final design. IES Virtual Environment[9] was used for these design studies and for the documentation required as part of the Living Building Challenge certification. Energy Pro was used to demonstrate code compliance.

Since the building is designed to operate largely in natural ventilation mode, the actual air flow through the spaces was modeled using Ansys Fluent[10] software, which uses computational fluid dynamics (CFD) analysis to predict actual patterns of air movement under different exterior conditions. This software was also used to simulate the radiant floor/ceiling system fluid flows in order to provide estimates of the amount of heat transfer into and out of the concrete slabs.

As noted above, the energy modeling was effective in assisting with the proper sizing of the solar PV system so that the requirements of the Living Building Challenge could be met. 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

The building's original opening day (Earth Day 2020) coincided with the mandated shutdown of public buildings due to the Covid-19 pandemic. The building's energy use for 2020-2021 therefore has not been representative of the normal operation with full staff and general public access. Furthermore, the new building and the historic City Hall are on the same public utility meter. A separate submeter has been installed on the new building, which will record each category of energy use when it is fully integrated into the BMS. This is necessary for the Living Building Challenge certification and is expected to complete its first year of measured data collection of energy use in 2022.

Energy Production versus Energy Use: Zero Net Energy

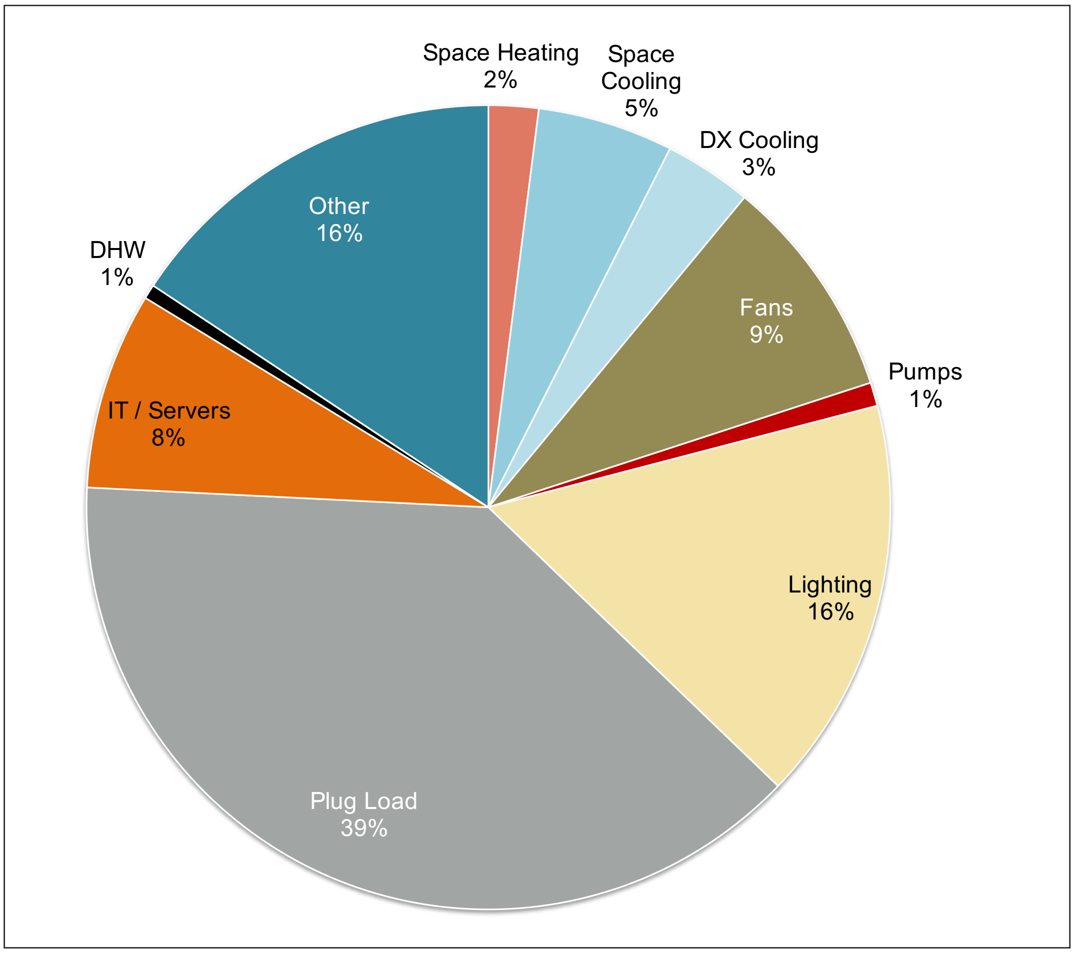
The roof-mounted solar PV system was installed and activated in June 2020, followed by the canopy-mounted system in October 2020. There was a drop in recorded output in April 2021 caused by the inverters being offline when the system was being integrated into the BMS, but otherwise the system has been producing electric power as planned. Much of this energy was put into the public utility grid until June 2021, when the building finally opened to the public and some partial occupancy commenced.

The solar PV system performance for the first full year of operation (October 2020 – September 2021), as atypical and somewhat sporadic during startup as it was, is shown in the chart on page 24, *Solar Photovoltaic System Performance*. For reference, the modeled energy use is shown on the same chart. As required for the Living Building Challenge performance data submittal, actual energy use will replace this modeled reference data in the future.

The second chart on page 24, *Cumulative Net Energy Performance*, sums the net energy production each month to that of the month prior, so that the annual total would be exactly zero if the performance is zero-net-energy (ZNE). The chart shows that this building is in fact *net positive*.

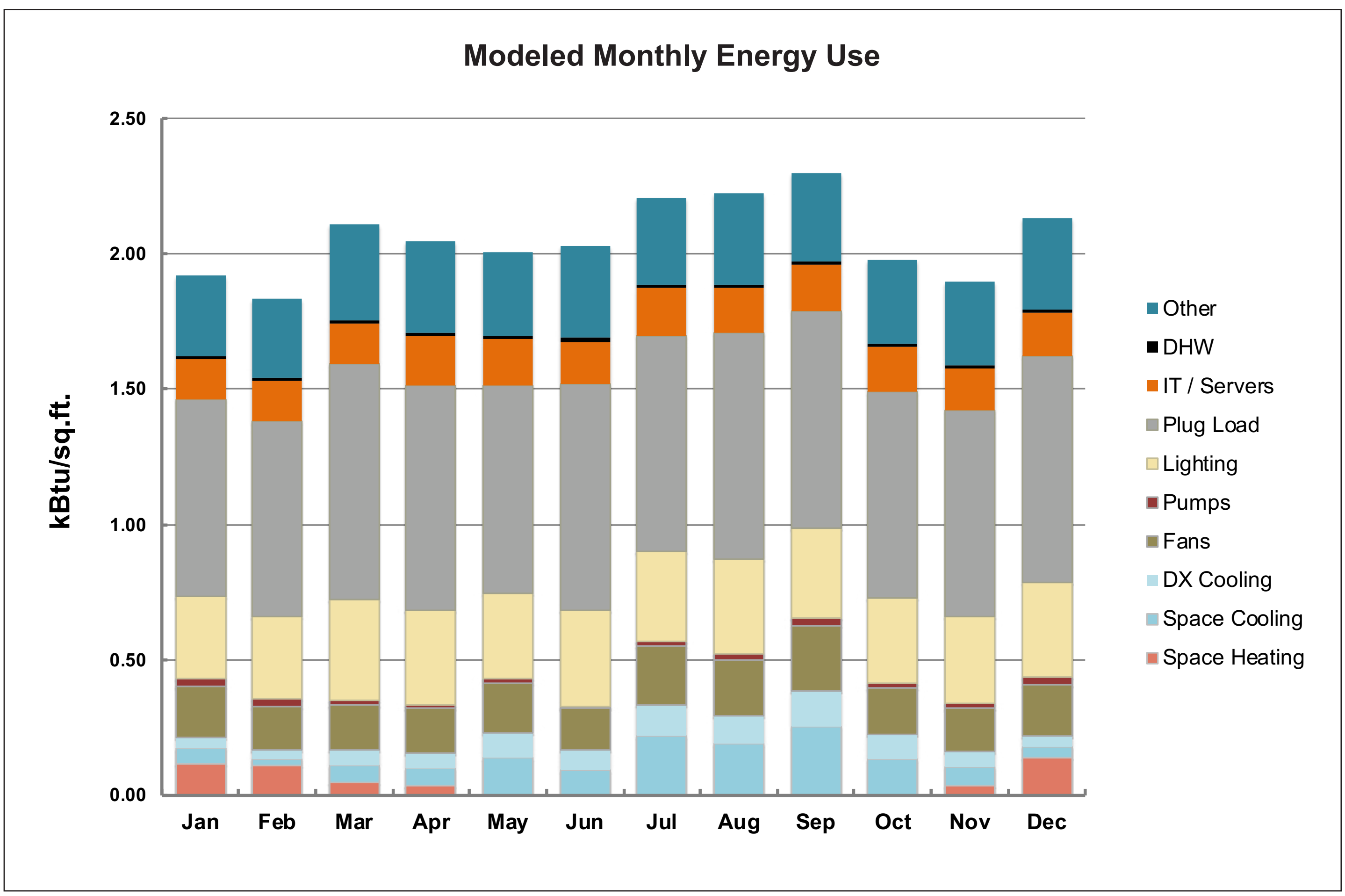
[9] See https://www.iesve.com/software

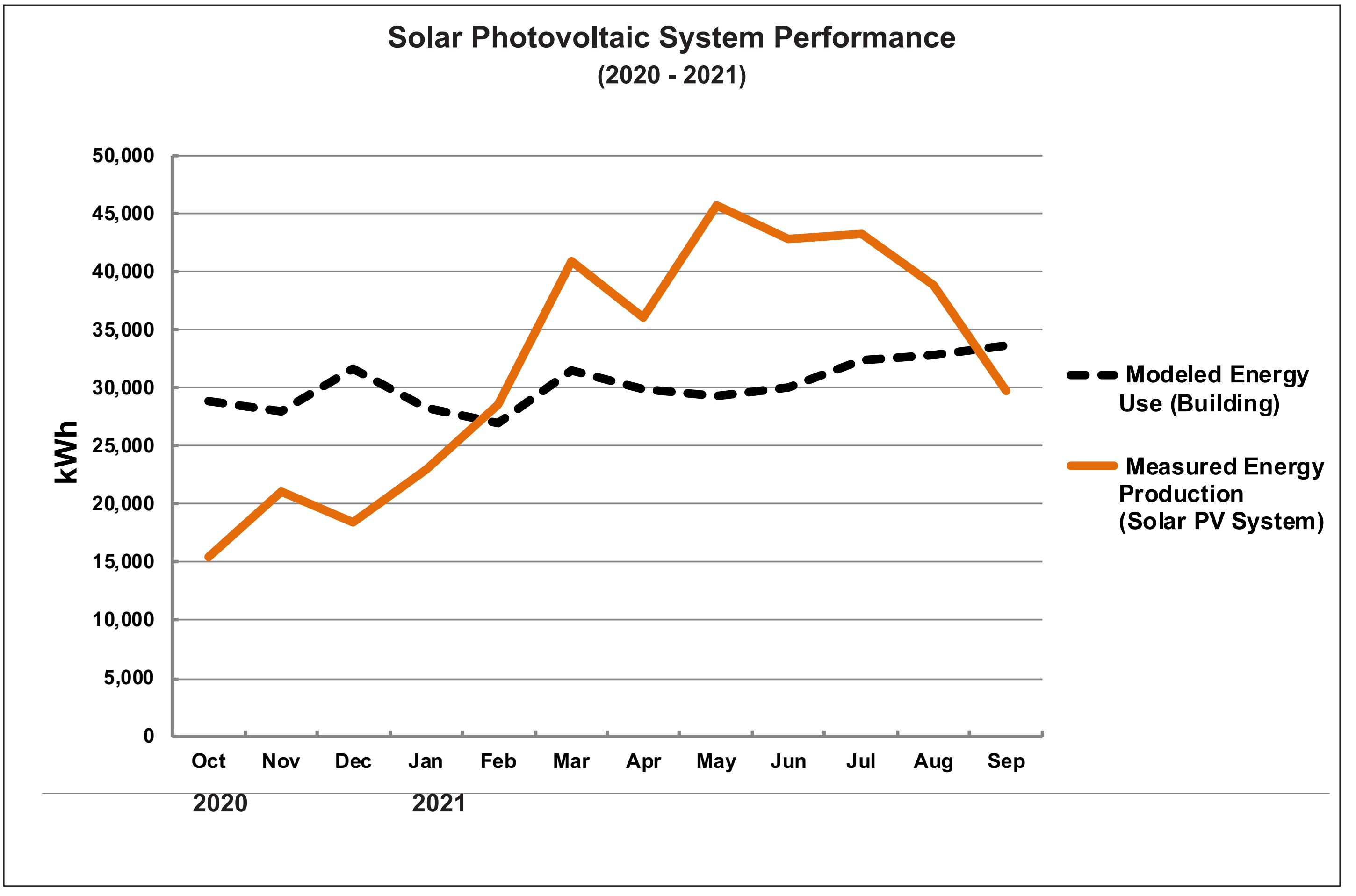
[10] See: https://www.ansys.com/products/fluids/ansys-fluent

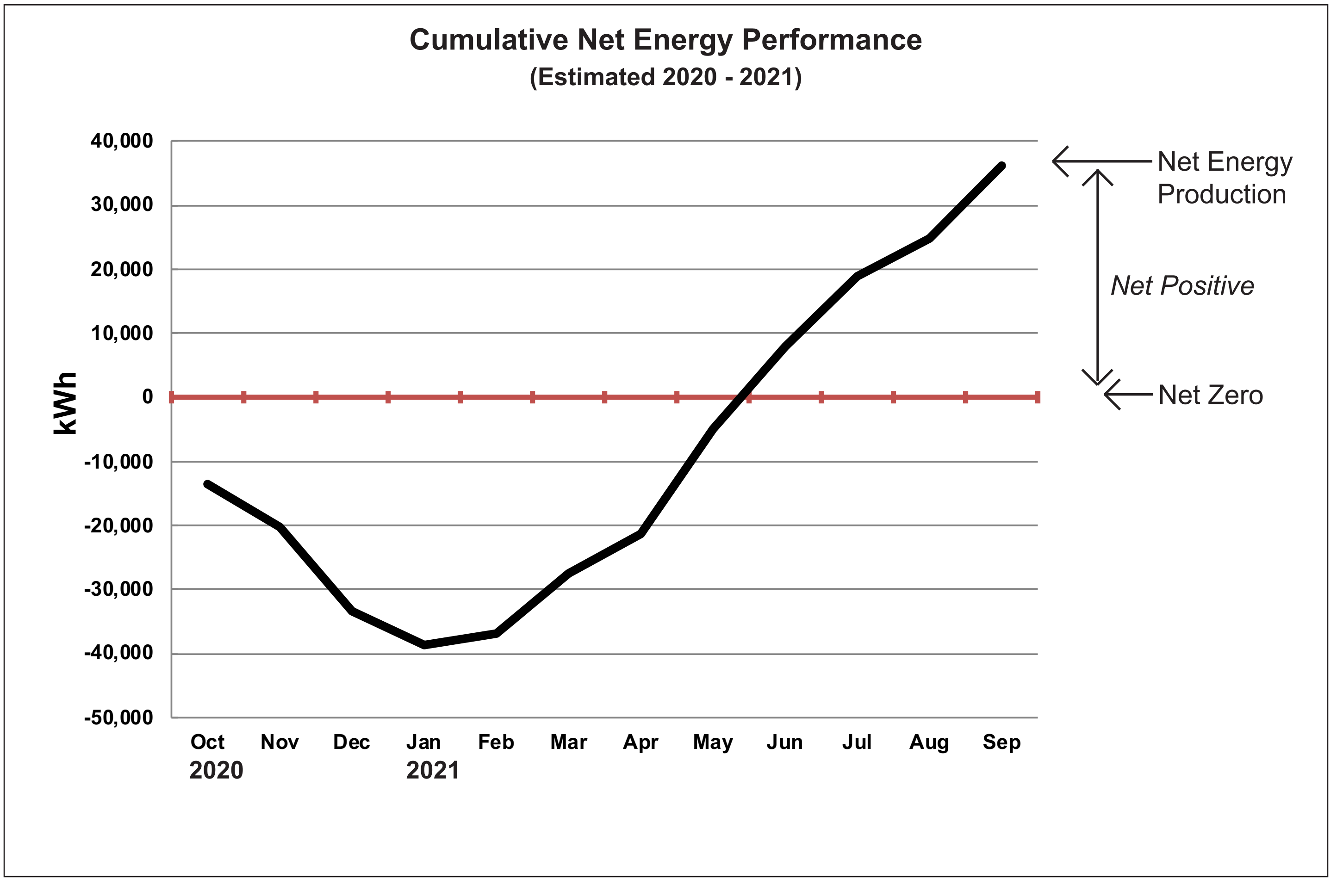


Modeled Energy Use (Annual)

363,300 kWh/year
Modeled EUI = 24.7




Solar Photovoltaic System Performance
(2020 - 2021)
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
kWh
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
2020
2021
Modeled Energy Use (Building)
Measured Energy Production (Solar PV System)


Cumulative Net Energy Performance
(Estimated 2020 - 2021)
40,000
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
-40,000
-50,000
kWh
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
2020
2021
Net Energy Production
Net Positive
Net Zero

Post Occupancy: Observations and Conclusions

The building has had almost no occupants since the scheduled opening date in April of 2020 and began increased though still less than normal occupancy (approximately 15%) in June 2021. There has been limited opportunity to perform a normal review of building operations and compare with design intent and project goals. However, there is every indication that the building will achieve the project objectives related to Living Building Challenge certification. As with every project, however, there are issues that might be addressed differently with the benefit of observing the completed product.

Post Occupancy: Energy Metering

In spite of the plan for energy use metering of the new building separately from the main City Hall building, this was not initially undertaken when construction was completed. This has been remedied at the start of actual occupancy in June 2021 and should result in valuable information for building management.

Real-time public display of the categories of separate sub-system energy use is possible as a potential added informational feature. As a communication tool with the general public, these displays can perform a useful public service.

Post Occupancy: Approvals Process

The building uses many innovative systems not usually seen by regular building officials. Even though the project was for and by the City of Santa Monica, this resulted in prolonged responses to these officials in order to resolve issues and questions. Although generally a recommended procedure for any project design team, a written record should be made of discussions and agreements concerning particular issues to forestall revisiting complex issues when building official staff changes over the course of construction. These procedures should be followed for the benefit of the client project managers, which inevitably experience some turnover as well. Continuity of staff is valuable with the complex and unusual design issues of a project such as this one.

Post Occupancy: Preparation for Living Building Challenge Certification

The Living Building Challenge consists of an ambitious set of design goals which can require an unusual set of building design strategies and systems. Previously LBC-certified buildings with similar systems or features should be referenced when possible to minimize delays in construction time. For the City Hall East building, for example, the contractor experienced some challenges in the construction of the radiant slabs, which contained embedded tubing for heating and cooling, post-tensioning steel and electrical conduit. The construction schedule for this particular item had to be extended because of the unanticipated coordination required. (Nevertheless, the building opened on-time because of schedule adjustments elsewhere.)

Post Occupancy: Embodied Carbon Assessment

The client and design team did not carry out an embodied carbon assessment as is customary for buildings designed today. The consensus among the members of the project team is that this would now be included in the design studies. For example, a cross-laminated wood structural system[1] would be studied and could possibly have been preferred to the post-tensioned concrete structure employed.

[1] See for example, https://en.wikipedia.org/wiki/Cross-laminated_timber
https://www.archdaily.com/893442/cross-laminated-timber-clt-what-it-is-and-how-to-use-it
https://archinect.com/news/article/150218387/california-adopts-suite-of-high-rise-timber-regulations
https://www.youtube.com/watch?v=YuAya0hRjwU

CASE STUDY NO. 2

Makers Quarter Block D Office Building

PHOTO: NICK MERRICK, HALL MERRICK PHOTOGRAPHERS

Makers Quarter Block D Office Building

Case Study No. 2

Data Summary

Building Type: Mid-Rise Office Building (New)

Location: San Diego, CA

Gross Floor Area: 53,325 sq.ft. / 6 stories

Occupied: July 2018

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

Measured EUI (Site):
14.3 kBtu/sq.ft. per year
(2019 - Partial Occupancy)

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

On-Site Storage Battery:
None

Measured On-Site Energy Production:
141,000 kWh per year (2019)
9.0 kBtu/sq.ft. per year (2019)

Developer/Client
Joint Venture:
Lankford & Associates,
HP Investors, Hensel Phelps Construction Co., San Diego

Design Team

Architect:
BNIM, San Diego

Structural Engineer:
BWE, Inc., San Diego

Mechanical/Electrical/Plumbing Engineer:
Syska Hennessy Group, San Diego Office

General Contractor:
Hensel-Phelps, San Diego

Solar PV System Contractor:
HMT Electric, Escondido

Among the more common building types in large and small cities across the country is the mid-rise office building, consisting of three to usually six stories in height. The first case study in this book is an example of the three-story type, designed to house permanent public functions. This second case study, *Makers Quarter Block D*, is the same general type, but built by a private developer as a speculative venture. As such, design decisions are driven by financial profit considerations in addition to other design goals and intentions.[1] These profitability criteria obviously affected the overall building program, but it is interesting to observe that the types of design strategies for energy-efficiency and zero-carbon are very similar for the same general type of climate.

Background

The building project was initiated by the owners of a five-block area south of downtown San Diego in 2005. The land was owned by the Navarro family that acquired the properties over two generations, starting from an initial furniture-making business (Jerome's Furniture) that was begun there in the 1950s. While the family business successfully expanded throughout Southern California, the family purchased properties near the original store in this area known as the East Village. The existing parcels in this part of San Diego were largely undeveloped, being utilized for warehouse, artist studios and other "maker"-related uses.

Now in its third generation, the Navarro family wanted to develop this large area into a vibrant part of the city, complete with residential, office and commercial uses. Lankford & Associates, as managing partner of the joint venture developer team, responded to an RFP issued by the owners in 2005 and the developer team won the competition. As a result, they were awarded the development contract for the entire area, which was called *Makers Quarter*. Block D is one of the five-block project areas to be developed. (See Vicinity Map on the opposite page.)

Before beginning any new projects in Makers Quarter, Lankford & Associates initially created several "activation" events at the property to introduce other uses to the area and change the perception of that part of the city—film festivals, beer festivals and other functions that would draw people to the area and give it life. The first project in the area was a new 270-unit apartment building, which created the beginning of a small community. Two renovations of existing buildings into shops and restaurants followed, including the shuttered "Coliseum", which had been a popular venue for professional boxing. These set the stage for the Block D development as a speculative office building.

In April of 2014, Lankford & Associates launched an invited competition for the design of a 50,000 sq. ft. Class A office building, including 10,000 sq. ft. of ground-level retail, to be located on Block D. The developer team believed that targeting a high level of innovative sustainable design characteristics would attract the type of tenant interested in this particular neighborhood: "edgy", informal, creative. A LEED-Platinum certification was seen as desirable.

Three design teams submitted proposals, with BNIM proposing a design that went further than the requirements of the competition brief—a zero-net-energy (ZNE) all-electric structure for the *core-and-shell* that would eventually become *zero-carbon* (ZC) when the utility grid is decarbonized by 2045. The developer team chose BNIM's proposed design and the process of planning approvals was begun in 2015.

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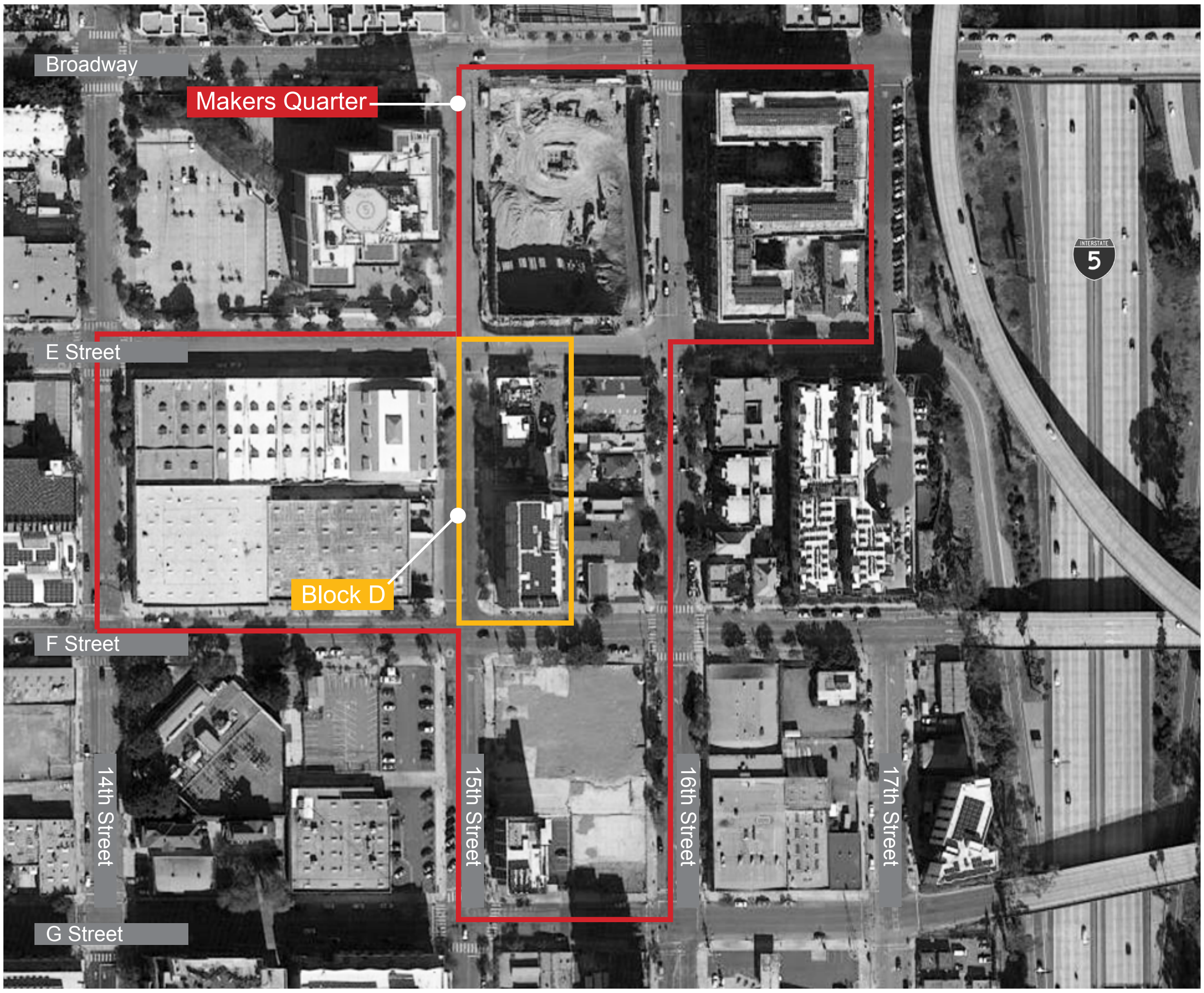
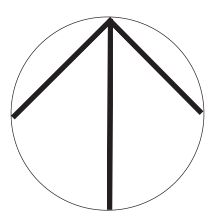
[1] See also *Case Study No. 9, Zero Net Energy Case Study Buildings, Volume 2*, "Speculative Office Building at 435 Indio Way", for an example of a detailed financial analysis of an all-electric renovation project for a one-story (low-rise) office building.



Makers Quarter Block D - General Vicinity Plan



Design Process and Low-Energy, Zero-Carbon Design Strategies

As with all such speculative building projects, the design process was driven by the projected financial outcomes, namely the balancing of estimated costs with the return-on-investment (ROI). The project team also factored in the now-adopted goal to achieve the LEED-Platinum and net-zero-energy certifications, which was seen as a factor in *increasing* the ROI though construction costs might be slightly higher. In fact, this proved to be correct, as the developer successfully negotiated two tenant leases during construction, with the remaining office space almost entirely leased shortly after completion of construction in 2018.

The prospect of the LEED-Platinum certification was also a factor in obtaining the initial financing for the project, which can be difficult for a project with a "ground lease". (The Navarro family retained ownership of the land at Block D.) Combined with the quick leasing of the building's tenant space, this confirmed that the project's financial performance met all of the original investment goals.

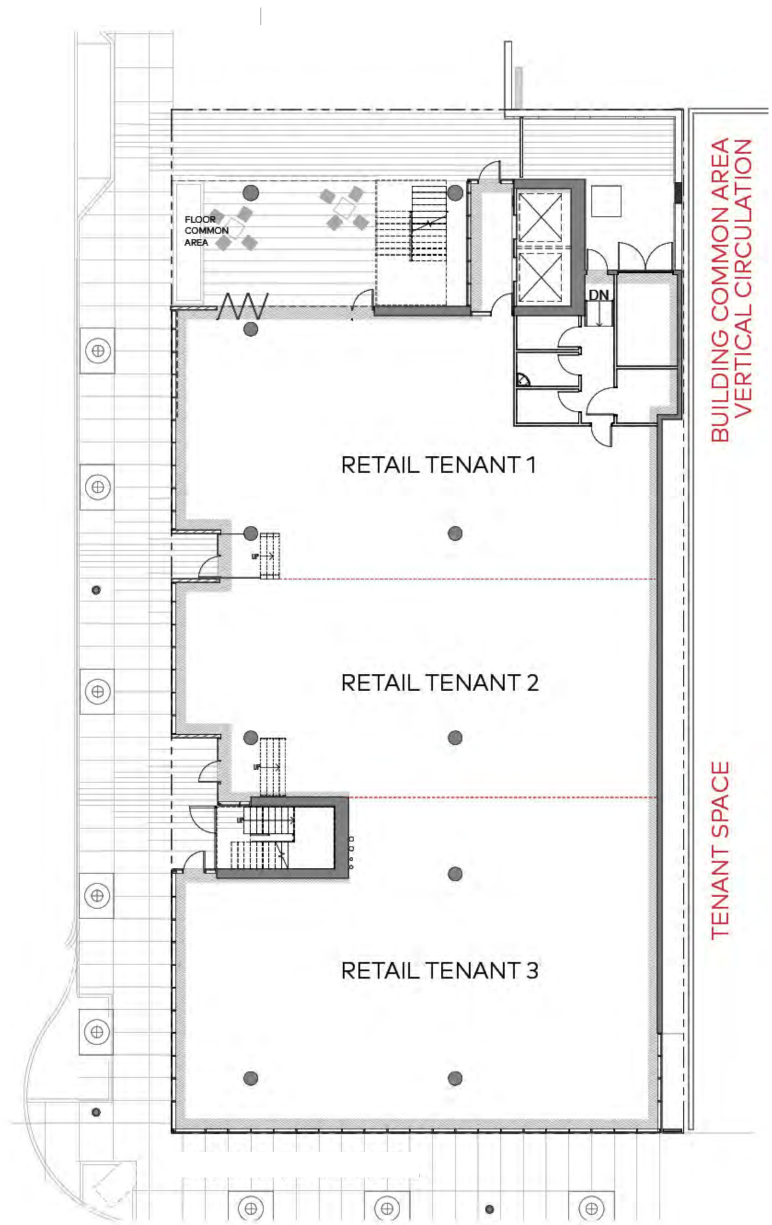
Planning Concept and General Design Considerations

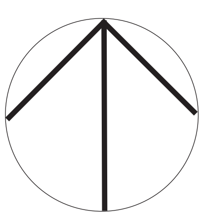
Pursuit of the *zero-carbon* designation required that the building be all-electric. Natural gas was available in the street adjacent to Block D, but the BNIM design team had proposed an all-electric design, which would eventually mean zero-carbon operation.

The constraints on the design included a relatively small site, which made it challenging to maximize the leasable area in the building within the planning requirements for this location in the city. Fortunately, these requirements did not include on-site parking, eliminating the high cost of creating basement parking levels. A second aspect of the San Diego planning code is that outdoor space such as balconies is not counted toward the assignable floor area of the building. This allowed the development of indoor-outdoor tenant suites, which fit with the mild year-round San Diego climate and the preferences of many of the building's targeted tenants—entrepreneurs, start-up firms, technology companies and artists.

The net result was that the building could be planned with the maximum rentable space within the site's buildable envelope as defined by the code.

(Opposite Page)
Rendering of ultimate buildout of Makers Quarter (outlined in red). Block D Office Building is circled in yellow. (Courtesy of BNIM)



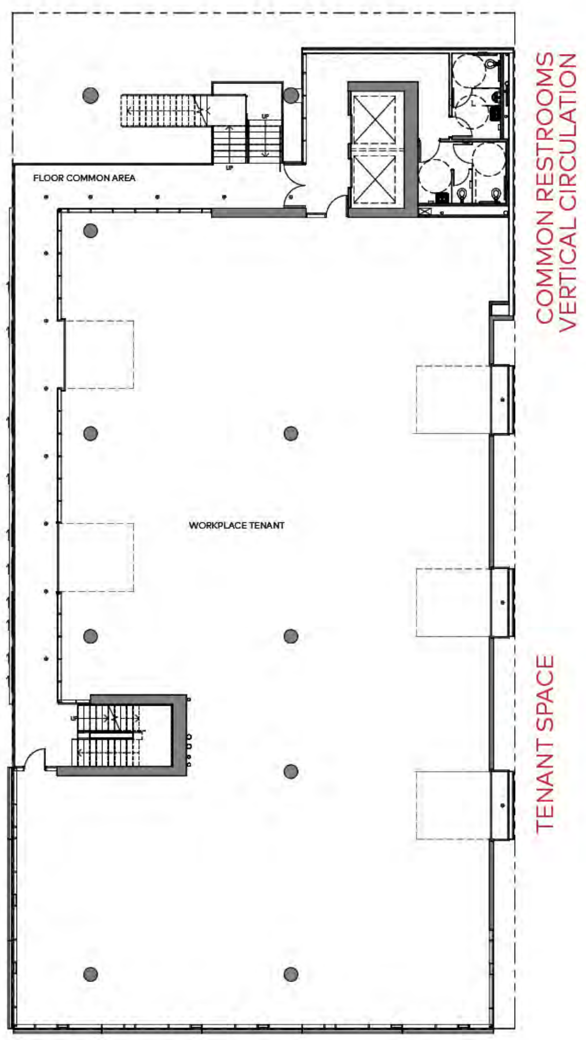


NORTH

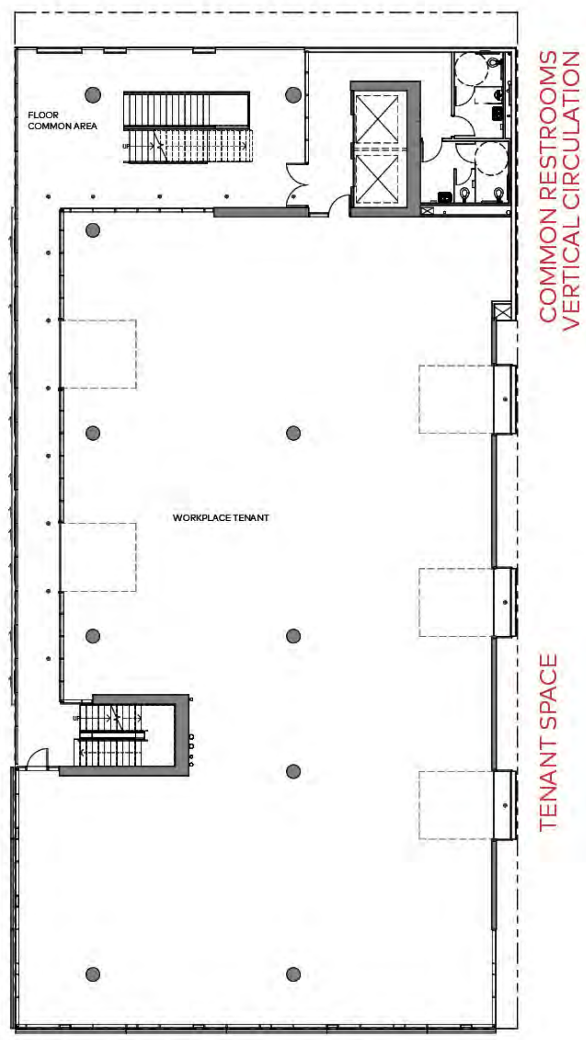
GROUND FLOOR PLAN

0 2 4 8 16 FT

MAKERS QUARTER BLOCK D OFFICE BUILDING: FLOOR PLANS AND BUILDING SECTIONS

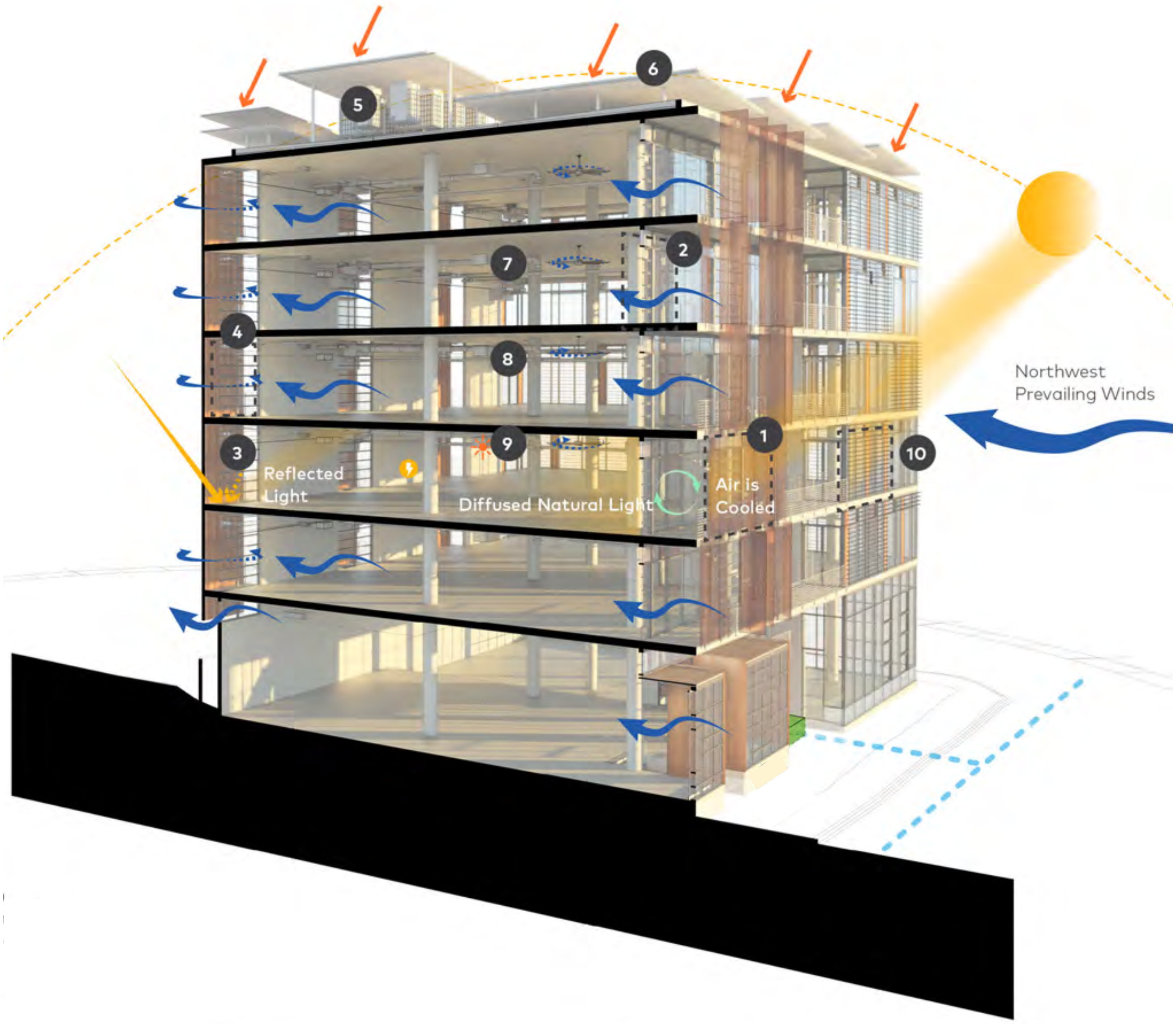


SECOND FLOOR PLAN



FLOOR PLANS - LEVELS 3 - 6

(Below) East-West section-perspective highlighting key design strategies. (Courtesy of BNIM)



1 Operable vertical sunshade panels on west side facing 15th Street
2 Overhead sectional garage doors for natural ventilation
3 Light/air openings at adjacent lot property line
4 Overhead sectional garage doors for natural ventilation
5 VRF mechanical equipment under solar photovoltain arrays
6 Solar photovoltain arrays
7 Motion/daylight sensors for electric light control
8 Variable large room fans for air movement comfort
9 Exposed concrete slab for night flush operation
10 Automatic exterior blinds at south end of building

Natural Ventilation

It is the year-round ideal climate of San Diego that permitted the principal energy-efficient design strategy: *natural ventilation*. Control of the natural outdoor air flow through the occupied spaces provides the basis for cooling comfort for almost the entire year. Block D has the ideal orientation to facilitate this air flow, namely a narrow lot with the long east and west exposures. The building therefore captures cooling ocean breezes from the west and provides outlets for the cross-ventilation on the east sides of the slender office suites.

The cross-ventilation was aggressively designed with the introduction of overhead sectional garage doors on each office floor, which open the indoor office space directly to the outdoors in several distributed locations. On the west side, the office space connects directly with the large common balcony areas that are sheltered from the western sun by large movable sunscreens. These shaded and protected outdoor areas are used by the tenants as part of the regular work space, useful in this manner for much of the year.

For those rare times when heating or cooling is required, the garage doors and openable windows must be closed for the HVAC system to operate. Conversely, when outdoor air conditions warrant, the building management system (BMS) automatically opens the windows and shuts off the HVAC system to allow cooling with the outdoor air. User-controlled ceiling fans can be operated to increase indoor comfort conditions by providing additional air movement, especially when the natural ventilation is necessarily restricted.

It is noteworthy that the tenants are informed about the design and operation of the building energy systems and features, with instructions about how to maximize comfort while minimizing energy use. The tenant leases include some language to this effect, specifying when certain operations may or may not be done. In addition, the plans for the *tenant improvements* (TI) are reviewed to ensure that nothing is done to counter the operation of these systems. Tenants are encouraged, for example, to locate partition walls in the direction of the cross-ventilating air flow and to avoid placing them where they will block this air movement.

(Left) Natural ventilation was designed using cross-ventilation created by the use of sectional garage doors, five per floor. (Photo: Basic Agency.)

(Opposite page, top) Vertical metal panel sunshades on the west elevation are manually operable by tenant preferences.

(Opposite page, bottom) Interior view at south end of the building—external blind system is automatically operated.

Building Envelope

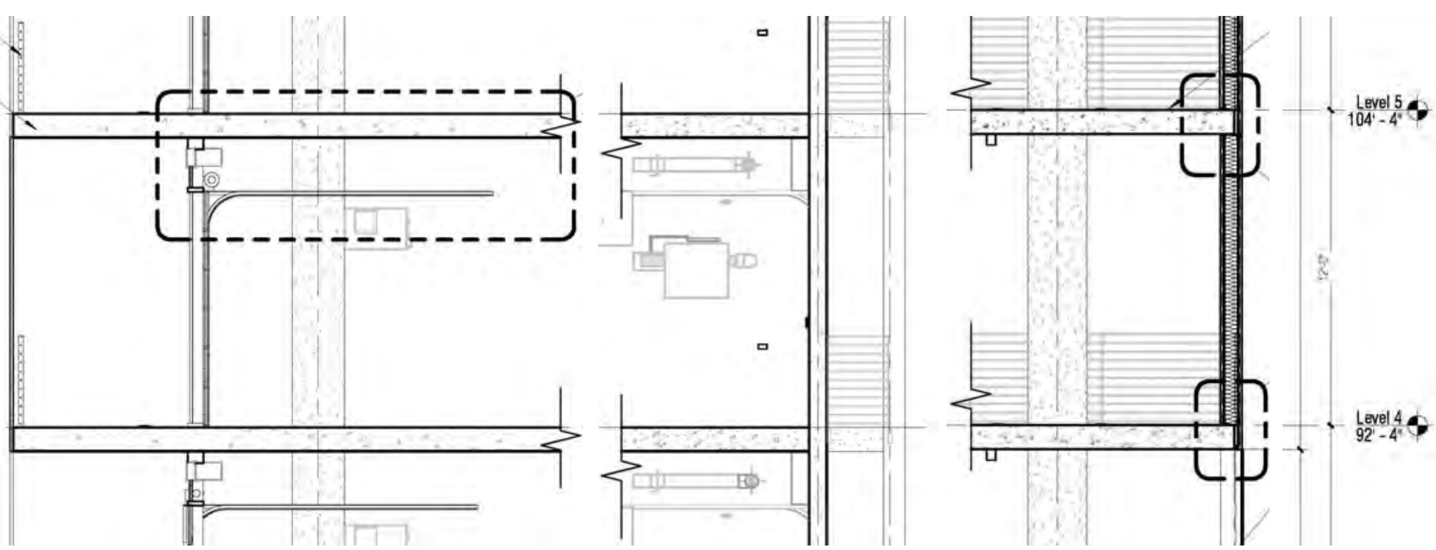
The natural ventilation features, as described in the previous section, are the principal components of the building façades. The overhead sectional garage doors have a series of enhancements to minimize air-infiltration and seal off the indoor office space when not open: (1) at the bottom, a U-shaped vinyl weather-seal; (2) at the sides, an EPDM rubber jamb seal that engages while closing; (3) at the top, a flexible vinyl flap header seal.[2]

The sun control elements consist of the manually-operated perforated-metal panels on the west and north sides, adjacent to the outdoor balcony spaces, and the automated exterior blinds located at the south end of the building. The perforated-metal panels provide shading and enclosure of the balcony spaces and can be arranged by the occupants to provide shading where it best suits them. Thus, they are also an essential part of the character of the tenant office suites.

The exterior blinds on the south end of the building (partial west and east sides) are automatically operated in response to solar sensors so that full shade is provided on the extensive amount of glazing while maximizing the openness to daylight. Combined with electric lighting controls, this minimizes electrical energy use for lighting and cooling.

The typical wall sections of the building for three façades are shown below. In general, the R-value of the opaque part of the wall averages R = 13. The roof is R = 25 and all concrete slab floors are uninsulated. The West wall contains both the glass curtain wall[3] and the roll-up garage doors leading to the balcony areas. The East wall is a bare concrete structural wall, left uninsulated as part of the *core and shell* construction; the tenant is expected to add a layer of insulation as part of space build-out, bringing it to the R-13 average value. The North wall is made up of metal panels that include 6” mineral wool insulation for an average R-value of R=23.

(Below) Typical wall sections at the West, East and North sides of the building.
(Courtesy of BNIM)



WEST EAST NORTH

[2] Raynor AlumaView AV175, https://raynor.com/commercial/commercial-sectional-garage-doors/alumaview-aluminum-rail-and-stile-doors/alumaview-av175/

[3] U = 0.29, SHGC (typical) = 0.38, SHGC (East side) = 0.29.

PHOTO: NICK MERRICK, HALL MERRICK PHOTOGRAPHERS

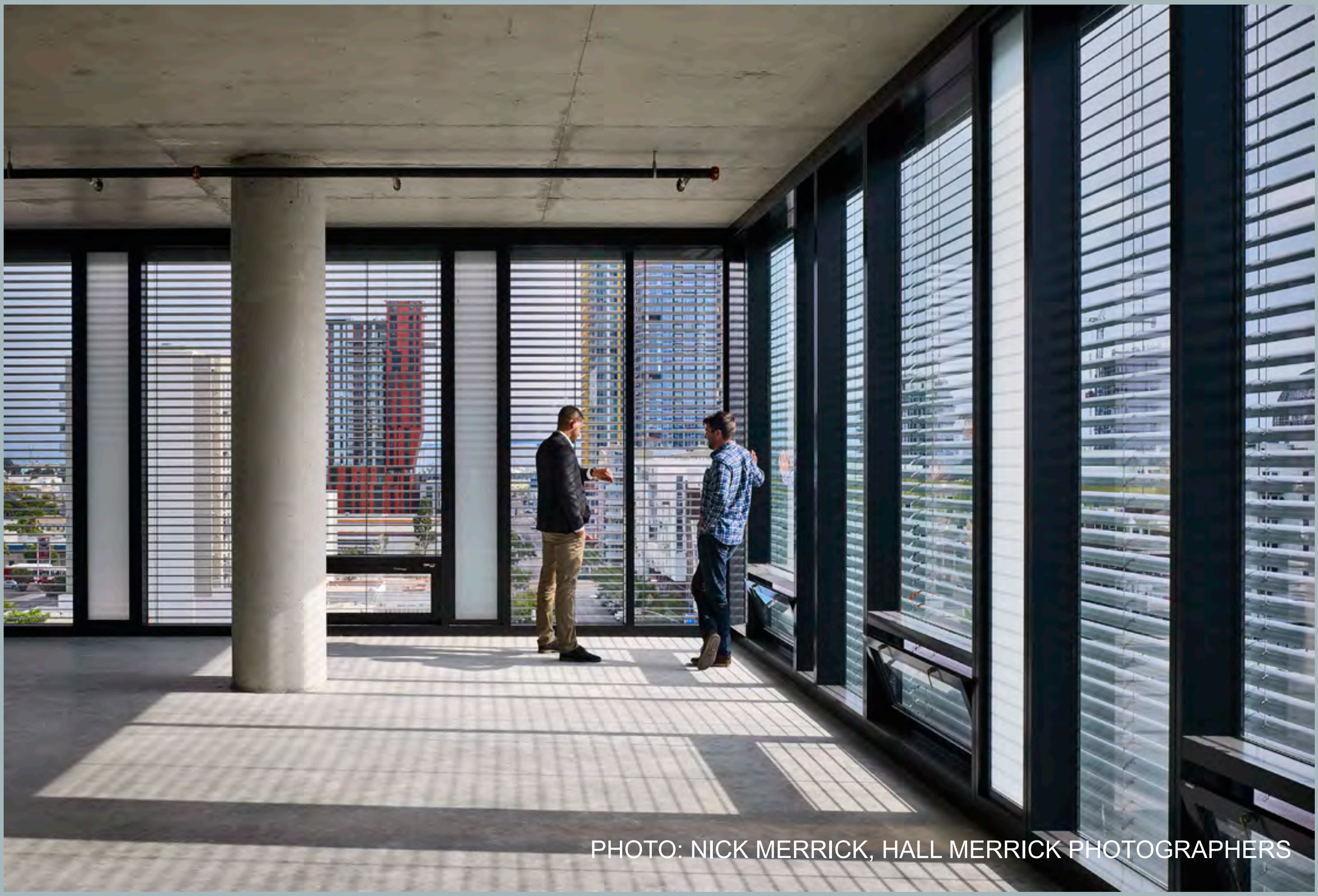
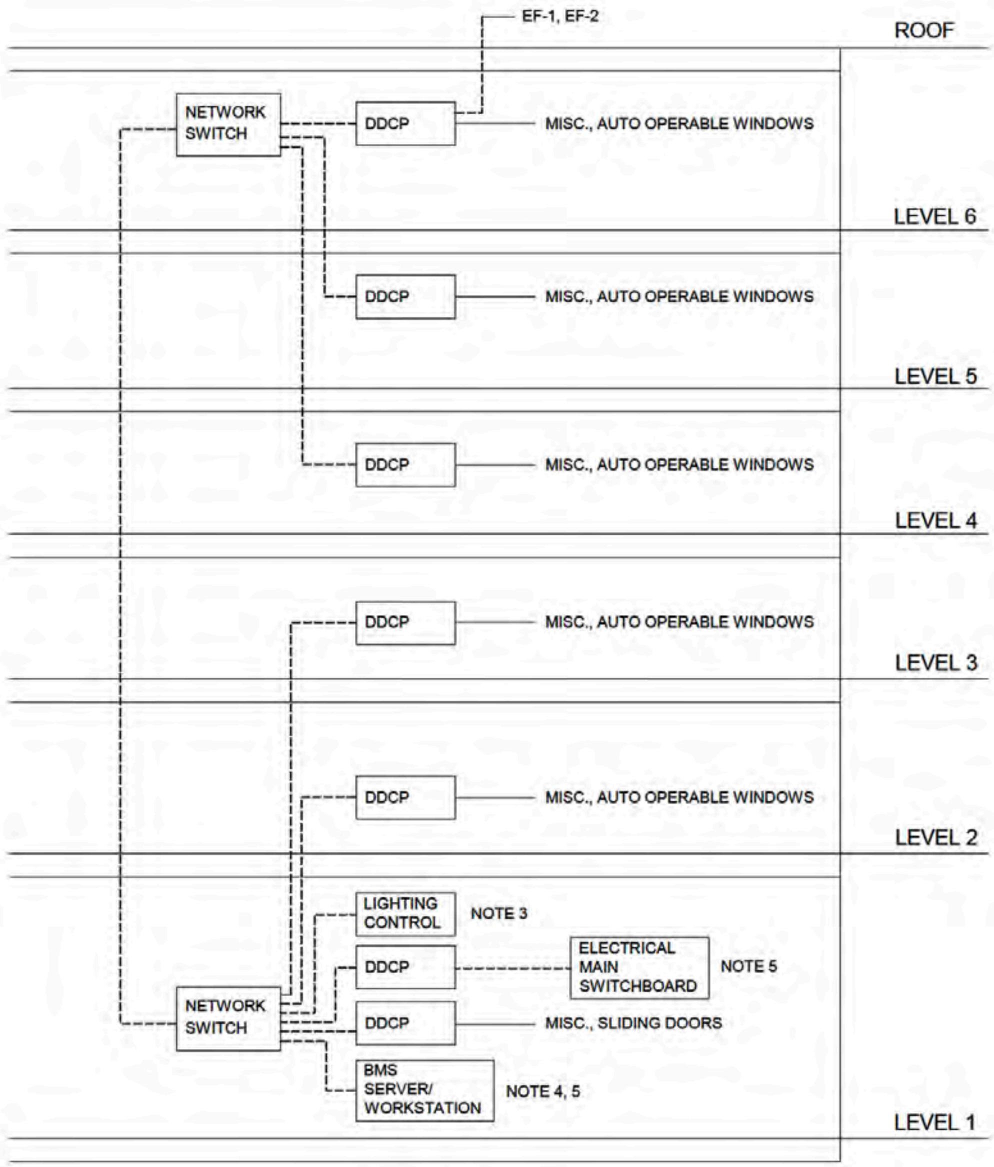


PHOTO: NICK MERRICK, HALL MERRICK PHOTOGRAPHERS



LEGEND

----------	ETHERNET	WCO	WINDOW CONTROL OPEN
—— - ——	BACNET MS/TP	WCC	WINDOW CONTROL CLOSE
DDCP	DIRECT DIGITAL CONTROL PANEL	CS	CURRENT SENSOR
		SS	START/ STOP
### - ###	MECHANICAL EQUIPMENT	CU	CONDENSING UNIT
		RC	REMOTE CONTROLLER
NETWORK SWITCH	NETWORK SWITCH	DSC	DOOR CONTACT SWITCH
		VRF	VARIABLE REFRIGERANT FLOW SYSTEM

NOTES:
1. REFER TO MECHANICAL PLANS FOR EQUIPMENT LOCATION AND QUANTITY
2. PROVIDE BMS WORKSTATION AT LEVEL 1 IN TEL/CO ROOM.
3. LIGHTING CONTROL SYSTEM TO BE INTEGRATED WITH BMS VIA BACNET PROTOCOL.
4. BMS INTEGRATED WITH VRF SYSTEM VIA BACNET PROTOCOL (SOFTWARE GATEWAY).
5. BMS INTEGRATED WITH ELECTRICAL MAIN SWITCHBOARD VIA MOD BUS PROTOCOL.
6. BMS INTEGRATED WITH AUTOMATIC SHADE SYSTEM. THE AUTOMATIC SHADE SYSTEM IS CONTROLLED VIA LOCAL SWITCHES AND OVERRIDDEN VIA BMS VIA BACNET ROUTER.

1 BMS NETWORK ARCHITECTURE
SCALE:NONE

(Opposite) An excerpt from the BMS diagram for the Block D office building.
(Courtesy Syska & Hennessy)

Daylighting and Electric Lighting

The natural daylight level is harvested on the south end of building by using the exterior blind system, which adjusts the angle and spacing of the louvers in response to the angle of the solar incidence as measured by a photocell detector. Thus the collection of glare-free daylight can be maximized while providing full shading of the curtain wall glazing.

Daylight controls on the LED electric lighting system provide the required reduction in electric light levels in response to measured daylight available. Occupancy sensors add to the energy-efficient operation of the electric lighting system.

Heating, Ventilating and Cooling Systems

For the relatively brief time of the year when mechanical cooling and heating may be required, a small heat pump is used. The heat pump is connected to multiple-zone fan coil units with variable refrigerant flow (VRF) lines in a small but very efficient system. By modulating refrigerant flow depending on the particular loads of a zone, just the right amount of heating or cooling is delivered to the zone.

The entire building is served by the VRF system, including the first floor restaurant and retail spaces. Each of the office floors has a dedicated outdoor air supply unit (DOAS) to provide fresh air; each DOAS unit has an energy recovery feature that exchanges thermal energy between the incoming outdoor air and the outgoing exhaust air. The small size of the VRF system also has the advantage of simply occupying less space on this limited site. In fact, the bulk of the equipment is located on the roof underneath an elevated solar photovoltaic panel array.

There is some added energy savings due do the *demand control ventilation* (DCV) system, which minimizes the amount of fresh outside air introduced into a space depending on the measured CO_2 concentration there. CO_2 sensors located in the space determine whether fresh outside air needs to be delivered there. There is a slight savings of fan energy and, on occasion, energy required to condition the outside air with the use of a DCV feature.

Building Management System and Control Systems Integration

The operation of the natural ventilation system, including the control of operable windows and panels in the façade, the VRF system, the automatic exterior blinds, data collection and performance monitoring—all have control systems that are integrated by one master building management system (BMS) to provide coordinated operation per the design intent. The different communication protocols of the various control systems (*BACnet, Modbus*, etc.) require this coordination, especially in modern "smart buildings". The client opted for a BMS platform[4] that automatically controlled all the subsystem operations and recorded the overall performance data.

An example of this control system coordination is the operation of the automatic exterior blinds and the natural ventilation system components. As the sun tracks toward the southwest, the blinds would close to minimize heat gain as the day warms up and solar heat gains intensify. In concert with this, the thermostat would signal when the rear doors and front openings would need to open to manage the internal space temperature. The comfort range defined in the BMS is expanded beyond the typical range to allow for greater temperature swings to be associated with natural ventilation. The BMS switches the system back to the tighter comfort range as the internal space temperatures rise too high; the openings are simultaneously closed and the mechanical VRF systems are activated.

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[4] LOCBIT: https://www.locbit.com/

Commissioning

The commissioning process included the BMS along with the building equipment operation. The coordination of the different communication protocols required programming revisions to make the BMS interface function properly and to establish the appropriate comfort temperature range.

Electric Kitchen Facilities

The tenant spaces include the possibility of installing all-electric kitchens as part of company-provided cafes serving lunches and snacks. In addition, the ground floor is programmed for the possibility of all-electric commercial kitchens or cooking facilities for retail tenants such as restaurants, coffee shops and similar community food outlets.

Natural gas is available in the adjacent street but the building manager encourages any potential tenant contemplating food service to consider the advantages of an all-electric food preparation facility.

(Below) Rendering of an interior design for an employees' cafe in an upper floor tenant space with all-electric cooking equipment. *(Courtesy of idGROUP)*

Renewable On-Site Energy Supply

The six-story building uses a flat-panel solar photovoltaic (PV) system as its on-site renewable energy supply. Since the stated project goal is to achieve a zero-net-energy performance for the *core-and-shell* part of the building, the size of the PV system had to be as large as possible for this large multistory building on a relatively small site. The only possible location for the PV system is the roof since the site is completely covered by the building. To maximize the system size, PV panels are even mounted above the VRF mechanical equipment and other sections of the PV array are extended beyond the roof parapet itself on metal trellis structures. (See solar PV panel roof layout on the following page.)

In addition, the PV panels that extend beyond the parapet are *bifacial* type, with a transparent rather than opaque backsheet so that they collect solar energy from both sides. The production of these panels is increased by about 20% over that produced by conventional PV panels.

The resulting installation consists of 175 standard panels (LG NeON R) totaling 63.9 kW and 132 bifacial panels (Sunpreme – Maxima 320) totaling 50.7 kW, projected to produce a total of 173,000 kWh per year. Actual production in 2019 was 141,000 kWh—see discussion in the following section.

(Below) Bifacial solar PV panels mounted on metal trellis structures projecting beyond the face of the building increase the overall size of the system.

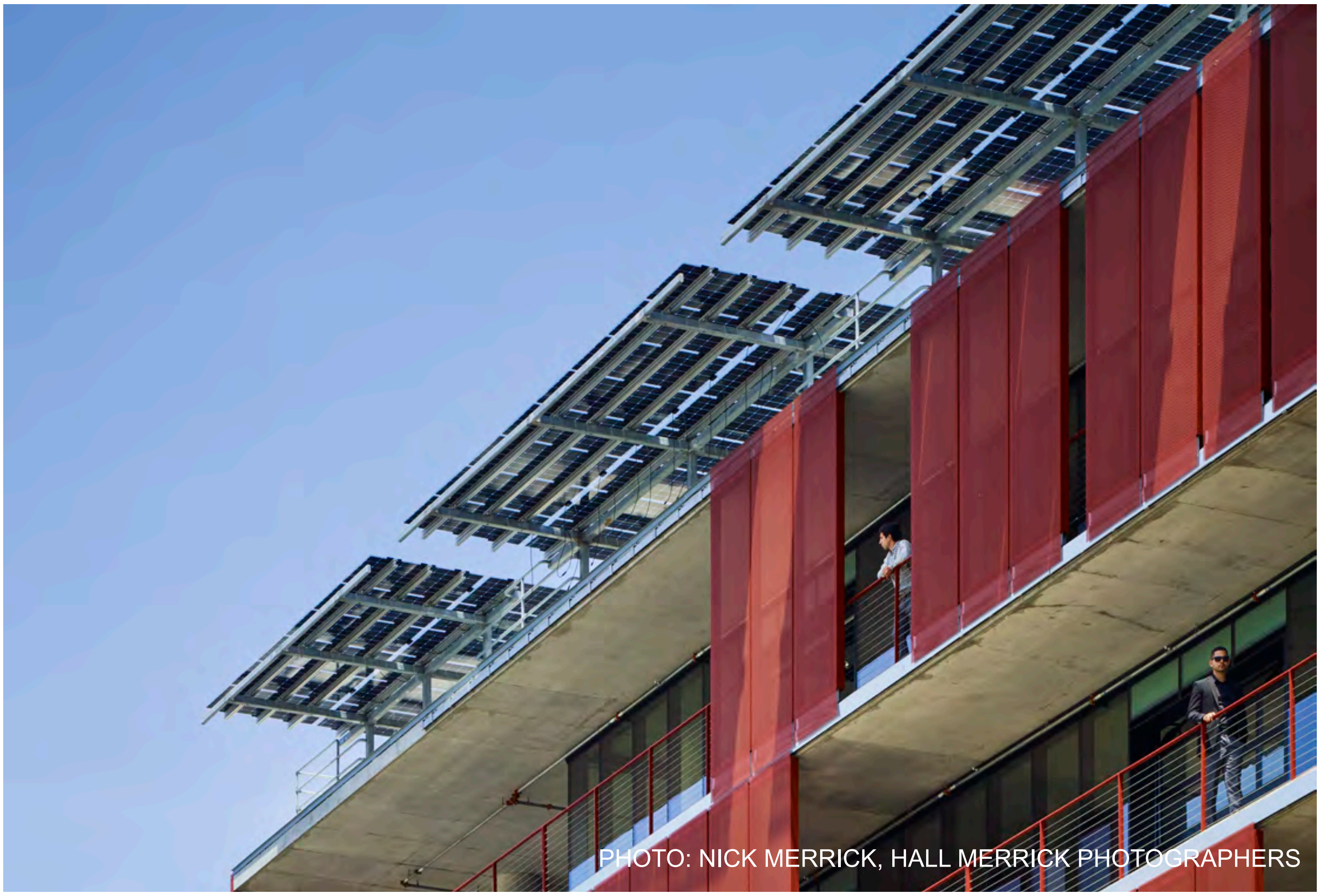
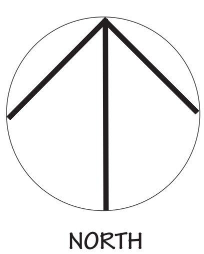
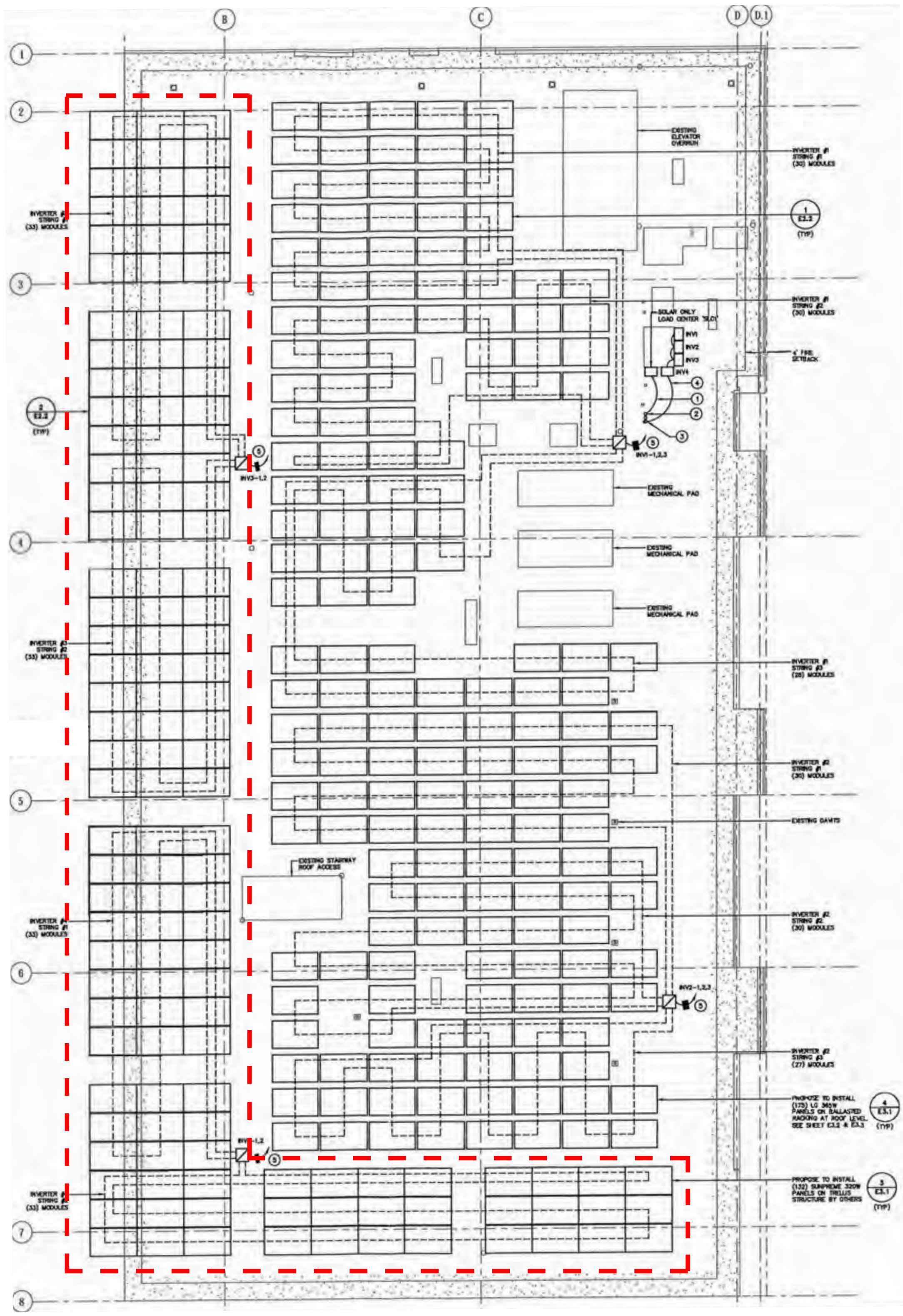


PHOTO: NICK MERRICK, HALL MERRICK PHOTOGRAPHERS

(Right) Solar PV panel layout on the roof. Trellis-mounted bi-facial panels are located within the dashed lines.





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

Energy Use — Modeling

Energy modeling was carried out during the design phase using *Integrated Environmental Solutions Virtual Environment (IESVE)* software to run parametric studies of various design features and their effect on energy use. *Energy Pro* was used for Title-24 compliance and the Savings by Design program.

The energy model was done for a fully leased (fully occupied) building since the systems were being designed for such a case. Designing for natural ventilation and daylighting, with optimized sun control in the benign climate of San Diego, results in extraordinarily low energy use by the HVAC systems. This can be seen in the summary pie chart of the modeled annual energy use by category of load (heating, cooling, lighting and equipment) on the following page.

The effect of this mild climate on the modeled monthly energy use, shown in the bar chart on page 45, is to produce an energy use profile that is fairly constant throughout the year, with a modeled EUI less than 30.

Energy Use — Actual Measurement and Comparison to Modeling Results

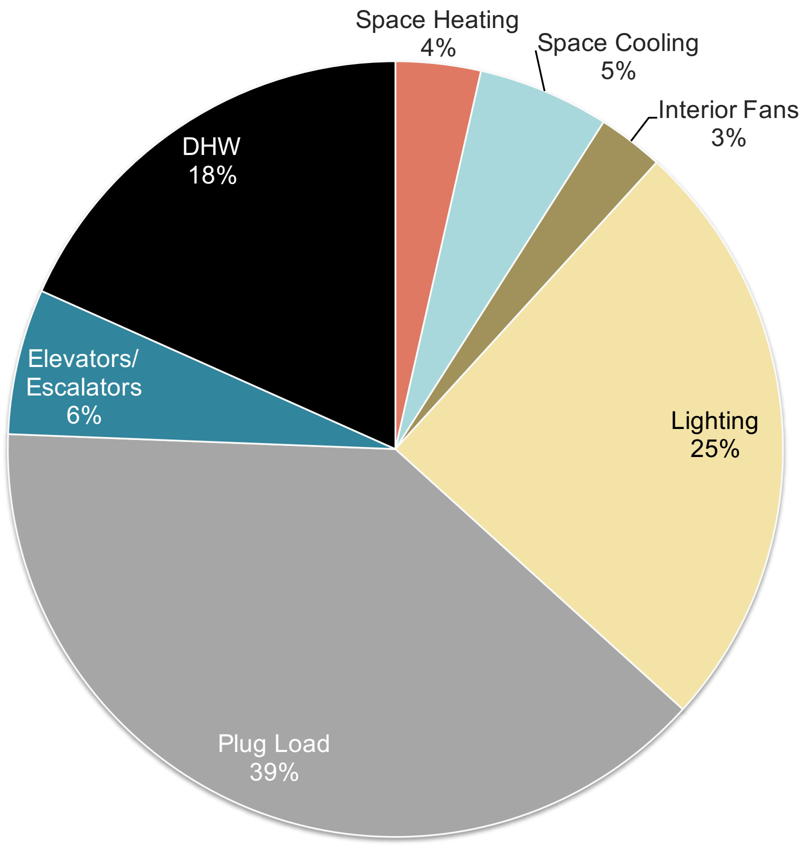
The building was completed and partially occupied in December 2018. A major tenant moved into three upper floors in August 2019, bringing the building to virtually full occupancy. A few months afterward, the pandemic shutdown occurred, which distorted the actual energy use patterns of the building. The measurement of the energy performance, which is recorded for the one single year of normal occupancy (2019), is skewed by the period of partial occupancy in the first eight months of the year.

The annual energy use for the entire year is half that of the modeled fully-occupied building, as can be seen in the chart at right. Note that the recorded data only differentiates between the *core-and-shell* spaces (the “Common Area”) and the leasable spaces (the “Tenant Area”). As can be seen in the chart of the measured monthly energy use on p. 44, the energy use increases by a factor of almost four when the building goes to full occupancy. A simple calculation of the EUI assuming a monthly energy use equal to that of the last months of 2019 yields a value of approximately 22, which is less than the modeled EUI of 29.2.

Measurement data for one year of post pandemic occupancy is required for full evaluation, but it appears that the actual building energy performance is easily better than that modeled.

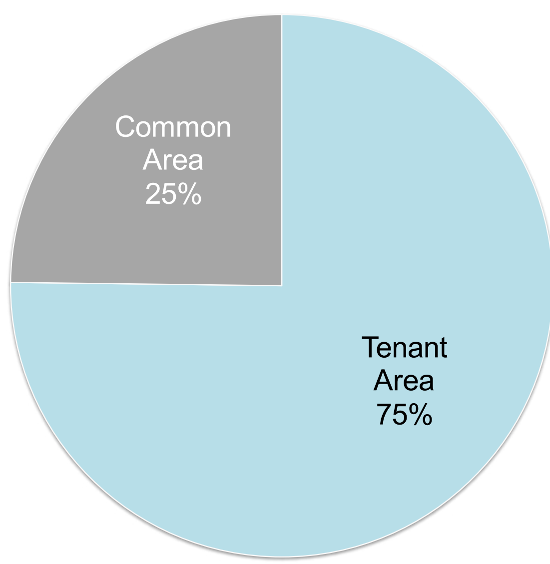
Modeled Energy Use
(Annual)

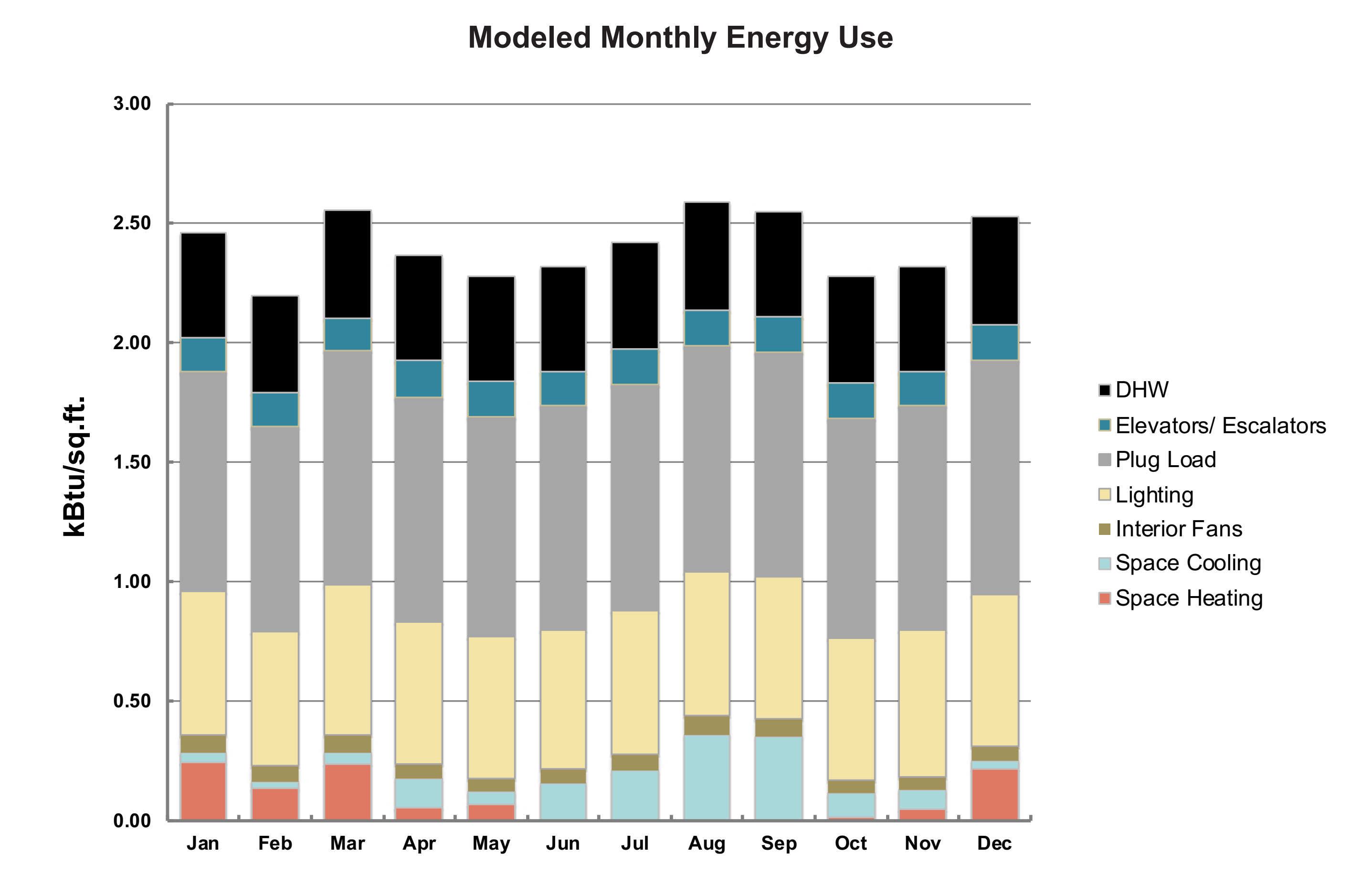
456.000 kWh/year
Modeled EUI = 29.2

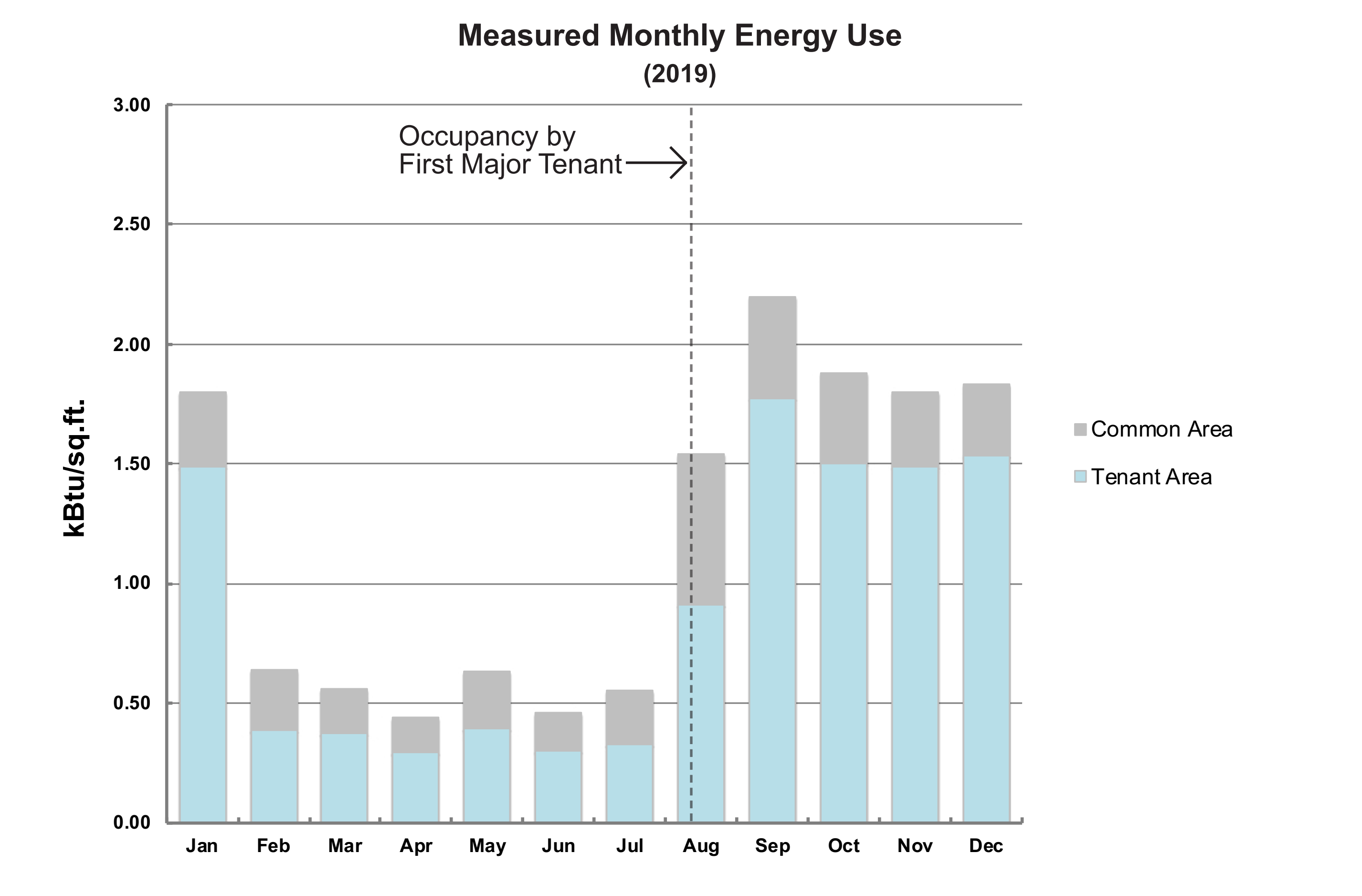


Measured Energy Use
(2019)

224,000 kWh/year
Measured EUI = 14.34




Modeled Monthly Energy Use
kBtu/sq.ft.
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
DHW
Elevators/ Escalators
Plug Load
Lighting
Interior Fans
Space Cooling
Space Heating


Measured Monthly Energy Use
(2019)
kBtu/sq.ft.
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Occupancy by
First Major Tenant
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Common Area
Tenant Area

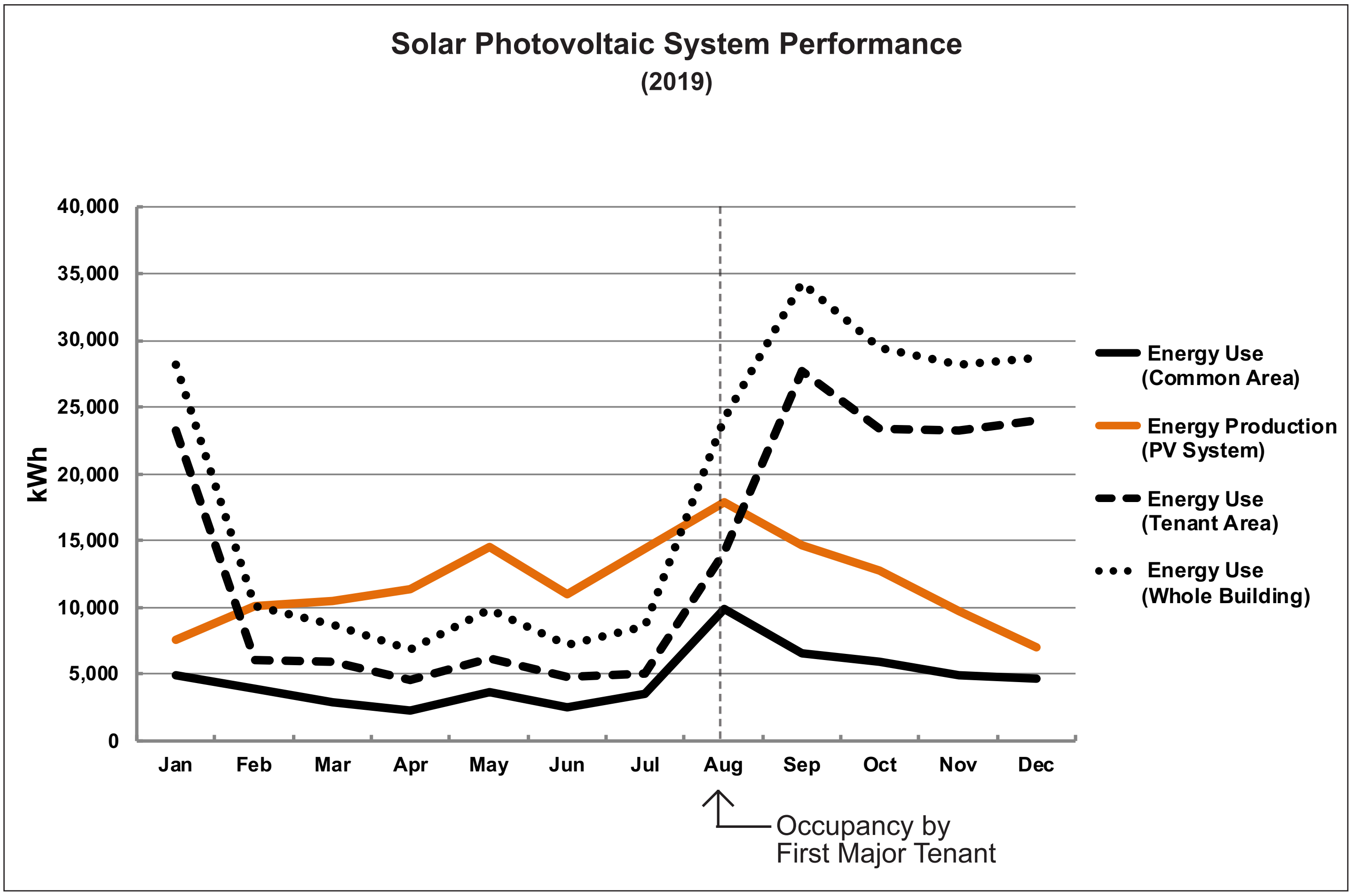
Energy Production versus Energy Use

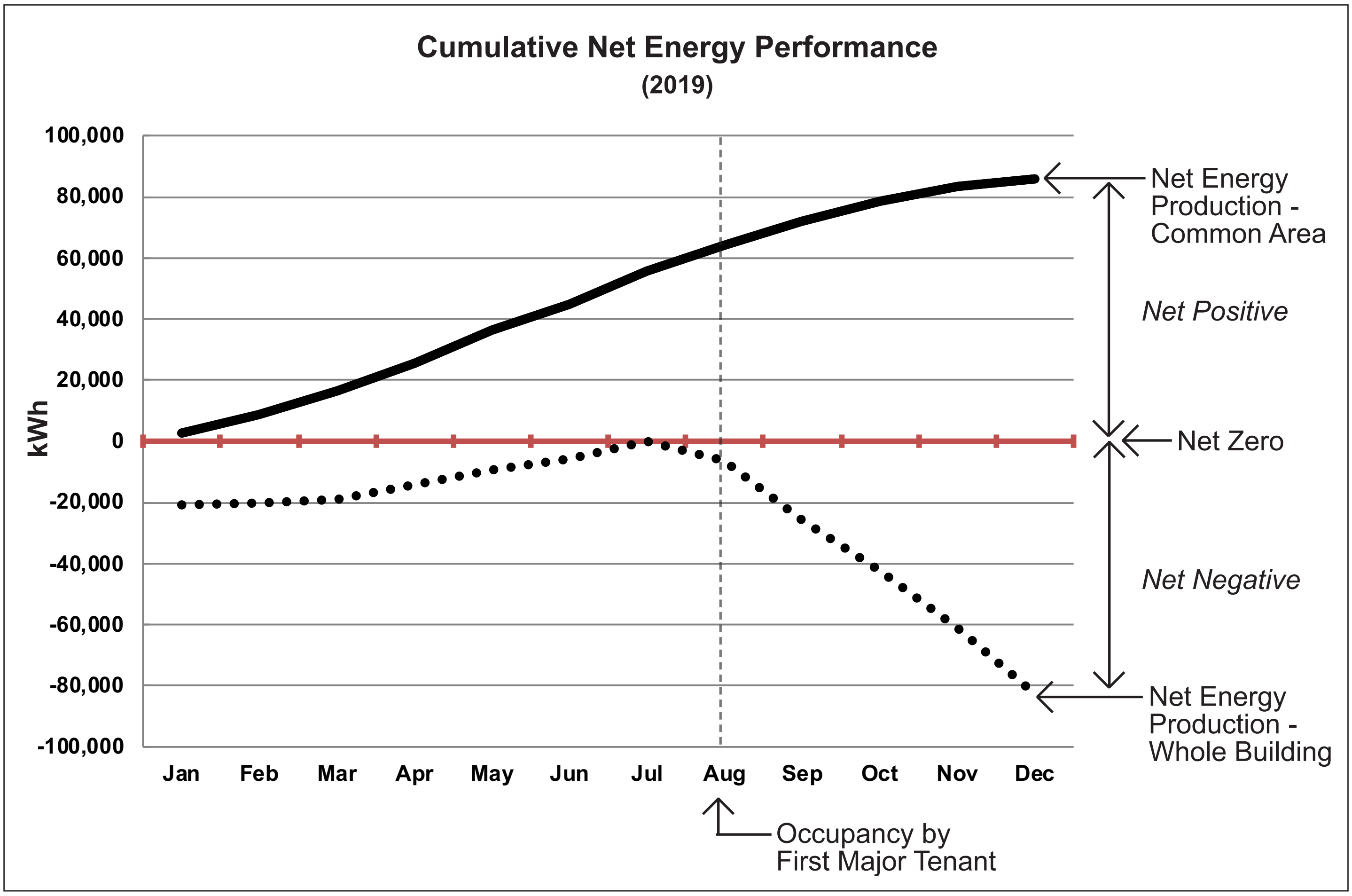
The roof-mounted solar PV system was fully operational during 2019 while the occupancy was only partial for the first seven months of the year. The result was that the solar energy production was higher than the energy used for those months, including even the tenant spaces, as can be seen in the chart on the opposite page, *Solar Photovoltaic System Performance*.

When the building went to full-occupancy in August, energy use exceeded energy production except for the Common Area. In fact, the energy produced by the solar PV system remained greater than the energy used in the Common Area throughout the year. Thus, the goal of achieving a ZNE performance for the *core-and-shell* (Common Area) was realized in 2019 as shown by the recorded data.

The second chart, *Cumulative Net Energy Performance*, sums the net energy production each month to that of the month prior, so that the total at the end of the year would be exactly zero if the performance is zero-net-energy (ZNE). If the curve is above zero at the end of the year, the building's total energy performance is *net positive*. If the curve falls short of the zero axis, the building is said to be performing at *net negative*.

The chart shows two curves: one for the Common Area and a second curve for the entire building (Common Area + Tenant Area). The curves clearly indicate that the entire building cannot perform at the zero-net-energy level, especially when a normal year of occupancy ensues. However, the *core-and-shell* portion of the building (the Common Area) achieved *net positive* performance in 2019. Since the energy performance of this part of the building is expected to remain the same under normal occupancy, that particular ZNE project goal has been realized.


Solar Photovoltaic System Performance
(2019)
kWh
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Energy Use (Common Area)
Energy Production (PV System)
Energy Use (Tenant Area)
Energy Use (Whole Building)
Occupancy by First Major Tenant


Cumulative Net Energy Performance
(2019)
kWh
100,000
80,000
60,000
40,000
20,000
0
-20,000
-40,000
-60,000
-80,000
-100,000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Net Energy Production - Common Area
Net Positive
Net Zero
Net Negative
Net Energy Production - Whole Building
Occupancy by First Major Tenant

Post Occupancy: Observations and Conclusions

Generally, the client and developer for this project reports that the low-energy design strategies for the project, particularly the natural ventilation strategy, were cost-effective and achieved the objective of attracting the desired type of tenants to the Makers Quarter neighborhood of the city. The LEED-Platinum certification and the maximum sizing of the solar photovoltaic array also established the market reputation for the future projects of this neighborhood.

There were the usual challenges to the development of the Block D office building specifically, such as the limited size of the site and optimizing the amount of leasable space within that small footprint. The small amount of floor area required for the energy-efficient systems compared to conventional heating and cooling systems was an advantage in this regard.

The decision to develop the project as an all-electric one was partly a cost-saving choice as well as a marketing one. The appeal of a “zero-carbon” space proved to be substantial with the early tenants of the building. (In fact, the architectural design firm for the project, BNIM, decided to locate their local office in the new building.)

Post Occupancy: Natural Ventilation

The functional use of the balconies on the west side of the building, made easy by the large areas of the operable garage doors, proved to be popular with the tenants now occupying the spaces. These open areas are fully functional as expanded office space while providing comfortable conditions for most of the year without the intervention of mechanical heating or cooling. When the garage doors are closed, the control system for the windows and panels operates to create the required fresh air flow through the tenant office space.

Post Occupancy: VRF System

The challenge created by any rooftop mechanical equipment was the potential conflict with necessary arrangement of the solar photovoltaic arrays. The VRF system proved to have less such impact because of its smaller space requirement, but there was still an issue with roof area. The solution to build above the equipment while using bifacial solar panels proved to be effective.

Post Occupancy: Commissioning

The commissioning of the BMS and all the linked systems—automatic vertical blinds, operable windows and panels, lights, occupancy and motion detectors, VRF system zones, etc.—proved to be a challenge as expected. The commissioning was successfully completed on schedule, however, and the building systems are operating as designed.

Post Occupancy: Embodied Carbon Assessment

The client and design team did not carry out an embodied carbon assessment as is customary for buildings designed today. The consensus among the members of the project team is that this would now be included in the design studies.

(Opposite page) Rendering of the interior design for the Reception area of an upper floor tenant space, *(Courtesy of idGROUP)*


SPACES.

CASE STUDY NO. 3

Kaiser Medical Office Building

PHOTO: MARCO ZECCHIN

Kaiser Medical Office Building

Case Study No. 3

Data Summary

Building Type:
Medical Outpatient Clinic
Location: Santa Rosa, CA
Gross Floor Area:
87,300 sq.ft.
Occupied: June 2018

Modeled EUI (Site):
34.9 kBtu/sq.ft. per year
Measured EUI (Site):
34.5 kBtu/sq.ft. per year (2018-19)

On-Site Renewable Energy System Installed:
620 kW (DC) Solar PV
Measured On-Site Energy Production:
916,550 kWh per year (2018-19)
35.8 kBtu/sq.ft. per year (2018-19)

Client
Kaiser Permanente, Oakland

Design Team
Architect:
HPS Architects, Palo Alto
Structural Engineer:
Thornton Thomasetti, San Francisco
Mechanical/Electrical/Plumbing Engineer:
Integral Group, Oakland
Landscape Architect:
Joni L. Janecki and Associates, Santa Cruz

Construction Manager and General Contractor:
Turner Construction, Oakland
Solar PPA:
KPCA Investments LLC, St. Louis, MO.

Kaiser Permanente has been providing healthcare services in eight states as an integrated managed healthcare system. It is one of the largest nonprofit healthcare plans in the United States and maintains approximately 40 medical centers (including hospitals) and over 700 types of medical buildings. The *medical office building (MOB)*, a common building type among these, generally provides a local population with routine care and houses doctor's offices, exam rooms and some basic procedure rooms.

MOBs are also common with other healthcare providers, so they represent a relatively common building type with similar special programmatic requirements. They are therefore a good case study for the purposes of this book—how specific design strategies aimed at zero-carbon performance and energy-efficiency can be successful and cost-effective at the same time under tight institutional constraints.

This case study describes and analyzes a recently-built and occupied MOB that may be the first zero-net-energy (ZNE) such building in the country. LEED-Platinum and LEED-Zero Energy certification has been confirmed and the building has received a 2021 USGBC Leadership Award.

Background

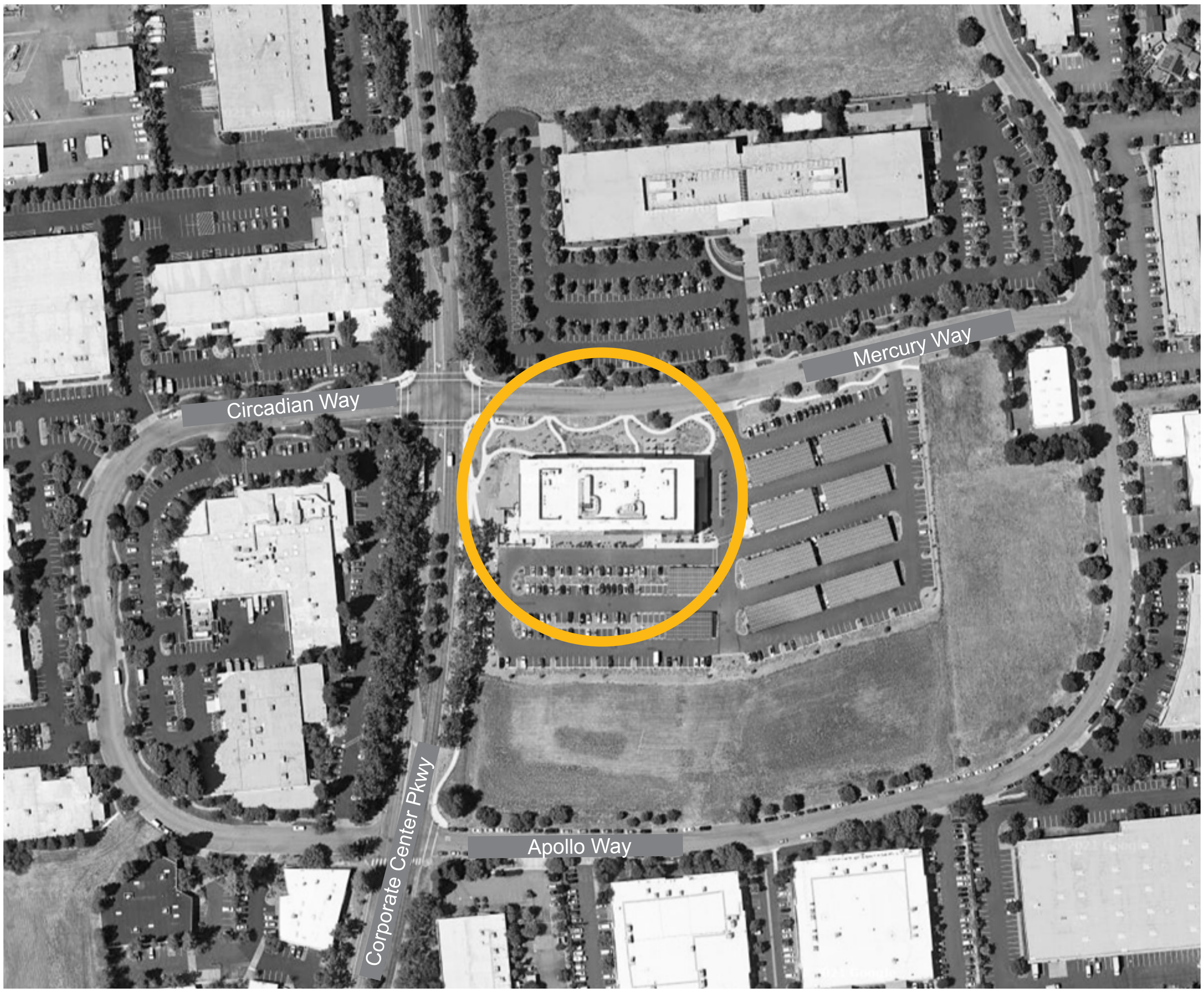
Kaiser needed a new MOB for the community of Santa Rosa, a city in Sonoma County, north of San Francisco. The six-acre site, part of an industrial park southeast of the downtown, was already owned by Kaiser and had been cleared of a small previously-built structure. Though not technically a greenfield site, it nevertheless was uncontaminated and lacked the basic utility services needed for a new MOB. In fact, cost studies showed that the cost to install a utility line to provide natural gas service to the site would be $1 million. This fact led to the early decision to design an all-electric facility for this site.

For the basic building program, Kaiser planned a roughly 90,000 sq. ft., three-story building to house 60 doctor's offices, 95 exam rooms, eight procedure rooms and the waiting areas associated with each. The program also called for a café with an outdoor terrace. A large parking area surrounding the building would be built to accommodate the cars of the 200 professional staff and the large number of patients coming to the facility. A number of electric vehicle charging stations are included in the site amenities program.

Kaiser used a design-assist project delivery method, similar to *CM at-Risk*[1]. The design team therefore was able to have valuable cost and constructability input from a veteran general contractor at various stages of design when proposed systems and design alternatives were being evaluated.

[1] *CM at-Risk* is a project delivery method where a construction manager (CM), usually a general contractor, is hired under a separate contract, to deliver the project within a *Guaranteed Maximum Price (GMP).* The CM participates in the design process, providing cost opinions at various stages of design. Not only is the CM acting on behalf of the owner, but often provides valuable input to the design process in terms of constructability, cost control and value engineering.

(Overleaf)
Aerial view of southwestern Santa Rosa with new Kaiser MOB in the foreground.



Kaiser Medical Office Building - General Vicinity Plan

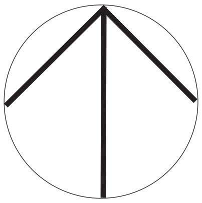
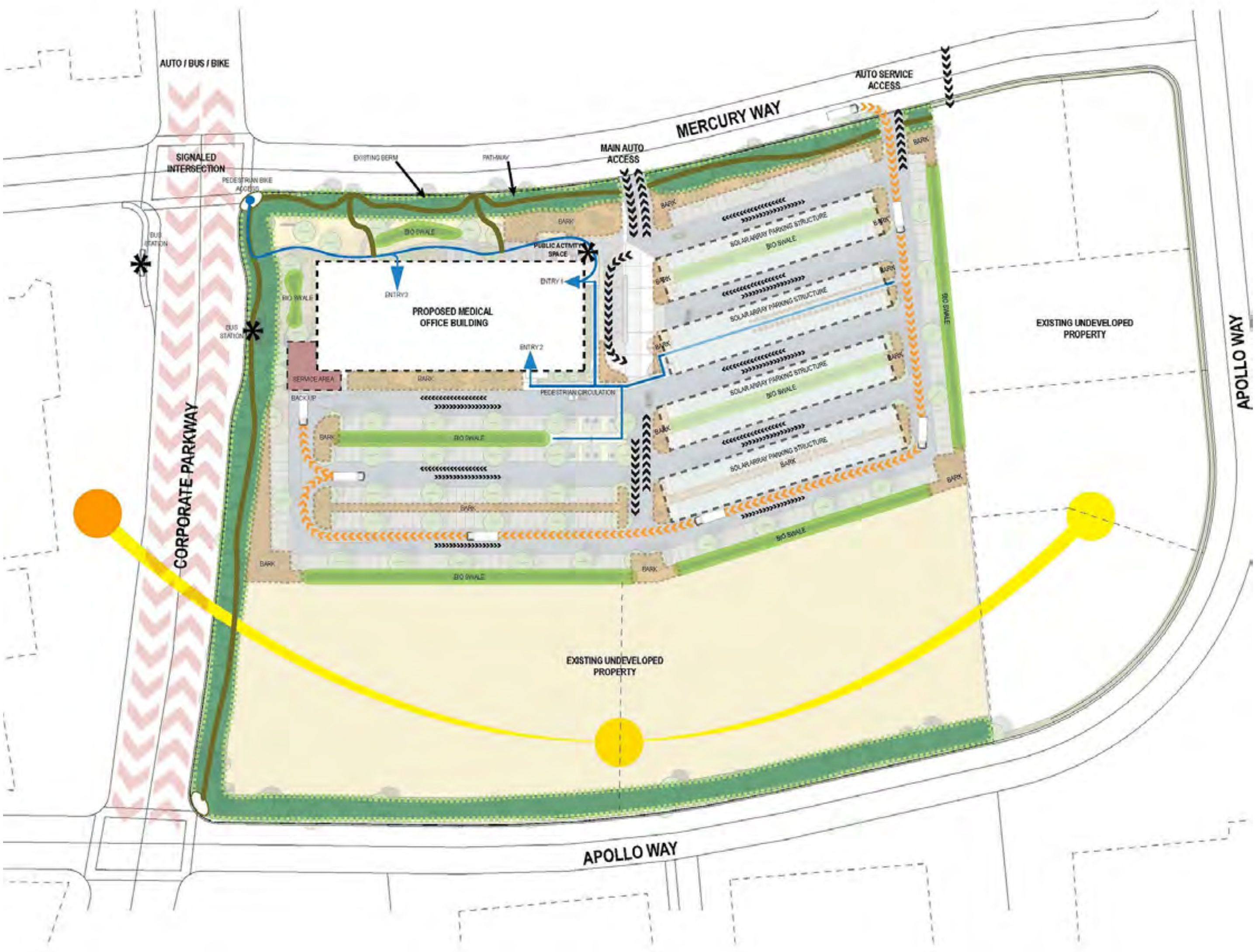
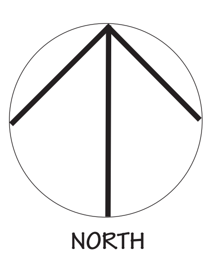


PHOTO: © STEVE PROEHL

(Below) Site analysis drawing for the Kaiser MOB (Courtesy of HPS Architects)





Design Process and Low-Energy, Zero-Carbon Design Strategies

Planning Concept and General Design Considerations

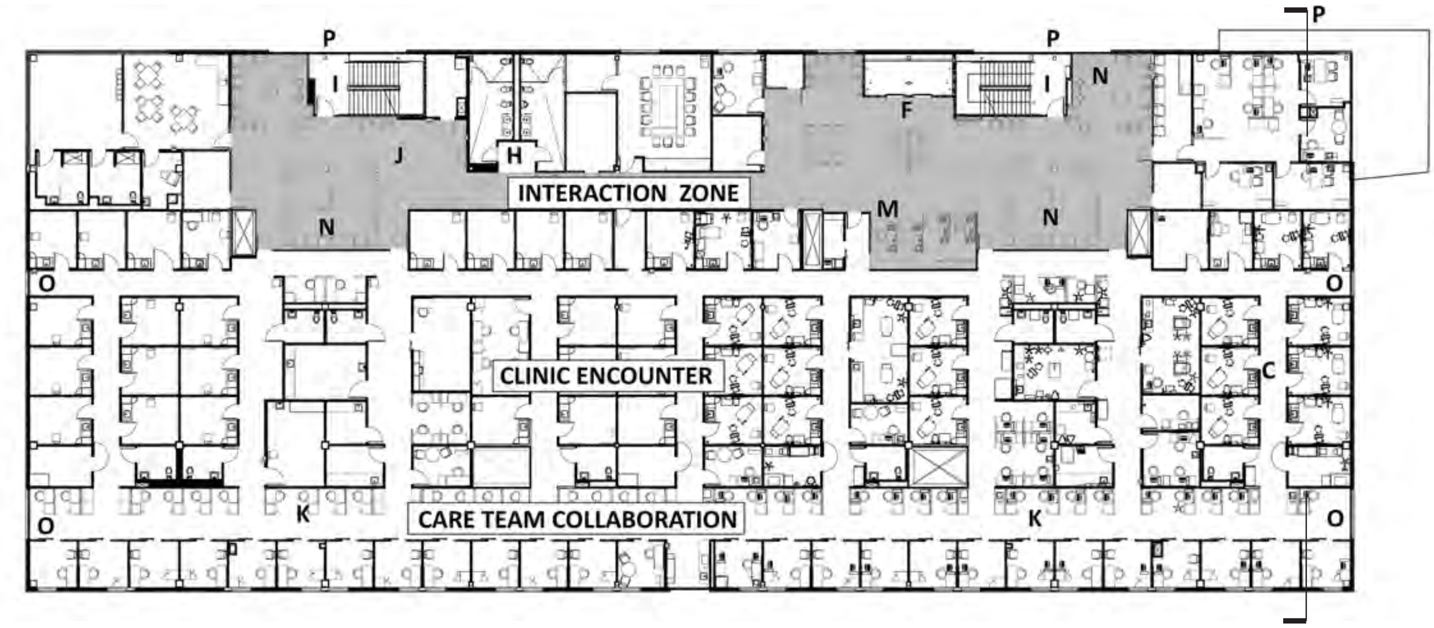
Kaiser has had a number of established energy consumption (EUI[2]) goals applicable to every project. These numbers have been ratcheting downward in recent years as the projects successfully meet their design goals in practice, from approximately EUI = 140 in 2010 to an average EUI = 70 for buildings opened in 2015. Kaiser was interested in going further with this MOB project, due to open in 2018, with an EUI in the neighborhood of 40.

For Kaiser, the ultimate criterion for any design decision is "cost effectiveness" as determined by life cycle cost analysis. The design strategies to achieve this further-improved EUI performance goal were to be routinely tested during the entire design process by ongoing cost analyses and modeled energy savings.

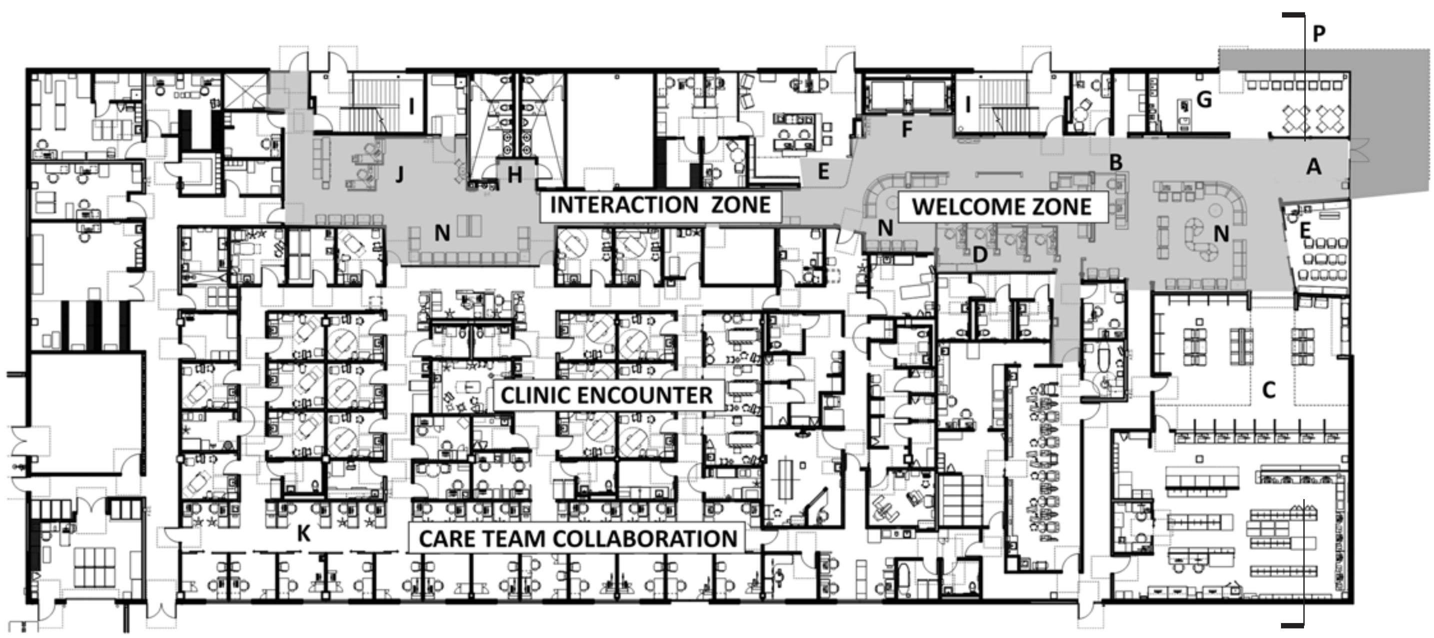
The design team further proposed that Kaiser consider a goal of zero-net-energy (ZNE) performance by including an on-site solar PV system in the building program as well. Kaiser agreed to add this feature if the cost parameters indicated that it would be cost effective by the same life-cycle cost criteria and would meet the pre-established project budget. This proved to be challenging during a period of construction cost escalation that occurred while the project was in the design phases. Fortunately, the project delivery method ensured an accurate evaluation of the costs of these design alternatives.

(Below) View of the Kaiser MOB site from the north. (Photo: © Steve Proehl)

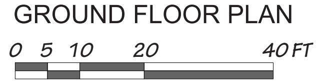
[2] EUI = Energy Use Intensity, kBtu/sq/ft. per year

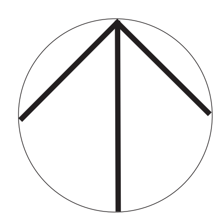


SECOND FLOOR PLAN



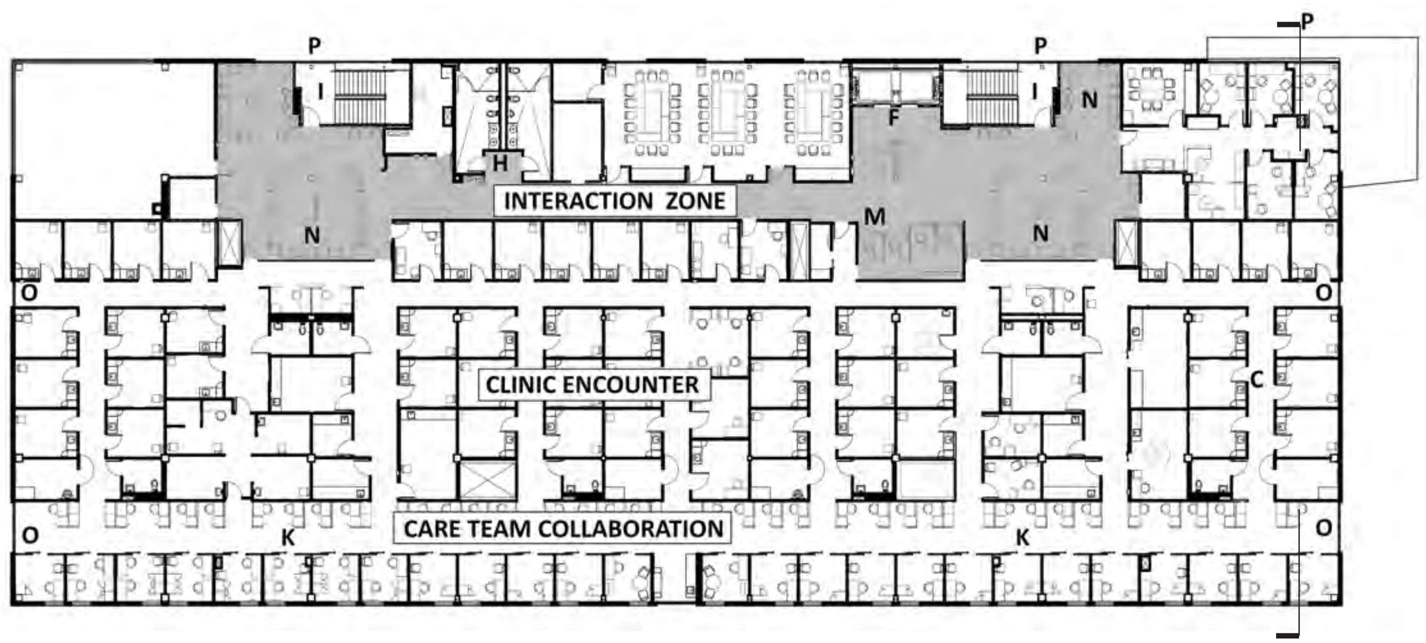
GROUND FLOOR PLAN





NORTH

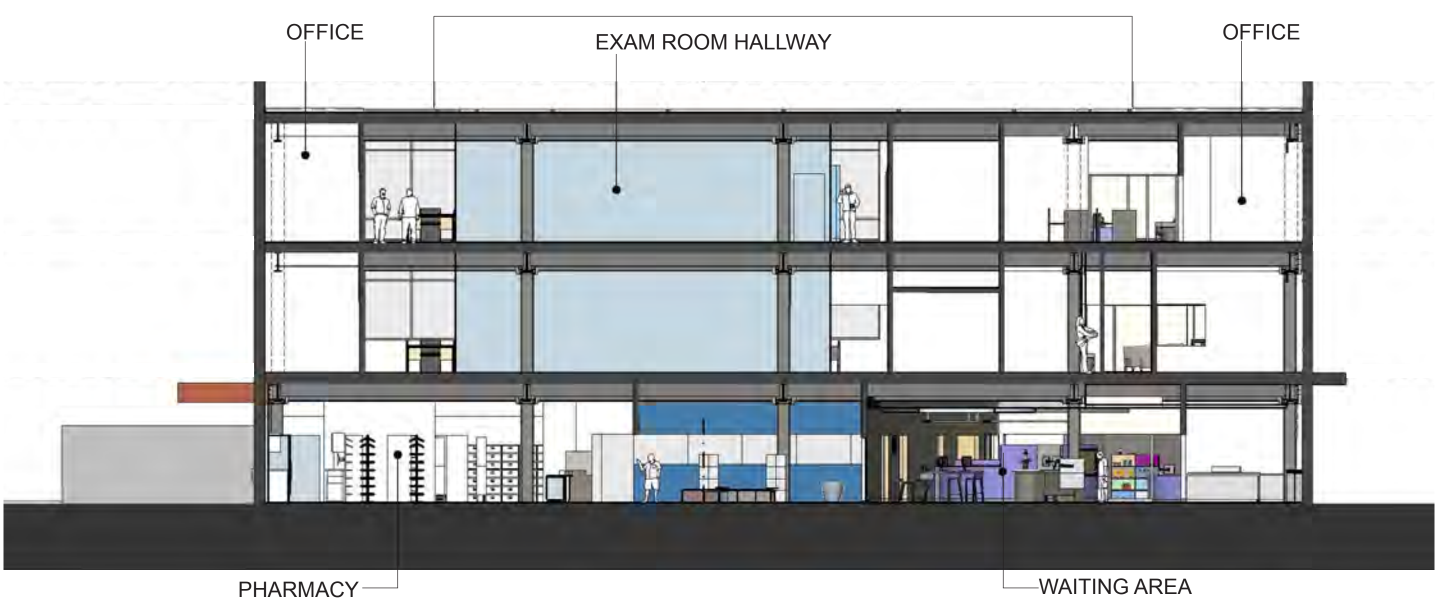
KAISER MEDICAL OFFICE BUILDING: FLOOR PLANS AND BUILDING SECTION



THIRD FLOOR PLAN

KEY:

A	VESTIBULE	I	STAIRS
B	GREET	J	CLINIC CHECK-IN
C	PHARMACY	K	TRANSLUCENT OFFICE WALL
D	LAB / IMAGING CHECK-IN	L	CONFERENCE
E	HEALTHY LIVING	M	CENTRAL RECEPTION
F	ELEVATOR	N	WAITING AREA
G	COFFEE BAR	O	HALLWAY FENESTRATION
H	PUBLIC RESTROOMS	P	PROMINENT FENESTRATION



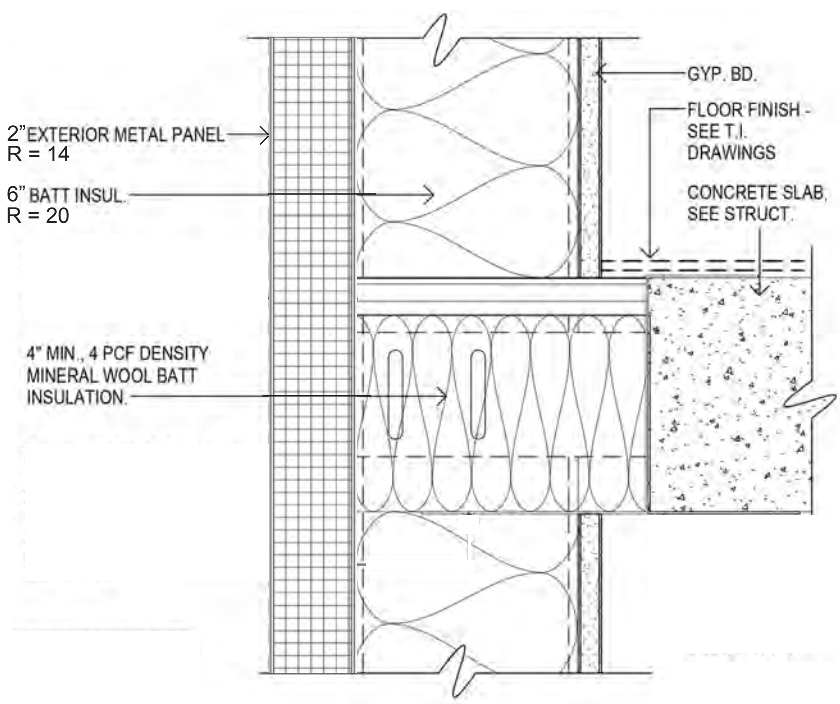
TRANSVERSE (CROSS) SECTION (LOOKING WEST)

(Opposite Page) The glazed openings differ for the north facade *(Top)*, which emphasizes daylighting, and the south facade *(Bottom)* , which emphasizes solar control. See discussion.
(Photos: Marco Zecchin)

Building Envelope

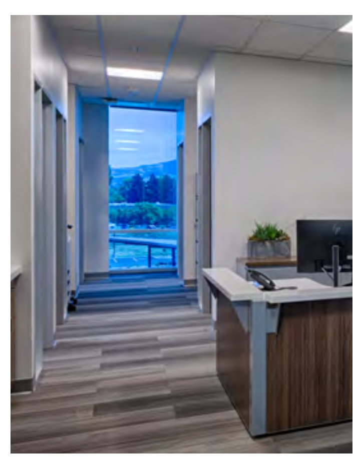
To provide the best sun control design and glare-free daylighting, as well as for simplicity of structure, the building was shaped into an elongated rectangle with the long sides facing south and north. Most of the programmed spaces were either small doctor offices with only occasional occupancy or larger public spaces like waiting areas. The offices are concentrated along the south side, where the sun control could be designed to provide shading without the intervention of the occupant. Likewise, the waiting areas are gathered along the north side, where the diffuse daylight provides abundant glare-free lighting without the need for electric lighting. This plan organization was dubbed "architectural zoning" by the design team.

For the solid walls, the cladding selected was an interlocking insulated metal panel[3]. Kaiser typically requires cement plaster exterior finish for cost reasons, but this product was specified because of the energy saved by eliminating the thermal bridging that occurs at the metal stud framing. The total R-value of this well-insulated opaque wall is R = 35. The rigid roof insulation installed under the "cool roof" membrane has an R-value equal to R = 15.



For the minimally-sized glazed areas on the elevations receiving direct sun, electrochromic glass[4] is used. This product has a coating that darkens the tint of the glass dynamically depending on the incident light spectrum. When this glazing is used, expensive sun-shading devices are not needed for fine-tuned solar control of the small glazed openings, thus offsetting the higher cost of this product. For the substantial glazed areas of the north elevation, insulated glass with high *visible light transmission (VLT)* was used for the desired daylighting.

(Below) Electrochromic glass is used on south, east and west elevations for sun control. (Photo: Marco Zecchin)



[3] Designwall 2000 Architectural Wall Panel. See: https://www.kingspan.com/us/en-us/product-groups/architectural-panel-facade-systems/benchmark-architectural-wall-panels/design-wall-2000
[4] Dynamic tinting insulated glass by Crystalite, http://crystaliteinc.com/pages/products/view-glass/. See also "Case Study No. 9, Speculative Office Building at 435 Indio Way", *Zero Net Energy Case Study Buildings Volume 2*, April (2016).

(Opposite page. top) Conventional HVAC package unit design with simultaneous heating and cooling using a VAV reheat system
(Opposite page, middle) All-electric *thermodynamically-zoned heat pump system*
(Opposite page, bottom) Detail section view of package unit with electric heat pump
(Diagrams courtesy of Integral Group)

Heating, Ventilating and Cooling Systems

This HVAC system usually specified for this type of building is the relatively energy-efficient rooftop package unit that uses variable-air-volume supply to meet the heating or cooling demand in a zone. If a zone requires additional heating, then separately heated fluid is pumped to a reheat coil in the duct serving that zone. The result often is simultaneous heating and cooling even with a VAV system because the air-handling unit is serving zones at both the interior and exterior of the building. The heating of the fluid also is typically done using a separate gas boiler.

Rather than install two package units for the entire building, one for the east half and one for the west half, as shown in the diagram (opposite page, top), the designers opted to install five small heat pumps to serve each of the four exterior zones and the interior zone separately. This ensures that there is no simultaneous heating or cooling because the zones are separated and a particular heat pump is either heating or cooling accordingly, as indicated in the diagram (opposite page, middle).

This alternate design approach also has the advantage of being simpler and less costly to build since the reheat piping is eliminated and system controls are simpler. The installed cost of the reheat piping would have nearly doubled the cost of the entire system. In addition, the simpler design would mean lower maintenance costs than the conventional design. This large initial cost savings and likely lower maintenance cost led to the approval of this all-electric design approach by Kaiser.

Not only is this *thermodynamically-zoned heat pump system* intrinsically more efficient than a standard VAV-reheat system, it also provides more refined control of individual space temperature through use of *therma-fusers*[5], which are particularly good for buildings with many small rooms with highly transient occupancy. These devices minimize the air supplied to these rooms, thereby saving a significant amount of fan energy use.

Domestic Hot Water (DHW)

The building contains many sinks for hand washing and would ordinarily require much energy for heated DHW. A separate heat pump provides this hot water most efficiently.

Master System and Control Systems Integration

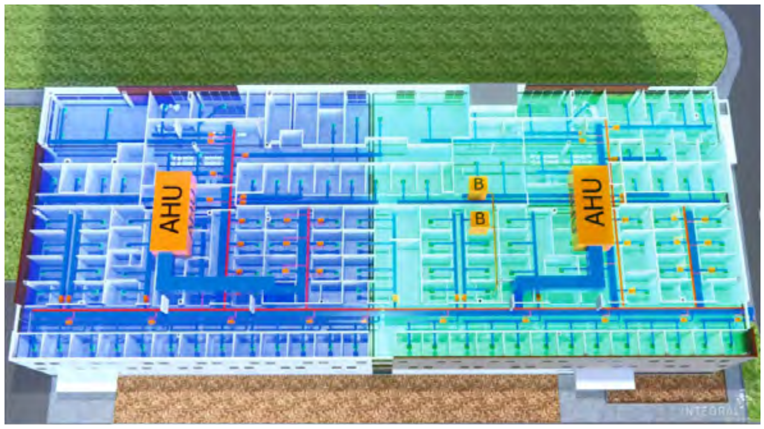
There is a standard centralized Building Management System (BMS) that is used in the Kaiser MOB facilities. Since the HVAC system is not the usual system to be installed and operated, the control systems required a slightly different coordination.

Commissioning

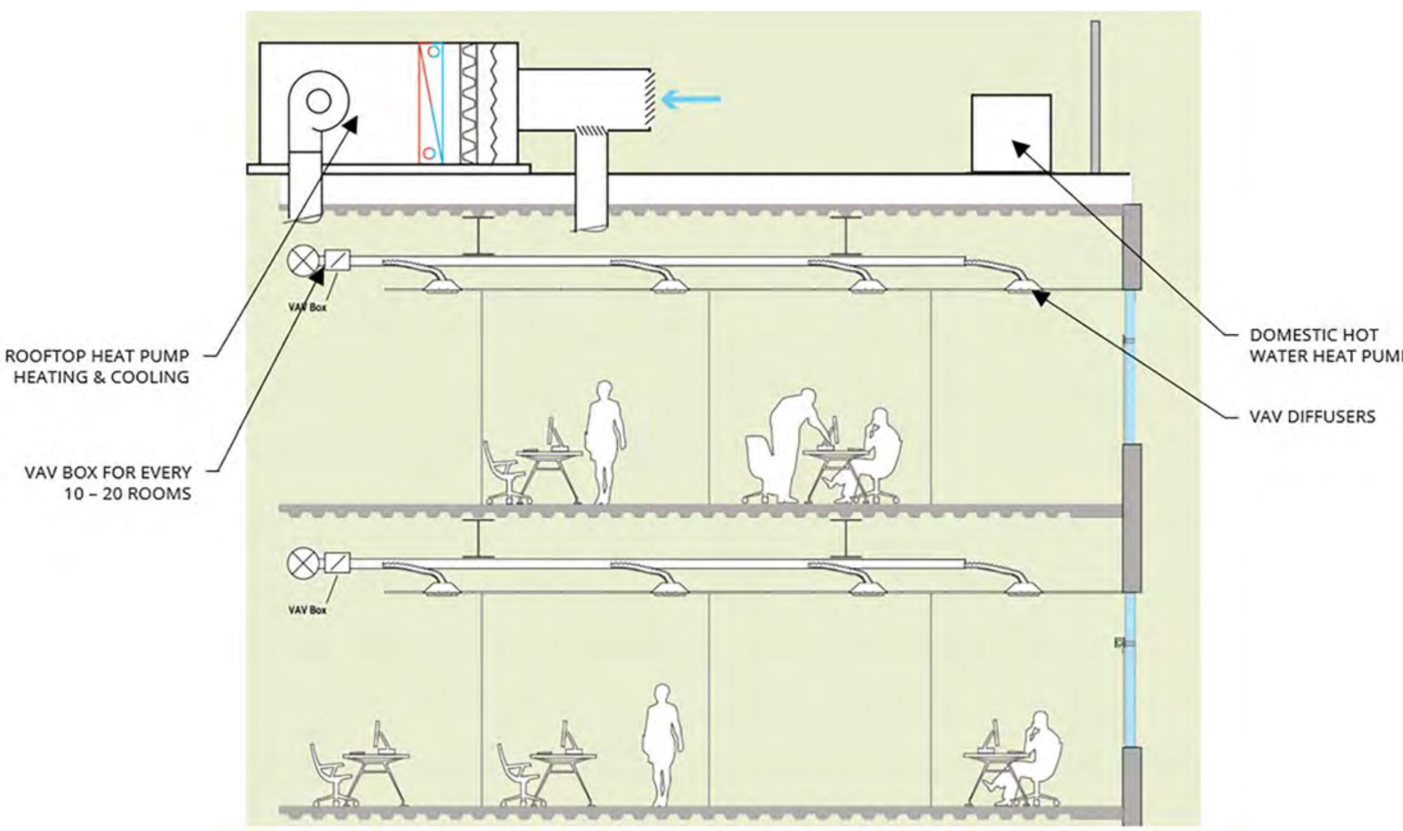
The principal commissioning activity involved the integration of the control systems for the HVAC components. This commissioning activity was started after the building was occupied and open to users, however, rather than being completed before occupancy. (See discussion in the *Observations and Conclusions* section below.)

[5] A *therma-fuser*™ provides individual room control of air supply diffuser according to the room thermostat rather than simply zone control for several rooms. See: https://acutherm.com/product/therma-fuser-stand-alone-diffusers/

Typical Gas-Electric MOB : VAV Reheat System



All Electric MOB : Thermodynamically Zoned Heat Pumps (TZHP)



Embodied Carbon Analysis

The early design of this project occurred in the period 2015-16, when the use of embodied carbon databases[6] or embodied carbon estimating tools[7] was not commonly known or practiced. Therefore, an analysis was not done at that time.

Renewable On-Site Energy Supply

Given the cost criteria established by Kaiser, the design team explored an option for including a solar PV system sufficient to offset the annual energy use of the facility, thereby creating a zero-net-energy (ZNE) performance, that did not affect the initial construction budget and was less expensive per kWh produced than that supplied by the public utility. This option required Kaiser to sign a third-party *power purchase agreement (PPA)*[8], where the third party incurs all of the system's cost initially and for the duration of the contract, and sells the power generated by the solar PV system to the owner at a fixed rate that is typically lower than the local utility's rate.

The public utility is connected to the owner's building as usual and provides net metering credit to the owner. Kaiser would therefore use the local public utility as the "battery", drawing energy as needed when the on-site system was not sufficient. Because the building is designed to perform at ZNE, this amount of energy needed is minimal.

Since Kaiser is a nonprofit company, it is not eligible for the solar tax credits and rebates. The solar PPA is an even more attractive option in this case since these credits customarily go to the third party company and the value accrues to the owner in reduced payment terms.

This was an easy design proposal for Kaiser to approve—zero first cost, zero maintenance cost and lower rates for electric energy than that offered by the local utility.

Since the roof of the building would primarily be occupied by the zone heat pump package units, the best alternative was to locate the system on the surrounding site. Canopies above about half the parking area were designed to support the solar PV panel arrays, which are rated to produce a total of 620 kW at full capacity. Ten large canopies support 1,788 solar panels manufactured by REC Group[9].

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

Energy Use — Modeling

Energy modeling was carried out during the design phase using *Integrated Environmental Solutions Virtual Environment (IESVE)* software to run parametric studies of various design features and their effect on energy use. This was combined with detailed cost analyses to determine the

[6] See, for example, *The ICE Database*. https://circularecology.com/embodied-carbon-footprint-database.html#.XVWHdo7VnIw
[7] See, for example, *Tally*. This is a Revit plug-in and works well during the design phases. https://choosetally.com/
[8] A third-party PPA is a contract between a private company (the third party, in addition to the owner and the building contractor) to design, permit, finance and install a solar PV system on the owner's property essentially at no cost to the owner. For more information on the pros and cons of a solar energy PPA, See the Solar Energy Industries Association website: https://www.seia.org/research-resources/solar-power-purchase-agreements.
[9] See: https://usa.recgroup.com/my-business

cost feasibilty of different design strategies. Charts showing the modeled annual and monthly energy use by category of load (heating, cooling, lighting and equipment) are shown below and on the following page.

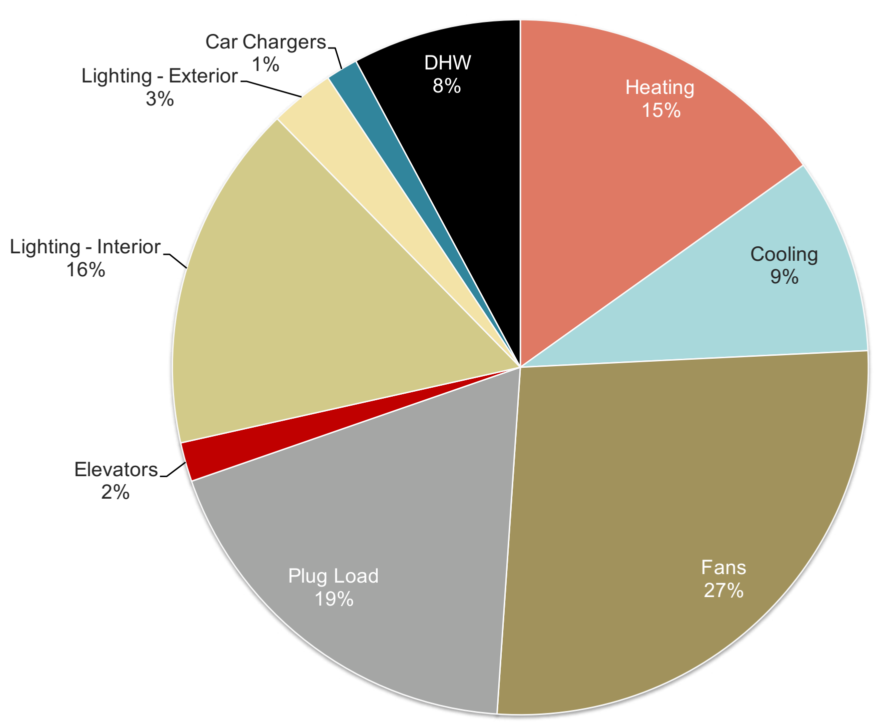
The total annual energy use according to the modeling analysis was estimated to be 34.9 kBtu/sq.ft. per year.

Energy Use — Actual Measurement and Comparison to Modeling Results

The individual energy loads were not separately metered, so the energy consumption by category of use is not available. The total measured annual energy use as reported by the public utility and solar PPA company came to 34.5 kBtu/sq.ft. per year, remarkably close to that produced by the energy modeling. A chart showing the monthly energy use totals for the start-up year October, 2018, through September, 2019, is shown on the following page.

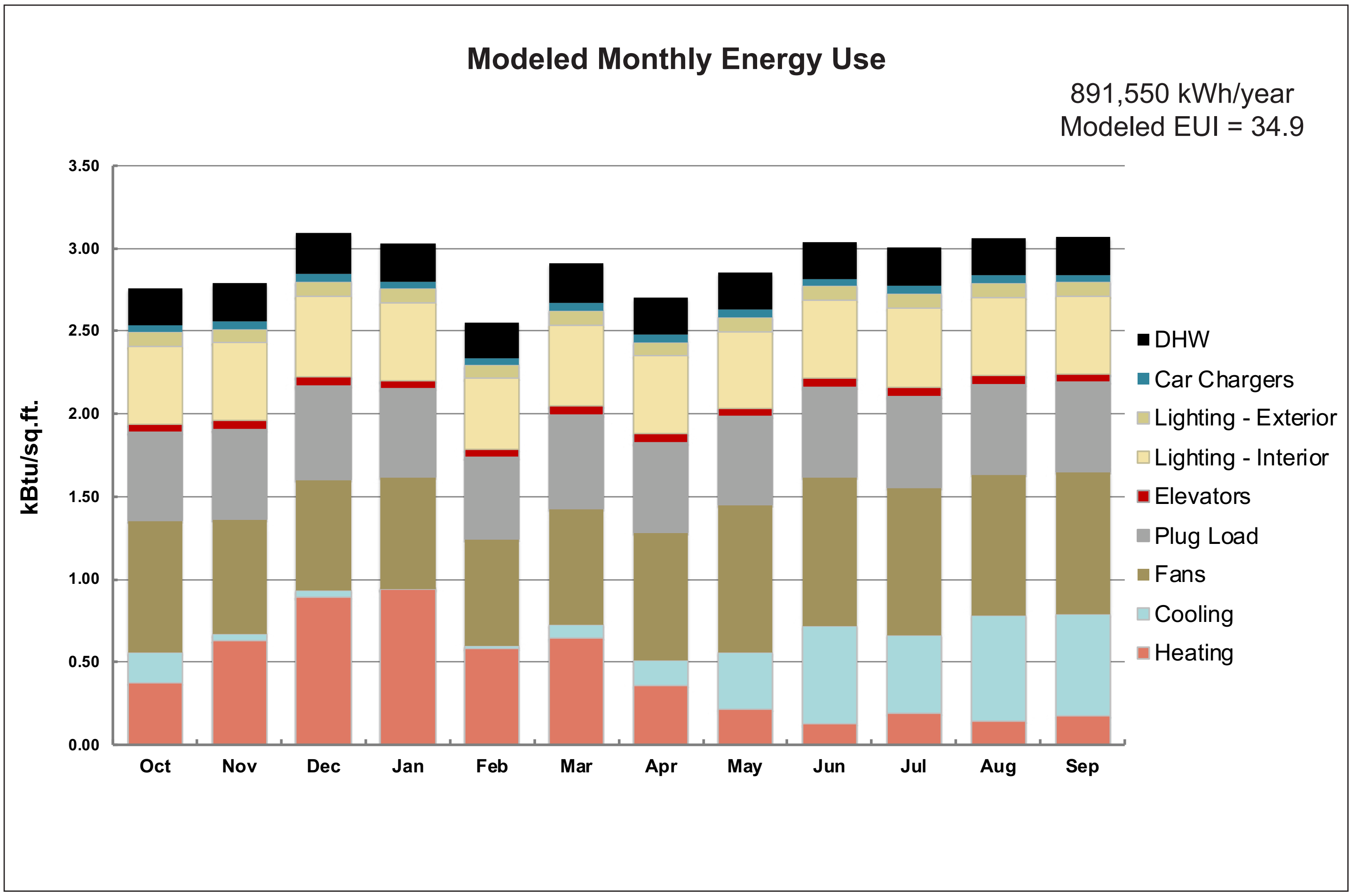
Energy Production versus Energy Use: Zero Net Energy

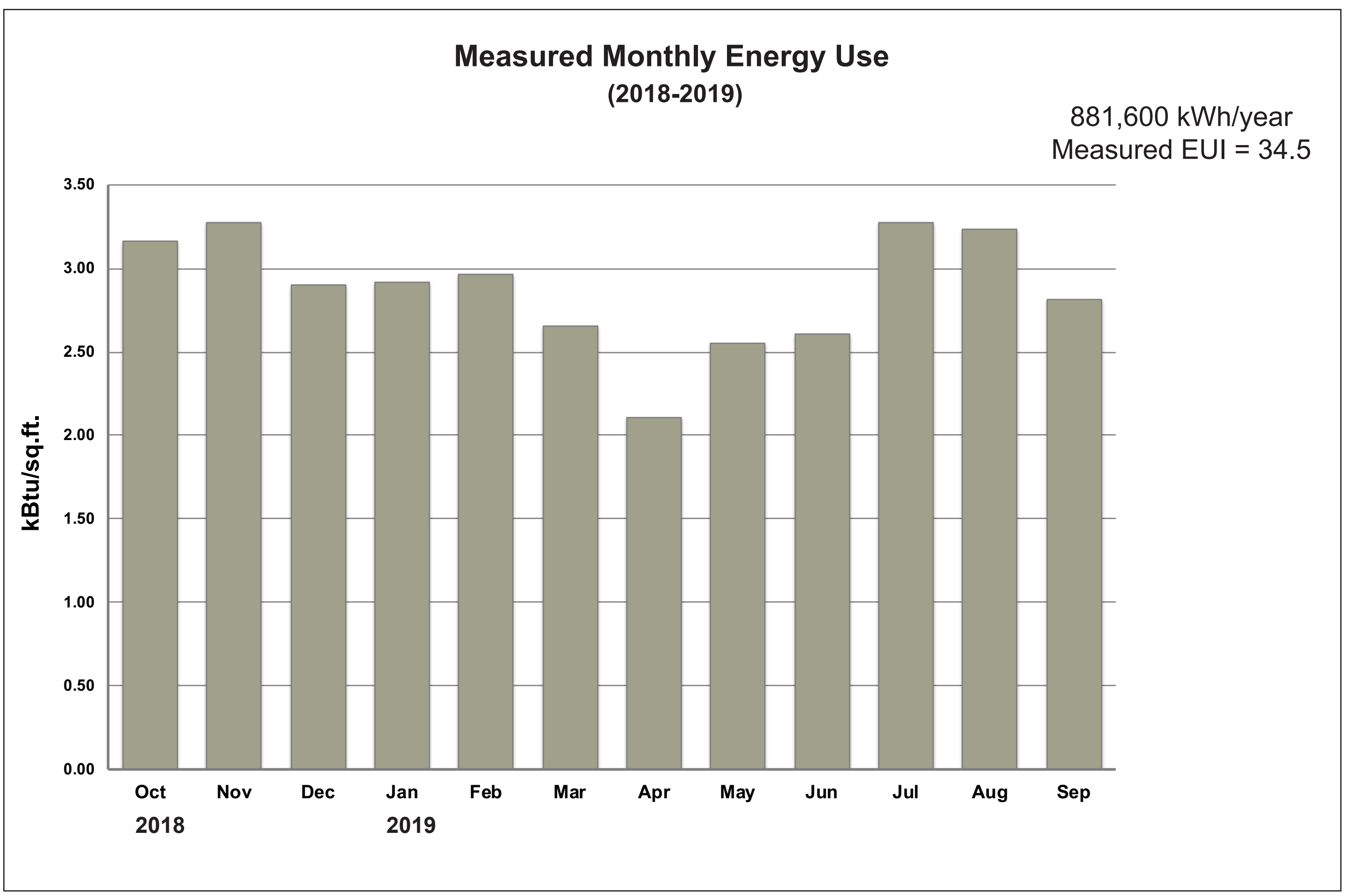
The monthly solar PV production is metered and reported by the solar PPA company. For the initial twelve months beginning in October 2018, the total energy produced was 916,550 kwh per year, or 35.8 kBtu/sq.ft. per year, making the performance *zero-net-energy* for that year. The charts on page 67 show the monthly energy production versus energy use as well as the cumulative net energy performance over those twelve months.

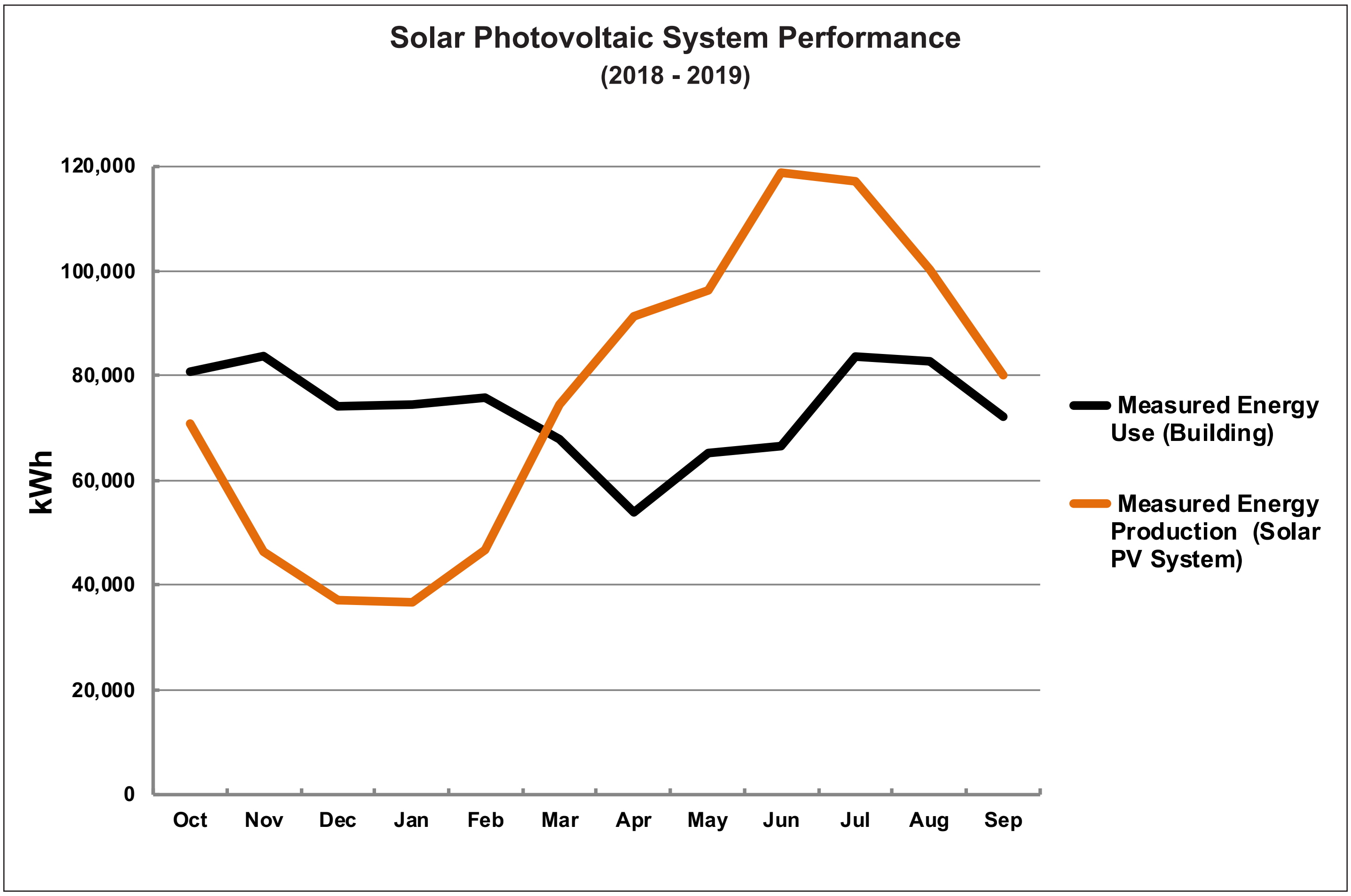


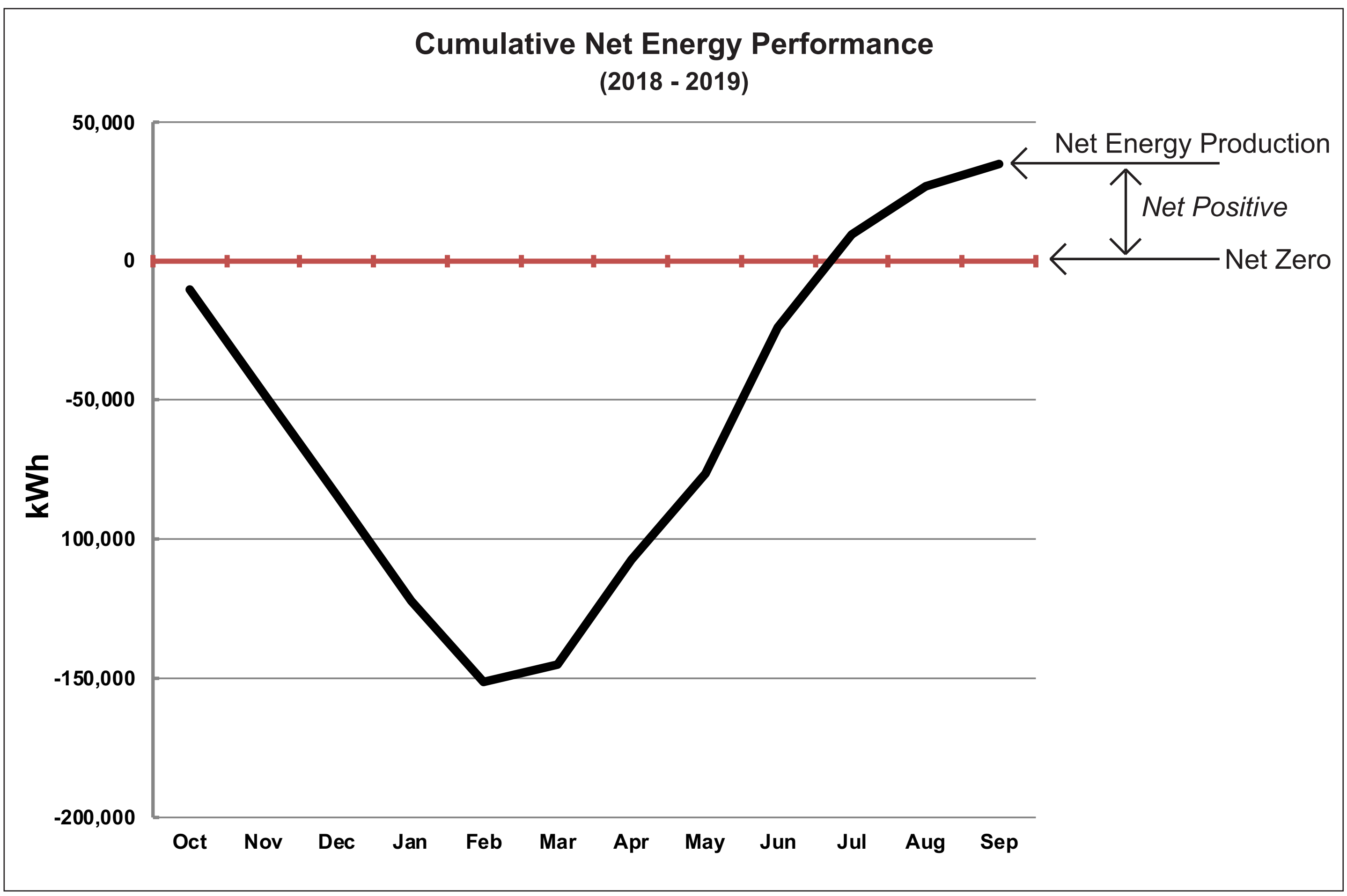
Modeled Energy Use (Annual)

891,550 kWh/year
Modeled EUI = 34.9


Modeled Monthly Energy Use
891,550 kWh/year
Modeled EUI = 34.9
kBtu/sq.ft.
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
DHW
Car Chargers
Lighting - Exterior
Lighting - Interior
Elevators
Plug Load
Fans
Cooling
Heating


Measured Monthly Energy Use
(2018-2019)
881,600 kWh/year
Measured EUI = 34.5
kBtu/sq.ft.
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
2018
2019


Solar Photovoltaic System Performance
(2018 - 2019)
kWh
120,000
100,000
80,000
60,000
40,000
20,000
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Measured Energy Use (Building)
Measured Energy Production (Solar PV System)


Cumulative Net Energy Performance
(2018 - 2019)
kWh
50,000
0
-50,000
100,000
-150,000
-200,000
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Net Energy Production
Net Positive
Net Zero

(Opposite Page)
Care Team collaboration office with electrochromic glazing in windows..

Post Occupancy: Observations and Conclusions

The building was occupied in June 2018, with the on-site solar PV system coming fully online in September of that year. Normal occupancy continued until the spring of 2020, when the pandemic caused changes in occupancy patterns and system operations. In this period, there has nevertheless been good opportunity to observe the functioning of the building systems and user behaviors. Among these, the most noteworthy is the commissioning issues that arose in this first year of occupancy, which are discussed below.

Remarkably, with regard to energy use, this all-electric building has achieved all the project goals, including an EUI = 35 and zero-net-energy performance.

Post Occupancy: Integrated Design Process

The involvement of a construction management firm / general contractor in the design phases was regarded as very positive for a cost-based design process. This ensured that accurate information was available when considering alternative design strategies.

Post Occupancy: Solar PV System

The use of a solar PPA is highly successful on this project with regard to cost, maintenance and performance. A zero-net-energy building requires the first-cost investment in a solar PV system large enough to offset the annual energy use. For most clients, this can be a large added first cost. But the PPA solves this cost issue—no first cost incurred and electric energy costs currently less than that supplied by the public utility. This is a common experience across many building types, particularly if the client is a non-profit and is not eligible for the sizable tax rebate.

Post Occupancy: Commissioning and Controls Systems

According to the design team, the biggest challenge was coordinating the controls systems design and commissioning. Commissioning should be completed *before* the building is occupied so that the building systems are operating correctly when the occupants first experience the building environment and its controls. Unfortunately, the building was occupied as the commissioning work commenced, so that control system malfunctions were the intial occupant experiences. These negative experiences were compounded by high turnover in the commissioning firm's staff, resulting in poor coordination with Kaiser maintenance staff.

These issues were ultimately resolved, but the frustration of the users and maintenance staff with the building systems lingered for some time afterward. In fact, the unconventional approach to the building systems design was perceived as the cause of the time required to commission the controls systems properly, when in fact the installed systems are less complex than those conventionally used.

It is highly recommended, especially for projects that utilize an integrated design process, that the controls system subcontractor who will be responsible for the building commissioning participate in the later design phases as well.

Post Occupancy: User Behavior

A *User Manual* was not created, which might have mitigated the issues encountered during the belated commissioning experience. Also, for example, the use of *thermafusers* was not known to the users, so they were not aware of their ability to control their individual space temperature by varying the air mix via this room device.


PHOTO: MARCO ZECCHIN

CASE STUDY NO. 4

Redford Conservancy at Pitzer College

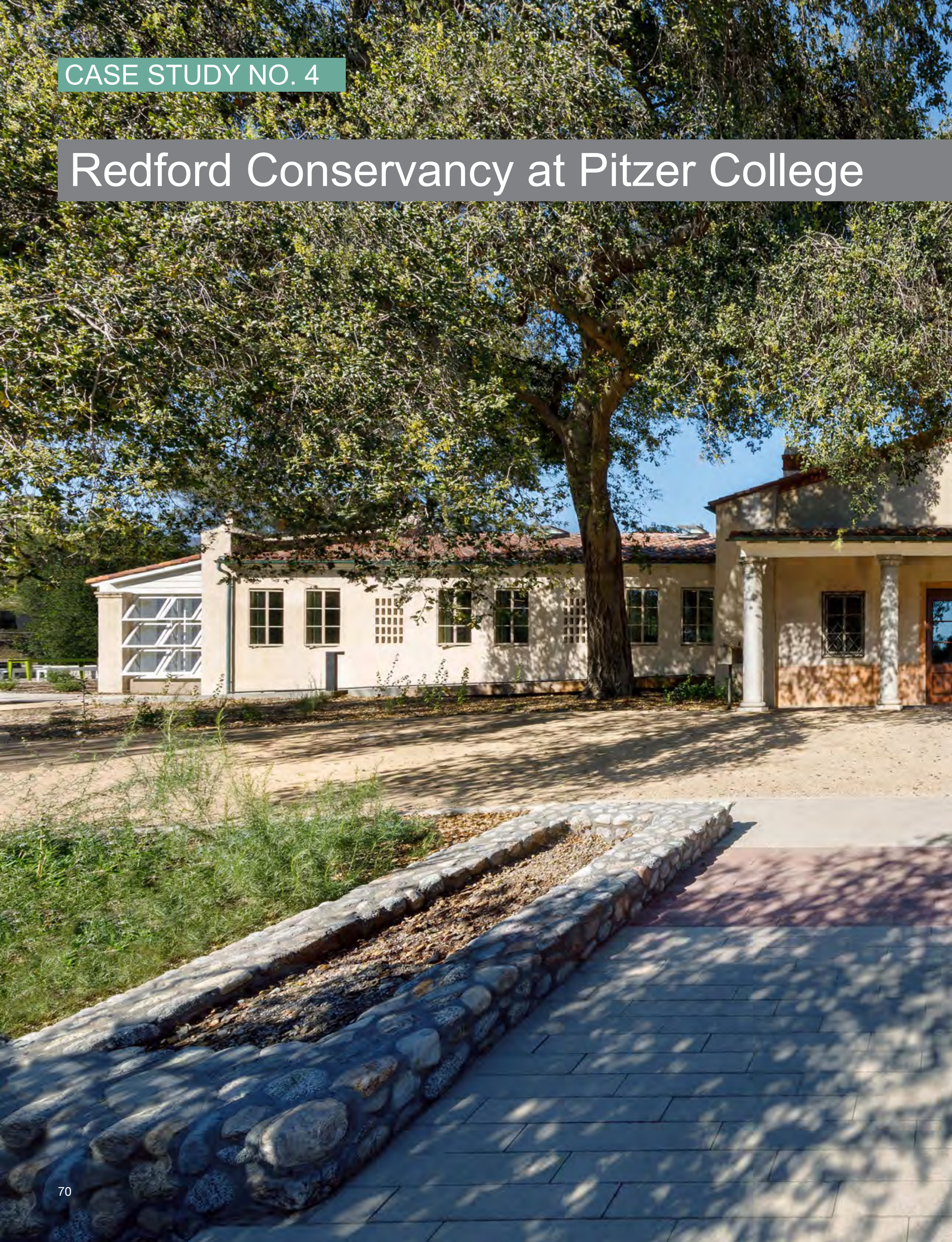


PHOTO: COSTEA PHOTOGRAPHY INC.

Redford Conservancy at Pitzer College

Case Study No. 4

Data Summary

Building Type:
Multi-use Classroom Building

Location: Clarement, CA

Gross Floor Area:
14,125 sq.ft.

Occupied: December 2017

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

Measured EUI (Site):
15.8 kBtu/sq.ft. per year

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

Measured On-Site Energy Production:
83 MWh per year (2018-19)
26.6 kBtu/sq.ft. per year (2018-2019)

Client
Pitzer College, Claremont, CA

Design Team

Architect:
Carrier-Johnson + Culture, San Diego

Structural Engineer:
KPFF Consulting Engineers, Los Angeles

Mechanical/Electrical/Plumbing Engineer:
Integral Group, Los Angeles

Landscape Architect:
MLA Studio, Los Angeles

General Contractor:
KAR Construction, Ontario

New buildings are generally less complicated to design than renovations of existing buildings, which typically have design constraints that strongly affect the space program, the structure and the optimization of energy systems for low-energy use. For that reason, case studies of renovations can be revealing in terms of successful strategies and creative solutions to design constraints commonly encountered. Even more importantly, renovation may be preferable to building a new structure when considering *embodied carbon*, so that a case study for the two alternatives can be invaluable in illustrating the evaluation process for the embodied carbon at construction and the operating carbon over the life of the building.

The Robert Redford Conservancy Building at Pitzer College is such a case study—an all-electric renovation of an abandoned building that would normally be marked for demolition. But, motivated by a desire to preserve the historic nature of the building and the site, a client and its design team studied the alternative of a renovation and re-purposing of the structure. The result was a successful ILFI-certified (zero-net-energy), LEED-Platinum project that minimized the embodied carbon required and (most importantly) met all programmatic goals.

Background

In 2012, Pitzer College, one of the seven Claremont Colleges, was planning to begin an interdisciplinary academic program focused on environmental issues, climate resilience and sustainability, particularly in the surrounding geographic region of Southern California. This program would include an outreach to local K-12 schools in environmental education and a collaboration with the local Tongva Indigenous community in the study of environmental issues of the local region.

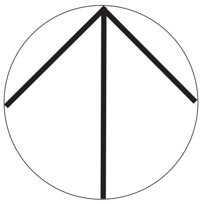
This program was branded a "conservancy", since the goals are broadly to conserve and protect the natural resources and ecology of the region and in particular the land where the Claremont Colleges are located. When the principal benefactor and donor requested that this conservancy program be dedicated to a close family friend and environmental activist, who was also a Pitzer College board trustee, the College responded by naming the innovative interdisciplinary program in his honor: *The Robert Redford Conservancy for Southern California Sustainability at Pitzer College*.

Then in 2015, the program leaders and the facilities group at Pitzer College looked at the possibility of physically locating the Conservancy in a field station owned by the Claremont Colleges consortium across the street from the seven affiliated colleges. This park-like natural setting, which had been an ancillary consortium property for decades, was also the location of an abandoned building of the approximate size required for most of the Conservancy programs. The need for relatively inexpensive space plus the characteristics of the site, which could be used directly with some of the teaching and research programs, led to a feasibility study for renovating this structure and making it the home of the Conservancy. This feasibility study was denoted Phase 1.

The nature of the stated mission of the Conservancy made renovation of the existing structure with a small addition of some outdoor classrooms the preferred choice to the alternative of demolition of the existing building and constructing an entirely new facility in its place. Nevertheless, the feasibility study considered these two alternatives with their associated construction costs, energy use and embodied carbon totals. The consultant team hired for the study, led by Carrier Johnson + Culture, also developed a detailed space program for the Conservancy with the faculty and other stakeholders.

The feasibility study and facility space program were completed in June, 2015. It resulted in the decision by the College to renovate the abandoned existing building and nearby grounds to accommodate the newly defined space program, which called for an interdisciplinary natural science lab, environmental analysis studio, an Indigenous resource collaboration space, offices,

Redford Conservancy at Pitzer College - General Vicinity Plan



classrooms and storage rooms. The total gross floor area required for this space program was determined to be 14,125 sq. ft.

The building program document included the initial target project goal for sustainability of *LEED-Gold*, which was identified by the project team as achievable without significant extra cost. This goal was able to be “stretched” to LEED-Platinum and *zero-net-energy* performance during the design phase through application of successful design strategies and a donation of the solar PV system to the project. (See discussions below.)

Design Process and Low-Energy, Zero-Carbon Design Strategies

For the next step in the process after Phase 1, the consultant team for the feasibility/programming study was selected as the design team for the project, who then proceeded to develop the ideas outlined in the building program.

Planning Concept and General Design Considerations

The initial challenge was to accommodate as much as possible of the identified space program within the useful parts of the existing building and to devise additional useful space for the remaining program elements. This was all very dependent on the state of the existing structure and what could be done with it. This proved to be challenging.

Though not listed on any historic registry, the existing structure had historical value to the college and the local area. It was built in 1931 as a 20-bed quarantine facility and infirmary for students of the recently-founded (1925) consortium of the Claremont Colleges. It was located on the 12-acre field station property across from the Colleges to provide isolation at the end of the pre-antibiotic era. The design of sun-filled, naturally ventilated spaces was the conventional approach in these times, intended as a method of treatment as well as quarantine.

In the mid-1970s, the facility was closed since it was both obsolete and in need of extensive seismic upgrading. Shortly afterward, the building caught fire and received severe water damage of the interior during the fire suppression response. The City of Claremont would not grant a demolition permit because of the historic aspects of the building. Because the field station in which it was located was intentionally kept in its natural state over decades, the remnants of the building remained undisturbed (at least by humans) until 2015. The Conservancy project would restore the building to its original outward appearance while transforming the interior to its new program uses.

(Opposite Page)
Final site plan rendering. (Courtesy Carrier Johnson). Photos: Costea Photography Inc.

The design team accommodated the entire Conservancy space program by three principal steps:

1. Reclaiming over 8,000 gross sq. ft. on the main level by clearing the entire structure of debris, internal walls, asbestos and lead paint bulk remains;

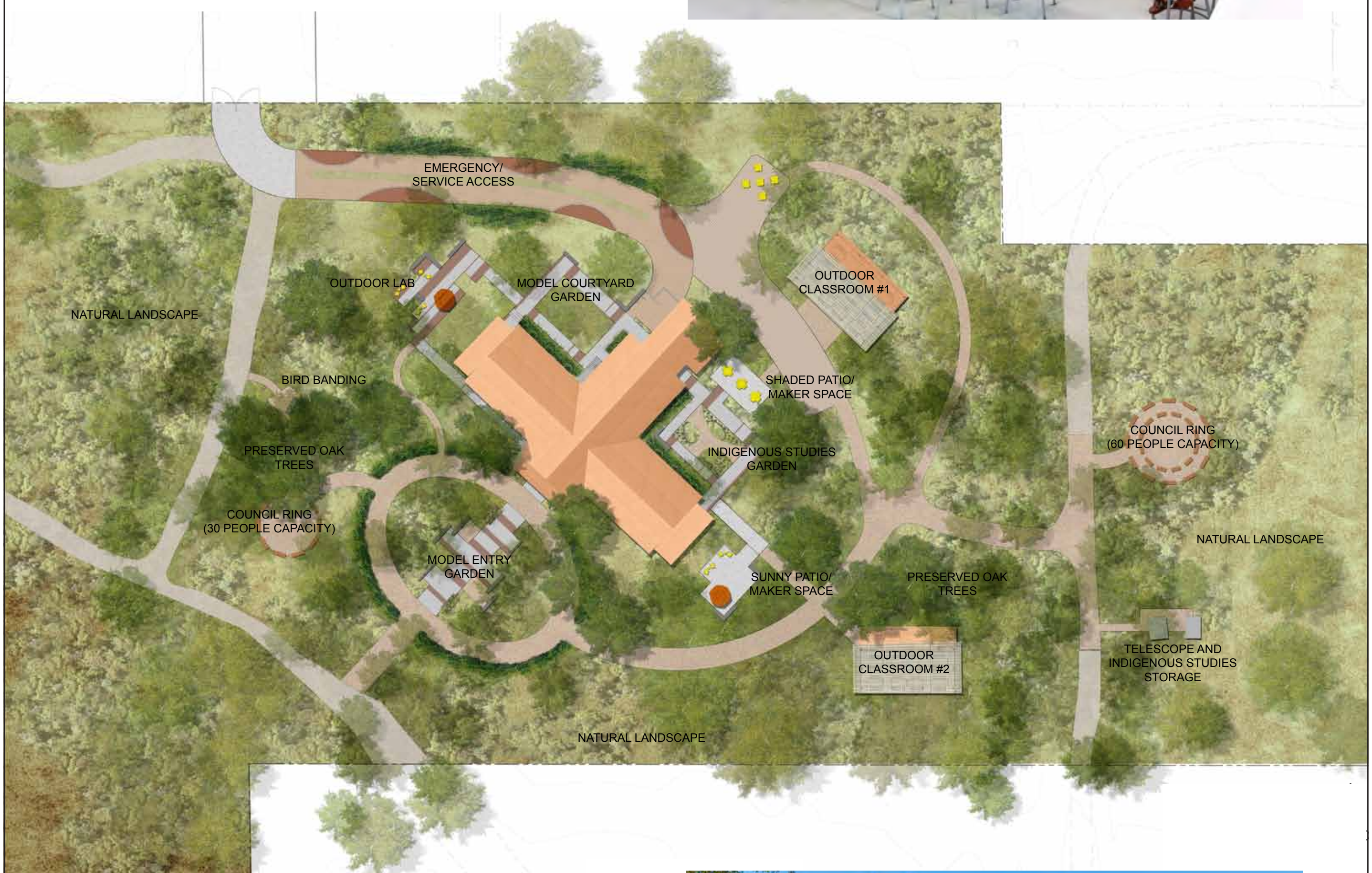
2. Renovating the basement space to create almost 2,500 sq. ft. of new, usable floor area;

3. Creating 3,500 sq. ft. of usable space as outdoor classrooms near the building, under protective canopies.

The benign climate allows this third innovative approach to fulfill the program requirements without creating a modern addition to the historic building. The building is therefore completely modernized internally, incorporating the Conservancy program while restoring the exterior to its original 1931 appearance.

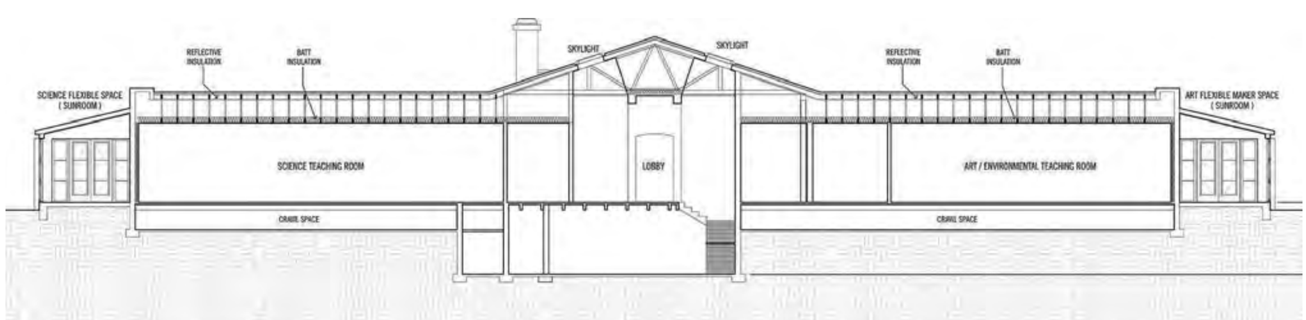
With the planning requirements satisfied, the design team then developed design strategies to achieve and then to stretch the project goals for each of the building features and systems, eventually reaching LEED Platinum and ZNE certification.


PHOTO: COSTEA PHOTOGRAPHY INC.

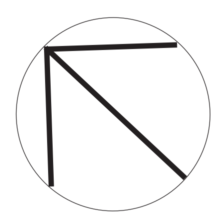

EMERGENCY/
SERVICE ACCESS
OUTDOOR LAB
MODEL COURTYARD
GARDEN
OUTDOOR
CLASSROOM #1
NATURAL LANDSCAPE
BIRD BANDING
SHADED PATIO/
MAKER SPACE
PRESERVED OAK
TREES
INDIGENOUS STUDIES
GARDEN
COUNCIL RING
(60 PEOPLE CAPACITY)
COUNCIL RING
(30 PEOPLE CAPACITY)
NATURAL LANDSCAPE
MODEL ENTRY
GARDEN
SUNNY PATIO/
MAKER SPACE
PRESERVED OAK
TREES
OUTDOOR
CLASSROOM #2
TELESCOPE AND
INDIGENOUS STUDIES
STORAGE
NATURAL LANDSCAPE

GROUND FLOOR PLAN

0 5 10 20 40 FT

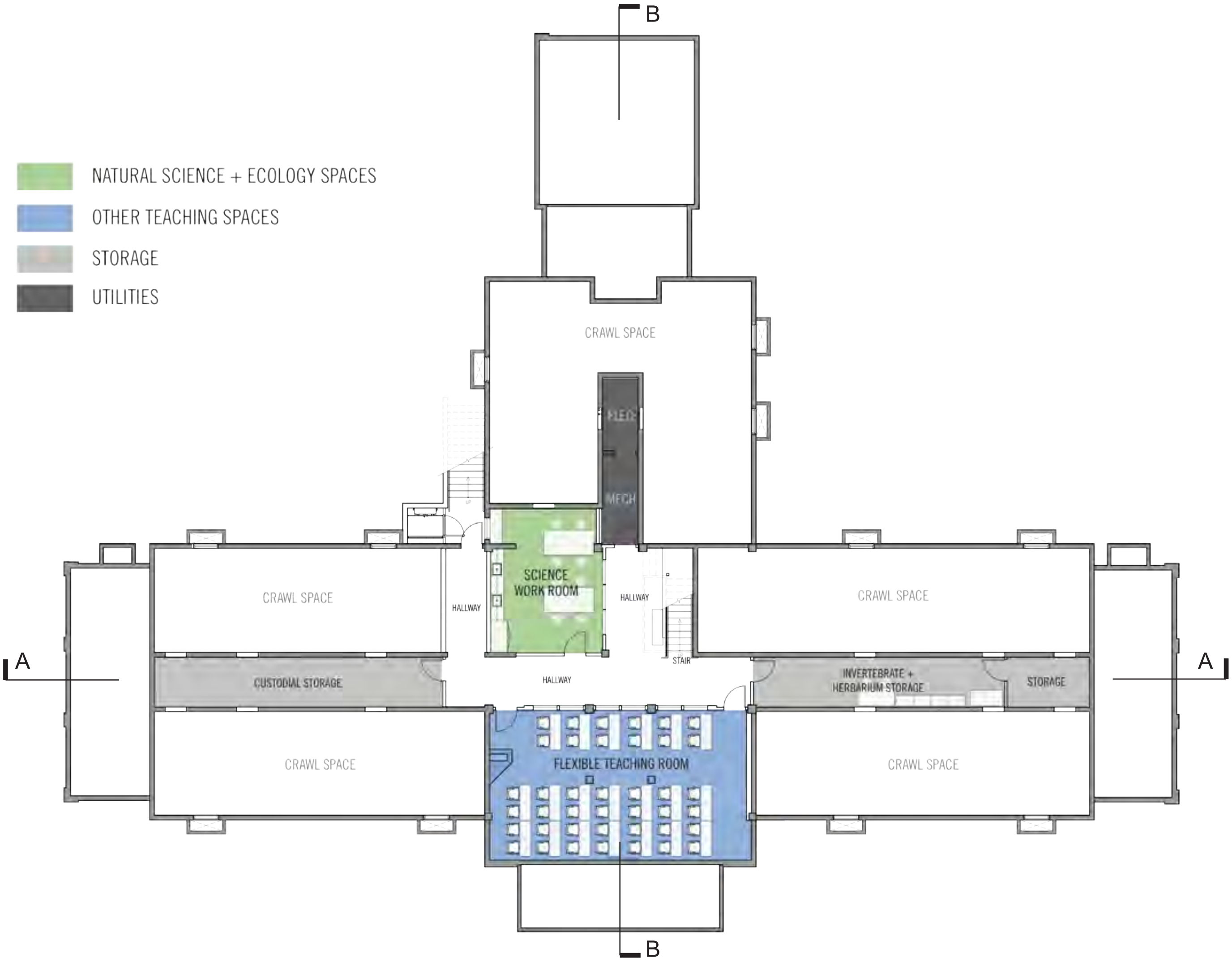


SECTION A-A

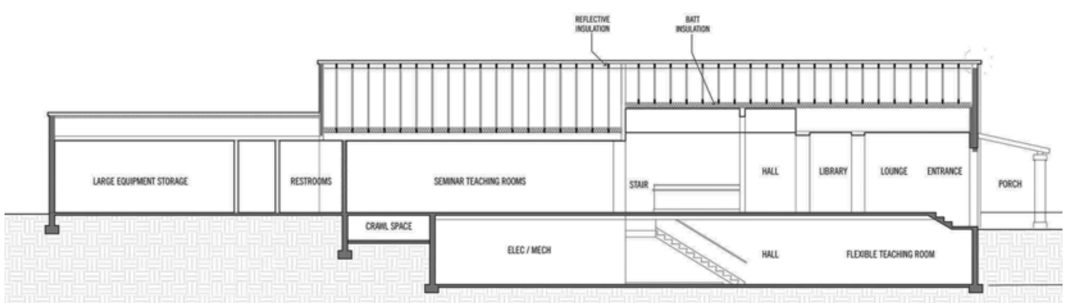


NORTH

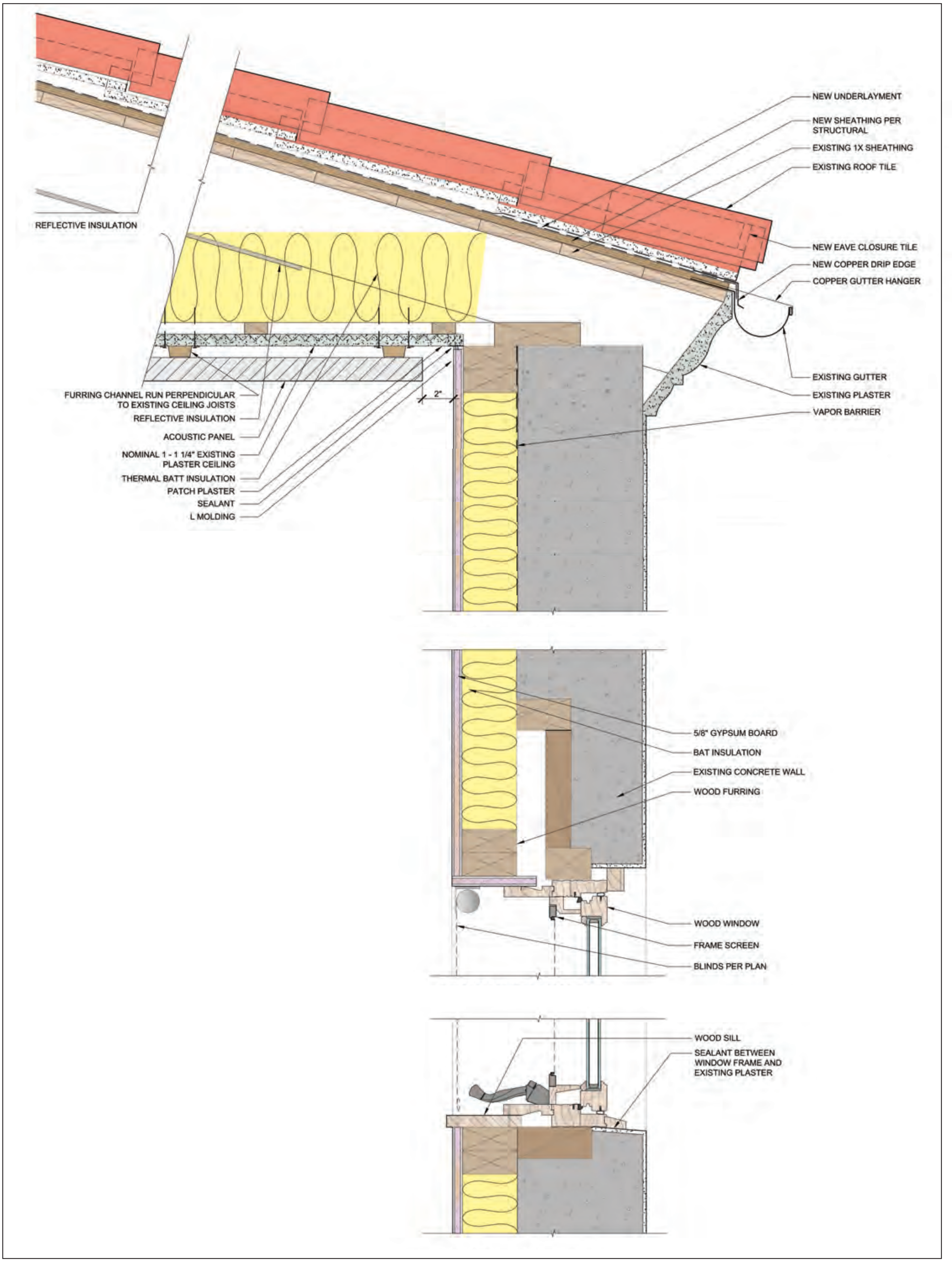
REDFORD CONSERVANCY : FLOOR PLANS AND BUILDING SECTIONS



BASEMENT FLOOR PLAN



SECTION B-B


NEW UNDERLAYMENT
NEW SHEATHING PER STRUCTURAL
EXISTING 1X SHEATHING
EXISTING ROOF TILE
NEW EAVE CLOSURE TILE
NEW COPPER DRIP EDGE
COPPER GUTTER HANGER
REFLECTIVE INSULATION
EXISTING GUTTER
EXISTING PLASTER
VAPOR BARRIER
2"
FURRING CHANNEL RUN PERPENDICULAR TO EXISTING CEILING JOISTS
REFLECTIVE INSULATION
ACOUSTIC PANEL
NOMINAL 1 - 1 1/4" EXISTING PLASTER CEILING
THERMAL BATT INSULATION
PATCH PLASTER
SEALANT
L MOLDING
5/8" GYPSUM BOARD
BAT INSULATION
EXISTING CONCRETE WALL
WOOD FURRING
WOOD WINDOW
FRAME SCREEN
BLINDS PER PLAN
WOOD SILL
SEALANT BETWEEN WINDOW FRAME AND EXISTING PLASTER

(Opposite) Upper wall section at existing wall and roof showing retrofitted insulation and finishes. *(Courtesy of Carrier Johnson)*

Building Envelope

The original exterior walls were constructed of uninsulated reinforced concrete with an internal layer of red hollow clay bricks for running wiring and plumbing lines. With the removal of the unreinforced masonry, the concrete structural walls could be surfaced on the interior with furred wood framing holding R = 11 fiberglass batt insulation. The wood joist floor above the existing crawl space was repaired and insulated with R-19 fiberglass batt insulation, bringing its overall R-value to R = 21, while the existing concrete basement floor had to remain uninsulated.

The roof over the attic space was insulated with the same fiberglass batts and a layer of radiant heat barrier material attached to the sloping roof rafters. This radiant barrier prevents heat buildup on warm summer days, keeping the attic space cool. It's equivalent R-value is R = 15, producing a nominal R-value for the roof of R = 30.

The single-pane glazing in the historic window frames was replaced with low-e double-glazed units (transmissivity 0.62). Because the window frames were considered historic, only the glass could be replaced. It was not possible to consider entirely new high performance windows with thermal breaks.

Daylighting and Electric Lighting

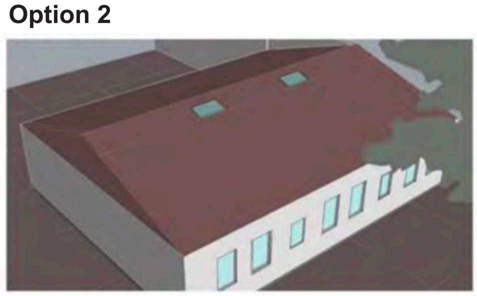
The design team located each of the two large labs (teaching rooms) in the main area of each of the two wings of the main level of the building. (See Ground Floor Plan.) This allowed optimal daylighting from two sides of the room as well as possible top-lighting from the ceiling. The original building had been built with a large skylight in each of these two main roof areas, but they were removed in a later renovation. Re-introducing this form of daylighting for the teaching rooms was seen as a desirable restoration measure for the historic building as well as a good energy design strategy.

Three possible configurations of skylights[1] were studied: (1) two skylights centered in the room, (2) two skylights separated for more even light distribution in the room and (3) two pairs separated for higher daylight levels overall. Daylight analysis was done for each option to determine the number of hours per year when the daylight levels would exceed or equal the IES[2] recommendations for classrooms and also to visualize the light distribution in the rooms under overcast and clear sky conditions. Some results are shown in the illustration on the next page. Based on this analysis, the design team opted for the two separated skylights (Option 2) for best light quality and performance.

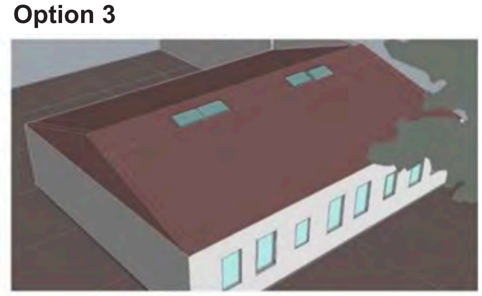
(Below) Three options for skylights above the classroom spaces. *(Courtesy of Carrier Johnson)*

Option 1

Option 2



Option 3

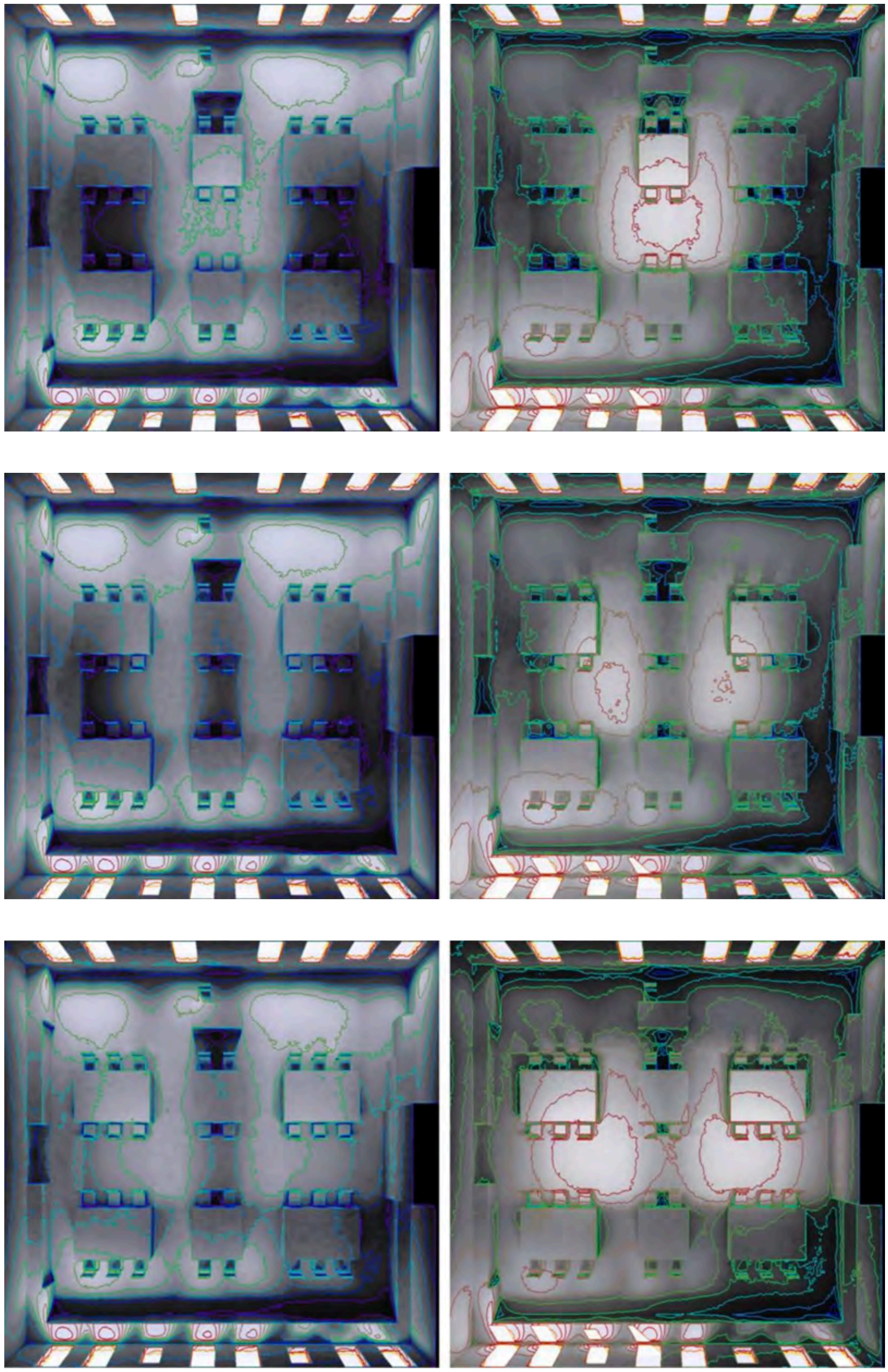


[1] Velux VSE S01 Roof Window, with diffusing glass, visual light transmissivity = 0.50.
[2] Illuminating Engineering Society. For a short list of IES recommended light levels see: https://waypointlighting.com/uploads/2/6/8/4/26847904/ies_recommended_light_levels.pdf

(Opposite Page) Science Teaching Room / Classroom with skylights above.

(Right) Daylight analysis for three options of skylight configurations in the large Teaching Rooms / Classrooms for overcast sky (left image) and clear sky (right image). (Courtesy Integral Group)

Dec. 21, 12 noon, Overcast Sky | Sept. 21, 12 noon, Clear Sky



Option 1
Two skylights centered in room

Option 2
Two skylights separated configuration

Option 3
Two pairs of skylights (4 total) separated configuration

PHOTO: COSTEA PHOTOGRAPHY INC.

(Opposite Page)
Arrays of operable windows throughout the building provide fresh air and cooling via daytime natural ventilation and night purge ventilation.
(Photos: Costea Photography Inc.)

Natural Ventilation

The seasonal air temperature ranges at the site are ideal for natural ventilation for fresh air and cooling: cool night temperatures for space pre-cooling and daytime air temperatures within the comfort range most of the year. In addition, the historic building was designed originally to maximize natural ventilation through the large areas of openable windows and doors. Natural ventilation is an obvious design strategy to employ in the renovated building.

The designers used the existing crawl space beneath the wood joist floors combined with the operable skylights to create an air flow path through the main spaces, with the air intake at openings in the exterior wall of the crawl space and a connection to the occupied space above through floor grilles. The air flow is driven by the natural buoyancy of the air traveling vertically to the open skylights combined with the draft created by the prevailing breeze above the roof. Thus, the cooling air flow can be done entirely without fans for most of the year. Large ceiling-mounted, slow-moving room fans create comfort conditions on those days when there is little or no air movement due to lack of prevailing breezes.

This effect is enhanced by broken shards of the red hollow clay bricks that line the crawl space, which were placed there after the original interior walls were demolished and the bricks were broken into pieces. This effectively adds thermal mass to the crawl space, which is used to pre-cool the incoming outside air. This thermal mass is typically chilled during *night purge ventilation*[3] of the building.

Heating, Ventilating and Cooling Systems

The renovated building employs a *Mixed-Mode System* to maintain comfortabe conditions throughout the year.[4]

The natural ventilation system design described above is utilized when outside air temperatures are within the comfort zone. Outside of those comfort conditions, this natural ventilation is shut down by automatically closing the skylights and the air-intake dampers at the crawl space wall. In this case, either heating or cooling is required, which is provided by ductless fan coil units in each room, tied to a heat pump.

The operation of this mechanical heating and cooling system requires that all operable windows (and the skylights) are closed. Window contacts ensure that the system cannot operate if a window is open. If outside air temperatures rise during the day such that cooling is desired by the occupants, closing the windows in the space will cause the thermostat-controlled fan coil unit to start operating. Since the windows are all manually operated, the occupants effectively control the temperature conditions in each space through their adjustment of these windows.

[3] See: https://knowledge.autodesk.com/support/revit/learn-explore/caas/simplecontent/content/night-purge-ventilation.html. See also: https://www.windowmaster.com/expertise/natural-ventilation-and-mixed-mode-ventilation/night-cooling-ventilation/.
[4] See: https://cbe.berkeley.edu/mixedmode/aboutmm.html.
See also: *Zero Net Energy Case Study Buildings, Volume 2*, "Case Study No. 10: West Berkeley Library", (2016), p. 88:http://online.flipbuilder.com/bernheimdean/yxkr/

(Right) Canopies above the Outdoor Classrooms accommodate the solar PV arrays for the entire building, (Photo: Costea Photography Inc.)

Renewable On-Site Energy Supply

As the design phases were being completed, the Conservancy building was on track to meet its new (stretch) goal of LEED-Platinum and the project was modeled to be "ZNE-Ready". A project benefactor (and Pitzer College parent) then came forward with a donation of the entire solar PV system sufficient to make the project ZNE-certified. With this donation, the project was on track to achieve all of its "stretch" goals listed at the beginning of the process.

The solar PV system was installed on the two roof canopies above the outdoor classrooms, which were the correct combined size to accommodate the required panel arrays. The system consists of 160 SunPower E-Series Commercial Solar Panels E20-327-COM, nominally generating 52 kW.

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

Embodied Carbon

A detailed embodied carbon analysis was done as part of the design process. As mentioned in the *Background* section above, this analysis was done both for the renovation of the existing historic building and for a representative new building at the same site. Since the decision to renovate was already made for "conservancy" reasons, the analysis was an academic exercise. It is nevertheless instructive for the methodology and result. See the Sidebar on the opposite page for a summary discussion.[5] (Graphs courtesy of Integral Group)

Energy Use — Modeling

Energy modeling was done during Phase 1 to assist with the initial planning, then continued into the design phases to evaluate design alternatives. The software used was IES-VE, which also has the capability to do daylighting analysis. The modeled annual energy use (pie chart) and modeled monthly energy use (bar chart) are shown on the following pages.

Note that two EUI values are given: one conventional EUI for the total gross enclosed and conditioned area of the building (the conventional definition) and an EUI that is calculated using the additional areas of the outdoor classrooms and their additional energy use totals (lighting, plug loads). This second EUI represents the actual gross area of all the functional spaces of the building, even the spaces that are technically not "conditioned space" or enclosed by walls.

[5] See also: *The Building Decarbonization Practice Guide – A Zero Carbon Future for the Built Environment, Vol. 1-7*, William J. Worthen Foundation, https://www.collaborativedesign.org/get-the-guide-bdpg, 2021
See also: *AIA-CLF Embodied Carbon Toolkit for Architects, Parts 1, 2 and 3*, Carbon Leadership Forum, https://carbonleadershipforum.org/resource-library/, 2021.

Sidebar: Embodied Carbon Assessment

Embodied carbon in a building refers to the greenhouse gas emissions associated primarily with the extraction and manufacturing of materials used for the construction of the building. It also includes carbon generated by the smaller effects of transportation to the building site, construction processes and disposal of materials at demolition ("end-of-life").

Operational carbon in a building refers to the greenhouse gas emissions associated with the energy use in the operation of the building in its lifetime. As energy efficiency in buildings increases and renewable energy sources replace fossil fuel sources, the total operational carbon will gradually be minimized and embodied carbon will become the focus of significantly reducing carbon emissions in the building sector.

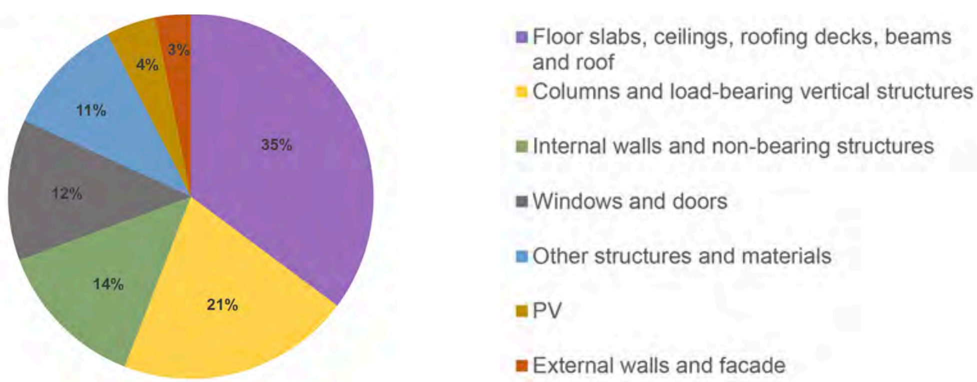
Embodied carbon reduction is primarily accomplished by choosing the materials and building systems with lowest carbon emission quantities due to raw material extraction, manufacturing and shipping to the building site, while satisfying the particular design requirements of the building. During the design phase, alternative design choices can be compared for embodied carbon quantities.

Units of embodied carbon quantities are typically metric: *kg CO2*, or kilograms of carbon dioxide. A "metric ton" of embodied carbon is *1000 kg CO2*. (Note: for greenhouse gases other than carbon dioxide, the unit of measurement is *kg CO2e*, where CO2e is "carbon dioxide equivalent". For example if methane is used to make the product, the number of kilograms is multiplied by 25 to calculate the equivalent to that mass of embodied carbon in the material for its global warming effect.)

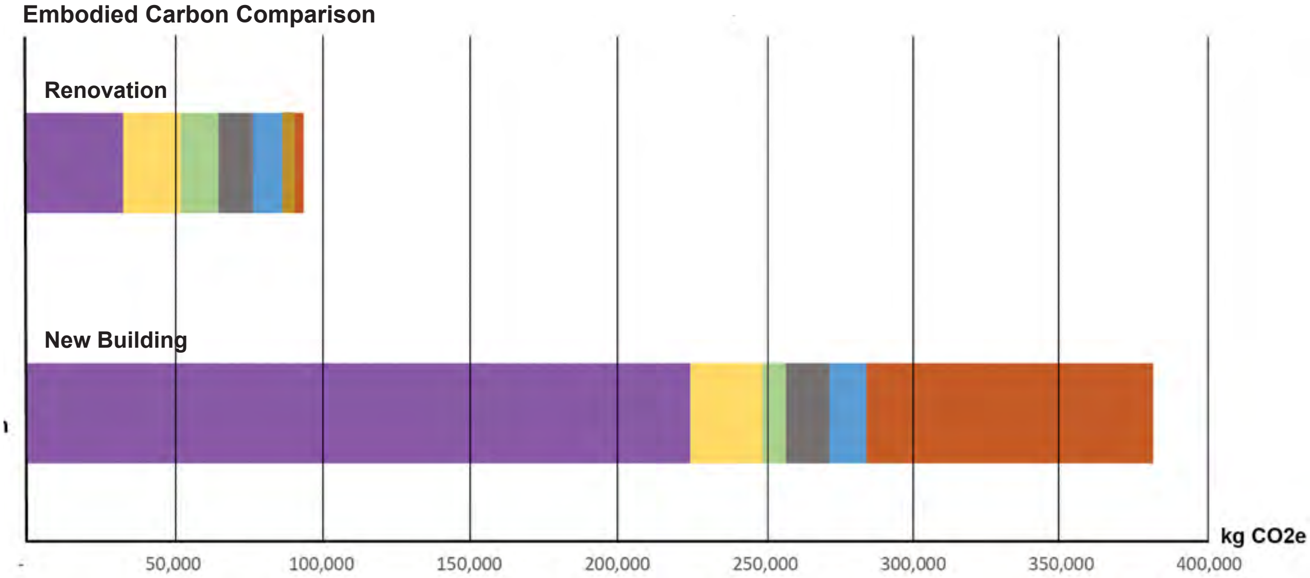
The methodology of comparison of design or material alternatives is called *Life Cycle Assessment* or *LCA*. This type of software uses built-in datasets of materials and embodied carbon information to evaluate all component parts of a building model. *Tally*[1] is currently most used by design professionals as a plug-in software package for the *Revit* BIM software. The data inputs for the LCA analysis are obtained directly from the Revit model of the building. *EC3*[2] is a similar LCA tool that incorporates individual product specifications.

Another LCA software tool, *One Click LCA*[3], was used to compare the two principal design options for the Redford Conservancy, namely reusing the existing 1931 building or building an entirely new building on the site. The embodied carbon of the new building was found to be 380 metric tons compared with 90 metric tons for the renovated building. For the renovation alternative, this even included the solar PV panels that were to be installed sufficient to render the building zero-net-energy (ZNE) operationally.

Embodied Carbon Breakdown - Renovation



Embodied Carbon Comparison

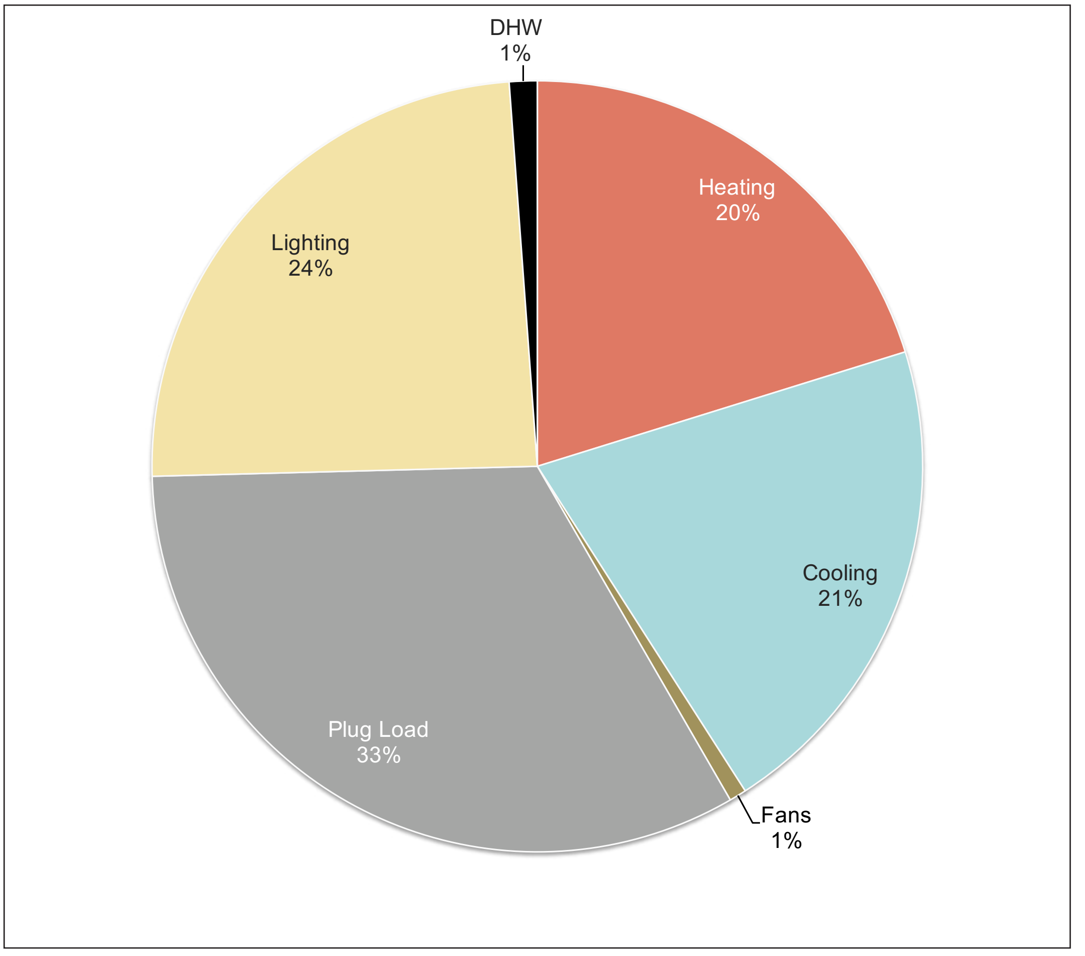


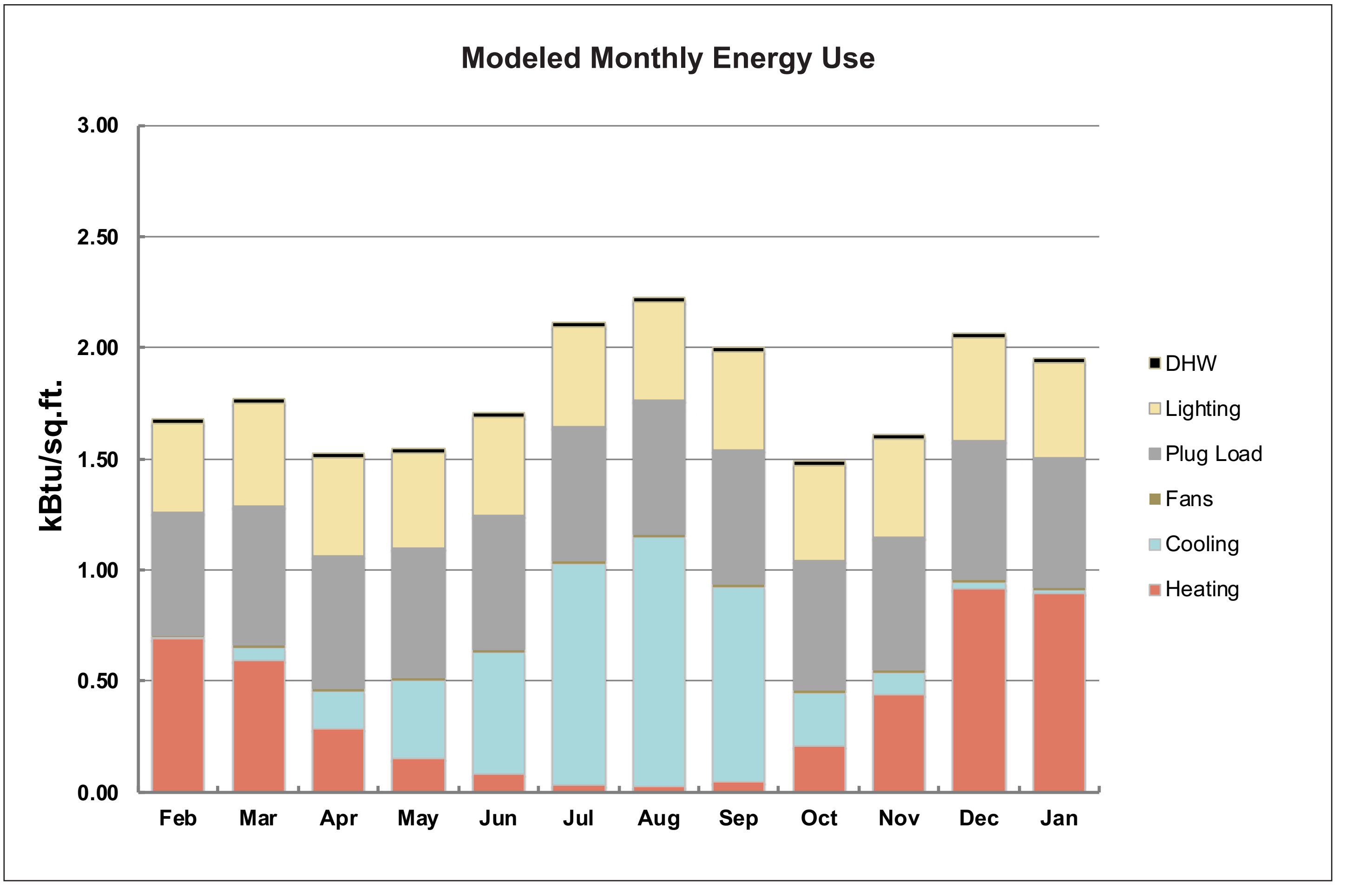
[1] *Tally*, Autodesk, https://choosetally.com/overview/
[2] *EC3*, Carbon Leadership Forum, https://carbonleadershipforum.org/what-we-do/initiatives/ec3/.
[3] *One Click LCA*, https://www.oneclicklca.com/

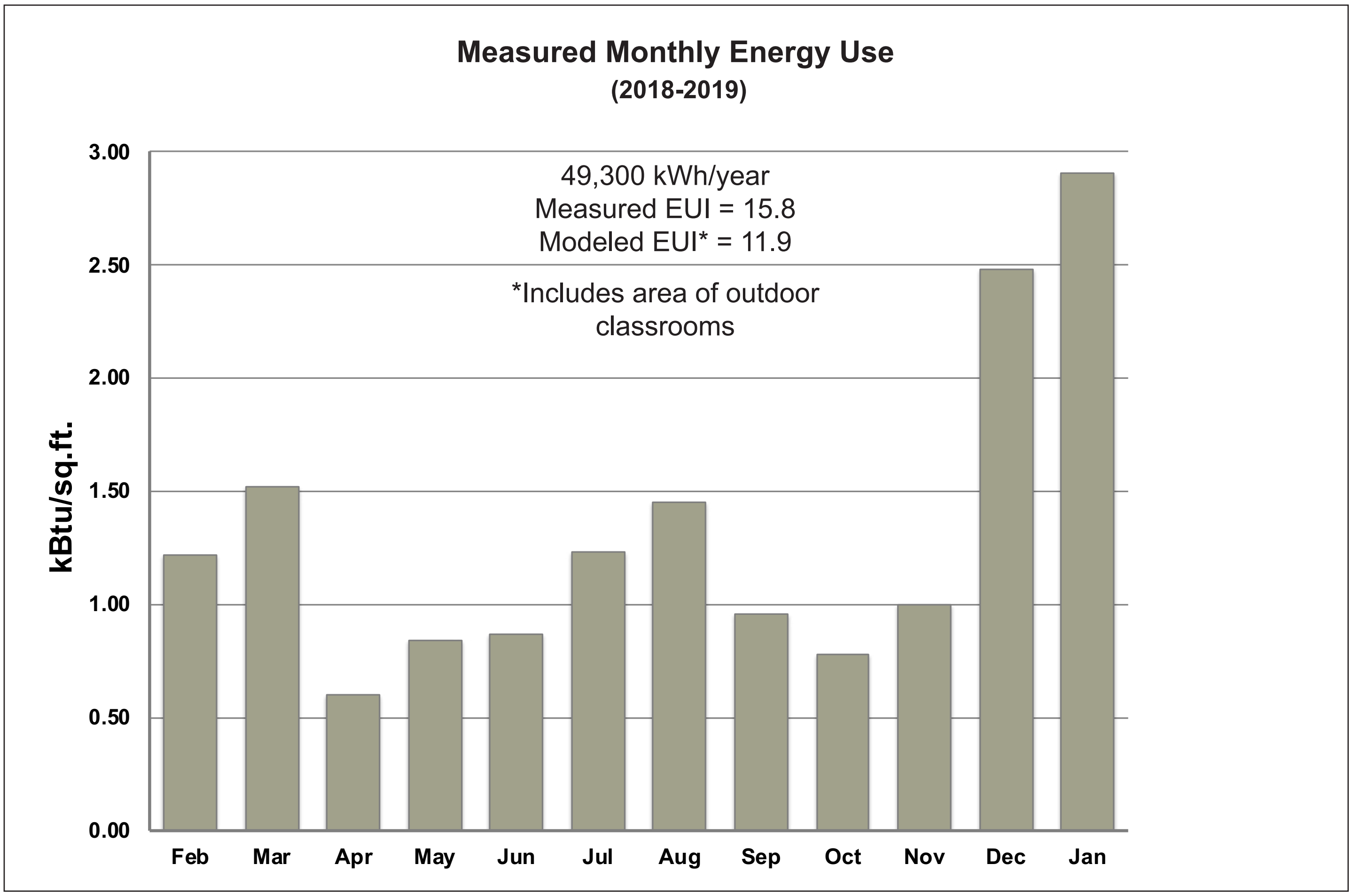
Modeled Energy Use (Annual)

67,600 kWh/year
Modeled EUI = 21.7
Modeled EUI* = 16.3

*Includes area of outdoor classrooms



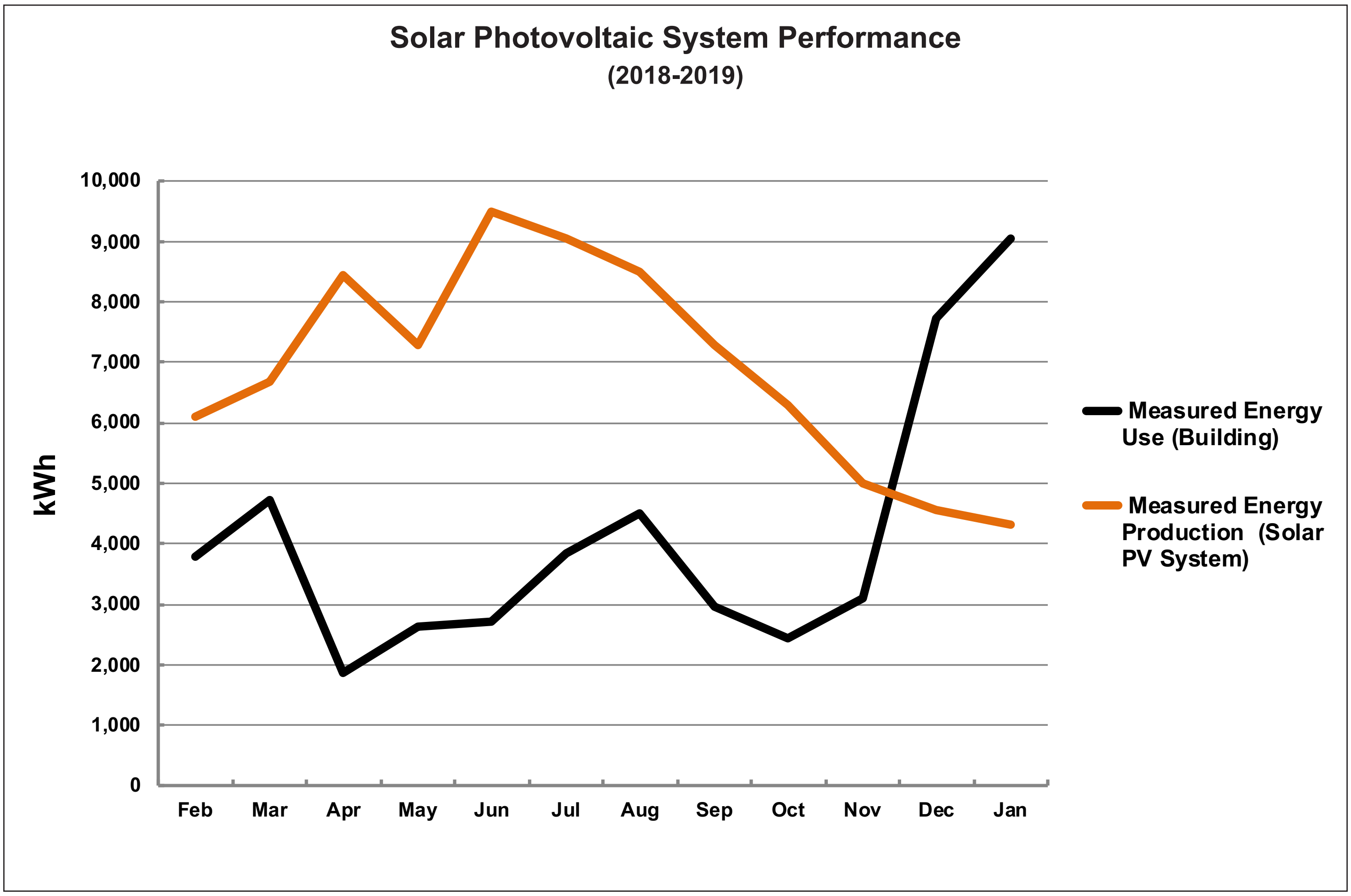




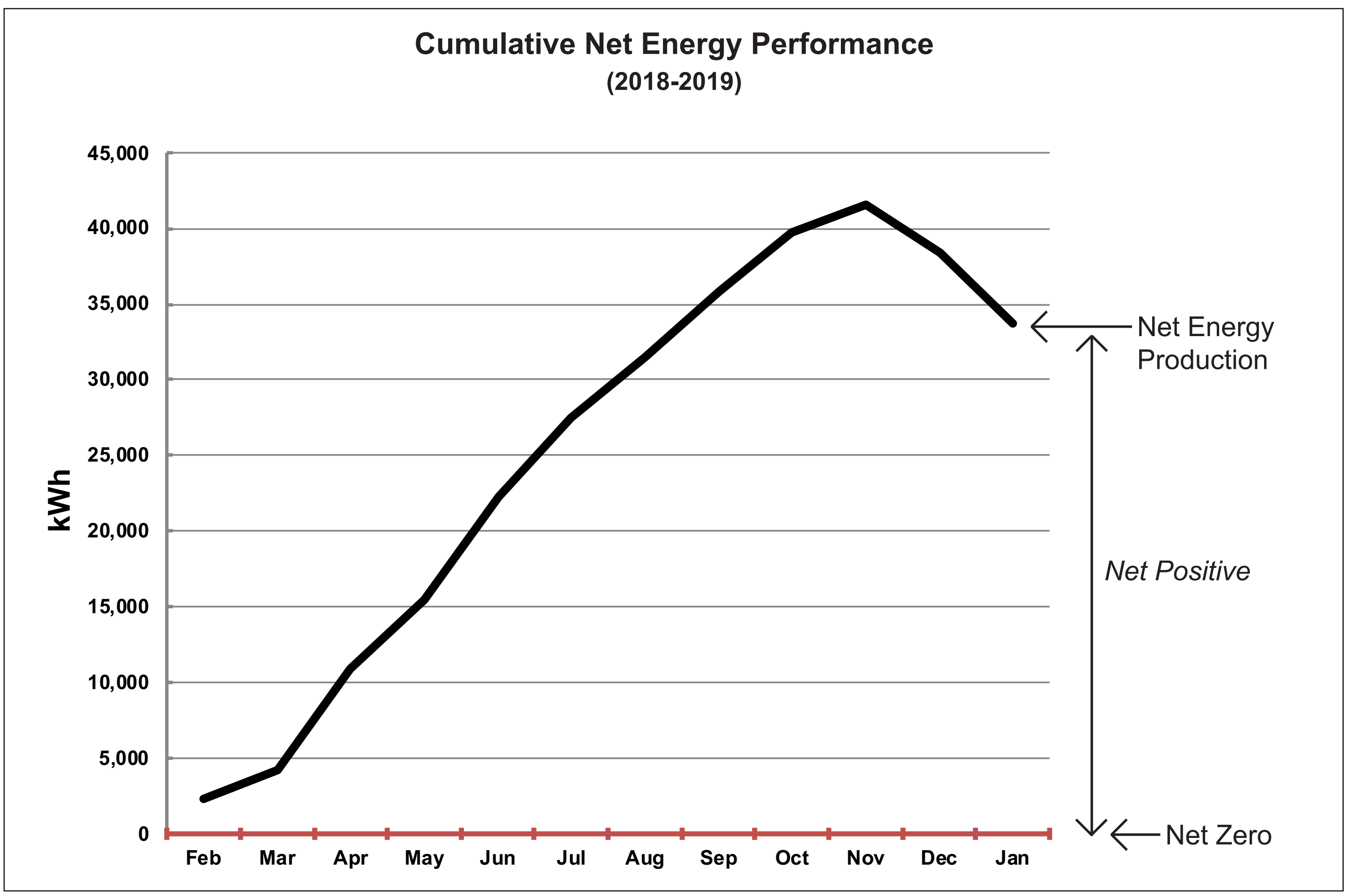
Energy Use — Actual Measurement and Comparison to Modeling Results

In such a small instructional building, individual metering of the energy loads did not seem practical. The data collected during the first full year of occupancy (2018) is therefore taken from the net metering bills from the electric utility and the separate metering done for the solar PV system. Since the electric utility bills contain a statement about net electrical energy separately drawn from the grid and also given to the grid by the on-site solar PV system, a simple calculation using the monthly amounts of energy generated by the solar PV system yields the total monthly energy use.

Shortly after this first year of data collection, the building was closed because of the pandemic. Nevertheless, a full year of monthly data on energy use and energy production from February 2018 through January 2019 was recorded. A bar chart showing actual energy use for that initial year is given above and can be compared to the modeled energy use bar chart on the opposite page. The differences are attributable to variances in actual use compared to the modeled schedule of use during this academic program start-up period.



Solar Photovoltaic System Performance
(2018-2019)
kWh
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Measured Energy Use (Building)
Measured Energy Production (Solar PV System)



Cumulative Net Energy Performance
(2018-2019)
kWh
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Net Energy Production
Net Positive
Net Zero

Energy Production versus Energy Use: Zero Net Energy

The monthly solar PV production is separately metered. For the initial twelve months beginning in February, 2018, the total energy produced was 83,000 kWh, or 26.6 kBtu/sq.ft. per year, making the performance easily *zero-net-energy* for that year. The chart on the oppposite page (top) shows the monthly energy production of the solar PV system versus energy use over those twelve months.

The second chart on the opposite page (bottom), *Cumulative Net Energy Performance*, sums the net energy production each month to that of the month prior, so that the annual total would be exactly zero if the performance is zero-net-energy (ZNE). The chart confirms that this building is in fact *net positive* by a large margin.

Post Occupancy: Observations and Conclusions

Post Occupancy: Controls and Monitoring

The systems are quite simple and therefore easy to maintain. The absence of metering the various energy uses and the possibility of reporting the data to the various users, does not allow behavioral responses to changes in usage. As an educational facility specifically concerning the subjects of conservancy and the natural environment, such data reporting displays or other methodologies would provide both awareness and udnerstanding.

Post Occupancy: Natural Ventilation

The natural ventilation system as part of the *mixed-mode* environmental management approach to heating, cooling and fresh air supply requires the direct involvement of the user. Each building user must understand how the system works to ensure comfortable conditions at all times. The building has only recently been re-occupied, so this aspect will be assessed in the near future for impact on overall energy use and efficient operation.

Post Occupancy: Solar PV System

The solar PV system was donated to the Conservancy and installed on the canopies above the outdoor classrooms. The Pitzer College facilities department is therefore responsible for cleaning and maintaining the system to ensure maximum production by the system. This is a new responsibility for the department and there will be an inevitable *learning curve*. (This is in contrast to the PPA arrangement of Case Study No. 3, Kaiser Medical Office Building, where a third party is responsible for the maintenance and operation of the system.)

CASE STUDY NO. 5

SFUSD Claire Lilienthal Middle School

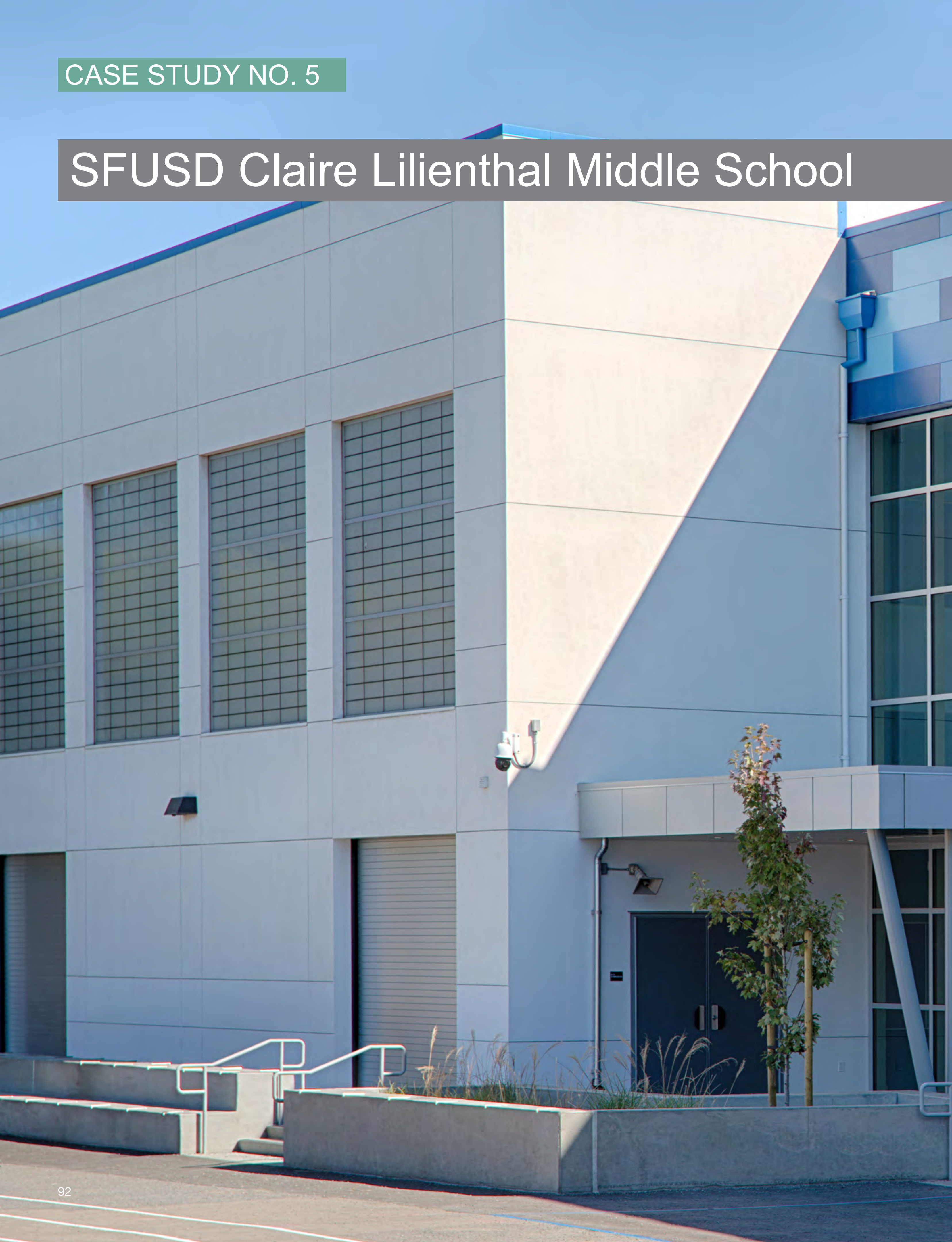


PHOTO: © TECHNICAL IMAGERY STUDIOS

SFUSD Claire Lilienthal Middle School

Case Study No. 5

Data Summary

Building Type:
Public School Classrooms

Location: San Francisco, CA

Gross Floor Area: 21,995 sq.ft.

Occupied: Aug. 2019 - Mar. 2020; Sep. 2021 - present. (Unoccupied Mar. 2020 - Aug 2021)

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

Measured EUI (Site):
16.7 kBtu/sq.ft. per year (See discussion)

On-Site Renewable Energy System To Be Installed:
67.8 kW (DC) Solar PV

Measured On-Site Energy Production:
TBD - System to be installed in 2022.

Client
San Francisco Unified School District

Design Team

Architect:
Lionakis, Oakland

Structural Engineer:
Lionakis, Oakland

Mechanical/Plumbing Engineer:
Capital Engineering Consultants, Alameda

Electrical Engineer:
Alliance Engineering Consultants, San Carlos

General Contractor:
Zolman Construction & Development, San Carlos

In 2011, San Francisco voters passed Proposition A, part of which authorized the San Francisco Unified School District (SFUSD) to issue general obligation bonds in the amount of $531 million for the renovation and new construction of schools throughout the city. Many schools had installed "temporary" classrooms, consisting of trailers or "bungalow", to relieve space needs and provide seismic safety on various school sites. These facilities were aging and there was a priority to replace them with buildings that were more suitable programmatically.

The replacement building programming included not only space programs but also a uniformly strong design standard for the buildings' structure, and in particular a standard for sustainable design and, where feasible, zero-net-energy design.

Background

SFUSD had been preparing for the program for some time. The District had undertaken a series of studies of different school building types to determine the feasibility of aggressive sustainable design for both new building construction and retrofits. For energy-related design, this involved evaluating the potential for zero-net-energy (ZNE) performance with on-site renewable energy systems, with an emphasis on all-electric systems so that the buildings would eventually be fully zero-carbon (ZC).

These feasibility studies consisted of energy modeling of the different types of school buildings to establish certain EUI[1] benchmarks for each type and to determine the size of the solar photovoltaic (PV) system needed to make each type ZNE. In the process of energy modeling, the studies identified optimal design strategies to achieve these design objectives, all of which focused on all-electric technologies and operations. The result of these feasibility studies was the creation of a set of design "standards" that were adopted by the SFUSD. These standards were in place when the bond measure passed and the building program began, creating an efficiency in the design process for all the design teams.

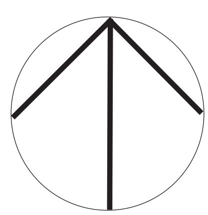
These standards were applied first to a project that was a precursor to those of the SFUSD Proposition A program: the Claire Lilienthal Middle School located on a 1.44 acre site in the Marina District in the northern part of the city near the waterfront. In fact, this was the first ZNE project to be undertaken by SFUSD.

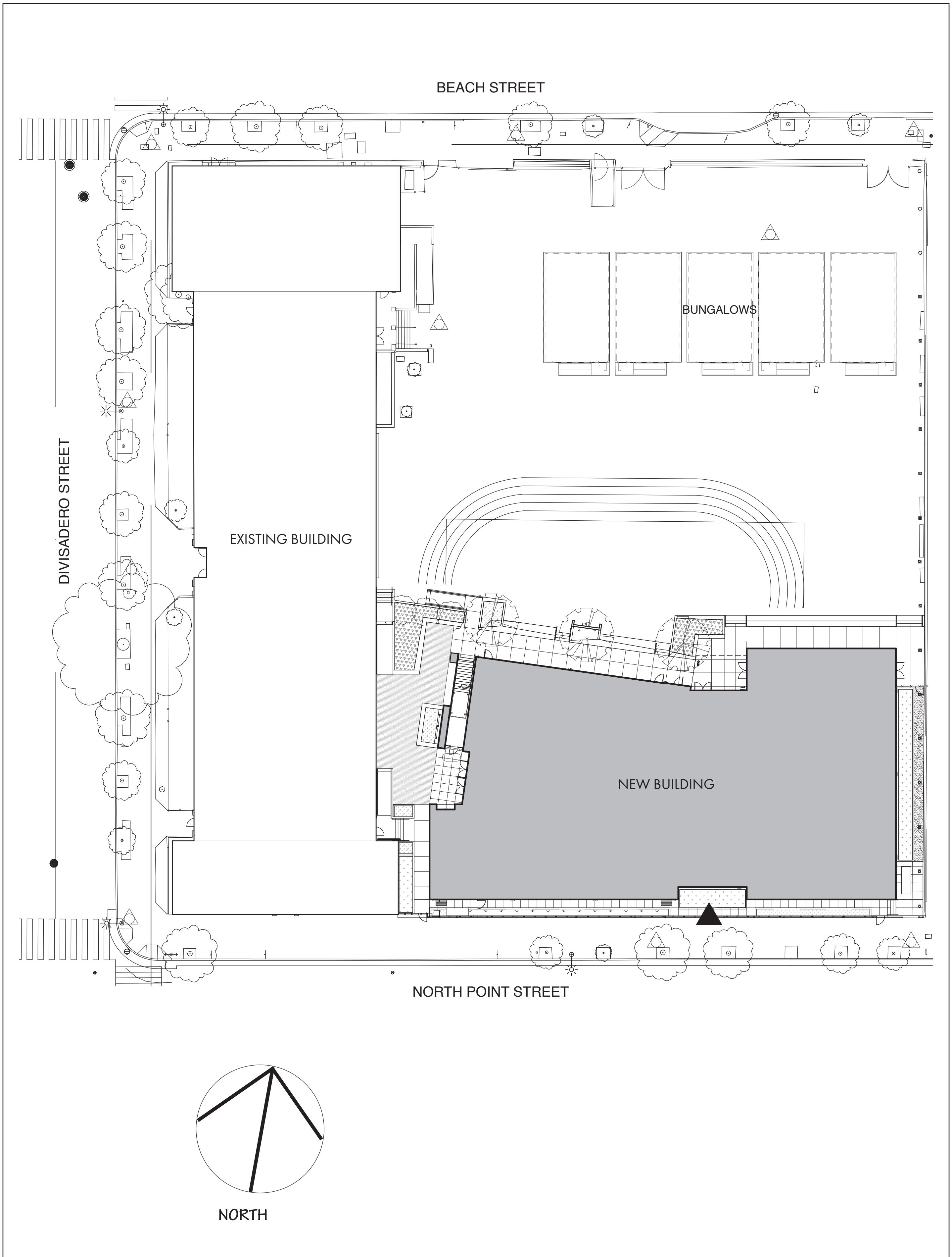
A standard RFP was issued in 2016 with the brief containing the newly adopted design standards and describing the new 12,000 square foot building as a "bungalow replacement" project. The brief also required the selected design team to carry out energy modeling at certain prescribed stages of design and demonstrate that the new building would achieve the specified target EUI. The design team was also required to document that the proposed design solution includes space for a solar PV system installation that would be adequate to produce ZNE performance.

The Lionakis/Capital Engineering design team was selected based on their previous experience with school projects and familiarity with the new ZNE design standards.

[1] EUI = Energy Use Intensity, the unit of measurement is kBtu/sq.ft. per year.

SFUSD Claire Lilienthal Middle School - General Vicinity Plan




BEACH STREET
BUNGALOWS
DIVISADERO STREET
EXISTING BUILDING
NEW BUILDING
NORTH POINT STREET
NORTH

(Opposite Page)
Site Plan for the new Claire Lilienthal Scott Campus (Courtesy of Lionakis)

Design Process and Low-Energy, Zero-Carbon Design Strategies

The site included one existing two-story building (built circa 1930) in addition to eight bungalows, which were designated for replacement. The existing building was scheduled for renovation as a separate project immediately after the new building was completed. It would ultimately serve grades 3-5 while the new building would be designed to accommodate grades 6-8, currently housed in the bungalows. Two classrooms would be added to the program for the new building along with a new gymnasium facility for the mini-campus, bringing the total new middle school facility to ten classrooms plus the gymnasium.

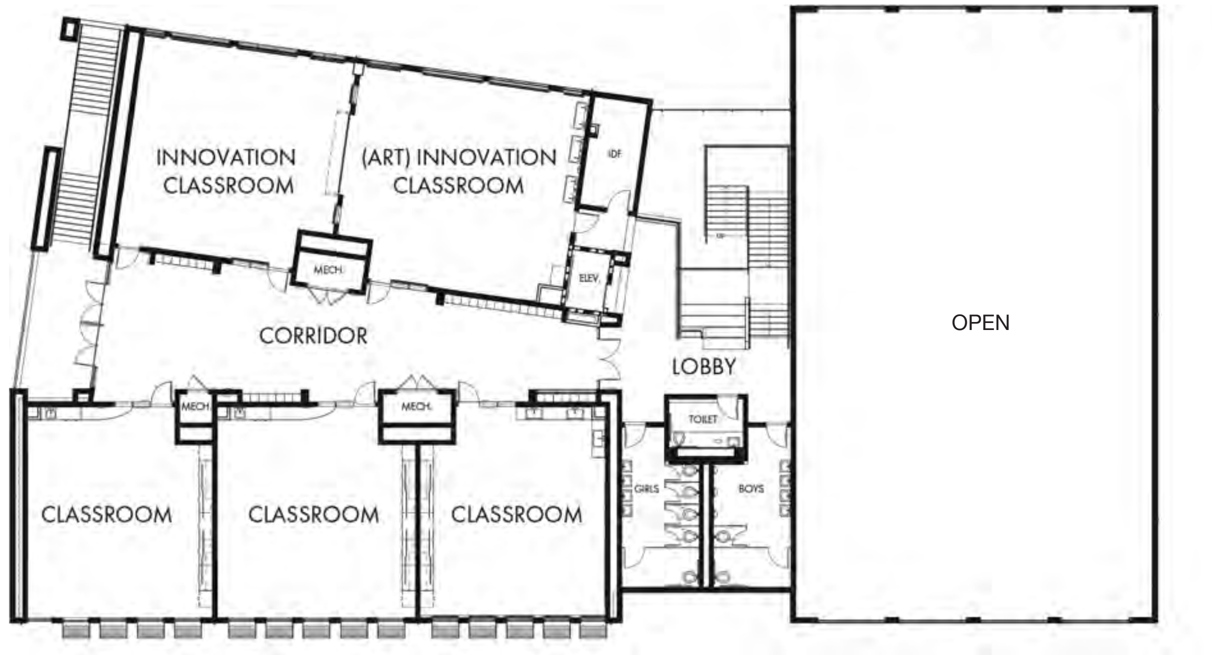
Planning Concept and General Design Considerations

Given site limitations, the *design parti* consists of two two-story classroom wings attached to the gymnasium. The two wings are canted to create a commons area between them, a natural gathering space for students and teachers. One wing hugs the south property line along North Point Street and is adjacent to one façade of the existing historic building. The second wing faces the shared play yard to the north. (See Site Plan)

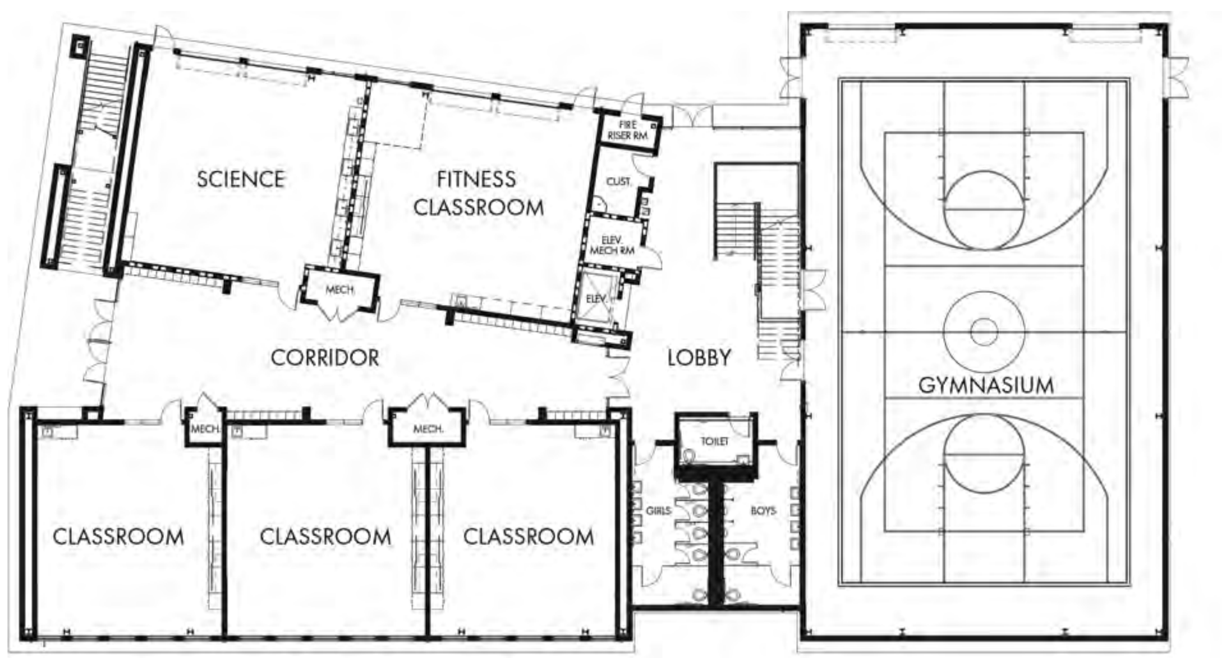
Six of the classrooms are standard size for about 35 students each. The remaining four are oversized classrooms for special purpose use such as *Maker Labs*, science labs, art and fitness equipment. Two of the latter are located on the ground floor and open directly to the yard via large rolling garage doors to enable indoor-outdoor use when the weather permits.

Meetings with neighborhood groups resulted in the agreement that the new building along the street frontage would align with the existing building and have the same type of visible roof form. Most importantly, there would be no added height due to building equipment, including solar PV panels. This created a challenge to reaching the "design standard" of the project, set at 20 kBtu/sq.ft per year by the earlier District studies, and still achieving ZNE performance. In fact, early analysis indicated that the energy produced by the PV system installed on the remaining two roofs would be only approximately 13.5 kBtu/sq.ft. per year.

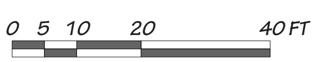
(Left) View along North Point Street, existing historic building at left and new middle school street facade beyond. (Photo: © Technical Imagery Studios)

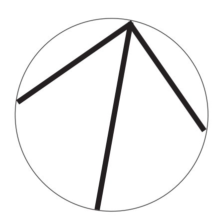


SECOND FLOOR PLAN



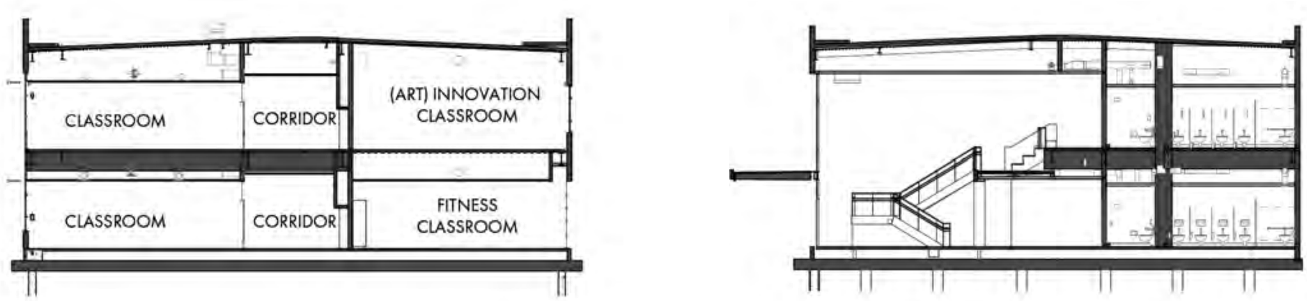
GROUND FLOOR PLAN





CLAIRE LILIENTHAL MIDDLE SCHOOL: FLOOR PLANS AND BUILDING SECTIONS

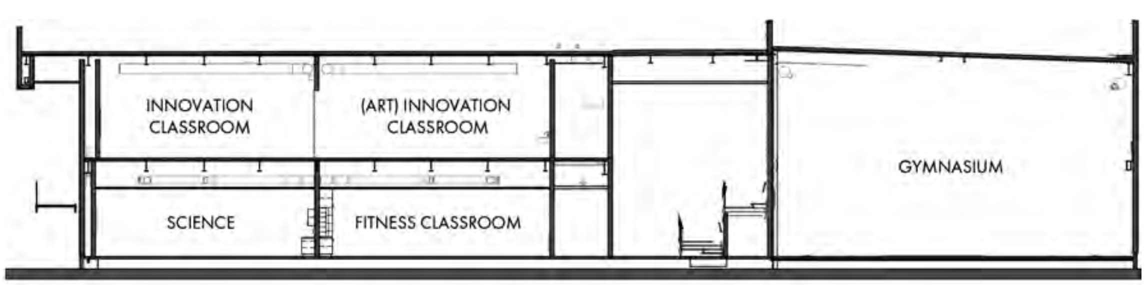
ROOF PLAN



LOOKING WEST

LOOKING EAST

TRANSVERSE (CROSS) SECTIONS



LONGITUDINAL SECTION

(Opposite Page) The building features large arrays of operable windows for cross-ventilation and daylighting. The gymnasium utilizes translucent wall panels and tubular skylights to daylight the space. (Photos: © Technical Imagery Studios)

Building Envelope

The first step in meeting the lower EUI target was to add more insulation to the exterior walls and roof. Light gauge metal framing is used in the wall construction, creating the potential for some thermal bridging, so a continuous layer of rigid insulation (R = 4) is applied over the entire exterior wall surface. The wall cavities are filled with batt insulation (R = 21), bringing the total R-value of the walls to R = 9.8, which includes the effect of thermal bridging. The rigid insulation on the roof is overlaid by a single-ply membrane, bringing the roof structure to R = 31.

The substantial window area, utilized for daylighting and natural ventilation, has dual pane insulated glazing units that have a low-e coating.[2] The frames are thermally broken: U = 0.45 and SHGC = 0.31. In addition, the windows on the south façade have custom exterior solar shading devices.

Daylighting and Electric Lighting

Daylighting has been a topic in school design for decades because of the perceived positive impact of glare-free natural daylight on learning. For the purpose of this case study, however, the focus is on the effect of the daylighting design strategies on reducing energy use. For the gymnasium, extensive clerestory lighting from two directions is provided by a translucent building panel system.[3] Several large tubular skylights[4] are utilized in the gymnasium to augment the clerestory panels by bringing controlled daylight into the middle of the large room.

For the classrooms, tall windows for good daylight penetration are combined with automatic daylight controls and occupancy sensors to minimize the need for electric lighting. The issue of preserving the maximum roof area for the installation of the solar PV panels essentially eliminated the possibility of utilizing the tubular skylights above the two-story classroom wing. Daylighting was limited to the side lighting provided by the tall classroom windows and the interior high windows in the wall to the common area between the classroom wings. The second floor common area is daylit by a number of the tubular skylights and some of that daylight is captured by the adjacent high windows of the interior classroom wall.

Natural Ventilation

A substantial portion of the window area is operable, allowing cooling breezes to provide much of the required space cooling in this mild climate.

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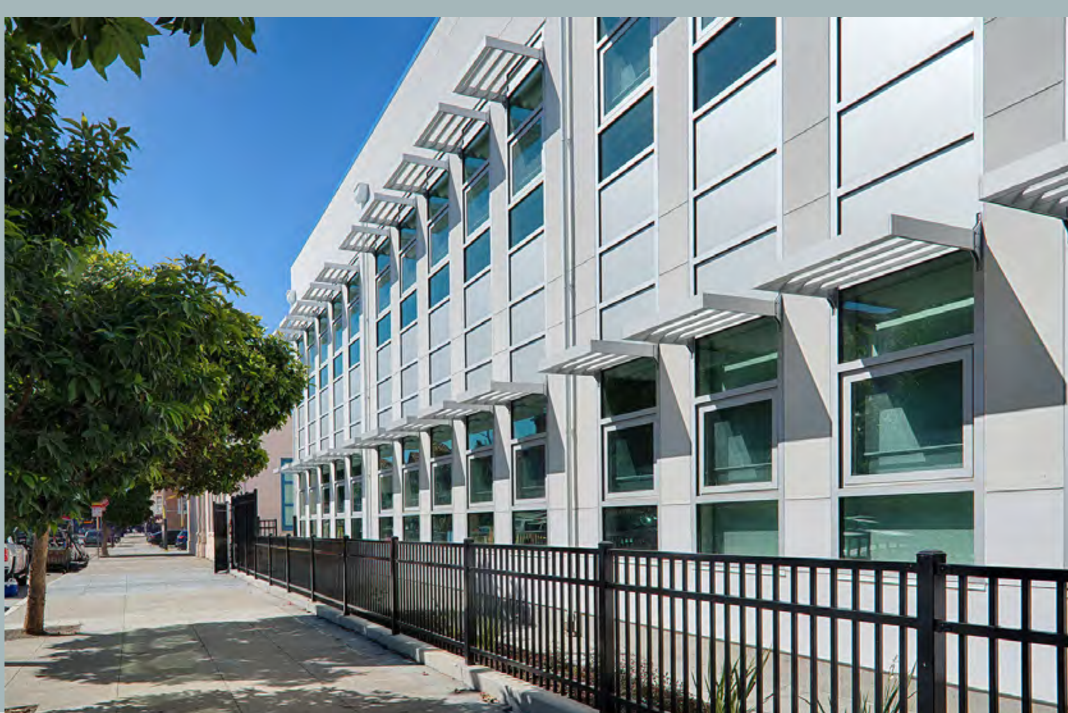
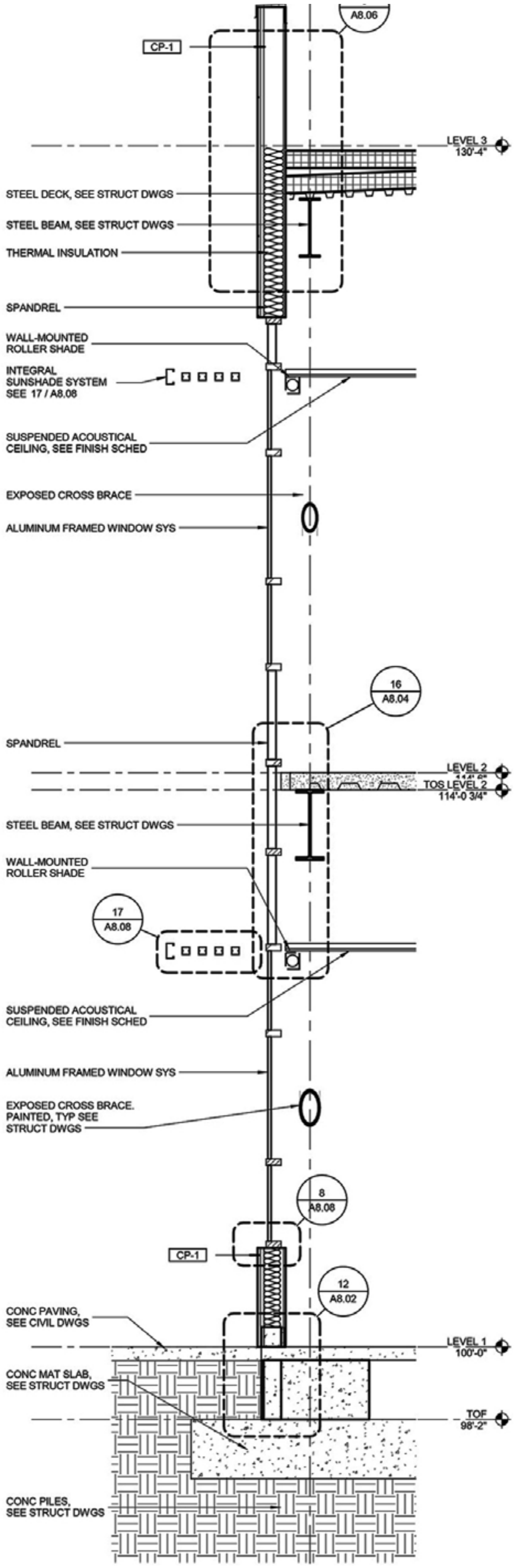
[2] Solarban 70 by Vitro Architectural Glass, https://www.vitroglazings.com/products/low-e-glass/solarban-70-glass/

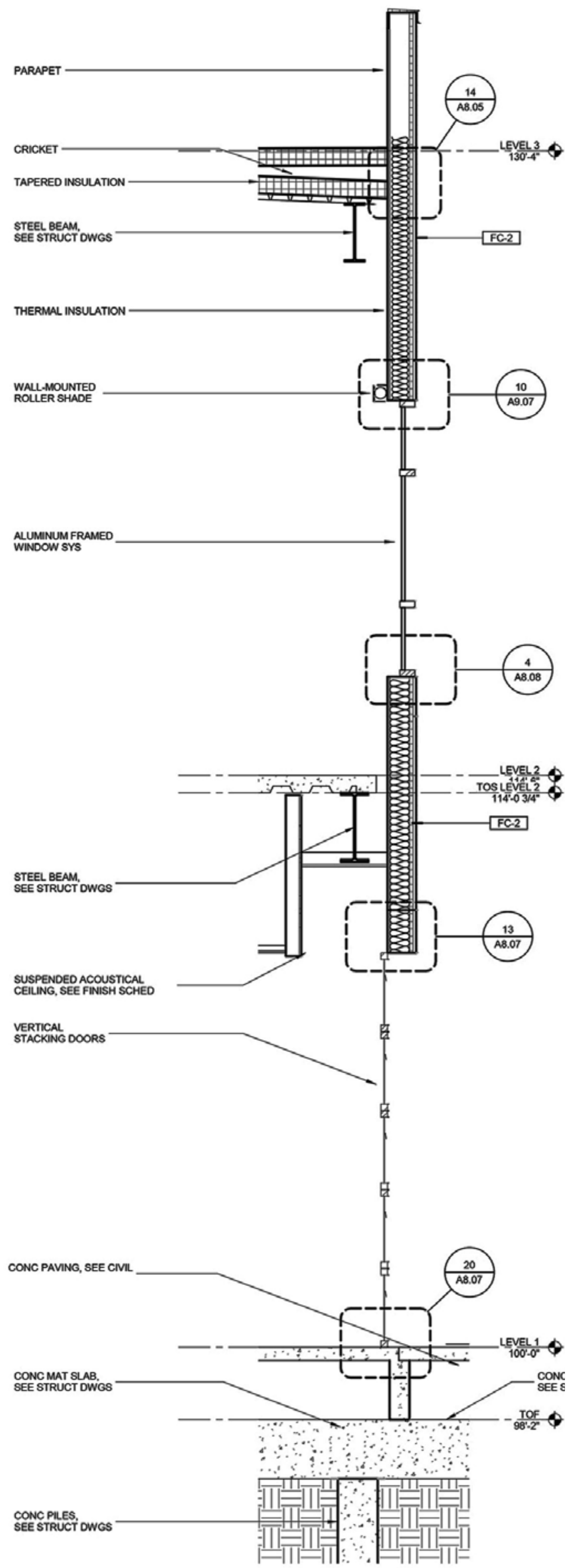
[3] Kalwall, https://www.kalwall.com/kalwall-products/

[4] Solatube Skyvault commercial skylights, https://solatube.com/commercial





SOUTH WALL SECTION



NORTH WALL SECTION

(Opposite Page) Wall sections at south and north facades showing continuous insulation detail, sun shade (south) and large glazing areas. (Courtesy of Lionakis)

Heating Systems

It is the SFUSD's policy to provide heating only, given the mild climate in San Francisco. Mechanical heating is provided when needed by electric heat pump package units on the roofs of the north classroom wing and the gymnasium. The gymnasium system is a high-efficiency VAV heat pump[5] serving the space immediately below the roof.

The classroom wings are provided with a variable refrigerant flow (VRF) heat pump package unit. This system uses refrigerant instead of air or water as the system's heat transfer medium, increasing the heat pump's overall efficiency. The classroom heat pumps are located at grade in order to maximize the roof area available for solar PV system. Each individual classroom is heated by a conventional vertical fan coil unit located in the room.

Domestic Hot Water

The toilet rooms are supplied by a conventional electric resistance water heater.

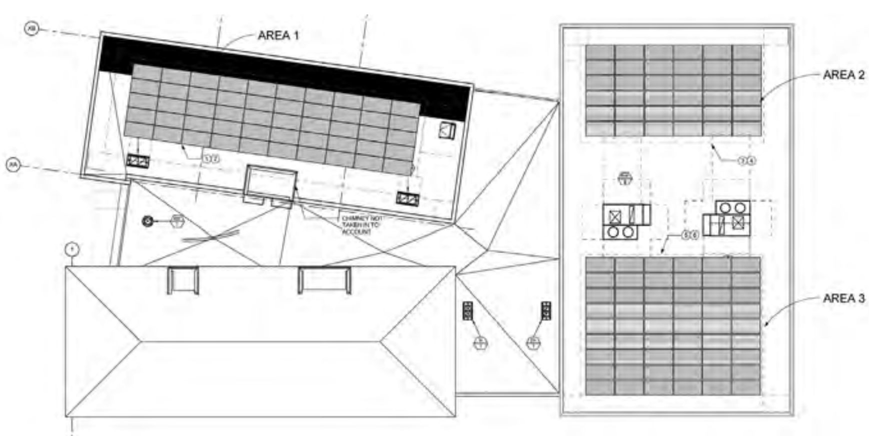
Master System Integration and Control Systems Integration

Because of the building's size, its environmental management is largely controlled by individual system controls and manual operation rather than a centralized system.

Renewable On-Site Energy Supply

The principal issue for the solar PV system is the limitation on available roof area for the panels required by the agreement at the neighborhood group meetings. As noted, the modeling of the performance of the solar PV system located only on the roofs of the gymnasium and the north classroom wing predicted an annual production total of 82,530 kWh assuming a high output panel of 415 watts, or 13.4 kBtu/sq. ft. per year. This matched the total annual energy use modeled for the building, so the ZNE performance goal was shown to be achievable at least according to the assumptions of the energy modeling.

SFUSD did not install the solar PV system for funding reasons when the building opened in the fall of 2019. The plan currently is to enter into a PPA (solar power purchase agreement) with a supplier in 2022. The solar PV system will be installed on the planned roof areas and SFUSD will pay a low rate per kWh for the electricity generated.



[5] Daikin Rebel package rooftop heat pump. https://www.daikinapplied.com/products/rooftop-systems/rebel

PHOTO: © TECHNICAL IMAGERY STUDIOS

(Opposite Page) Classroom interior showing operable windows for natural ventilation and daylighting.

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

Energy Use — Modeling

Energy modeling was carried out using Energy Pro, the mandated code compliance software in California. Per the District requirements for the project design process, computer modeling was done at certain stages of design to demonstrate that the new building would achieve the specified target EUI. The design team also utilized the modeling for parametric studies to determine required energy efficiency characteristics of the building features necessary to meet this target EUI. A chart showing the annual modeled energy use of the final design is shown on the next page, along with a chart of the monthly modeled energy consumption broken down by category of use.

As noted above, *PVWatts*[6] was used to estimate the annual energy produced by the high efficiency solar PV panels that could be fit on the two roof areas of the building. See the chart, *Solar Photovoltaic System Performance*, on p. 107 for the estimated monthly production as calculated using *PVWatts*.

Energy Use — Actual Measurement and Comparison to Modeling Results

Until August 2021, there was only one meter measuring the energy consumption of the existing building combined with that of the new middle school building. That month, a separate metering subsystem[7] was installed for the new building, which measures the energy used on each circuit and stores the data in the system. Therefore, there is not yet detailed measured data available on the building performance to confirm that the ZNE design goal was achieved.

Some indication is possible, however, by using data collected by the one meter for the period 2015-2020. This meter recorded the total energy use in the existing building for four years before the middle school began occupancy in late summer of 2019. At that time, the data recorded by that one meter is the combination of the energy used by the two buildings for that school year (2019-2020) before classes were suspended in the spring of 2020.

An approximation of the energy use for the new building for that one school year can be made from this combined data by subtracting the yearly average of the energy consumption previously recorded for the existing building alone. This approximation of annual energy use by the new building totals 107,550 kWh, or 16.7 kBtu/sq.ft. These numbers are a bit higher than the modeled energy use. When detailed metered data becomes available in the next year, a more accurate comparison can be made.

Energy Production versus Energy Use: Zero Net Energy

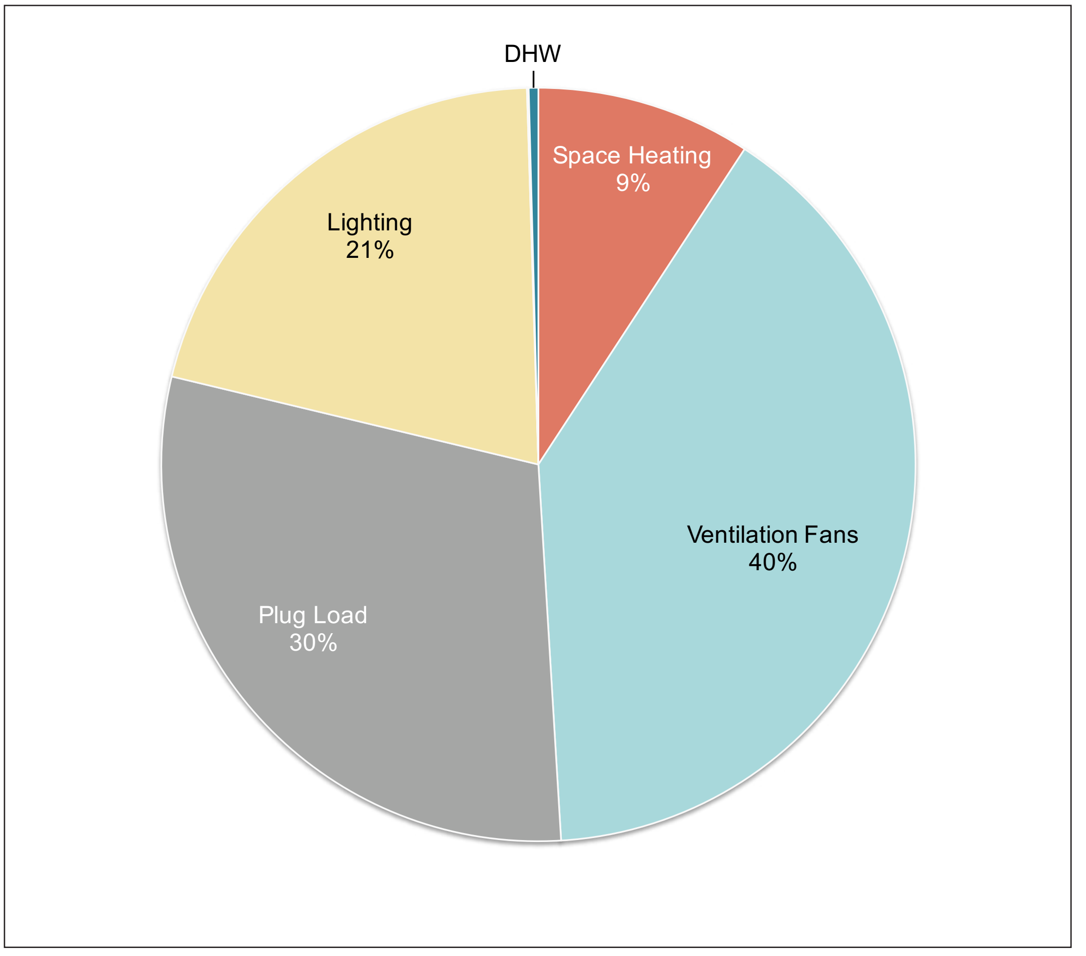
Similarly, when the solar PV system is installed as tentatively scheduled for 2022, the recorded data will show if the measured energy use of the new building can be entirely offset by the system production. The top chart on p.107, *Solar Photovoltaic System Performance*, uses the estimated annual production calculated with *PVWatts* in the meantime. The bottom chart on that page, *Cumulative Net Energy Performance*, sums the net energy production each month to that of the month prior, so that the annual total would be exactly zero if the performance is zero-net-energy (ZNE). The approximations show the building theoretically performing just below ZNE. Actual data from the years 2022-2023 may be different.

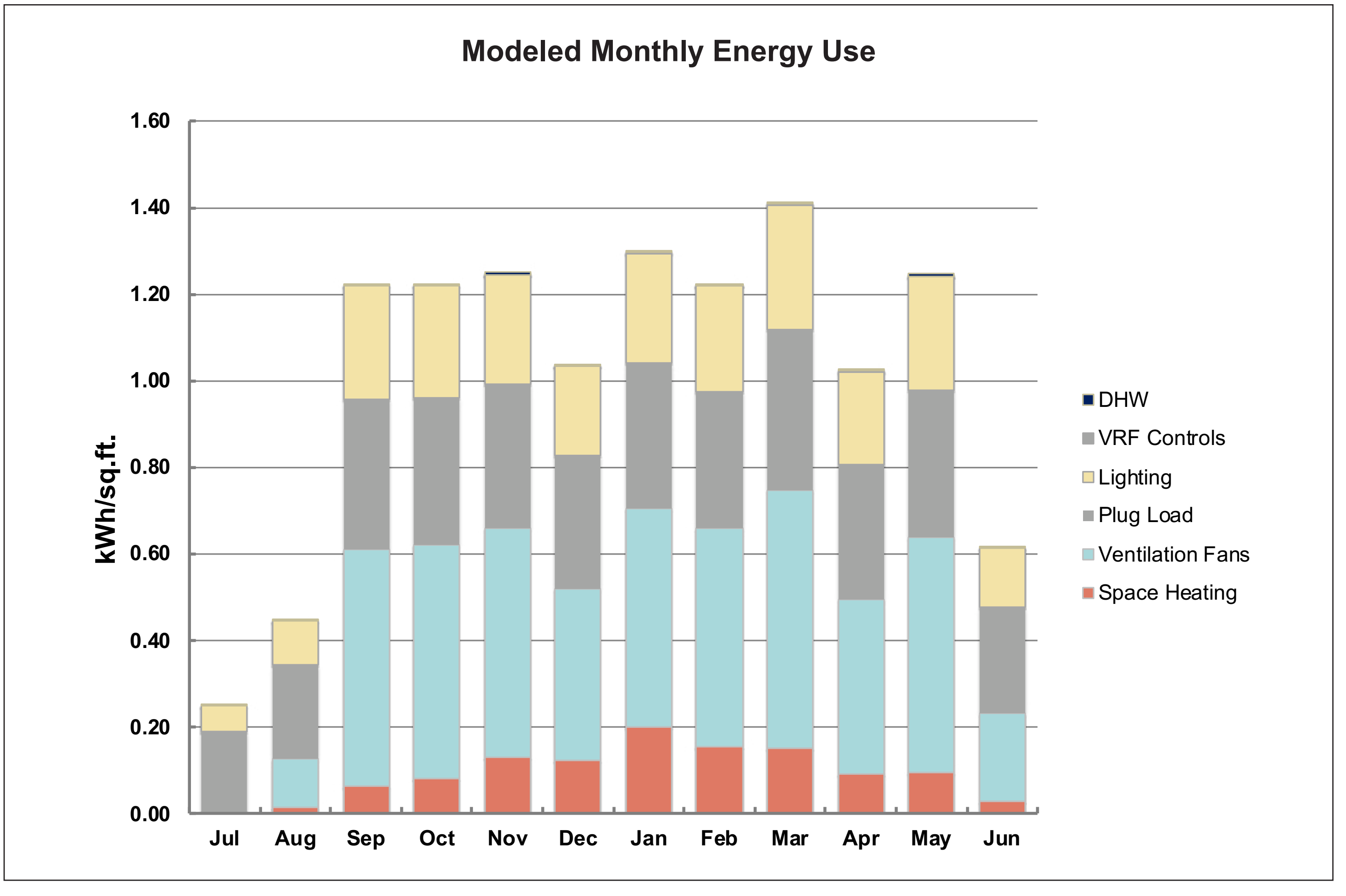
[6] National Renewable Energy Laboratory (NREL) calculator for estimating energy production of grid-connected solar photovoltaic (PV) energy systems. https://pvwatts.nrel.gov/

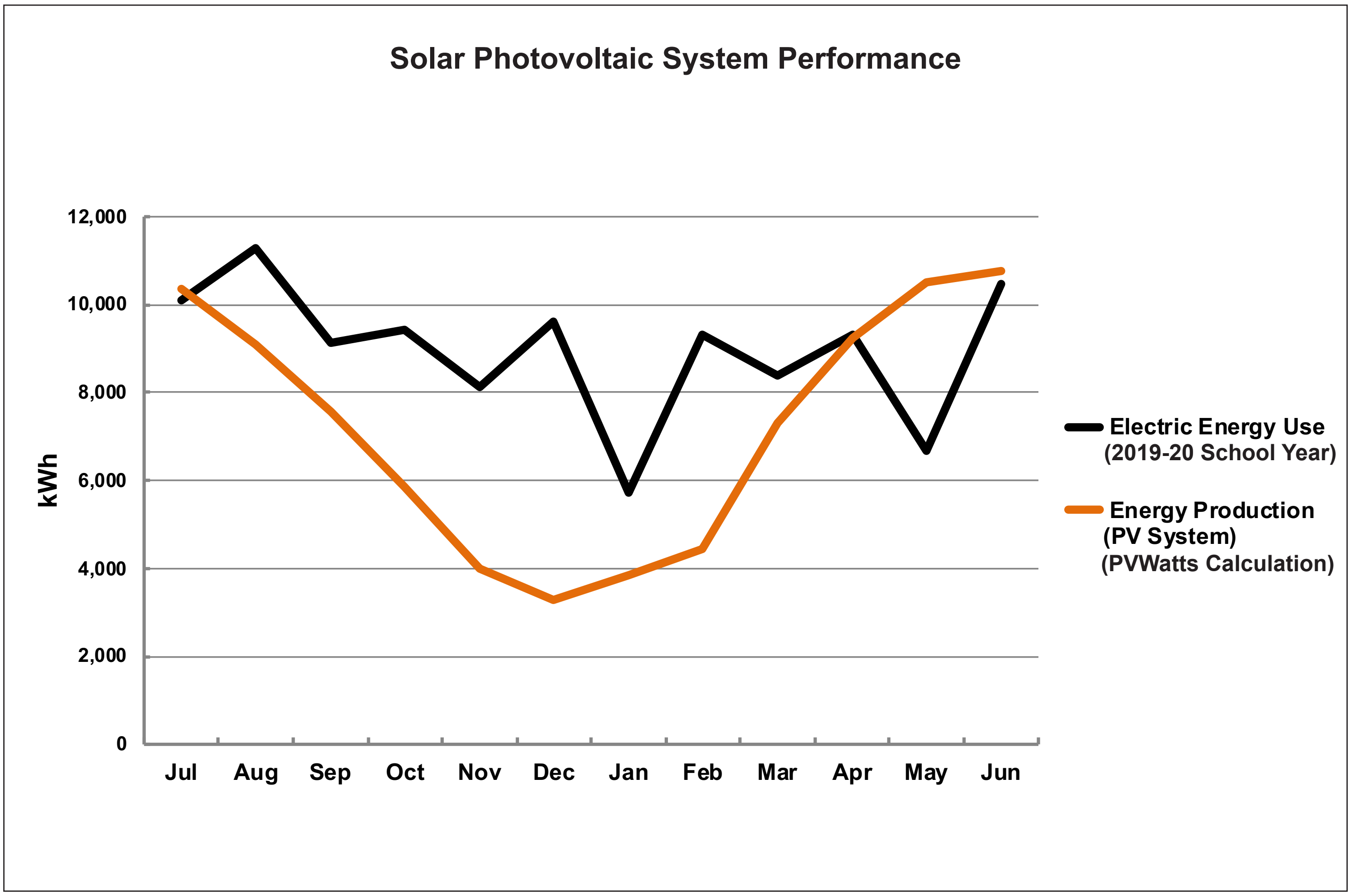
[7] The eGauge unit combines an energy meter, data logger and a web server. https://www.egauge.net/commercial-energy-monitor/#overview

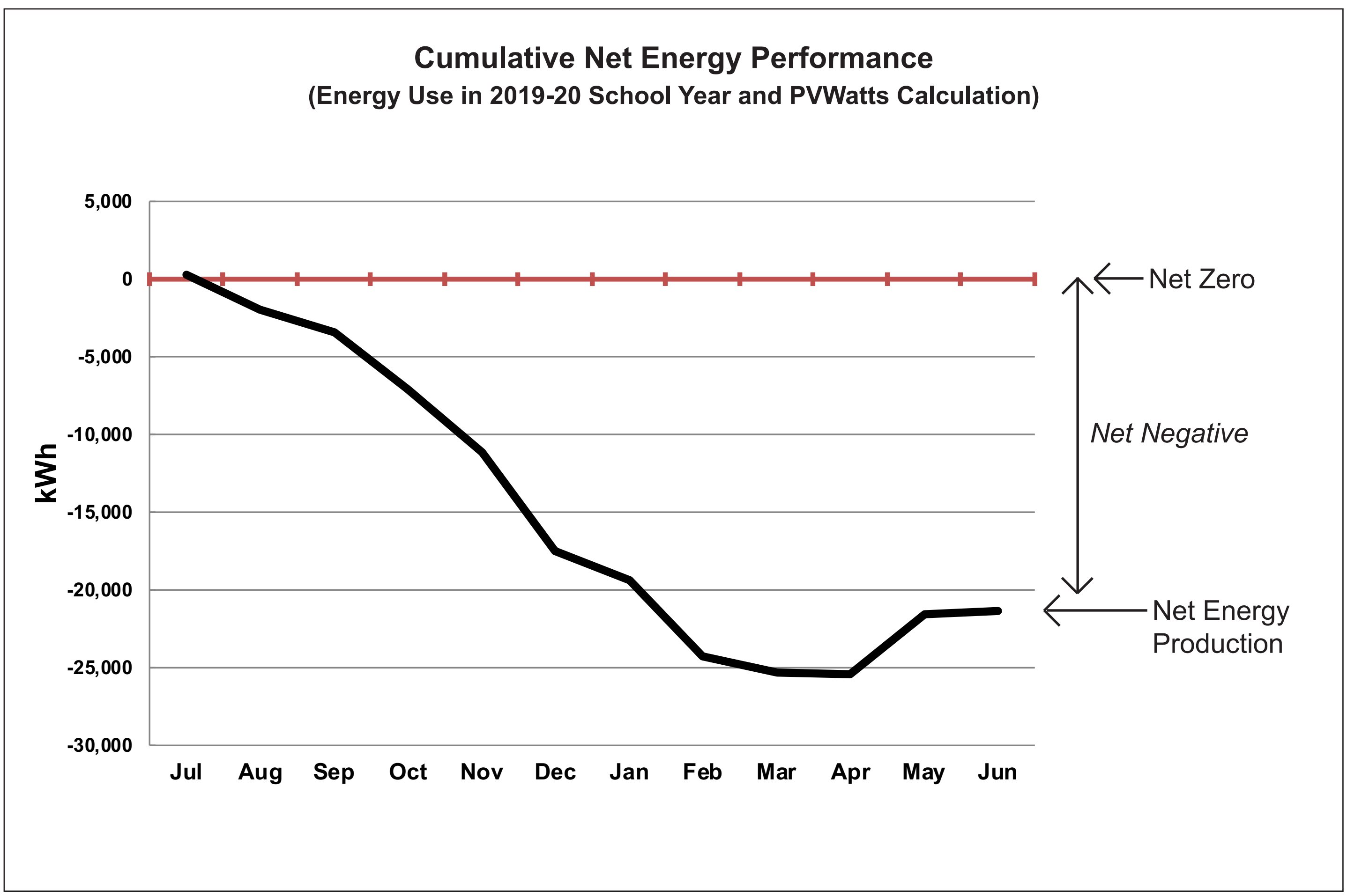
Modeled Energy Use (Annual)

82,476 kWh/year
Modeled EUI = 13.4






Solar Photovoltaic System Performance
12,000
10,000
8,000
6,000
4,000
2,000
0
kWh
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Electric Energy Use (2019-20 School Year)
Energy Production (PV System) (PVWatts Calculation)


Cumulative Net Energy Performance
(Energy Use in 2019-20 School Year and PVWatts Calculation)
5,000
0
-5,000
-10,000
-15,000
-20,000
-25,000
-30,000
kWh
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Net Zero
Net Negative
Net Energy Production

Post Occupancy: Observations and Conclusions

The post-occupancy period has been dominated by reaction to the Covid19 pandemic, which caused the school to close shortly after opening in the fall of 2019. Occupancy resumed in the fall of 2021, the new submetering system was recently installed at that time and the solar PV system will be operational in 2022. The set of *lessons learned* is in progress at the time of this case study. However, there are a number of observations that can be made in the early post-occupancy period.

Post Occupancy: Design Standards (EUI, ZNE)

The studies that preceded the beginning of the work mandated by Proposition A and that resulted in the SFUSD energy/carbon design standards and procedures proved very beneficial to both the District and the A/E teams. SFUSD had a road map for the future projects that would save time and money, and that would produce the optimal designs for each type of school building. The A/E teams were given a well-defined process and the benchmark targets for the design. Zero net energy and zero carbon (all-electric) design goals were pre-established with a process for achieving them.

Post Occupancy: Data Metering

The post-design / post-construction process was not so well defined. No provision was made for submetering the new building and obtaining the performance data for each energy sub-system. Careful performance monitoring of these systems and post-occupancy evaluation was not possible. This has been corrected by the installation of a separate data metering system for the new building. The data measurement is both an important check of the early-stage energy modeling and a verification that the project goals were in fact achieved.

Post Occupancy: HVAC Systems

The systems installed in the new building are highly energy efficient but also unusual for standard school building applications. The newer technologies involved in this new equipment are relatively unfamiliar compared to those previously installed and maintained in these buildings. The District maintenance staff has experienced a “learning curve” in the process of routine maintenance and troubleshooting issues. This was not unexpected and required a certain amount of staff training as a result.

Post Occupancy: Daylighting

Teachers generally report satisfaction with the daylighting provided by the tall classroom windows and control of natural ventilation. Some daylighting analysis was performed by the architects for the classroom and by the manufacturer of the translucent panels for the gymnasium, but no design adjustments were reported as a result.

Post Occupancy: Embodied Carbon Assessment

The Middle School building was designed in 2017 before analytical tools for embodied carbon assessment were widely available. The SFUSD development of energy/carbon design standards for school buildings prior to that likewise did not include a standard for evaluating embodied carbon. The client and design team therefore did not carry out such an evaluation as is customary for buildings designed today. The consensus among the members of the project team is that this embodied carbon assessment would now be included in the District design standards and the required design studies on specific projects.

PHOTO: © TECHNICAL IMAGERY STUDIOS

Conclusion ▷

Epilogue

Additional Exemplary All-Electric Low-Energy Buildings

The projects shown on these pages are recently-completed buildings, both new and renovated structures, that were designed with all-electric energy systems. These are noteworthy for their energy-efficient design, leading in most cases to an expected zero-net-energy (ZNE) performance when measured over the next few years. Some feature battery storage systems for load shifting to off-peak times and for added resiliency. Two of the projects (Sonoma Academy and SFUSD Central Kitchen) have large kitchens utilizing the latest all-electric cooking appliances.

These projects are listed here to provide the reader with additional resources to study all-electric buildings of all types.

The projects shown on these pages demonstrate the range in size and complexity of all building types that can be all-electric for both public and private clients.

Conrad Hilton Foundation Headquarters *(Below)*
Special Feature: Buliding ventilation via natural air flows created by thermal chimney effect

Building Type: Two-Story Office
Gross Floor Area: 22,240 gsf
Occupied: 2012

Modeled EUI (Site)
22.6 kBtu/sf-year
Measured EUI (Site)
34.0 kBtu/sf-year
On-Site Renewable Energy System Installed
24.1 kW (DC) Solar PV
Measured On-Site Energy Production
189,000 kWh/year
29.0 kBtu/sf-year

HVAC System
Passive Downdraft Ventilation with Water-Cooled Chiller
DHW
Solar Thermal with Electric Storage Tank

Project Team
Client:
Conrad Hilton Foundation
Architect:
ZGF Architects, L.A.
Mechanical Engineering:
WSP / Built Ecology

Agoura Hills, California

Conrad Hilton Foundation Headquarters

Sonoma Academy Guild & Commons Building *(Top)*
Special Feature: All-electric commercial kitchen serving entire school

Page Center at Sierra Nevada Aquatic Research Lab *(Bottom)*
Special Feature: Ground source heat pump in cold mountain climate

Santa Rosa, California

Sonoma Academy Guild & Commons Building

Building Type: Two-Story High School Classroom and Commons Building

Gross Floor Area: 19,500 gsf

Occupied: 2018

Modeled EUI (Site)
36.8 kBtu/sf-year

Measured EUI (Site)
34.1 kBtu/sf-year (20xx)

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

Measured On-Site Energy Production
210,646 kWh/year (2019)
36.8 kBtu/sf-year (2019)

HVAC System
Ground-Source Heat Pump w Radiant Slabs

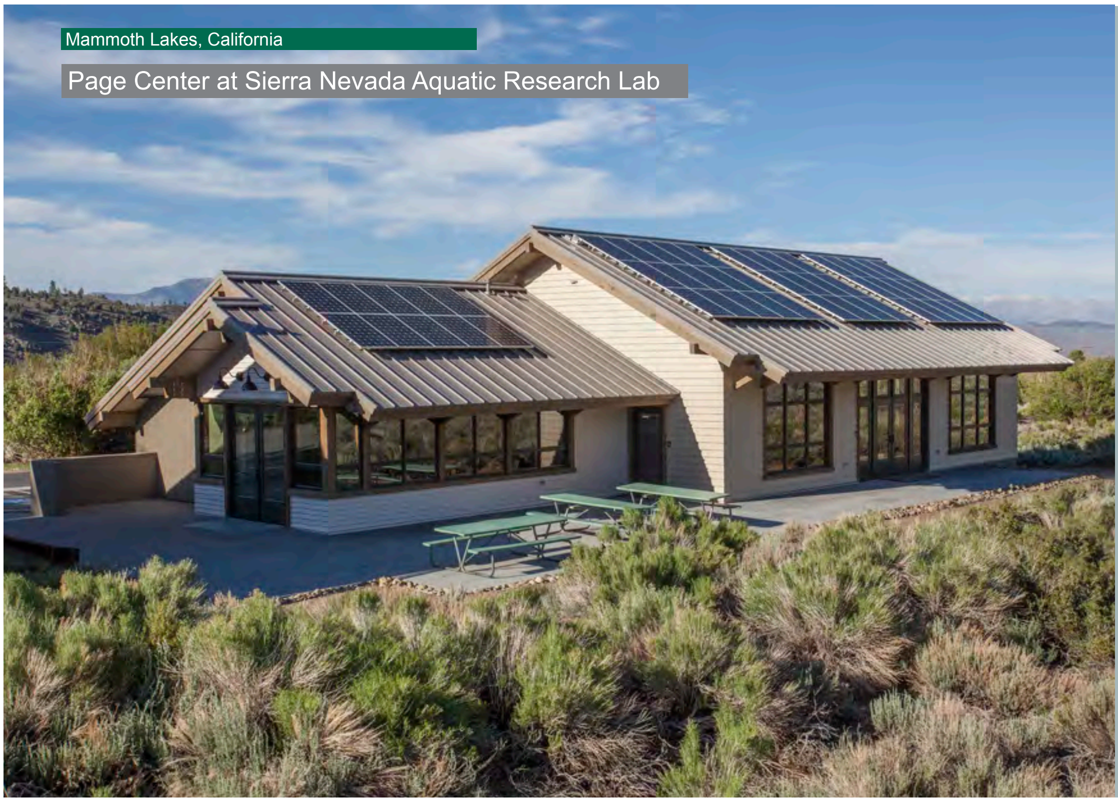
All-Electric Kitchen
Induction cooktops, Energy Star appliances (ovens, toast-ers)

Project Team

Client:
Sonoma Academy

Architect:
WRNS Studio, San Francisco

Mechanical Engineering:
Interface Engineering



Mammoth Lakes, California

Page Center at Sierra Nevada Aquatic Research Lab

Building Type: Academic Classroom Building

Gross Floor Area: 2,696 gsf

Occupied: 2015

Modeled EUI (Site):
41.3 kBtu/sf-year

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

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

Measured On-Site Energy Production:
24,763 kWh/year
31.4 kBtu/sf-year (2016)

HVAC System
Ground-Source Heat Pump, ERV

DHW
Electric Water Heater

Project Team

Client:
UC Santa Barbara

Architect:
Thompson Naylor Architects, Santa Barbara

Mechanical Engineering:
Mechanical Engineering Consultants, Santa Barbara

Emissions Testing Center - Calif. Air Resources Board *(Top)*
Special Features: Entire all-electric campus (including food services) with ZNE performance.

LBNL Integrative Genomics Laboratory *(Bottom)*
Special Features: Includes 5,000 gsf all-electric Modular Utility Plant (MUP), which had sufficient capacity to support four additional buildings slated for the future.

Building Type: Three-story Office/Lab Facility
Gross Floor Area: 403,300 gsf
Occupied: 2021

Modeled EUI (Site)
55 kBtu/sf-year
Measured EUI (Site)
To be completed 2022

On-Site Renewable Energy System Installed
3,800 kW (DC) Solar PV
Measured On-Site Energy Production
To be completed 2022

HVAC System
Chilled beam with evaporative cooling
DHW
Heat recovery w electric resistance

Project Team
Client:
California Air Resources Board, Sacramento
Architect:
ZGF Architects, L.A.
Mechanical Engineering:
Affiliated Engineers, L.A.

Riverside, California

Emissions Testing Center - Calif. Air Resources Board

Building Type: Four-Story Research Laboratory + Office
Gross Floor Area: 80,914 gsf
Occupied: 2019

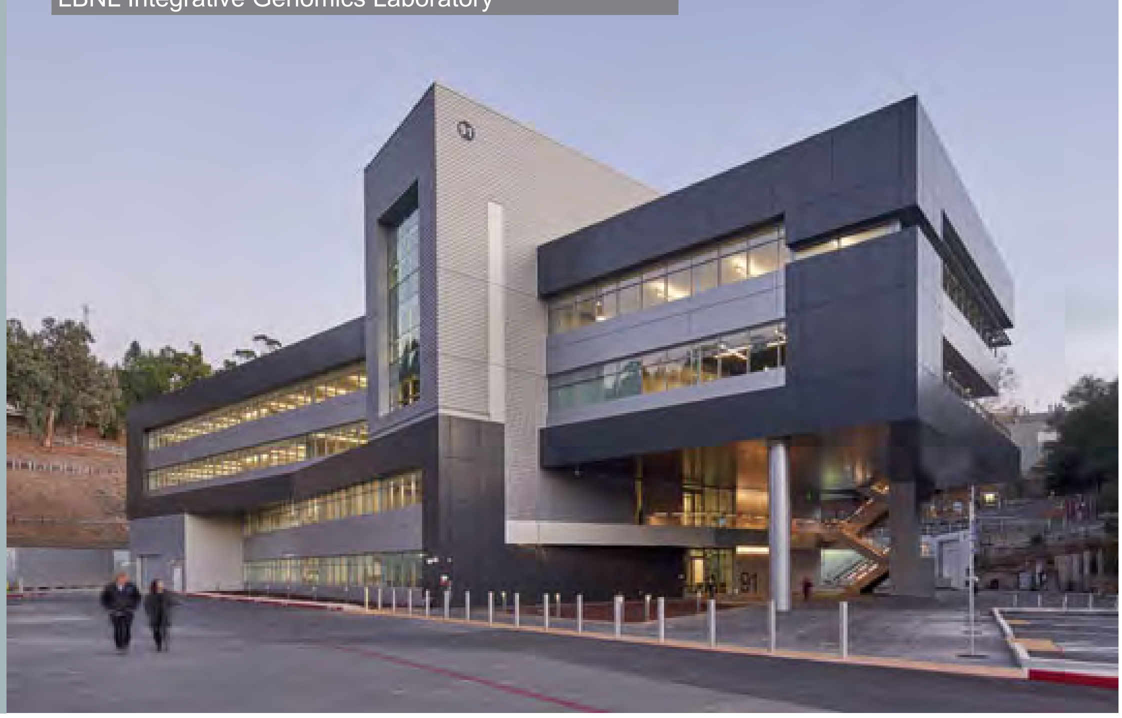
Modeled EUI (Site)
117 kBtu/sf-year
Measured EUI (Site)
106 kBtu/sf-year (2020-2021)
On-Site Renewable Energy System Installed (Planned)
300 kW (DC) Solar PV
Measured On-Site Energy Production
(PV system not yet installed)

HVAC System
Air Source Heat Pumps with chilled beams & radiant slabs. DOAS with heat recovery
DHW
Water/Air Source Heat Pumps

Project Team
Client:
Lawrence Berkeley National Laboratory
Architect:
Smith Group, S.F.
Mechanical Engineering:
Integral Group, Oakland

Berkeley, California

LBNL Integrative Genomics Laboratory



NIAC Headquarters Building *(Top)*
Special Features: 250 kWh battery packs for energy storage provides continued operation in event of community emergency or natural disaster.

Central Kitchen at McAteer - SF Unified School District *(Bottom)*
Special Features: Completely outfitted electric commercial kitchen.

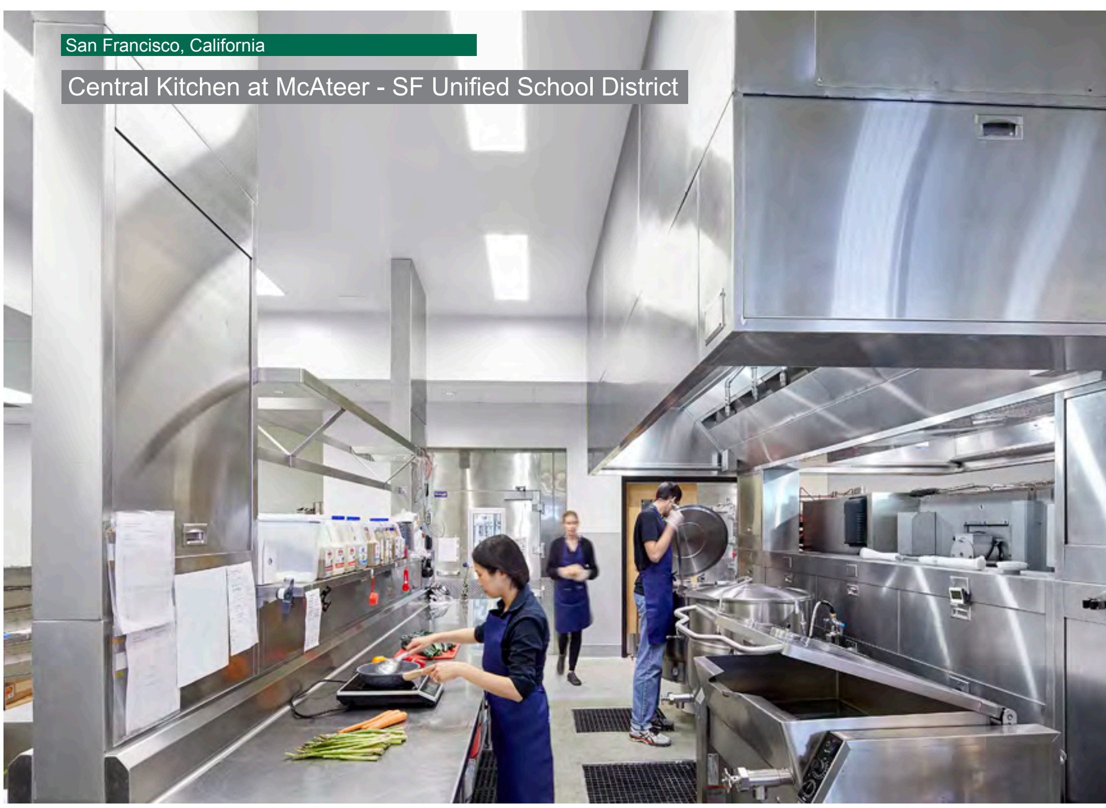
Building Type: Three-Story Office Building
Gross Floor Area: 26,000 gsf
Occupied: 2020

Modeled EUI (Site)
24.1 kBtu/sf-year
Measured EUI (Site)
To be completed 2022

On-Site Renewable Energy System Installed
125 kW (DC) Solar PV
Measured On-Site Energy Production
To be completed 2022

HVAC System
Air Source Heat Pumps with chilled beams & radiant slabs. DOAS with heat recovery
DHW
Heat Pumps

Project Team
Client:
Nonprofits Insurance Alliance of California, Santa Cruz
Architect:
EHDD Architecture, S.F.
Mechanical Engineering:
Integral Group, Oakland



Building Type: Central Kitchen for School District
Gross Floor Area: 9,000 gsf
Occupied: 2019

Modeled EUI (Site) - N/A
Measured EUI (Site)
To be completed 2022
On-Site Renewable Energy System Installed - N/A

HVAC System
Electric indoor fan coils, outdoor fan condensing units, demand ventilation system
All-Electric Kitchen
Induction cooktops, two-deck combi oven, two-deck electric convection oven, electric kettles, 60 Gal. electric tilt skillets, blast chill, mobile hot cabinet for batch cooking. Portable induction hobs for the special diet meal prep

Project Team
Client:
San Francisco USD
Architect:
Gould Evans, S.F.
Mechanical Engineering:
Capital Engineering Consultants, Alameda

Observations

A Period of Transition

As pointed out in the Introduction to this volume, these case study projects were designed in a period of transition from an emphasis on *zero-net-energy (ZNE) buildings* (emphasizing on-site renewable energy systems) to *all-electric buildings.* The continuing goal is the reduction of carbon emissions caused by buildings but the design strategies are shifting focus to reflect the fact that the electric utility grid is moving toward carbon-free production within 25 years.

ZNE buildings with on-site solar photovoltaic systems would nearly eliminate their operating carbon emissions by having minimal dependence on a largely fossil-fuel-based electric utility grid. But any all-electric building in California will effectively achieve the same type of emission reduction once the electric utility grid is 100% zero-carbon as mandated law (SB100).

Since this law just went into effect in 2018, the transition in design emphasis has only just begun. In many ways, the five case studies in this volume reflect the transition underway—all have roof-mounted solar photovoltaic systems of sufficient size to offset the annual energy demand of the building and were designed to be all-electric for project-specific reasons. While all five designs bear the hallmarks of ZNE buildings, they nevertheless also display the design strategies of the near future for energy-efficient, zero-carbon (operational) buildings.

Continuity: Proven Design Strategies

In addition to being transitional, the case studies in this volume show a continuity of design strategies with those employed by the case study projects of the previous volumes of this series, some of which were all-electric. (See the Prologue on page xii of the introductory sections.) These basic design strategies are proven successful at this point. However, there also continue to be issues with some aspects of these strategies that were not uniformly addressed during the design of even these exemplary projects.

- Building metering and performance verification

  When ZNE performance was the primary goal in previous case studies, planning during the design phases for energy metering of both the subsystem energy use (heating, cooling, lighting, plug loads, etc.) and the solar PV production was essential. Comparison to energy modeling results and troubleshooting subsystem inefficiencies were important aspects of achieving ZNE performance. Despite the transition to a decarbonized utility grid and the corresponding relaxation of ZNE as the ultimate design goal, energy metering nevertheless still has value for the facilities management of the building, identifying patterns of energy use or possible equipment malfunctions or just inefficient operation. Metering is also particularly useful to maintain maximum operational efficiency of the solar PV system, still a relatively unfamiliar system for most facilities maintenance staff.

  In two of the case study buildings in this book, however, the building metering system was not only not planned or installed initially, but their utility net-metering was not even separated from existing buildings present on the site. This condition is in the process of being corrected in both cases, so that important data for the new structures will begin to be collected in the near future.

  Energy efficiency and optimal solar PV system performance will still be high operational priorities in our decarbonized building future, both for individual owners and the public utility operators. Systematic metering will help to ensure this.

- Commissioning and control systems

  This decarbonized building future will be characterized by sophisticated, “smart” buildings that will be more comfortable and more energy-efficient. Modern building management systems (BMS) will control and coordinate the linked subsystems that produce these effects—automatic blinds for optimal sun control, operable windows for free cooling and fresh air, electric light controls to maximize daylight and minimize glare and occupancy sensors for waste-free cooling. This will be standard and cost-effective.

As some of the case studies of this volume demonstrate, however, the commissioning of these subsystems and the BMS is best when coordinated in the design process and certainly completed during the construction period. In one case, the commissioning was not completed prior to occupancy with predictable and unfortunate negative effect. As noted in previous case study volumes (see page xi of the Introduction), the commissioning has often been neglected as a building design discipline. In the era of smart building control systems, the commissioning agent should participate early in the process as a key member of the project team. This has been a continuing observation in these case study books.

- User training and involvement

Smart buildings to some degree can operate optimally to provide comfort and energy-efficiency through designed intelligent control systems. Within those designs, there is usually an accommodation for occupant interaction, but typically they operate best when the occupant is informed about the systems operations and behaves accordingly. Assuming that they are regular building users and have a sense of ownership of the spaces, then targeted signage, user manuals and orientation meetings work well to optimize the use of the buildings systems. Electronic flat screen displays that can display real time performance data about the building operation encourage more occupant involvement and understanding.

For these case studies, these efforts at informing the users were not surprisingly more successful at the educational institutions.

(Left) Examples of building signage developed along with occupant training sessions about how to control environmental conditions and operate basic systems in the workplace.

Looking Ahead

- Battery storage and peak load shifting

  With grid decarbonization will come serious issues of the public utility's need to manage the impact of the variation in both the electric energy demand on the grid and the electric energy supply coming from wind and solar sources. (See the discussion of *grid harmonization* in the Introduction, page x.) This will lead to more buildings with *energy storage systems* to take advantage of time-of-day energy price structures if they operate significantly during the peak load periods in the evening hours.

  An additional consideration may be *resiliency*, the ability to operate in short-term periods of service interruption from the public utility grid. Recent extreme natural events in several parts of the country that disrupted ordinary service to large populated areas have brought the planning issue forward, again suggesting some form of short-term energy storage system as an essential part of the design.

  None of the case study projects in this book considered this feature as a solution for a recently evolving design issue, but change is expected in the future.

- Assessing embodied carbon impacts

  Another newly emerging aspect of zero-carbon building design is *embodied carbon*. As the electric grid is decarbonized within the next 25 years, this will remain a source of building carbon emissions due to the construction of buildings, especially new buildings—thus the need to address this issue thoroughly in the design phases of future projects.

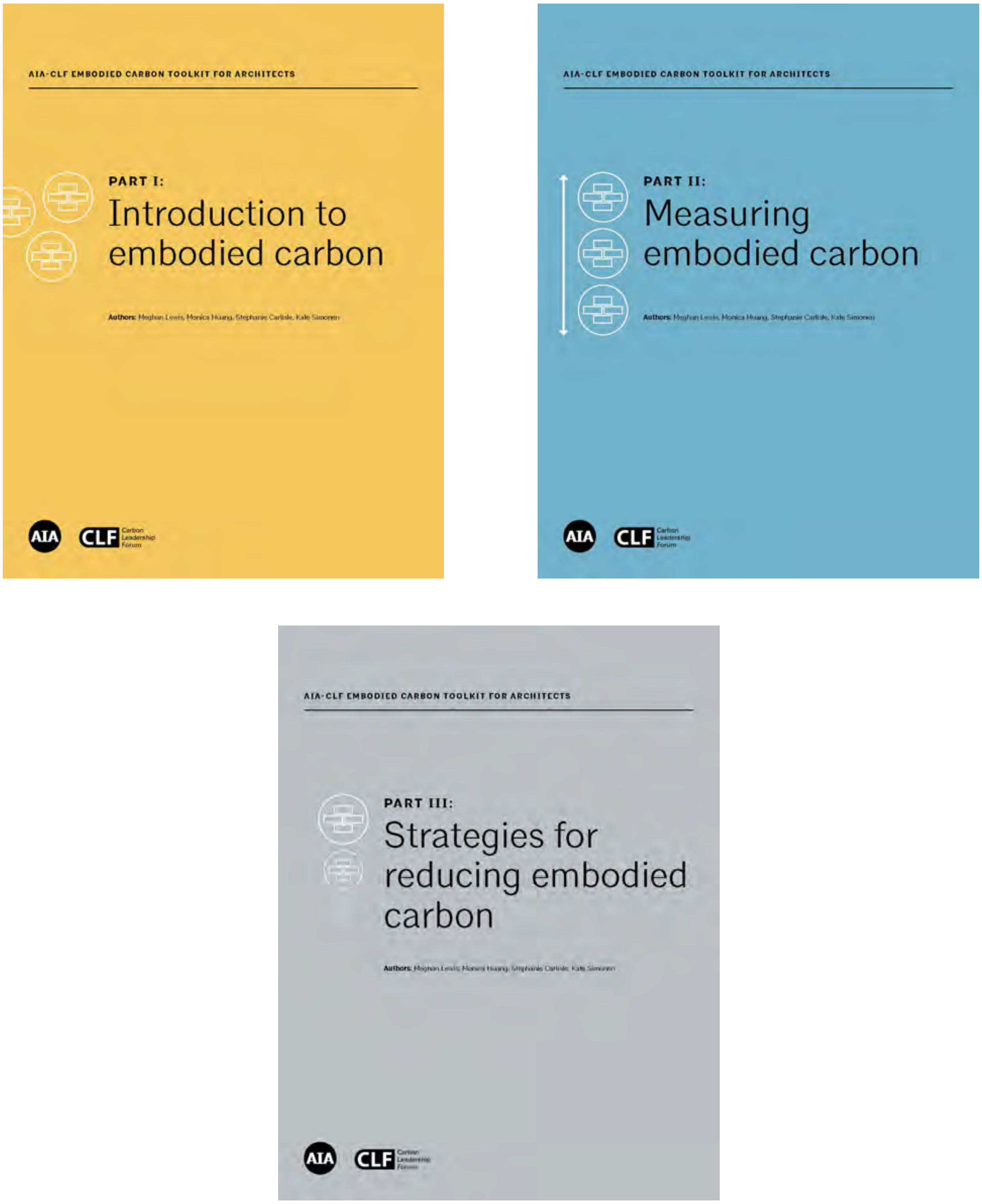
  Interestingly, one of the case studies seriously addressed this important issue—Redford Conservancy at Pitzer College, page 70. See pages 86-87 for a summary discussion of the basic methodology when doing an embodied carbon assessment. See also such publications as shown on the opposite page, which provide complete overview and methodology for embodied carbon analysis of building projects.

  As noted in the case study, the decision to renovate rather than build a new building was made for "conservancy" reasons, but the embodied carbon assessment was done in detail as a proof-of-concept. The result justified the decision by a wide margin.

  Representatives of other case study projects in this book observed that an embodied carbon assessment would have been carried out if the project had been initiated earlier.

  It is expected that such an exercise will be routinely carried out in the *decarbonized building future*. The embodied carbon assessment will no doubt yield results that are very particular to site, building program and cost, and will be one of several design considerations during the planning phases. But reliable analytical tools are emerging and are being added to the standard design toolkit of architects and engineers.

(Below) October 2021 publication, *AIA-CLF Embodied Carbon Toolkit for Architects*.



Acknowledgments

Many thanks to the following clients and designers of these exemplary projects who gave generously of their time to provide all of the information and insights into various aspects of their design and performance. Special thanks for their patience with the videoconference calls and follow-up emails about design details, their extra work putting together the requested performance data and their time spent reviewing the final copy for accuracy. Without their openness and supportive cooperation, the case studies would not be the guiding models that they are intended to be.

Client Representatives:

Amber Richane, Senior Project Manager
Drew Johnstone, Senior Sustainability Analyst
City of Santa Monica. *[For Santa Monica City Services Building, Case Study No. 1]*

Mary Pampuch, President and COO
Lankford & Associates, Inc. *[For Makers Quarter Block D Speculative Office Building, Case Study No. 2]*

Travis English, Chief Design Engineer & Director of Engineering
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