Zero Net Energy Case Study Homes

Volume 2

All-Electric Residential Projects Designed for Zero Net Energy and Zero Carbon

Written by
Edward Dean, FAIA
Bernheim + Dean, Inc.

Foreword by
J. Andrew McAllister, PhD
Commissioner,
California Energy
Commission

February 2020

Zero Net Energy Case Study Homes

Volume 2

All-Electric Residential Projects Designed for Zero Net Energy and Zero Carbon

Written by
Edward Dean, FAIA
Bernheim + Dean Inc.

Foreword by
J. Andrew McAllister, PhD
Commissioner,
California Energy Commission

February 2020

The publication of this book is funded by California utility customers and administered by Southern California Edison®. Southern California Edison is regulated by the California Public Utilities Commission.

Published in the United States of America 2020
Southern California Edison®
Los Angeles, California
www.sce.com

ISBN: 9798613193349
Library of Congress Cataloging-in-Publication (CP) Data available upon request.

This publication is available as a printed softcover book through Amazon, *www.amazon.com/books*.

Photographs by: Lawrence Anderson, Ryan Filgas, Natalia Knezevic, Fraser Almeida, Christian Kienapfel, Matt Abrams, Joseph Schell.

Cover Photo: Alejandro Ochoa, FSY Architects

Architectural Drawings: Matt Turlock

Energy Performance Graphs & Charts: Edward Dean FAIA, Bernheim + Dean Inc.

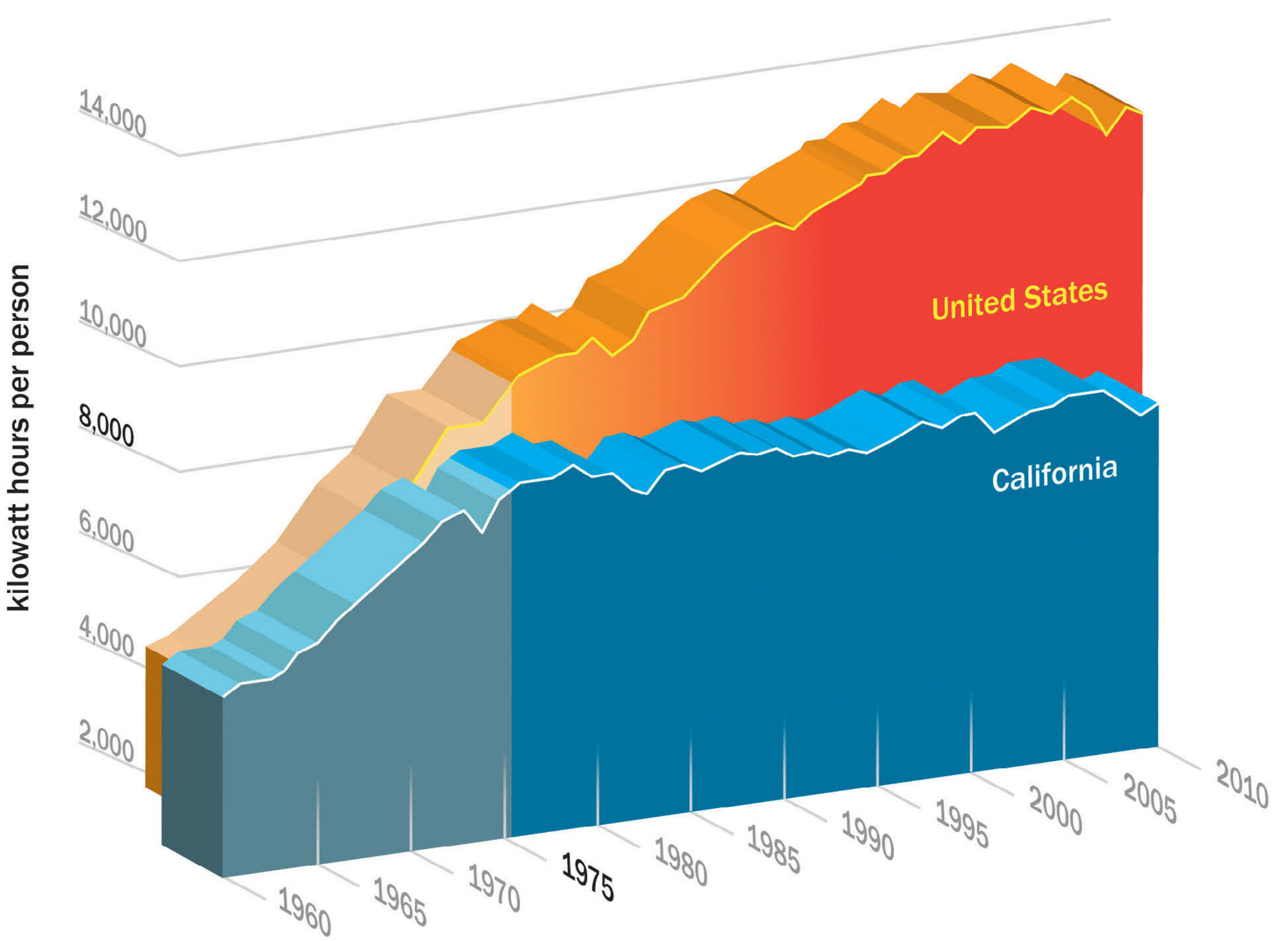
Table of Contents

Foreword

Taking the first steps on the journey to design and build a high-performing home can seem daunting. Whatever the main goal - Zero Net Energy, Passive House, Zero Emissions or all of the above – scant real-world, down-to-earth advice and direction have been available. Reading through this little volume will help. Whether your project is high-end or humble, new or retrofit, production or DIY, single-or multifamily, these cases will stimulate, instruct and inspire. Elegance of design and quality of construction combine to create indoor spaces that not only perform at the highest level, but also delight and nurture their occupants. The technical details are there for the building professional or reader who is so inclined, but equally important is the journey conveyed through each specific narrative. It's a diverse group of projects that reflects the rich and varied landscape of Southern California's cultural, economic and geographic tapestry.

Energy Efficient Building: A California Mainstay

California has long placed energy efficiency at the center of its energy policy. Beginning in the 1970s, California's per-capita electricity usage remained level, while that of the rest of the country rose by 30% - the "Rosenfeld effect," so named for our late friend, colleague and efficiency pioneer Art Rosenfeld. Drivers of this success story include muscular building energy codes, appliance efficiency standards, long-term commitment to energy research, market transformation programs, and a host of other nation-leading efforts.



Credit: Lawrence Berkeley National Laboratory

The case of California's *Building Energy Efficiency Standards (BEES)* – Title 24, Part 6 – is instructive for readers of this volume. The BEES set the minimum bar for the energy performance of a new building; indeed Californians have saved roughly one hundred billion dollars since the mid-1970s as a direct result of the standards. Less appreciated is the BEES' role in driving innovation. Once a particular efficient practice or technology has shown itself to be robust and cost-effective, it is a candidate for inclusion in the mandatory code. Costs then plummet further with the scale that a mandate guarantees.

Think about dual-pane windows. In the late 1970s and 1980s federal, state, utility and industry research and product development found great potential for energy savings from improved windows. Standardized performance metrics and testing protocols were developed to help ensure quality and consistency, and a non-profit entity – the National Fenestration Rating Council – was established, with guidance from the CEC, to manage testing and labeling. Researchers and manufacturers worked continuously on efficiency-oriented enhancements such as low-e coatings and gas fills. At that time a radical leap forward, dual-pane windows are now pervasive not just in California but across the nation and beyond, inexpensive and responsible for immense energy savings and emissions reductions over the last three decades.

Window innovation continues with the development of light, slim triple-pane windows that leverage thin-glass manufacturing technology developed for flat-screens. This advance will unlock still more cost-effective energy savings, not only in new construction but also – critically important – as a workable retrofit option for existing buildings.

Other measures that were developed collaboratively and recently required by code include advanced wall and attic assemblies; best practices for HVAC ducting; compact hot-water plumbing designs; quality verification of insulation installation (QII); and solar PV systems. Increasingly the BEES have recognized that investing in a quality building shell saves energy and increases occupant comfort over the 50+-year lifetime of any residential building.

Going Well Beyond Code

By definition, a minimum standard cannot be truly cutting-edge. To go beyond code requires some risk to design, specify, purchase, install, monitor and prove out new technologies and practices. Curious and energy-conscious homeowners are essential, together with California's deep bench of knowledgeable architects, designers, builders, researchers, and technologists. Local governments can adopt stretch codes. Ratepayer-funded incentive programs also help. These cutting-edge, beyond-code efforts produce learning and options to consider for the next triennial BEES Update. In this way, building codes both respond to and push the marketplace, in a virtuous cycle of innovation. Call it the California way.

The buildings detailed in this volume go far beyond minimum code requirements. All the case studies are special and instructive. I myself find particular inspiration in the Stratton-Lee home (Case Study #8), and I suspect that other DIY'ers will as well! The Stratton-Lee family turned an existing, 1950s-era production home into a comfortable, high-performing home with a small environmental footprint – just what California needs to reach our climate and energy goals. It's a story of vision, dedication, problem solving, frugality and family. Their experience will no doubt embolden many to roll up their sleeves and get to work.

California has set ambitious goals to double energy efficiency and decarbonize our entire economy by 2045. Residential and commercial buildings are directly responsible for 37% of energy consumption and around 20% of the GHG emissions in California. Going forward, every new construction and building upgrade project should incorporate efficient, integrated system design and equipment. Every appliance should minimize wasted energy. If we are to reach our energy and emissions targets, our buildings must perform!

Focus on Decarbonization

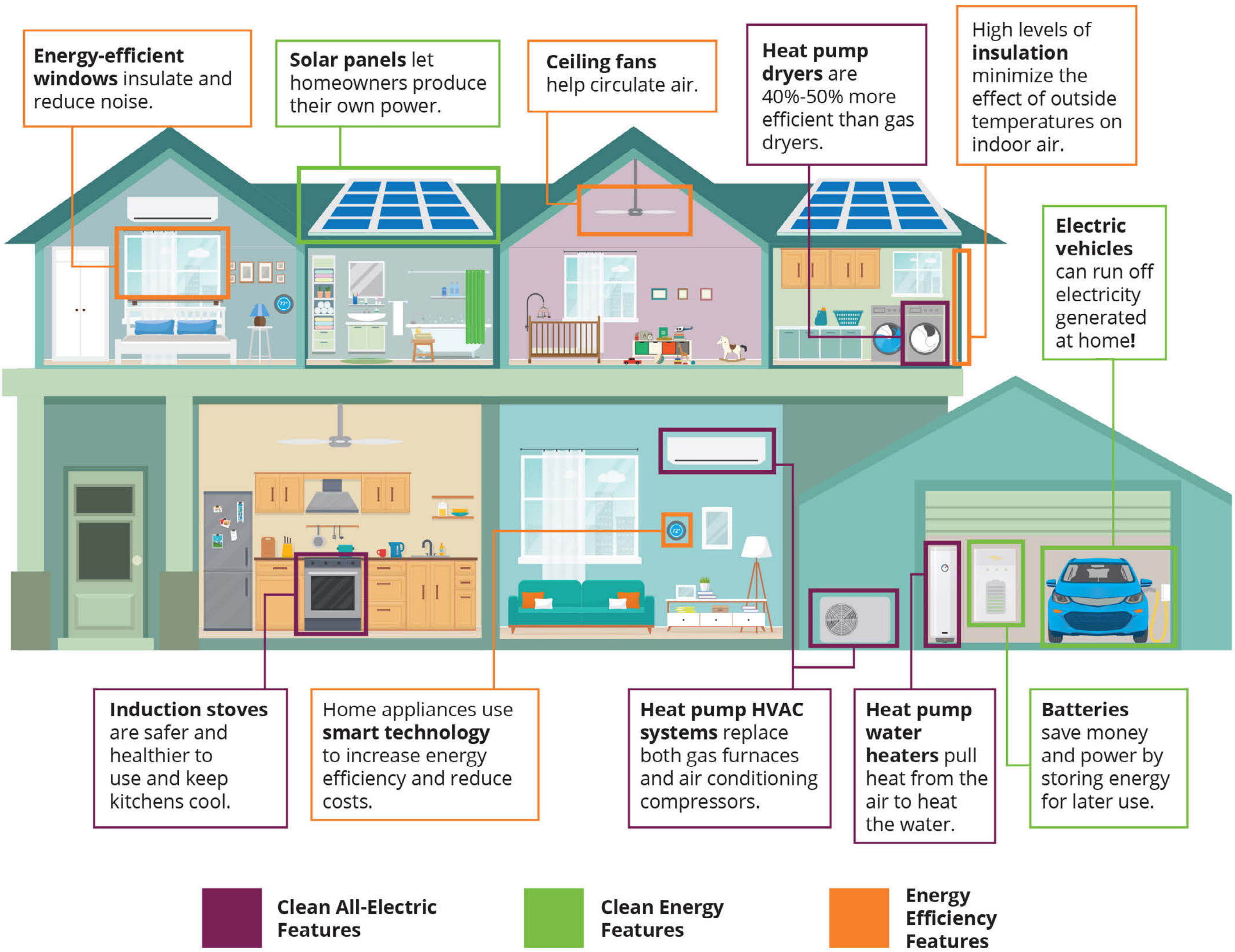
As we begin the third decade of the 21st century, it is time to reflect on California's deep and pioneering history of energy efficiency and innovation, to ask ourselves: what more can we do to reduce the impact of our built environment? First and foremost, our buildings must be platforms for decarbonization. That is, they must be able to use energy when it is carbon free, typically during the day when solar is abundant, and minimize consumption at other times. In this way, demand flexibility is emerging as essential for decarbonization. Energy systems – new homes, EV charging, replacement heating and cooling equipment, etc. – must be both highly efficient *and* flexible to the maximum extent possible. Flexibility means interactivity with the grid: the ability to manage energy usage, *proactively and situationally*, to minimize both its cost drivers and its carbon content. Several projects in this volume, for example, include energy storage and other "smart" grid-responsive technologies. We need more of that!

It's no small feat to design and build a new home – the largest investment most of us will ever make! It takes planning, persistence and courage to pull it off. My own family's new home is built to *Passive House* specifications and includes many of the energy-related elements detailed in these case studies. After managing that construction, I have a deep appreciation of the sustainable building process, the intricacies of the building code itself and the countless decisions, large and small, required along the way. The visionary homeowners and builders represented across these case studies deserve our gratitude and respect. Each project represents a step forward for our neighborhoods, communities and state.

This collection demonstrates what is possible and, I hope, will inspire others to do their own similar projects across California and beyond. I would commend everyone to experience in person these places or others like them, these high-quality indoor environments, with the luxury of time, in three dimensions and with all of one's available senses. These are low-maintenance, healthy, quiet, resilient homes – and they are absolutely marvelous.

So, dear reader, good luck on *your* project!

—J. Andrew McAllister, PhD, Commissioner, California Energy Commission



(Above) Diagram of all the possible features of a low-carbon home [zero-carbon in 2045]. (Source: "Anatomy of an All-Electric Home", https://www.edison.com/home/innovation/building-electrification.html.)

Introduction

This book is the second in a series on case studies of zero-net-energy (ZNE) homes and the fifth about ZNE buildings of all types, developed under the direction of the California Public Utilities Commission (CPUC) to support the adoption of ZNE building practices[1]. As in the previous volumes, each case study focuses on the process of decision-making that resulted in a built ZNE design and provides a detailed analysis of the project's performance, along with the all-important *lessons learned*.

This second volume presents details about the design, construction and performance of six ZNE residential projects in California, which continue the sequence of case studies from Volume 1 (namely Case Study No.6 through No.11). As in Volume 1 of *Zero Net Energy Case Study Homes*, the projects discussed in this second volume include single-family homes—one a major renovation and a second that is entirely new construction. Both of these case studies are built in low-rise urban neighborhoods of greater Los Angeles and thus offer instructive examples of solutions to common issues for single-family homes in these types of locations.

Volume 2 also adds several different types of residential construction that have achieved ZNE performance, which expand the range of housing types and broadens the base of discussion of the two volumes. One such type is affordable housing for the formerly homeless population. A second is affordable housing for seniors. The funding mechanisms and design criteria for these types of multifamily housing are different and strongly influence the design decisions for ZNE performance. In addition to these two types of residential projects, a third case study of market-rate multifamily housing performing at ZNE presents an interesting contrast in all aspects of this type of multi-unit project development.

Finally, the sixth case study represents a project process that is experienced by many homeowners in general, namely a *do-it-yourself (DIY)* multi-weekend home improvement project. In this case, the painstaking project work involved a complete overhaul of a basic 1960-era suburban house that results in ZNE performance with no real visible change to the external appearance of the house itself. Although the project is atypical with regard to the extent of the DIY work, it nevertheless provides a common template for the *to-do list* of ZNE features that can be incorporated into most California homes.

As with Volume 1, the appropriate metric and definition of ZNE as applied to the case study projects in this book must be described since the meaning varies among the several private organizations and government agencies that track progress in this area. This *Introduction* section will therefore reiterate these distinctions as they were explained in Volume 1 and set the common basis for each of the case studies that follow in this Volume 2.

In addition, a recent movement toward the emphasis on *decarbonization* as well as ZNE is prompting slightly different design solutions to emerge, as exhibited in some of the case study projects in this Volume 2. The next generation of "ZNE case study homes" will no doubt engage with *decarbonization* in their design, so this *Introduction* section concludes with an outline of this issue and its implication for the design of buildings.

[1] Paperback copies of *Zero Net Energy Case Study Homes, Volume 1*, can be obtained at Amazon.com: https://www.amazon.com/Zero-Energy-Case-Study-Homes/dp/1791732437/ref=sr_1_1?keywords=Zero+net+energy+case+study+homes&qid=1576886174&s=books&sr=1-1.
The three volumes of non-residential ZNE case studies, *Zero Net Energy Case Study Buildings, Volume 1-3,* can also be found at Amazon.com at: https://www.amazon.com/s?k=Zero+net+energy+case+study+buildings&i=stripbooks&ref=nb_sb_noss_2

Metrics of ZNE Residential Projects

1. Basic Technical Metrics

Depending on how the accounting of energy use over the course of a year is done, there are three distinct technical definitions of what is meant by a *zero net energy* or *ZNE* project currently used in practice: Site ZNE, Source ZNE and *TDV* ZNE. ("TDV" or "Time-Dependent Valuation" is the definition used in California's building code.)

As a practical matter, all three definitions have several aspects in common. First, the accepted time frame for ZNE accounting is one calendar year: a project is *ZNE* if the energy consumption equals renewable energy production over a one-year period. Second, the dominant form of renewable energy production selected is solar photovoltaic (PV) energy; there are other sources that would meet the renewables definition, but they are rarely selected as the most cost-effective and practical solution at the building level. Third, "at scale" deployment of ZNE residential projects presumes that the buildings are grid-connected. Though not a definitional requirement, grid-connectivity provides the most practical and cost-effective means of meeting ZNE performance targets.

A *Site ZNE* building has an on-site renewable energy supply, and the amount of energy used by the building over the course of a year is equal to the amount of energy supplied by the on-site system. For grid-connected buildings, the power drawn from the utility grid equals the power exported to the utility grid. This is known as *Site ZNE* since the line of transaction is drawn at the building site boundary. It is the one ZNE metric that can be directly metered and measured.

The *Source ZNE* metric recognizes that there are large energy losses attributable to the generation of electric energy at the power plant as well as additional energy losses associated with its transmission and distribution to the building site. Since these losses cannot be avoided for grid-connected buildings, the *Source ZNE* metric accounts for these losses, attributing them to the building's energy use. By this definition, the line of energy transaction is no longer at the building site boundary, but extends to include the grid itself. For individual projects where energy performance is measured and recorded, the absence of the ability to meter the *source energy* at any particular time makes the use of this metric impractical.

Finally, California uses a hybrid energy metric in its building code known as *Time-Dependent Valuation* or *TDV*, with hourly economic multipliers applied to the site energy consumption (and production) as modeled for that building by energy simulation software. This software is used to document energy code compliance at the time of permitting the project. The "economic multipliers" can be used by code officials to account for time-of-day costs of energy generation. *TDV-ZNE* represents a code path to ZNE in California, the future objective for the state energy code for building projects. However, like the *Source ZNE* metric, TDV-ZNE cannot be determined for a built project because there is no measured "TDV" data—it is only a useful metric before the project is constructed as a code required standard. Even then, TDV-ZNE is not a metric of a particular energy performance; rather, it is a metric of the *value* of a particular energy performance.

Since the emphasis in ZNE performance is on actual measured data over the course of a particular year, *Site Energy* is the only practical metric to use. <u>Site ZNE</u> is therefore the criterion used in this book for verifying zero-net-energy performance of residential projects. That is, all of the case study projects have measured site energy data for at least one full year that accounts for all energy use, both electric and gas, with the gas energy use shown to be offset by the on-site renewable energy system.

2. Other Designations of "ZNE Homes"

See the Introduction to Volume 1 for a thorough description of other "labels" that purport to be indicators that a residential project is *ZNE* in some form, including the U.S. Department of Energy's *Zero Energy Ready Home (ZERH)* program, the State of California's *Energy Design Rating (EDR)*, and three such categories as defined by the private non-profit organization, Net-Zero Energy Coalition (NZEC). The federal ZERH program is currently developing a multifamily-specific rating that "better aligns with the recently developed ENERGY STAR Multifamily New Construction (ESMFNC) program"[2].

3. Metric for Annual Energy Use: "Energy Use Intensity (EUI)"

One other metric also deserves reiterating from the Volume 1 discussion: *Energy Use Intensity*, or *EUI,* expressed in kBtu/sf per year, is a measure of the annual energy use per unit area. A State-funded technical study[3] in 2012 found that ZNE was technically achievable with EUI values varying (by climate zone) from 11.5 to 17.3 for single-family homes, and from 16.0 to 18.6 for low-rise multifamily homes.

Zero-Net-Energy (ZNE) and Decarbonization

The movement toward ZNE buildings is currently based on the need to reduce carbon emissions caused by the energy used in buildings, which totals approximately 40% of all energy used in the U.S. and 70% of all electricity generated. Almost all ZNE residential buildings have on-site solar PV systems for their source of renewable energy and are grid-connected for backup power during periods of low solar energy collection.

As the number of ZNE or partial-ZNE buildings has grown, particularly in the past ten years, this characteristic has created a growing dilemma for the public utility electric grid, called the *duck curve challenge*[4]. Basically, when the sun is shining, a large part of California's electrical demand is met by the on-site rooftop solar PV systems, so the demand on the utility grid is relatively low in the middle of the day. But then the demand increases dramatically in the evening as consumers typically rely on the grid during these hours. To meet this surge in electrical power demand, the electric utilities typically bring online fossil-fuel-fired "peaker" power plants, with the unavoidable side effect of the generation of large amounts of carbon emissions by those power plants.

Adding to this extra carbon emission effect caused by the growth of the residential solar PV market is the normal mix of energy sources for the utility electric power grid, composed of both renewable and carbon-based fuels. Because most ZNE houses rely on the grid for their backup energy supply throughout the day, they are occasionally using carbon-based power from the grid and therefore are not zero-carbon houses, at least not with the current *California Power Mix*[5].

[2] For more details, see: https://www.energy.gov/eere/buildings/zero-energy-ready-home-multifamily-program

[3] "The Technical Feasibility of Zero Net Energy Buildings in California", Arup, et al. 2010.

[4] For a complete description of this current challenging consequence, see https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy

[5] The 2018 California Power Mix by energy source was 47% carbon-based fuel, with the remainder provided by carbon-free sources of energy. https://ww2.energy.ca.gov/almanac/electricity_data/total_system_power.html

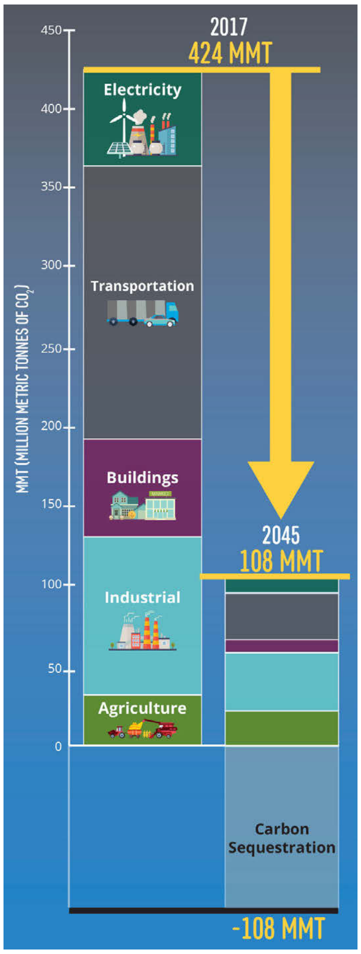
Furthermore, even for ZNE houses that utilize energy-efficient electric heat pumps for heating and cooling, and perhaps even domestic hot water, they often use natural gas for cooktops and consequently have a natural gas supply to the house. This carbon-based energy use is offset by the energy produced by additional on-site solar electric panels, so that the total annual energy used is still balanced by the total annual on-site renewable energy generation for the ZNE house.

So, there are several reasons why a ZNE house is probably not a zero-carbon house at the present time.

There is a movement to decarbonize the energy used in buildings because of the pressing need to mitigate the deleterious effects of climate change by reducing or eliminating carbon emissions from all sources. Transforming the building stock, particularly residential buildings, as much as possible to zero-carbon is the goal of this societal effort. (See a diagram for the possible features of a zero-carbon house on the following page.)

The first steps were taken to decarbonize the California public utility electrical grid in September 2018, when the governor signed Senate Bill 100 (SB 100)[6], which established the State policy requiring that renewable energy and zero-carbon resources supply 100% of electrical retail sales to end-use customers by 2045. *This effectively means that in 2045 all ZNE residential buildings that are all-electric will also be zero-carbon and that a zero-carbon future requires the electification of our homes and buildings[7].*

ZNE design and performance of residential buildings is clearly the first step toward complete decarbonization of the housing stock in California. Rapid progress continues to be made in this regard. In addition, the use of electric heat pumps for heating, cooling and domestic hot water supply in homes is a growing trend in the state and is responsible for the continuing progress toward decarbonization. Finally, the use of induction cooktops[8], recently gaining market acceptance, completes the recipe for the zero-carbon ZNE home.



(Above) Greenhouse gas(GHG) emission reductions in million metric tons (MMT) required to meet California 2045 targets as specified by SB100, 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)

[6] https://www.energy.ca.gov/sb100

[7] See: A. Mahone et al., "Residential Building Electrification in California—Consumer economics, greenhouse gases and grid impacts", (April, 2019), Energy and Environmental Economics, Inc.

[8] *Footnote from Volume 1 about induction cooktops:*

Induction cooking is a magnetically induced heating method for cooking as opposed to direct electric coils or gas burners. Of the three types, the electric coil is generally regarded as the least energy efficient, the poorest method for cooking because of its relatively slow response to controls and the least safe from casual burns. Gas burners have quick response to controls—their advantage over electric coils—but are a source of toxic chemical by-products and still have a serious burn risk. Induction cooking has all of the advantages of gas cooking, including the degree of control for cooking, is toxin- and carbon-free and the "burner" does not feel hot to the touch after a relatively short time. (Cookware must have ferrous content—stainless steel or cast iron, but not pure aluminum.)

Use of induction cooking, like the microwave oven when it first appeared, is a technological invention that must achieve a familiarity and an acceptance level among homeowners (and chefs). But it is the recommended choice for ZNE and zero-carbon homes. See the following articles for a technical comparison of cooktop alternatives:
(1) http://ovens.reviewed.com/features/induction-101-better-cooking-through-science;
(2) https://www.consumerreports.org/electric-induction-ranges/pros-and-cons-of-induction-cooktops-and-ranges/

Case Study Projects ▷

CASE STUDY NO. 6

Passive House Los Angeles (PHLA+)

PHOTO: FRASER ALMEIDA

Passive House Los Angeles (PHLA+)

Case Study No. 6

Data Summary

Building Type:
Single-Family (New)

Location: Culver City, CA

Gross Floor Area:
2,038 gross sq.ft. (1,750 sq.ft. conditioned)

Occupied: December 2018

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

On-Site Storage Battery:
14 kWh Tesla Powerwall

Measured On-Site Energy Production:
7,700 kWh per year
13.0 kBtu/sq.ft. per year (estimated from 7 months of data, 03/2019-09/2019)

Pre-Occupancy Calculated EUI (Site):
7.0 kBtu/sq.ft. per year

Measured EUI (Site):
10.2 kBtu/sq.ft. per year (estimated from 7 months of data, 03/2019-09/2019)

Owner/Client
Christian Kienapfel, AIA, CPHC, LEED-AP

Project Team

Architect:
PARAVANT Architects, Culver City, CA

Mechanical Engineering:
Zehnder America and Mitsubishi technical support

Certified Passive House Consultant (CPHC):
Sylvia Wallis, AIA, Los Angeles, CA

HERS Rater and Blwer-Door Test:
Dav Camras, Los Angeles, CA

General Contractor:
Guillermo Delgadillo & Associates, Montebello, CA

As in Volume 1 of *Zero Net Energy Case Study Homes*, it is simplest to start first with the case study of a new single-family house—built with new materials, modern construction methods and conforming to current residential building codes. In the first case study of this Volume 2 (the 6th in the series of case studies in both volumes), there is the added characteristic that it is also a second, detached house that exists on one lot with another house. Since many municipalities are now allowing a second dwelling unit on a single lot in certain zones as a means of creating more housing availability, it is valuable to see the practical effects on solar access and design for energy-use optimization of the increased density in semi-urban neighborhoods.

Background

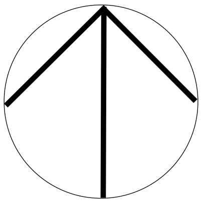
The owner had purchased a post-war ranch-style house in 2013 on a duplex parcel in Culver City (zoned R-3)[1], located near the coast within the greater Los Angeles area. The project came about from the desire to build a zero-net-energy (ZNE) home as a second dwelling unit on the property, which would also be a demonstration of the application of *Passive House*[2] principles to the design and construction of the structure. When the new house was completed, the plan was that the owner would then move into it and turn the existing house fronting the street into a rental unit. (This is the reverse of the usual practice of building a rental unit in the rear yard as a second dwelling unit.)

---

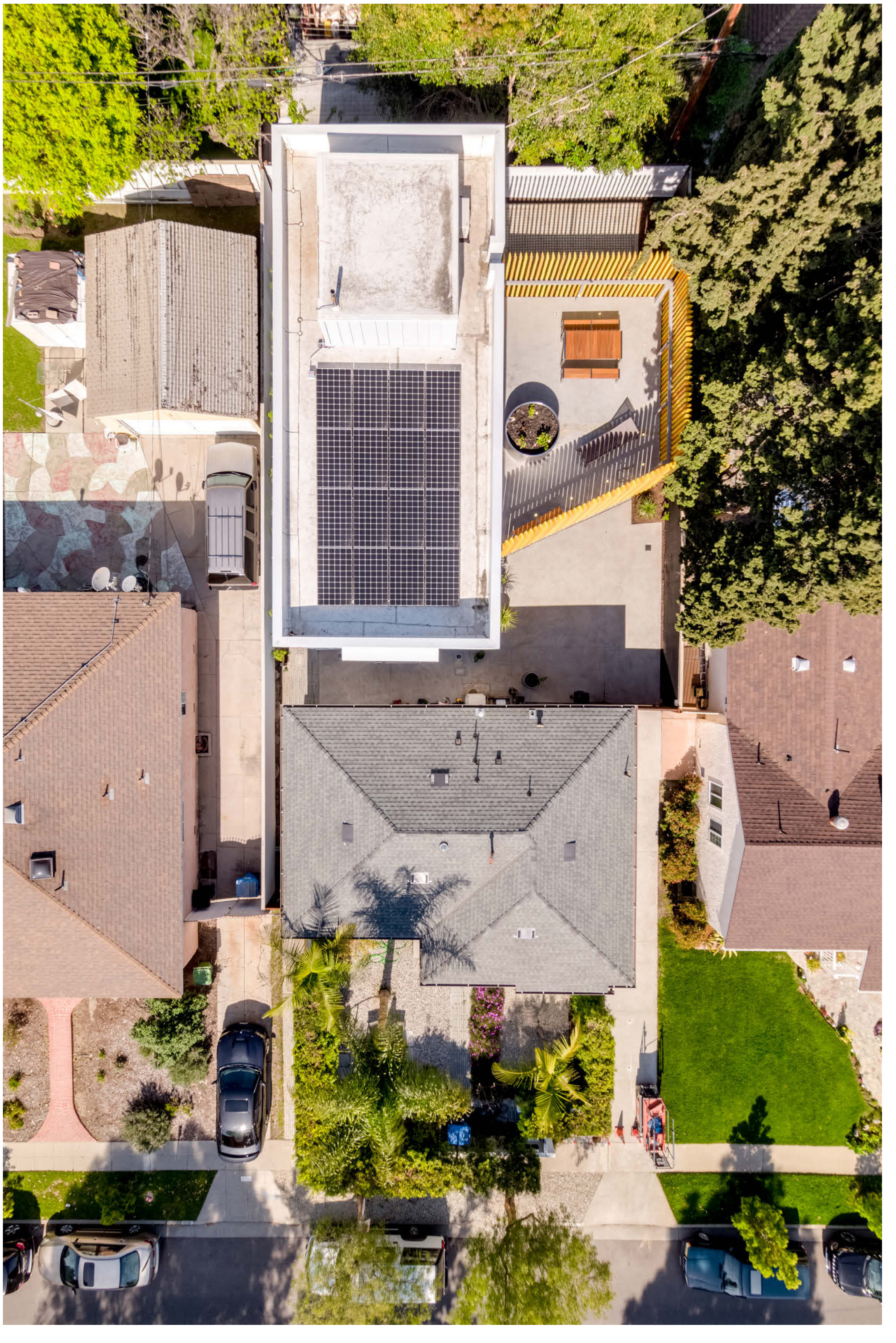
[1] In this case, two single family residences on a multifamily-zoned property.
[2] *Passive House* Is a standard for the design of energy-efficient, healthy and sustainable houses. See: https://www.passivehouse-international.org/index.php?page_id=78.

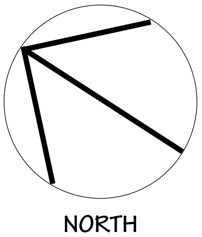
(Above) View to the north of the neighborhood homes, with downtown Los Angeles in the distance. (Photo by Fraser Almeida)

Passive House Los Angeles (PHLA+) - General Vicinity Plan



(Right) Aerial view of site and buildings. (Photo by Fraser Almeida)





Project Process

Building Program

The program called for 2,038 gross square feet on two levels, with a second-story deck that also serves as a carport. The footprint of the house is 900 square feet. The ground floor is intended as an open loft-like living space, including a home office and a full bathroom. The second floor contains three bedrooms, two bathrooms and access to the large deck. As part of the design program, the owner decided to make the house wheelchair accessible on the first floor for potential future needs.

See floor plans and building sections on the next pages.

Site Constraints

In a semi-urban site such as this one, plans to add a two-story structure to a property often elicit a neighbor's requests for additional limitations on size and height through a discretionary review process, which may affect solar access or incidentally constrain the size of the solar photovoltaic (PV) system. This project complies with all applicable regulations of the Culver City Planning Code and no modifications or variances were required for the design as submitted. Since the city has adopted a version of the "By Right" approvals process[3] for such residential projects, the discretionary review process was not required and the project was approved for construction as designed.

The existing one-lane driveway from the street, originally serving the existing house on the lot, provides required car access to the rear of the property.

Large cypress trees near the southern property line and southeast of the planned location of the house cast early morning shadow on the rooftop solar PV panels. The effect on rooftop solar PV performance was deemed to be minor when this constraint was studied.

Low Energy Design Strategies

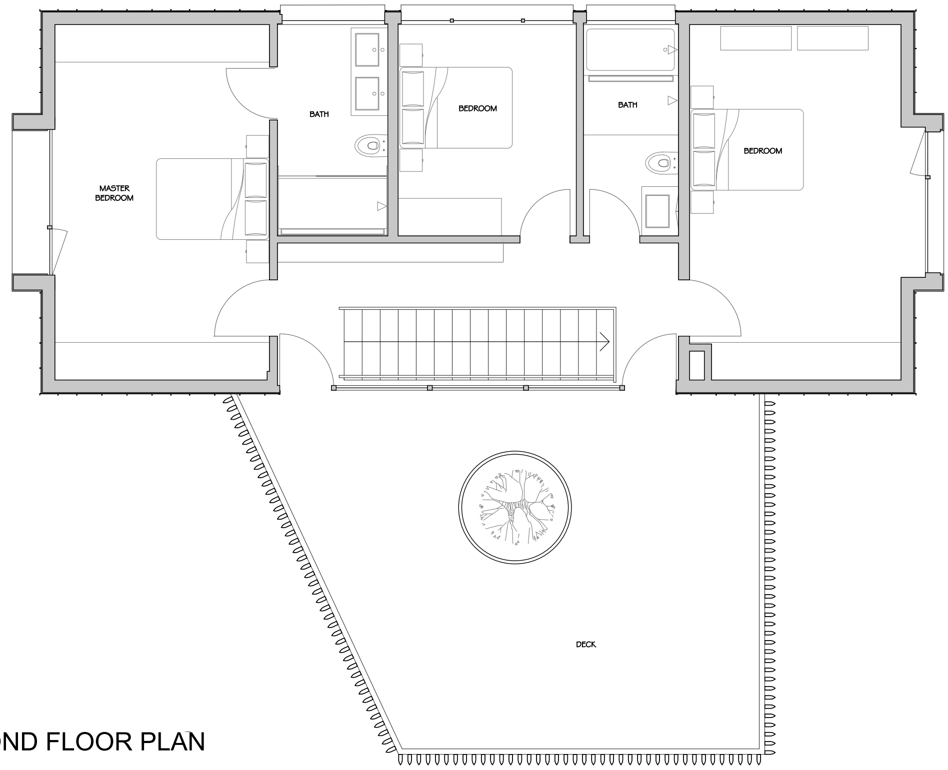
This case study home was designed and built to the *Passive House Standard* and received a *Passive House Certification* in 2019. At the present time, this standard and the certification cover energy efficient design only—they do not address on-site renewable energy generation[4] or energy performance verification. But they do set rigorous requirements for the usual design strategies for ZNE homes.

Building Envelope — Insulation and Windows

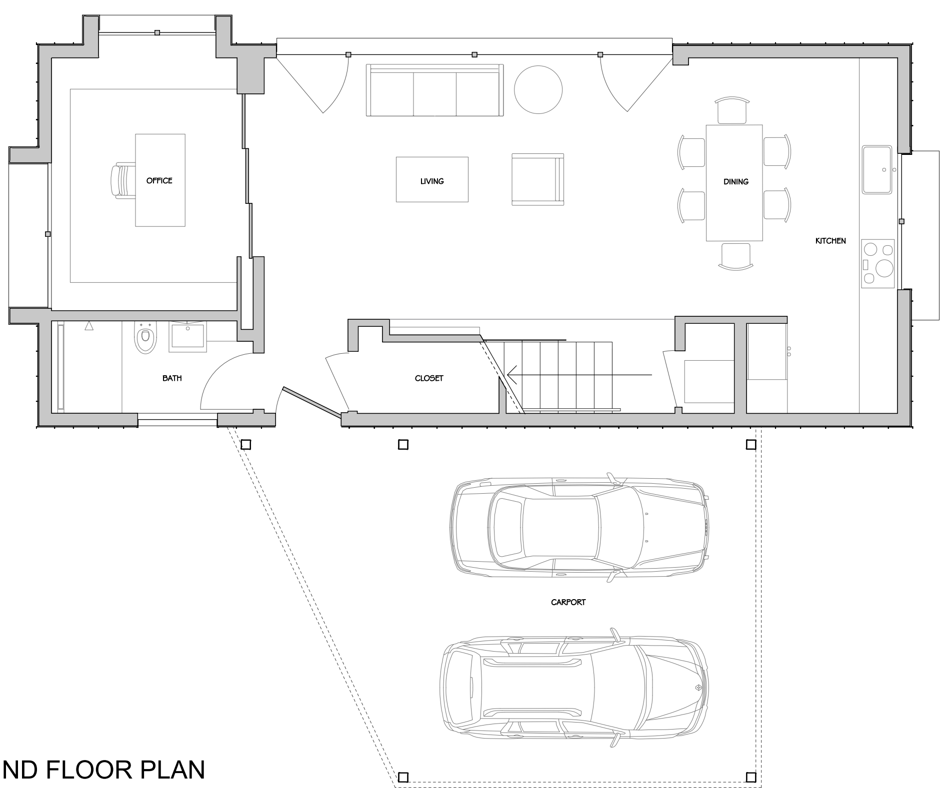
The wall construction, as typical of Passive House requirements, is heavily insulated. Since the location is in the relatively mild coastal marine climate of Southern California, 2X6 framing with blown mineral wool insulation[5] was deemed sufficient to satisfy the Passive House requirement. A 1.5"-thick layer of rigid mineral wool insulation[6] was added on the exterior of these studs to prevent thermal bridging, which brought the total wall assembly to R=31. Both types of insulation product are inorganic and fire-resistant.

---

[3] http://apalosangeles.org/how-to-get-by-right-zoning-right/
[4] *Passive House* is considering a new evaluation system based on the renewable energy generation at the project site. See: https://passipedia.org/certification/passive_house_categories/classic-plus-premium. PHLA+ achieves *Passive House Plus* in this new system.
[5] Jet Stream® Ultra Blowing Wool Insulation by Knauf.
[6] Rockwool Comfortboard™ 80.

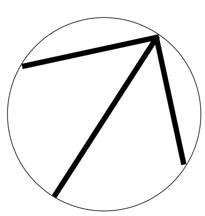


SECOND FLOOR PLAN



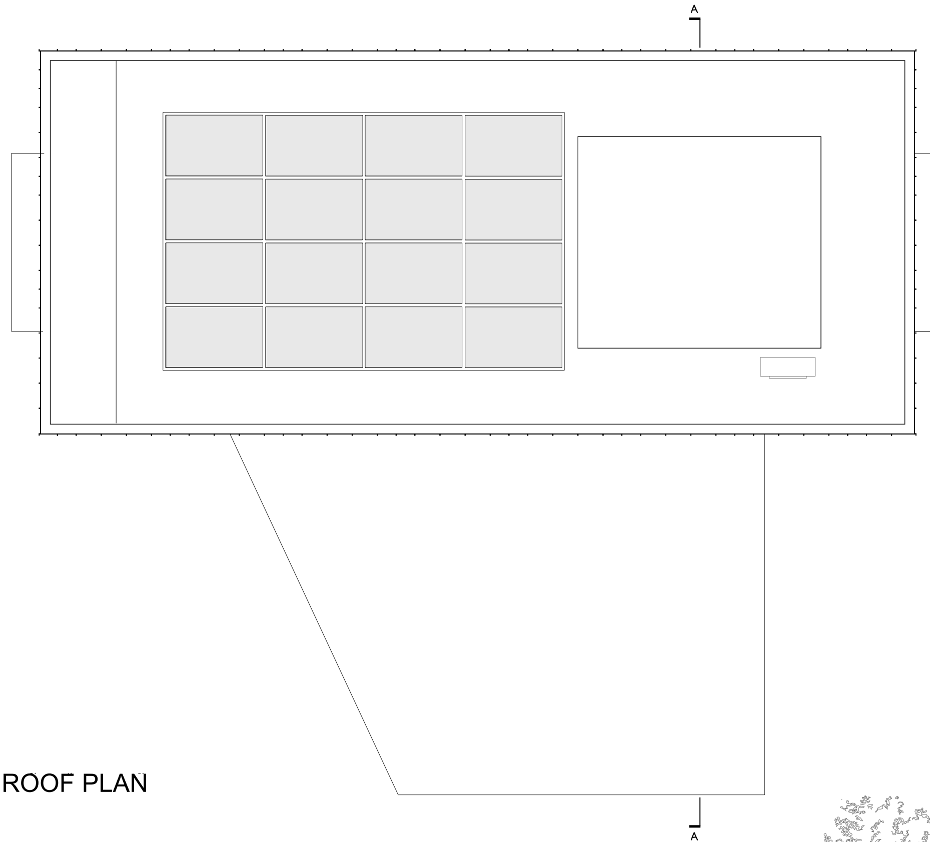
GROUND FLOOR PLAN

0 1 2 4 8 FT

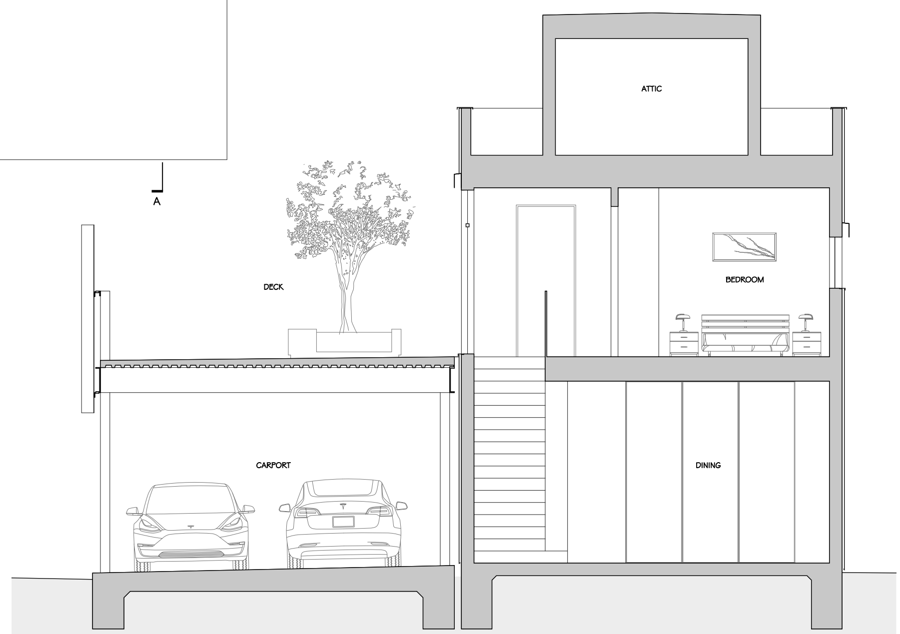


NORTH

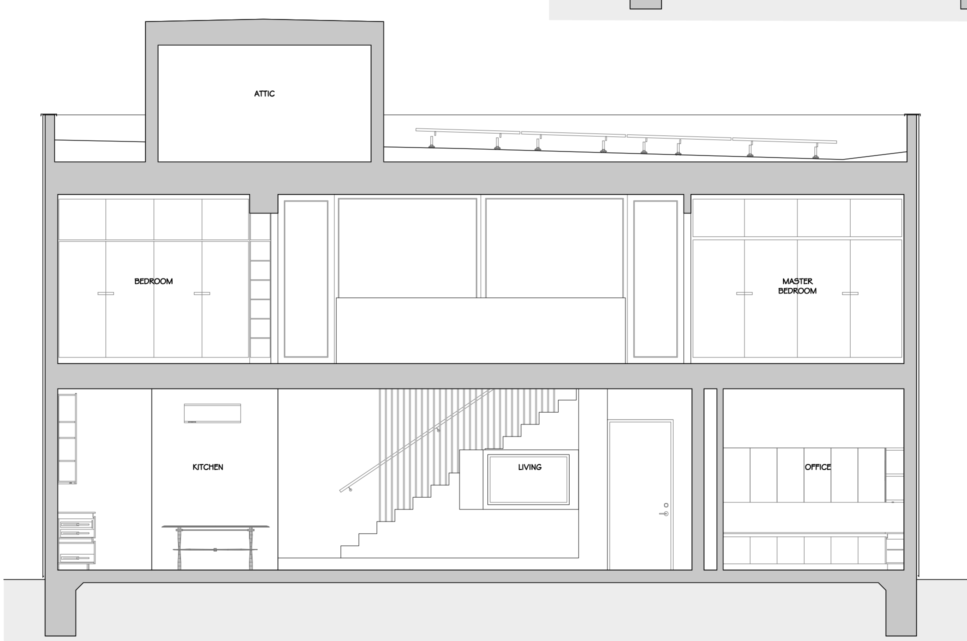
PASSIVE HOUSE LOS ANGELES (PHLA+): FLOOR PLANS AND BUILDING SECTIONS



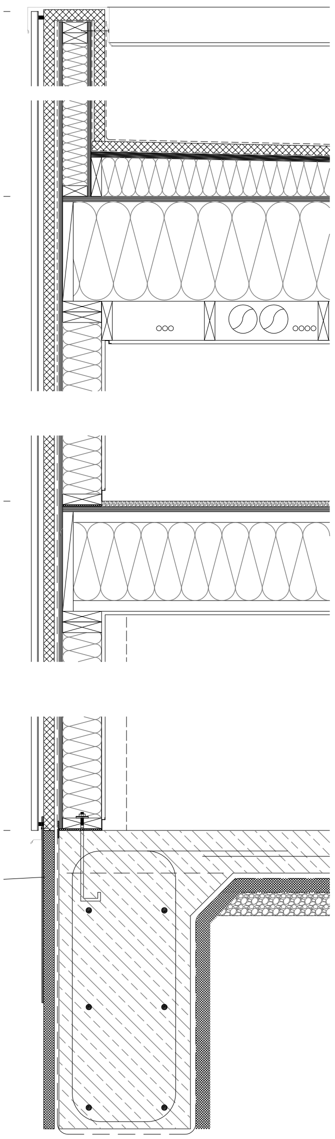
ROOF PLAN



TRANSVERSE (CROSS) SECTION



LONGITUDINAL SECTION



(Above) Wall section showing the design of the insulation layers in the exterior wall and roof. (Courtesy of PARAVANT Architects)

Building Envelope — Insulation and Windows (cont.)

The roof construction consists of a similar combination of types of insulation products, with the blown insulation between the roof joists and rigid insulation board[7], which provides the necessary slope for roof drainage in addition to mitigating thermal bridging. The net result is the high overall R-value for the roof assembly of R = 45. The concrete floor has a layer of rigid insulation below the slab, resulting in an insulating value of R = 10.9.

High quality windows and doors with thermal break details are typical of Passive House requirements. In the case of PHLA+, triple-glazed "tilt and turn" windows[8] manufactured in the European Union were selected for their thermal characteristics, air-tightness and for their sound attenuation characteristics. The flight patterns for airlines using nearby LAX were about to be relocated above the building site, so the owner opted for the higher grade of window for noise control. (See the discussion in the section below, "Post-Occupancy: Observations and Conclusions", for the practical issues that this design decision ultimately raised.)

A sophisticated "smart" window shading system[9] is employed to shade all the windows automatically and admit maximum daylight. This exterior blind system is controlled by sensors located on the roof to respond instantaneously to the sun's position to change the angle of the blades and the distance between them so that no direct sun reaches the glass. The result is that the house always feels light and open while minimizing solar heat gain.

Building Envelope — Airtightness

As noted in previous case studies in Volume 1, airtightness is one of the keys to minimize energy use in residential construction. Refer to the *Sidebar: Airtightness*, which summarizes this discussion and defines the airtightness standard for *Passive House* designs compared to other typical types of construction.

---

[7] SecurShield Polyiso™ by Carlisle. This product is a closed-cell polyisocyanurate foam.

[8] Zola clad-wood Arctic line, https://www.zolawindows.com/clad-wood#Slide4

[9] Warema external venetian blinds, https://www.warema.com/en/internal-venetian-blinds/external-venetian-blinds.php

(Right) View of automatically adjusting exterior blinds in response to solar position. (Photo by Christian Kienapfel)

Sidebar: Airtightness

One of the keys to minimize energy use in residential construction is *airtightness*. Building scientists confirmed this in the 1970s, and it led to many construction techniques, products and testing methods that are used today. These are essential in ZNE residential structures, as will be discussed in all the case studies in this book.

One of the principal techniques to develop airtightness is to seal the wall and roof planes using air/vapor barrier tapes and sheet material, plus carefully seal the joints at exterior windows and doors.

Another important technique is to seal the joint between the framing and the foundation system. This is achieved by using gaskets between the foundation and the framing to seal that common source of air leakage. The gaskets are typically compressed down to 1/16", which create an airtight seal.

Good quality (airtight sealing) windows and doors are essential. It is important to seal around these openings between the frames and the flashing material.

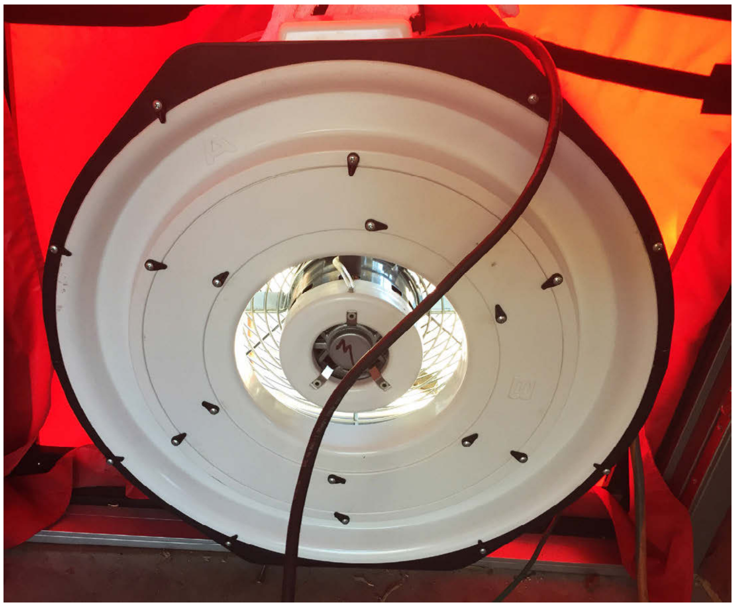
With "airtight" construction techniques employed to the appropriate degree, the house is then tested using a *Blower Door*[1] and associated testing meters and recording devices.

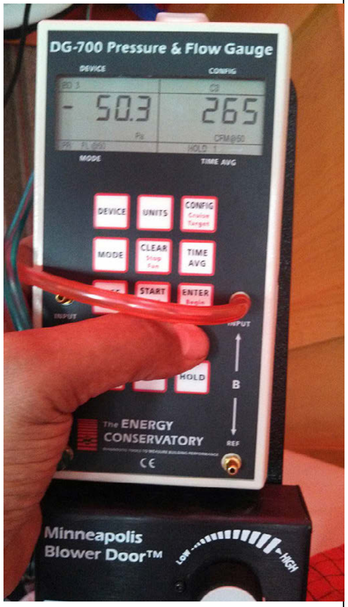
The result of the test is a number that gauges the airtightness of the house, typically reported as ACH50, the number of times that the volume of the indoor air would be replaced during an hour, or *air changes per hour*, at 50 pascals of pressure. The house is pressurized using the blower door and then the pressure difference is measured between inside and outside (after any leak points are located and sealed).The benchmarks for airtightness of a house can be described as follows:

- >20 ACH50: poor airtightness (i.e., leaky) house
- 5 ACH50: adequate tightness per California Title-24 energy standards
- 2.5 ACH50: "stuffy" house—needs fresh air ventilation system
- 0.6 ACH50: *Passive House*[2] standard

---

[1] For a description of the *Blower Door Test*, see https://www.energy.gov/energysaver/blower-door-tests.
[2] https://passipedia.org/planning/airtight_construction/general_principles/blower_door_test





(Above, left) An installed *Blower Door* with pressurizing fan; *(Above, center)* Close-up view of the pressurizing fan; *(Above, right)* Airtightness measurement device, called a manometer, for testing the number of air changes per hour at a certain air pressure created by the Blower Door. (Photos by Christian Kienapfel)

(Right) View of rooftop mechanical room interior with the heat pump water heater on the left and HRV on the right. (Photos by Christian Kienapfel)

Building Envelope — Airtightness (cont.)

As a certified Passive House, the structure is required to perform a *Blower Door Test* and achieve an airtightness measurement of 0.6 ACH50 or less. This house achieved 0.48 ACH50 when it was tested prior to occupancy by the HERS-rater. During the construction phase, in-progress airtightness tests were done with equipment provided by the Southern California Edison Tool Lending Library[10].

This degree of airtightness of the structure was successfully carried out as the result of certain details of construction and product specification, namely:

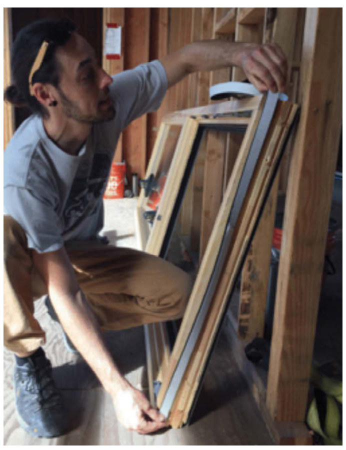
- Sealing around the openings for windows and doors was accomplished using self-expanding foam tape[11]. This self-adhering material is pre-chilled and installed around the window and door frames. Then, after the window or door is installed in the opening, the foam naturally expands to fill any gaps with an air- and weather-tight seal.
- A liquid air and waterproofing barrier[12] was applied over the exterior plywood after sealing all gaps in the framing with a filler material[13]. For compatibility, the rough door and window openings were sealed with a liquid flashing product[14].
- This approach to air-sealing and weatherproofing avoided conventional membrane systems and resulted in a relatively easy installation to produce an airtight structure.

Heating, Ventilating and Cooling Systems; Domestic Hot Water

Because the house is so tightly sealed, a balanced mechanical ventilation system is needed to ensure that fresh air is continuously supplied throughout. *Passive House* requires a *heat-recovery ventilator (HRV)* for this purpose. (In a climate requiring moisture control, an *energy recovery ventilator* or *ERV* would be used, but in this dry, mild climate, the HRV is sufficient[15].) The HRV ducts fresh air to living room and bedrooms and returns exhaust air from the kitchen, bathrooms and laundry room to a heat exchanger in the HRV unit before it is expelled from the house. The airstreams never mix and the system provides 24-hour continuous fresh air ventilation. The ductwork can be done with plastic rather than sheet metal, making for a simple and inexpensive installation. The 60-gallon heat pump water heater unit is located in a rooftop mechanical room along with the HRV.

The two level house employs only one ductless mini-split heat pump system to provide both heating and cooling. This is sufficient because the heating and cooling loads are very low and uniform in all parts of the house, and the HRV produces enough air mixing throughout. In fact, the loads are so low that the single mini-split unit is the smallest size available at 0.9 tons, which is sufficient for the entire house.

The kitchen exhaust fan is in a recirculation hood, so there is no exhaust directly outside, which would be accompanied by a wall penetration and potential for air leakage at the surrounding framing. The exhaust air is passed through an air/grease filter and re-enters the room. (The kitchen fan could have been directly exhausted to the outside by *Passive House* standards, but the owner opted for the recirculation option.)



(Above, top) Applying sealing gaskets at the foundation mudsills; *(Above, center)* Installing self-expanding foam tape around a window; (Above, bottom) Sealing all gaps in the framing.

---

10 https://www.sce.com/business/consulting-services/energy-education-centers

11 Hanno® joint-sealing tapes, https://www.hanno.com/en/joint-sealing-tapes

12 https://prosoco.com/product/cat-5/

13 https://prosoco.com/product/joint-seam-filler/

14 https://prosoco.com/product/r-guard-fastflash/

15 See M. Holladay, “HRV or ERV?”, Green Building Advisor, Jan. 2010, https://www.greenbuildingadvisor.com/article/hrv-or-erv


PHOTO: FRASER ALMEIDA


PHOTO: FRASER ALMEIDA


PHOTO: CHRISTIAN KIENAPFEL

Natural Ventilation

As required for Passive House, windows are openable to provide natural ventilation, a valuable source of cooling in this mild climate.

Lighting and Plug Loads

Lighting, plug loads and domestic hot water constitute roughly 75% of the modeled energy use because of the high energy efficiency of the building envelope and the heating and cooling equipment. All lighting is done with high-efficiency LED sources.

Since the house is designed to be all-electric, the cooking is done by induction cooktop and electric oven. The clothes dryer is a condensation dryer, which requires no vent to the exterior, thereby avoiding potential air leakage via a wall penetration.

Control Systems

Control of all energy systems is done simply using the control apps for the individual systems resident on two iPads. The iPads are mounted in prominent locations on a wall in the living area of the first floor and in the hallway of the second floor. There is no wiring since the iPad is connected to the house wifi, and it is a simple matter to control the systems or check on their status from this location.

Construction

Construction required one year and was completed at the end of 2018. During construction, particular attention was paid to details that would affect the airtightness of the construction and the continuous insulation characteristics with regard to thermal breaks and thermal bridging. The construction trades were reminded regularly of the airtightness issue in the course of their work. (See construction site photos on p. 12.)

Renewable On-Site Energy Supply

The on-site solar PV system consists of only 16 Sunpower panels, each capable of producing 335 watts, for a total of 5.36 kW.

The system is also connected to one Tesla Powerwall battery with storage potential of 13.5 kWh. This battery provides a free energy source in the evening when the energy consumption tends to be high and there is no power being generated by the solar PV panels. It essentially provides a method of load-shifting, which has a benefit when the utility rate structure sets a higher rate in the evening compared with the rate in the middle of the day. The battery also ensures that the house will have an uninterrupted power supply in case of a power outage at any time on the utility grid.

(Left) 13.5 kWh battery is mounted on the exterior wall near the carport. (Photo by Christian Kienapfel)

Energy Performance

Energy Modeling and Post-Occupancy Measurement

Energy Use—Modeling

Small house projects typically do not employ energy modeling as the design proceeds. Usually, the roof space is utilized to the maximum extent possible for the solar PV panels or space is left for the installation of additional panels once the use patterns of the house are established. With the advent of the battery storage component as an integral part of the solar PV system and the planned addition of an electric vehicle (EV), there is little need to estimate the energy demand in advance.

Passive House certification, however, requires the completion of a Passive House Planning Package (PHPP), which is a spreadsheet form of energy use calculation for the house by category of load. The PHPP therefore demonstrates that the high energy efficiency as prescribed by the Passive House standards are met. At the same time, it is a form of "energy modeling" for the house, providing expected amounts of monthly energy use over the course of a "typical" year for a specific climate zone. This can be used to size the solar PV system necessary to provide ZNE performance. The PHPP numbers can also be compared with the actual measured amount of energy use to identify any unusual effect of post-occupancy use patterns.

The results of the PHPP calculations for this case study house are shown in the chart on the opposite page.

Energy Use—Post-Occupancy Measurement

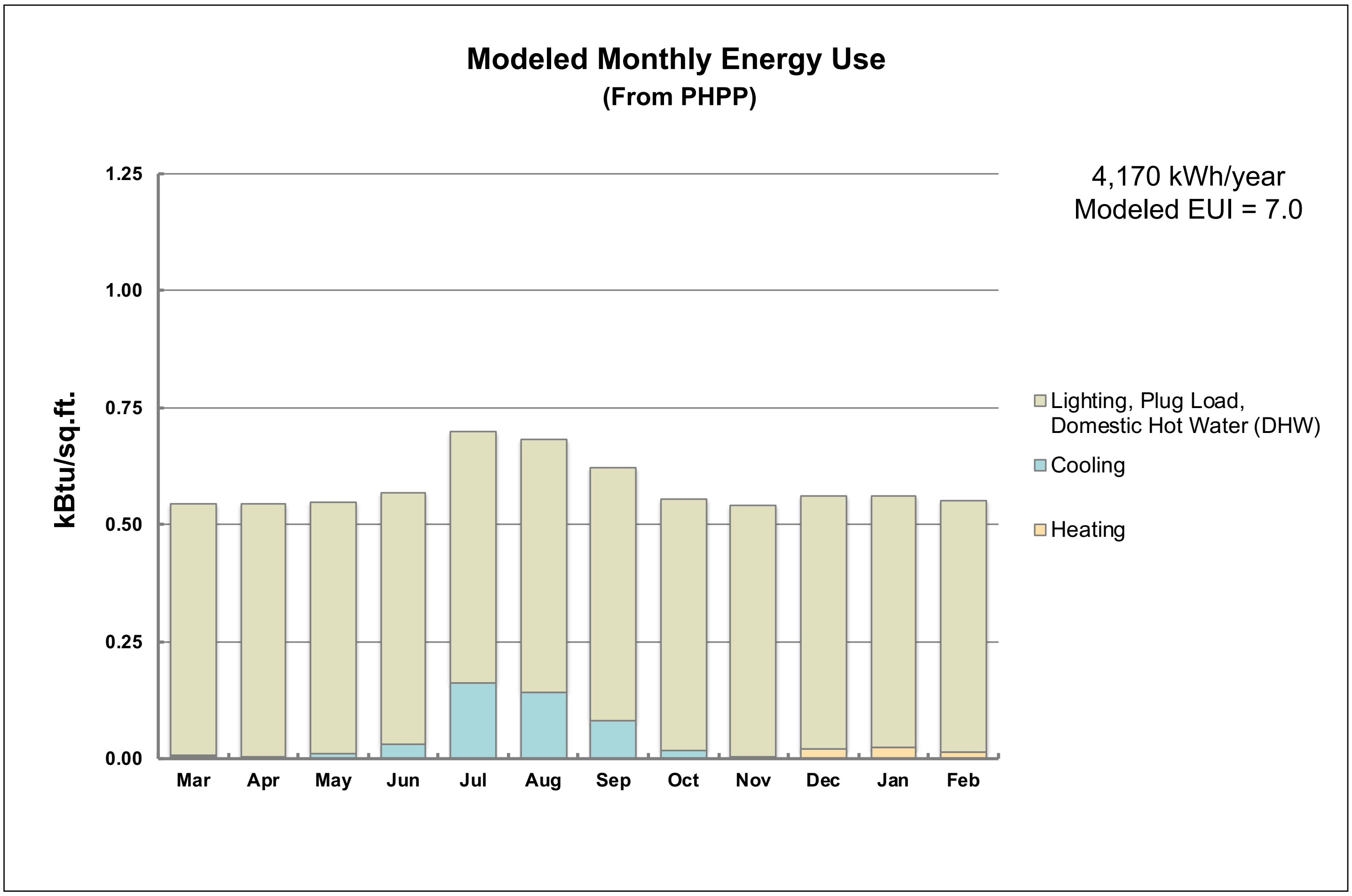
Southern California Edison (SCE) provides monthly *net meter* reports to the homeowner each month. A net meter report is the record of the total net electrical energy provided by SCE to the house every month. If the energy produced by the solar PV system exceeds the energy use for a reporting period, typically a month, the total net energy total provided by SCE will be negative for that month. (For a short term period such as an afternoon, the energy from the solar PV system can be sent to the battery or, if the battery is fully charged, the energy will be pushed out to the SCE electrical grid. In the latter case, the house electrical meter runs backward for a while.)

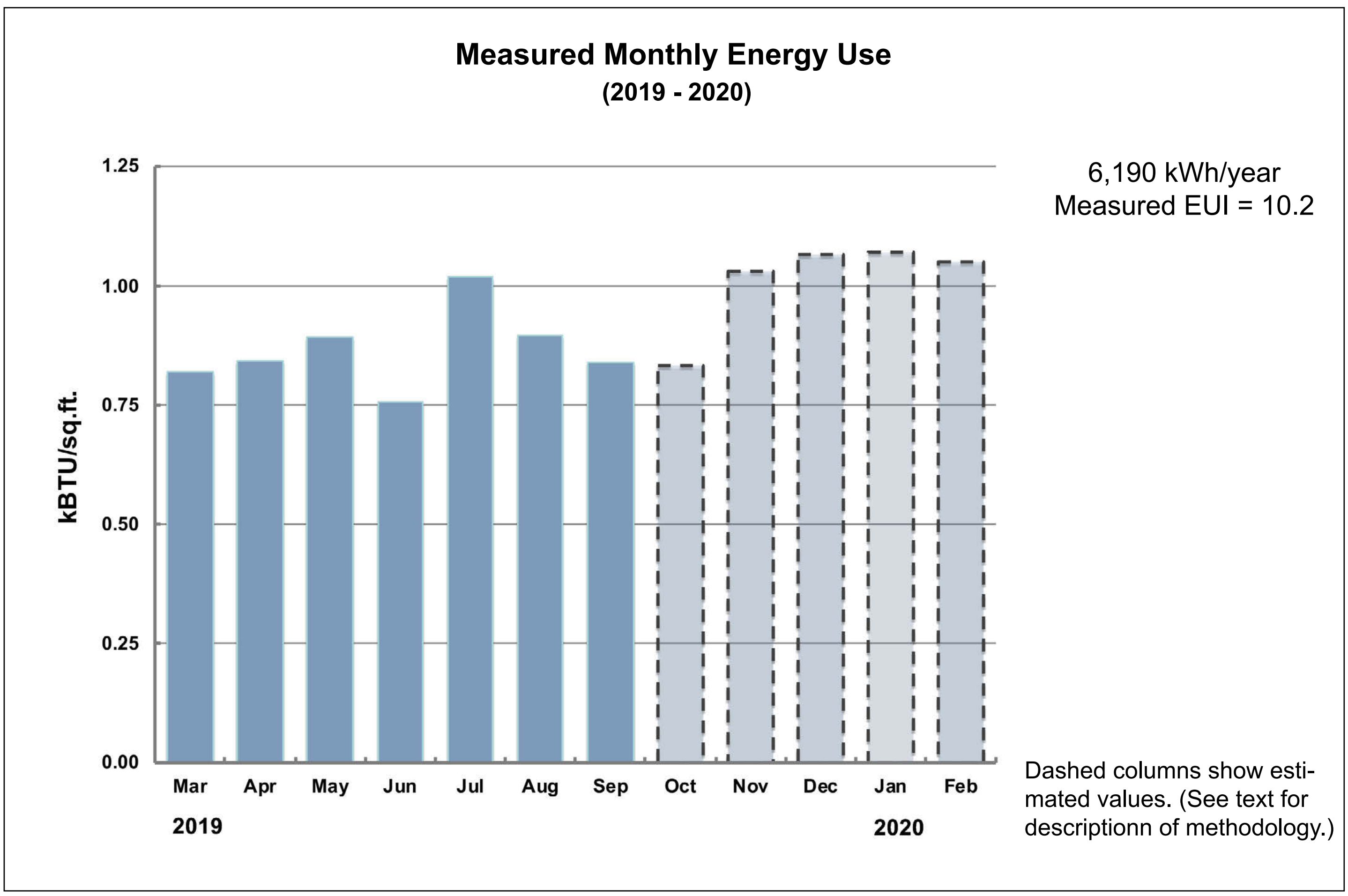
For solar PV systems without battery storage, if a meter is installed on the system to record the monthly energy generation, then the monthly energy use can be determined from this solar PV meter data and the SCE net meter report: a simple addition of the two numbers will provide the energy use of the house for that period.

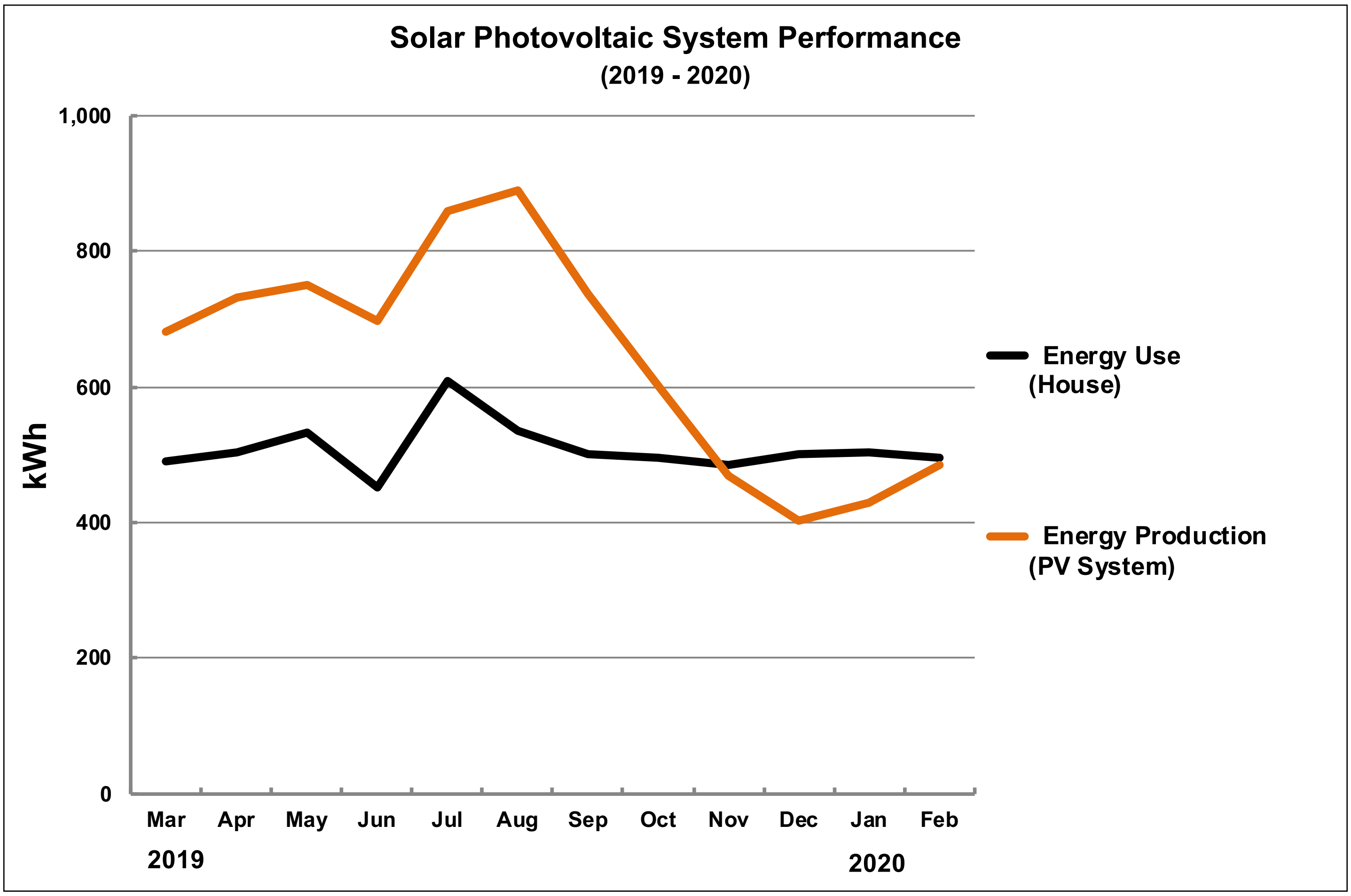
For solar PV systems with certain batteries (for example, as in this case, a *Tesla Powerwall*), the historic data on energy generation and energy flows to and from the SCE electric grid can be recorded and accessed using a built-in metering app at the battery. The house energy use is calculated by the metering app using the same simple addition of energy generated and the net energy imported from the SCE electrical grid. In addition, the charting output of this data by this built-in app at the battery is useful visual information about energy performance trends that the owner can employ to adjust energy use behaviors.

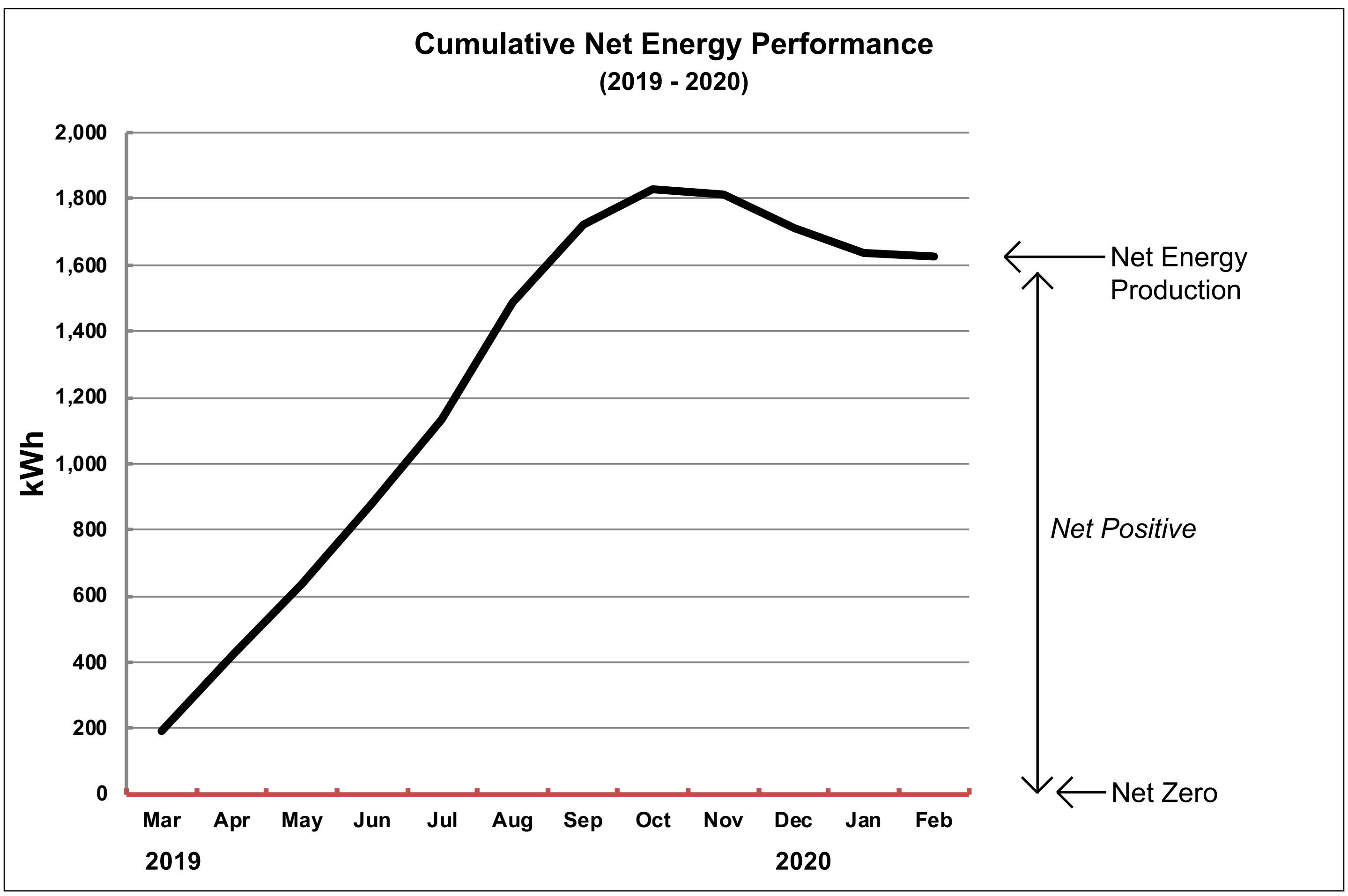
The charts of this case study utilize the data recorded by the Tesla battery system for the recorded period of operation from March through September of 2019. For the remaining five months of one full year (October 2019 through February 2020), both the energy use and on-site solar energy generated can be reasonably estimated in order to demonstrate the expected ZNE performance at the end of one full year.

The energy use for these final five months is estimated utilizing the PHPP calculation for those particular months multiplied by the factor that the actual energy use in the first seven months exceeded the PHPP model, namely 1.5. For the on-site solar energy generated during these final


Modeled Monthly Energy Use
(From PHPP)
4,170 kWh/year
Modeled EUI = 7.0
kBtu/sq.ft.
1.25
1.00
0.75
0.50
0.25
0.00
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Lighting, Plug Load, Domestic Hot Water (DHW)
Cooling
Heating


Measured Monthly Energy Use
(2019 - 2020)
6,190 kWh/year
Measured EUI = 10.2
kBTU/sq.ft.
1.25
1.00
0.75
0.50
0.25
0.00
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
2019
2020
Dashed columns show estimated values. (See text for descriptionn of methodology.)


Solar Photovoltaic System Performance
(2019 - 2020)
kWh
1,000
800
600
400
200
0
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
2019
2020
Energy Use
(House)
Energy Production
(PV System)


Cumulative Net Energy Performance
(2019 - 2020)
kWh
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
2019
2020
Net Energy
Production
Net Positive
Net Zero

five months, the estimated monthly amounts can be directly estimated by using the PVWatts® Calculator[16]. The correlation is almost exact for the actual recorded solar generation data and so the numbers for the final five months will be a reasonably close estimate.

The chart on p.17 shows the monthly energy use as metered between March and October of 2019 and estimated for the remaining period through February 2020. It can be observed that the actual energy use is 45% higher than that estimated by the PHPP. However, the actual EUI = 10.2 represents a low energy use intensity for three people in the 2,000 sq. ft. house. With the solar energy generated on-site, it will be performing at 25% better than ZNE at the end of the year.

Energy Production versus Energy Use: Zero Net Energy Performance

The charts on the opposite page show the solar PV system performance over the course of one year (March, 2019, through February, 2020), with the first seven months' performance based on actual data and a reasonable estimate for the balance of the year. The chart of solar energy production versus energy use shows that the house system will generate about 25% more energy than will be used by the end of the 12-month period.

The *cumulative net energy production* is a chart that essentially shows the progression of the energy performance toward ZNE by adding each month's net energy performance to the previous month's total—if, at the end of the 12-month period, the curve remains on the positive side of the "Net Zero" axis, then the building in indeed performing better than ZNE, i.e., *Net Positive*. (This chart can also be constructed from the monthly SCE net meter reports.)

Post-Occupancy: Observations and Conclusions

Although the house did not achieve the level of energy performance indicated by the PHPP calculation, it is still *Net Positive* by a large margin. The solar PV array appears to be right-sized to comfortably meet the building loads. As a demonstration of applied Passive House principles and a ZNE home, the project has proven to be a great success.

Since there are always "lessons learned" in any building project, there are issues to note for consideration in future projects. This is particularly true in these case study homes, which are on the leading edge of design and construction innovation and therefore unfamiliar to most building trades and designers.

For this project, as a case in point, the windows selected proved to be difficult to handle due to their weight. While the triple glazing provided desirable noise control characteristics, it proved to be unnecessary for ZNE performance in this relatively mild climate. The house remains a very quiet environment, but the tradeoff was significant added cost and on-site labor.

The air-sealing of the structure proved to be a challenge, especially with the Passive House standards. The building trades simply are not familiar with the "dos and don'ts" of the particulars of their trade with regard to the effect on airtightness. A specialized sub-contractor may be necessary unless the contractor has experience with air-sealing products and techniques. A certain amount of ongoing training in the methodologies of air-sealing wood-frame construction is recommended.

After almost one year's experience with the kitchen recirculation hood, the owner now thinks that a low-power direct exhaust fan is a better choice because of the lingering air pollutants from cooking by-products as well as odors.

[16] See https://pvwatts.nrel.gov/pvwatts.php. The PVWatts Calculator gives the monthly energy generated (kWh) by a particular solar PV system of a specified power level (kW), panel tilt, panel azimuth and geographical location.

CASE STUDY NO. 7

Perlita Passive House

PHOTO: LAWRENCE ANDERSON

Perlita Passive House

Case Study No. 7

Data Summary

Building Type:
Single-Family (Renovation)

Location: Los Angeles, CA

Gross Floor Area:
2,120 gross sq. ft. (Unheated spaces not included.)

Occupied: December 2018

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

On-Site Storage Battery
14 kWh Tesla Powerwall

Measured On-Site Energy Production:
9,600 kWh per year
15.6 kBtu/sq.ft. per year

Pre-Occupancy Calculated EUI (Site):
9.5 kBtu/sq.ft. per year

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

Owner/Client
Shelle Higgins
Xavier Gaucher

Project Team

Architect:
Eve Reynolds, Arcolution, Los Angeles, CA

Mechanical Engineer:
Xavier Gaucher

Structural Engineer:
Henry Downey, HRD Engiineering, North Hollywood, CA

Certified Passive House Consultant (CPHC):
Xavier Gaucher

Landscape Architect:
Tony Paradowski, Superjacent, Los Angeles, CA

Construction Consultant:
Nico Design

The second case study in this Volume 2, like that of Volume 1 of *Zero Net Energy Case Study Homes*, is a major renovation of an existing house. As noted in the first book, a renovation project must deal with existing construction, less-than-optimal features affecting energy-efficiency and (often) labor-intensive correction of code deficiencies. Because of these factors, there is often a marginal cost savings in renovation versus new construction. But there are sustainability and *embodied carbon*[1] considerations in the re-use of an existing structure that are factors in the decision to renovate rather than build new.

The *Perlita Passive House* is also of interest as a case study because it meets the *Passive House Standards* at the same time that it uses an existing house with mid-twentieth century construction methods. Application of the highly energy-efficient techniques required for Passive House certification[2] is instructive in comparison to other types of ZNE houses described in the Volume 1.

Background

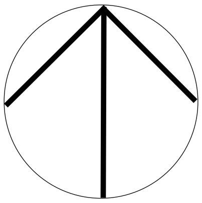
The owners had built a new house on a lot in France, finishing construction in 2008.Three years afterward, they discovered the Passive House Standard and that particular approach to building an energy-efficient house. Suddenly, all the shortcomings of their original project were apparent. When they moved to Los Angeles in 2015, they embraced the Passive House methodology of

[1] L. Strain, "Ten Steps to Reducing Embodied Carbon", (Mar., 2017), https://www.aia.org/articles/70446-ten-steps-to-reducing-embodied-carbon.

[2] For a description of the Standards for Passive House certification, see: https://www.passivehouse-international.org/index.php?page_id=150

(Above) The original house, built in 1906, as viewed from the street.

Perlita Passive House - General Vicinity Plan



building and certification. They decided to apply it to their new home, which they purchased in August, 2015, and began the renovation process of transforming it to Passive House standards.

The house had been built more than a century ago in 1906 in the Atwater Village neighborhood, which is just northeast of downtown Los Angeles. It was a small, simple one-story house with a partial basement. Planning, design and the permitting process required 15 months, with construction starting in January, 2017. The owners moved in when the finishing work was still underway, but nearly completed, in November, 2017.

Project Process

Building Program

The original house was only 1,100 sq. ft., so to accommodate their basic living program the owners were required to add a second floor. This allowed them to create an open loft space with office and bathroom on the ground floor and to organize the two addition bedrooms with bathrooms and a quiet family space on the second floor.

The existing partial basement was not included in the design since it is not a practical space. It is isolated from the finished house.

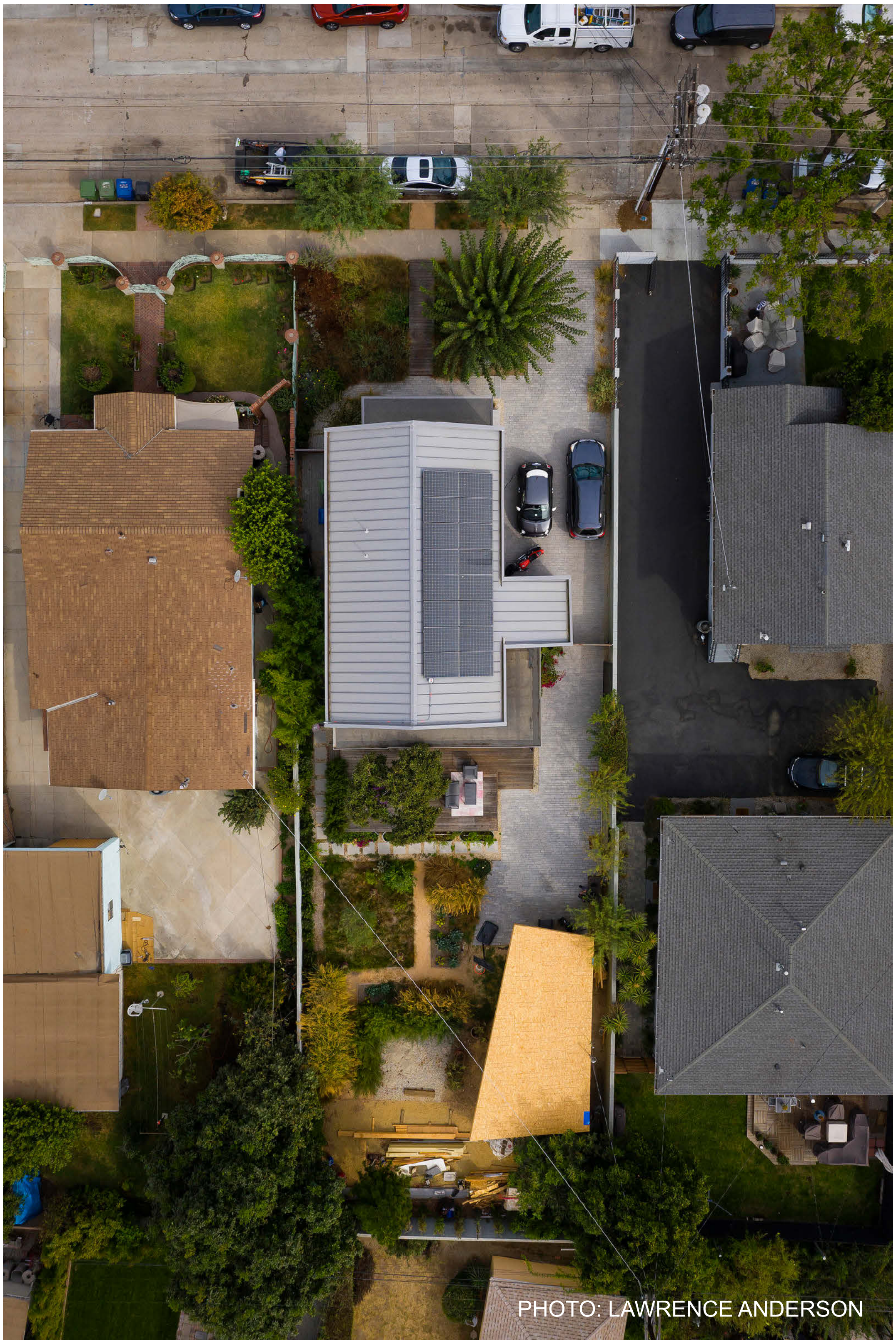
Site Constraints

The house is located in a dense neighborhood of small lots and various types of housing, including low-rise apartment buildings. The local climate is similar to that of Pasadena, requiring both heating and cooling.

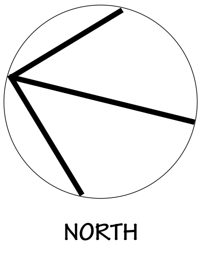
Despite its age, nothing historical was deemed noteworthy about the existing house, which made for a routine approval process. The plans nevertheless called for retaining the original foundation, concrete floor slab and the wall framing.

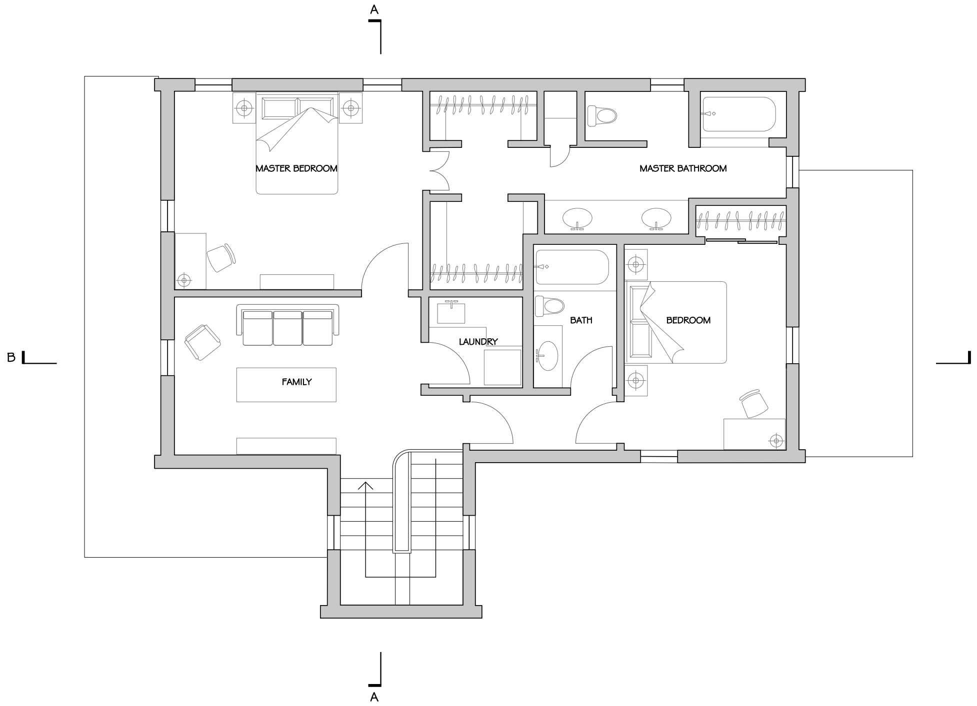
Solar access at the site was unobstructed by nearby structures or tall trees, guaranteeing good solar generation potential at this site, which is typical of this general area.

(Right) View of “deconstructed” original house. The original framing is full-size 2X3 and is used in the reconstructed walls on the first level.

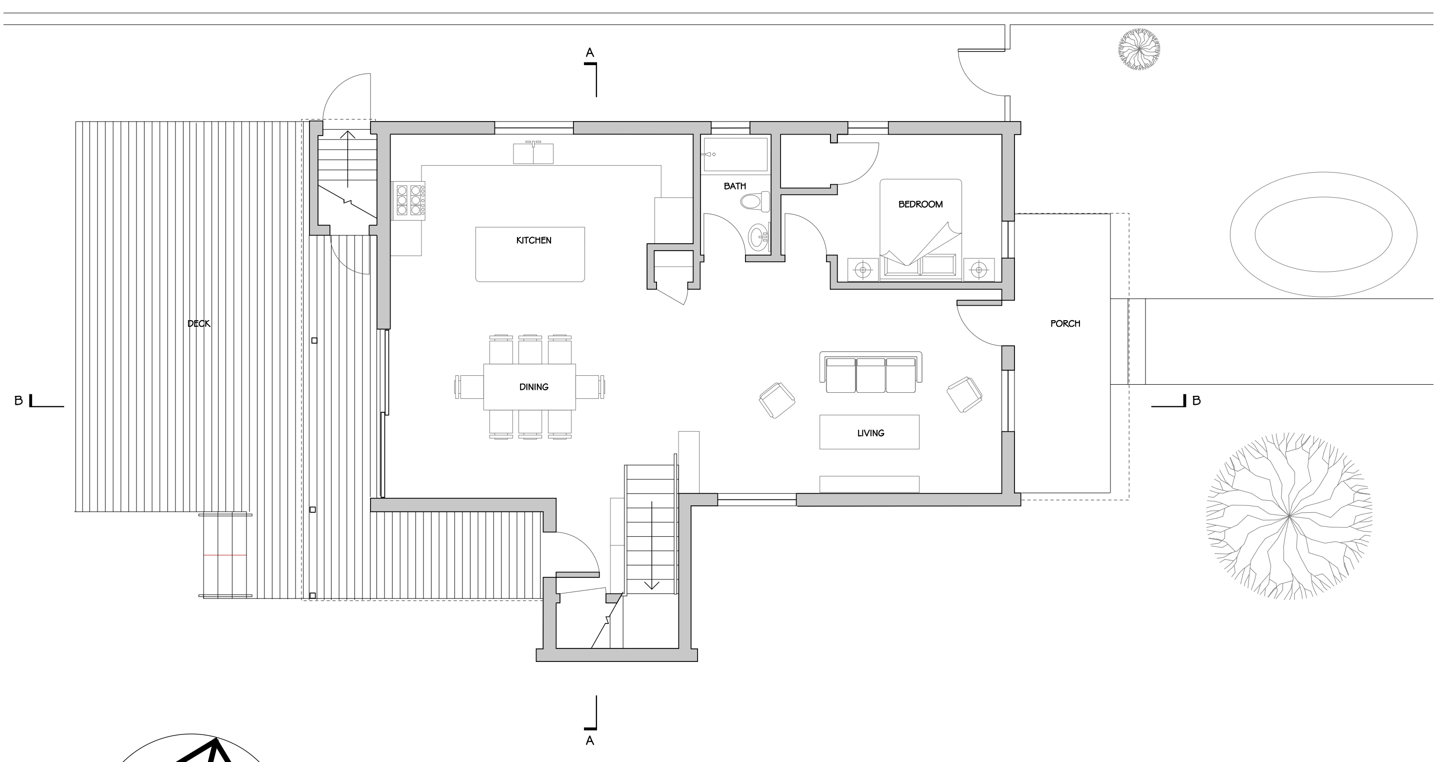


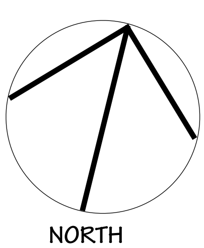
(Left) Aerial view of site and neighboring buildings.



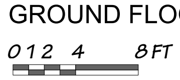


SECOND FLOOR PLAN

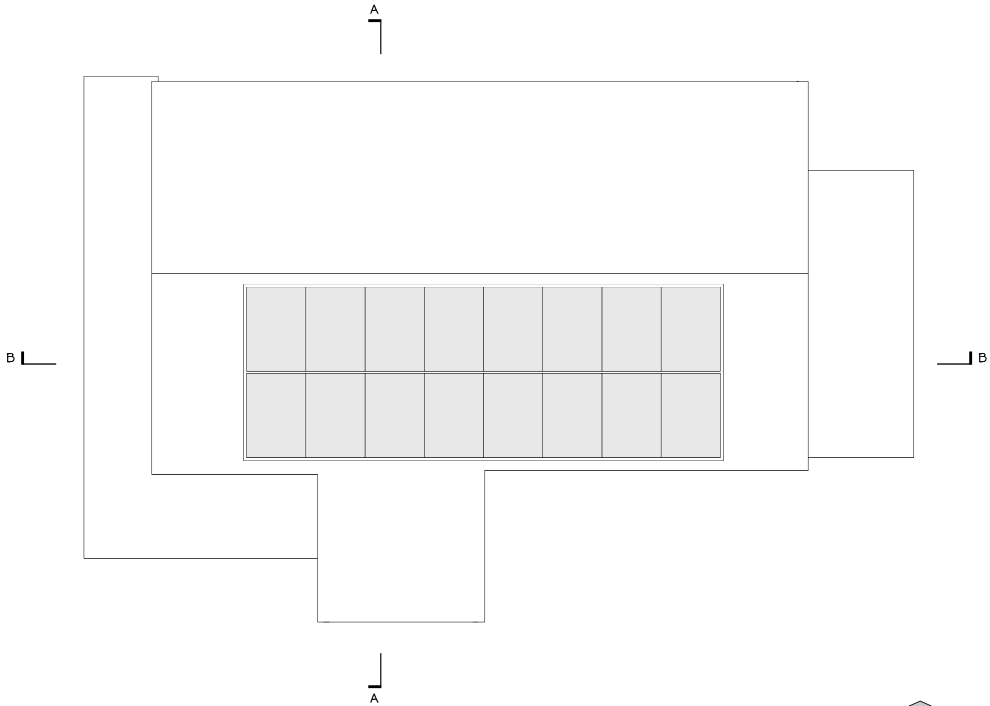




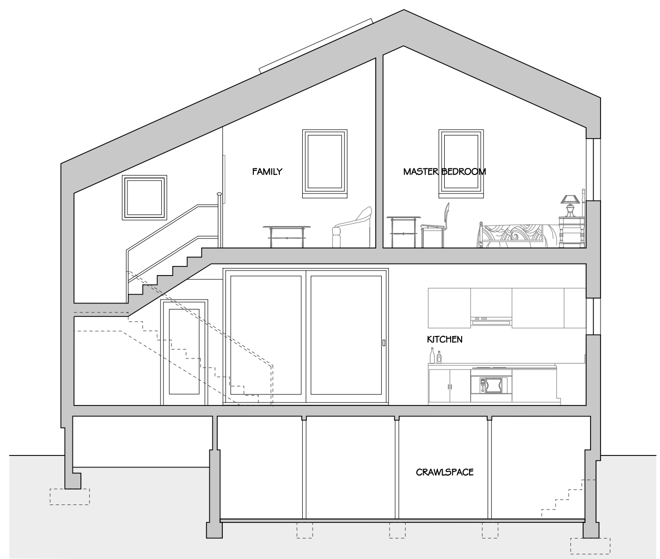
GROUND FLOOR PLAN



PERLITA PASSIVE HOUSE: FLOOR PLANS AND BUILDING SECTIONS



ROOF PLAN



TRANSVERSE (CROSS) SECTION

LONGITUDINAL SECTION

Low Energy Design Strategies

The new house utilizes the ground floor slab and wood framing of the single story original house, keeping the existing footprint of this structure and simply adding a new floor directly above it and a new stair connecting the two levels. The completed structure received its *Passive House Certification* in 2017, based on the design characteristics as recorded in the *Passive House Planning Package (PHPP)*. The high standards achieved for this certification incorporate the best comprehensive low-energy design strategies and are described in the following sections.

Building Envelope — Insulation and Windows

Passive House standards call for heavily insulated walls and roof, usually requiring a layer of rigid insulation on the outside of the wall studs to eliminate thermal bridging. Because the house is on a relatively narrow lot with the narrow driveway typical of houses built in the early part of the twentieth century, the owners did not want to expand the wall thickness toward the outside. Instead, they framed a second row of studs on the inside to maintain the driveway clearance. The new studs in the interior layer of framing were offset from the row of exterior studs in order to eliminate the thermal bridging effect. This type of double-framing is repeated on the second level for a consistent structural solution even though it is all new framing. (See the wall details on the opposite page that illustrate this framing method.)

The interior floor area is reduced very slightly, but the overall floor area on the two levels meets the program satisfactorily and the result is a building envelope that is needed to meet the rigorous Passive House standards for heating and cooling. Mineral wool insulation is used throughout because of its inorganic properties (no mold possible) and its slightly better thermal performance per inch. The final overall R-values are R = 22 for the exterior walls and R = 38 for the roof, which includes the effect of thermal bridging even with the offset wooden studs.

A small "attic space" or mechanical room was created above the eastern half of the house, essentially to house the air-handling unit. This small room is within the heavily insulated and air-sealed roof structure.

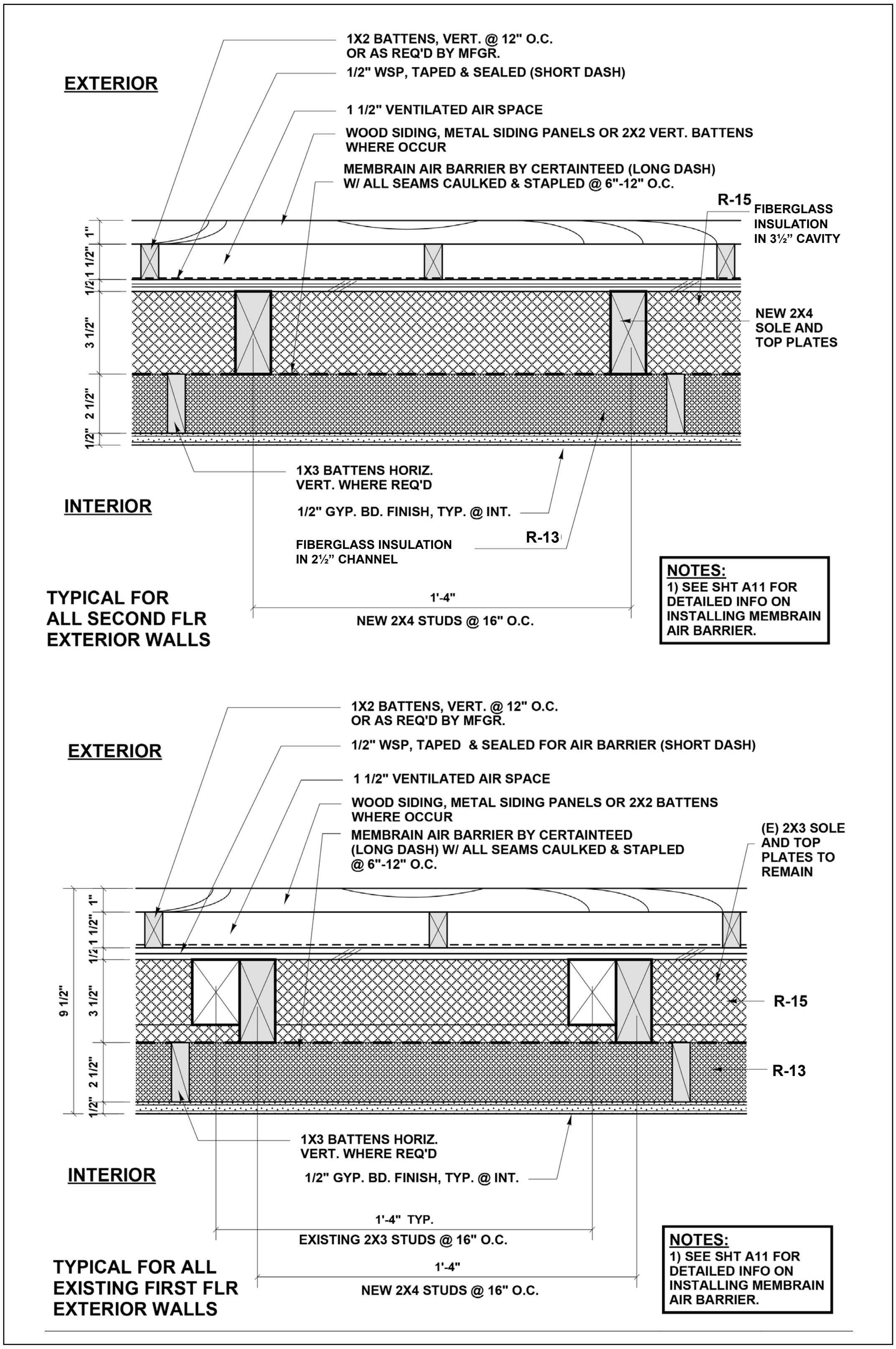
(Above) The renovated house, completed in 2017, as viewed from the street.

All window and door glass was specified as double-glazed in response to the relatively mild climate, as opposed to triple-glazing as required to meet the Passive House standards in colder climates. It was determined that the maximum heating and cooling load requirement of the standards could be met by the less expensive type of glazing.

The window and door manufacturer[3] was selected based on NFRC certification, availability of the detailed data required to calculate the U-Value for the PHPP and a guarantee of airtightness.

---

[3] Zola clad-wood Arctic line, https://www.zolawindows.com/clad-wood#Slide4

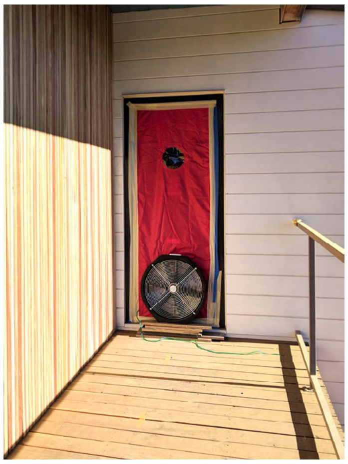


(Left, top) Exterior wall framing detail at the second floor, which is all new framing.

(Left, bottom) Exterior wall framing and insulation detail at the first floor showing incorporation of existing 1906 wall studs into the new framing and added insulation on the *inside* of the wall with offset studs to mitigate thermal bridging;


PASSIVE

PHOTO: LAWRENCE ANDERSON



(Above) Blower Door and pressure gauge as used in the Blower Door test. (Photos courtesy of Xavier Gaucher)

Building Envelope — Airtightness

Like all ZNE houses, design detailing and attentive construction supervision are required to produce the energy efficiency that airtightness provides. (Refer to the *Sidebar - Airtightness* discussion in Case Study No. 6 that appears in this Volume 2.)

Passive House standards are particularly rigorous in this regard, requiring a Blower Door test that yields a maximum air leakage rate of 0.6 air changes per hour at 50 pascals of pressure, or 0.6 ACH50. In recognition of the differences that may occur with a renovation of an existing house, the Passive House standard for renovation is set at 1.0 ACH50.

The Perlita Passive House employed a special airtightness membrane product that is intended to seal the construction in a less labor intensive manner than tapes, gaskets and specialized caulking. A special construction drawing was used to guide the subcontractor on the installation of the air-tightness membrane product for the various conditions that would be encountered during construction. The net result was that the house achieved the standard of 1.0 ACH50 with the Blower Door test.

Heating, Ventilating and Cooling Systems; Domestic Hot Water

Because of the airtight construction, the house needs to be equipped with a system that provides quantifiable fresh air distribution with minimum power. In a highly energy-efficient house such as a Passive House, that usually means specifying a Heat Recovery Ventilator (HRV) with its built-in heat exchanger and simple ducting system for moving the fresh air to and from individual spaces. The air inside the house is heated or cooled as needed using a simple system like a mini-split heat pump, keeping the fresh air ventilation separate from the conditioned air supply.

The owners chose instead to use a combined system—a standard air-handling unit (AHU) with a 1.0 ton heat pump and a constant low-volume flow of fresh air. Since the cooling loads are significantly higher at this site's inland location than for the coastal location of Case Study No. 6, this choice was more cost-effective in terms of equipment and ductwork and eliminated the need for two supply vents in each room. The disadvantage was energy efficiency since there is no heat exchanger as in the HRV. The good air-filtration, also a feature of an HRV, proved to be particularly noticeable during a recent wildfire event.

As in the previous ZNE case study home, the kitchen exhaust fan is a recirculating unit to avoid an additional penetration of the building envelope.

The heat pump water heater is located in the small, unconditioned basement space. (The owners refer to the basement as their wine cellar since the heat pump water heater cools the air in the room while it is making hot water.)

Lighting and Plug Loads

Lighting, plug loads and domestic hot water constitute roughly 75% of the energy use because of the high energy efficiency of the building envelope and the heating and cooling equipment. All lighting is done with high-efficiency LED sources and all appliances are high efficiency Energy Star®.

Since the house is designed to be all-electric, the cooking is done by induction cooktop and electric oven. The clothes dryer is a condensation dryer, which requires no vent to the exterior, thereby avoiding potential air leakage via another wall penetration.

Control Systems

The house does not have a special “smart” control system, but simply relies on individual control apps for each system accessible through a laptop computer.

Construction

Construction required one year and was completed in February, 2018, although the owners moved back in from their temporary rental in November, 2017. The owners acted as general contractor and hired a building contractor to act as a construction consultant for a fee.

Renewable On-Site Energy Supply

The on-site solar PV system consists of sixteen (16) Sunpower panels at a maximum output of 360 watts, facing a few degrees east of due south and installed directly on the roof, which slopes at an angle of 24°. The total size of the system is 5.6 kW.

Twelve panels are dedicated to the house energy use and four additional panels were added as an estimated energy supply for an electric vehicle (EV) based on anticipated daily use.

The entire system is also connected to one Tesla Powerwall battery with storage potential of 13.5 kWh. This battery provides an energy source in the evening when the energy consumption tends to be high and there is no power being generated by the solar PV panels. It is a means of “load shifting” so that the renewable energy that is normally sent to the utility grid during the day is instead stored on-site at the battery for use later to supply the house.

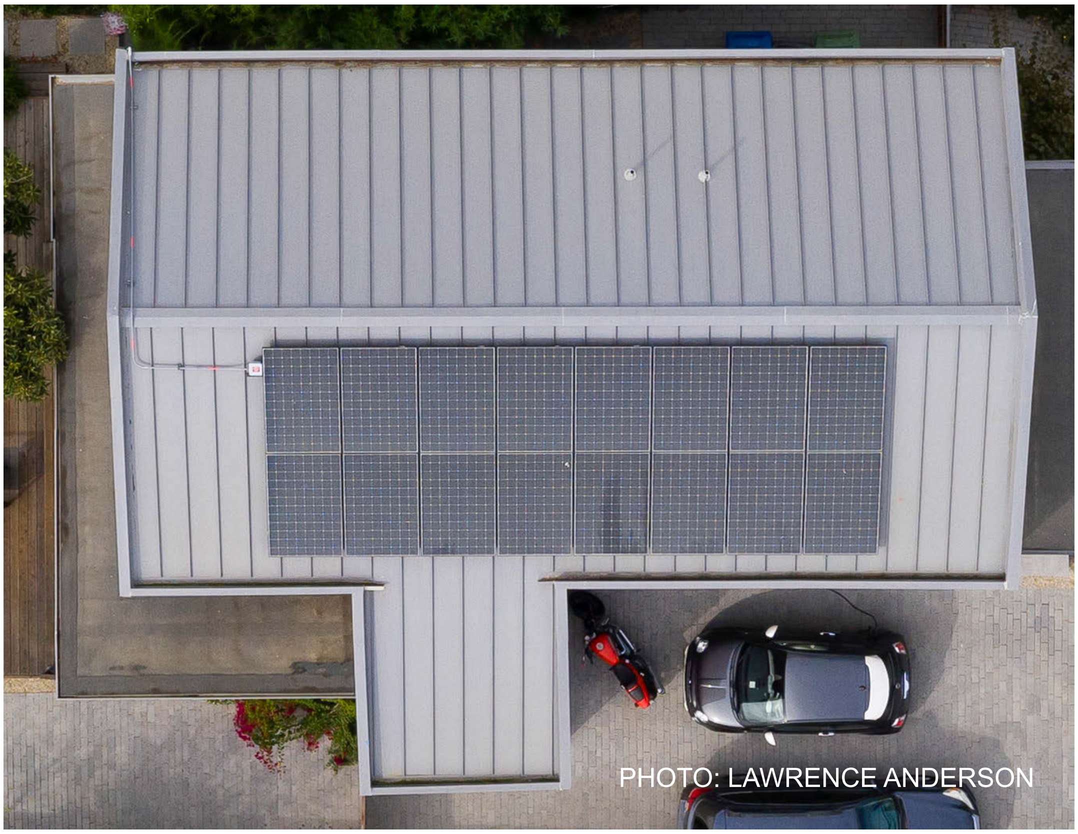


PHOTO: LAWRENCE ANDERSON

(Left) Sixteen solar PV panels provide 5.6 kW (DC) power for the house and one electric vehicle (EV). The EV is generally charged in the afternoon directly from the PV panels after the battery is fully charged.

Energy Performance
Energy Modeling and Post-Occupancy Measurement

Energy Use—Modeling

As with the Passive House in Case Study No. 6, the Perlita Passive House was required to submit a completed *Passive House Planning Package (PHPP)*[4] to document that all required standards for certification were met[5]. The computational spreadsheet "software" (an Excel form) is accurate enough in its design, detail and climate information to "predict" closely how the house will actually perform and, as such, is often called a "modeling tool" by Passive House consultants. The resulting monthly energy use estimate can help in the sizing of the solar PV system that results in a ZNE-performance for the house.

It is also interesting to compare the results of the PHPP calculations with the actual measured performance over the course of a year. The results of the PHPP calculations for this case study house are shown in the chart on the opposite page; the measured performance data for one year beginning in July 2018 are shown in the chart directly below for comparison.

Energy Use—Post Occupancy Measurement

The Tesla Powerwall has the capability of generating and displaying real time reports on energy generation, energy storage and net import/export to the utility power grid. The energy used to charge the EV is metered separately, allowing the energy used for the house alone to be calculated from the Tesla data. This monthly energy use for the house is shown by the chart on the opposite page.

Energy Production versus Energy Use: Zero Net Energy Performance

The charts on the following page show the solar PV system performance over the course of the year starting in July, 2018. The chart of solar energy production versus energy use includes the monthly energy use data for the EV as well. The relative impact of the EV charging patterns can be seen in comparison to the energy use of the house alone.

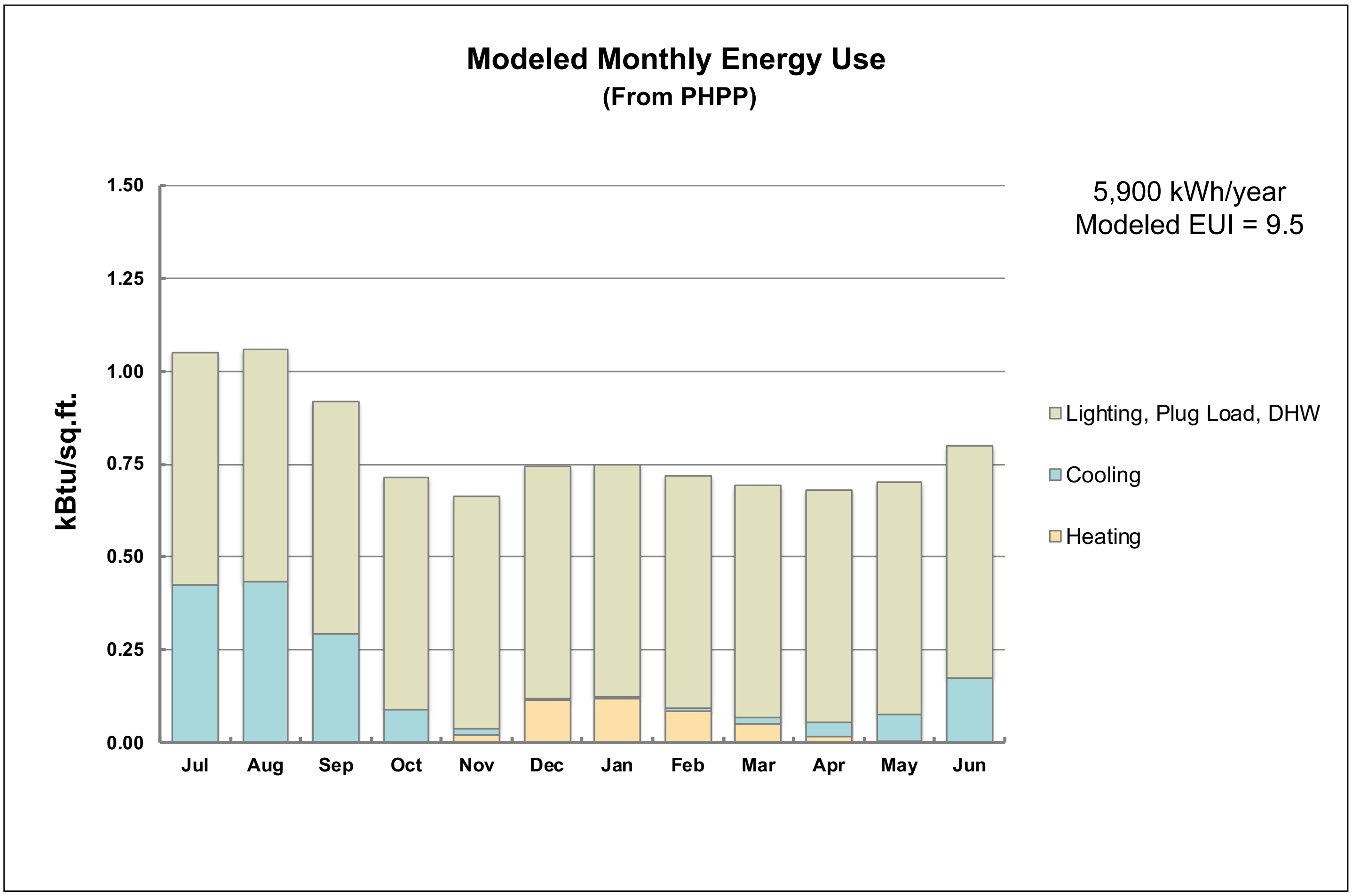
The *cumulative net energy production* is a chart that essentially shows the progression of the energy performance toward ZNE by adding each month's net energy performance to the previous month's total—if, at the end of the 12-month period, the curve remains on the positive side of the zero axis, then the building in indeed performing better than ZNE, i.e., *Net Positive*.

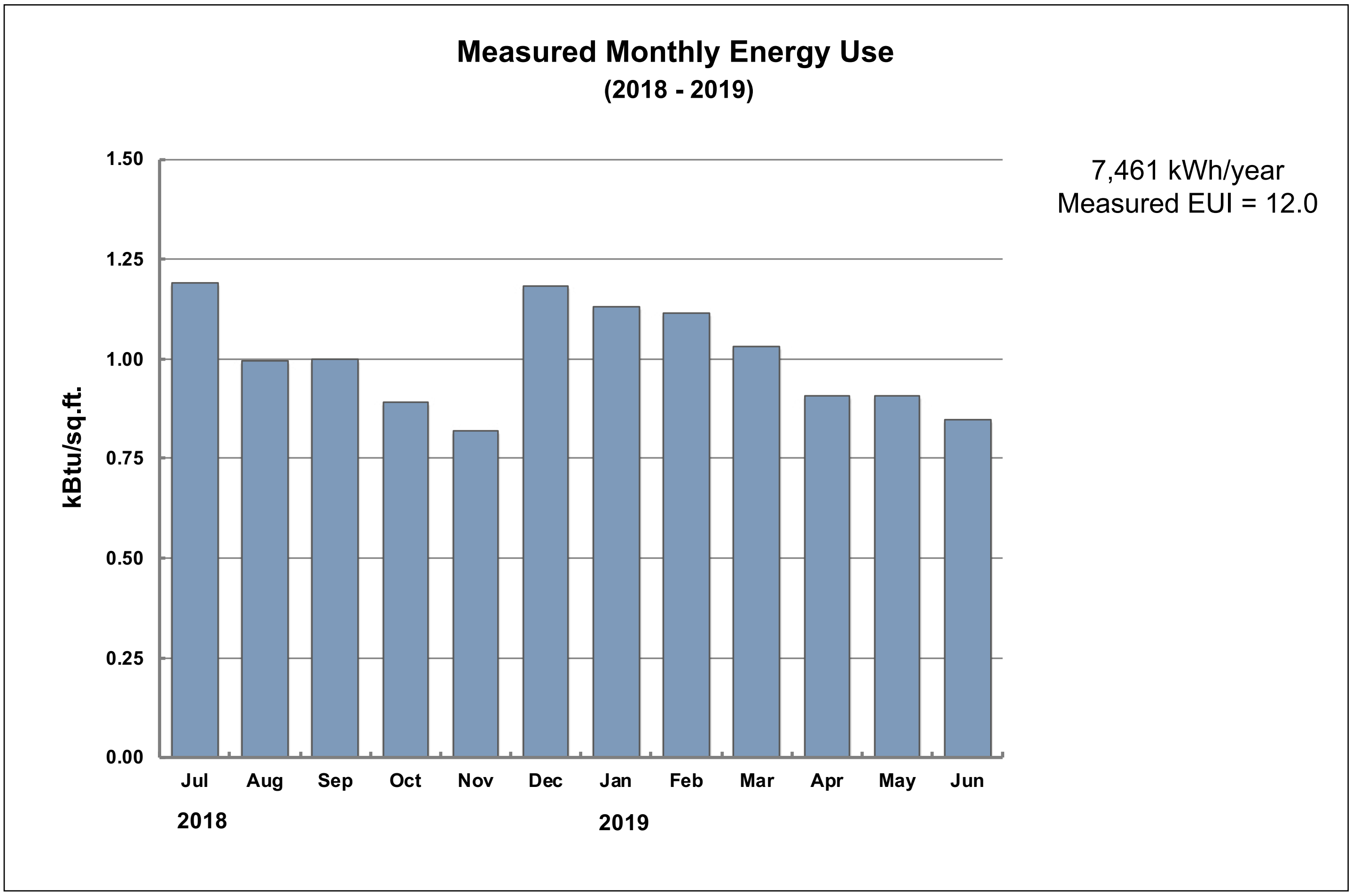
For this case study, even when the renewable energy used to charge the EV is included with the energy used by the house, the cumulative net energy productiion over the course of one year is net positive. The conclusion is that the solar PV system is right-sized for the owners' current use patterns for *both* house and EV.

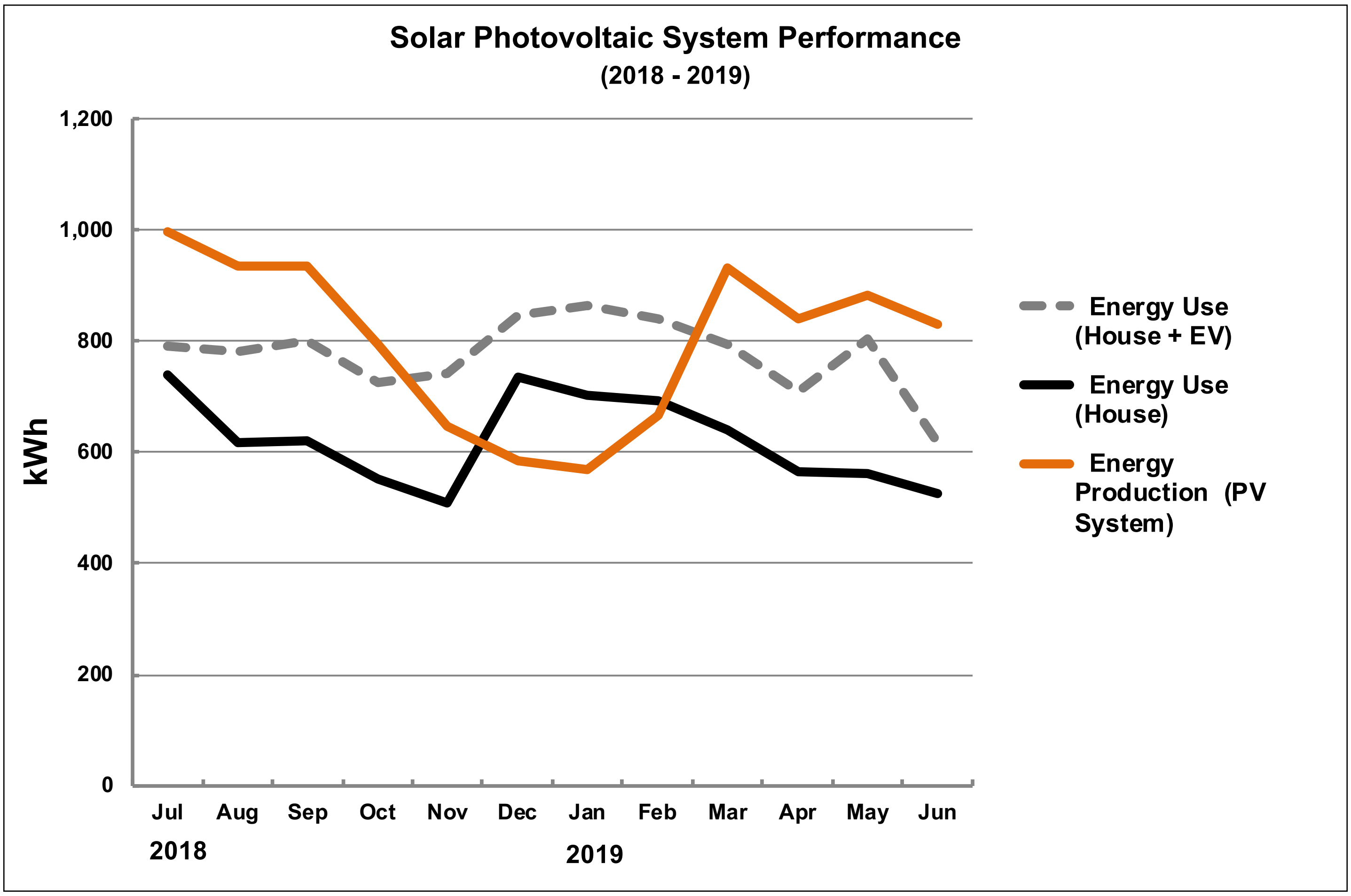
---

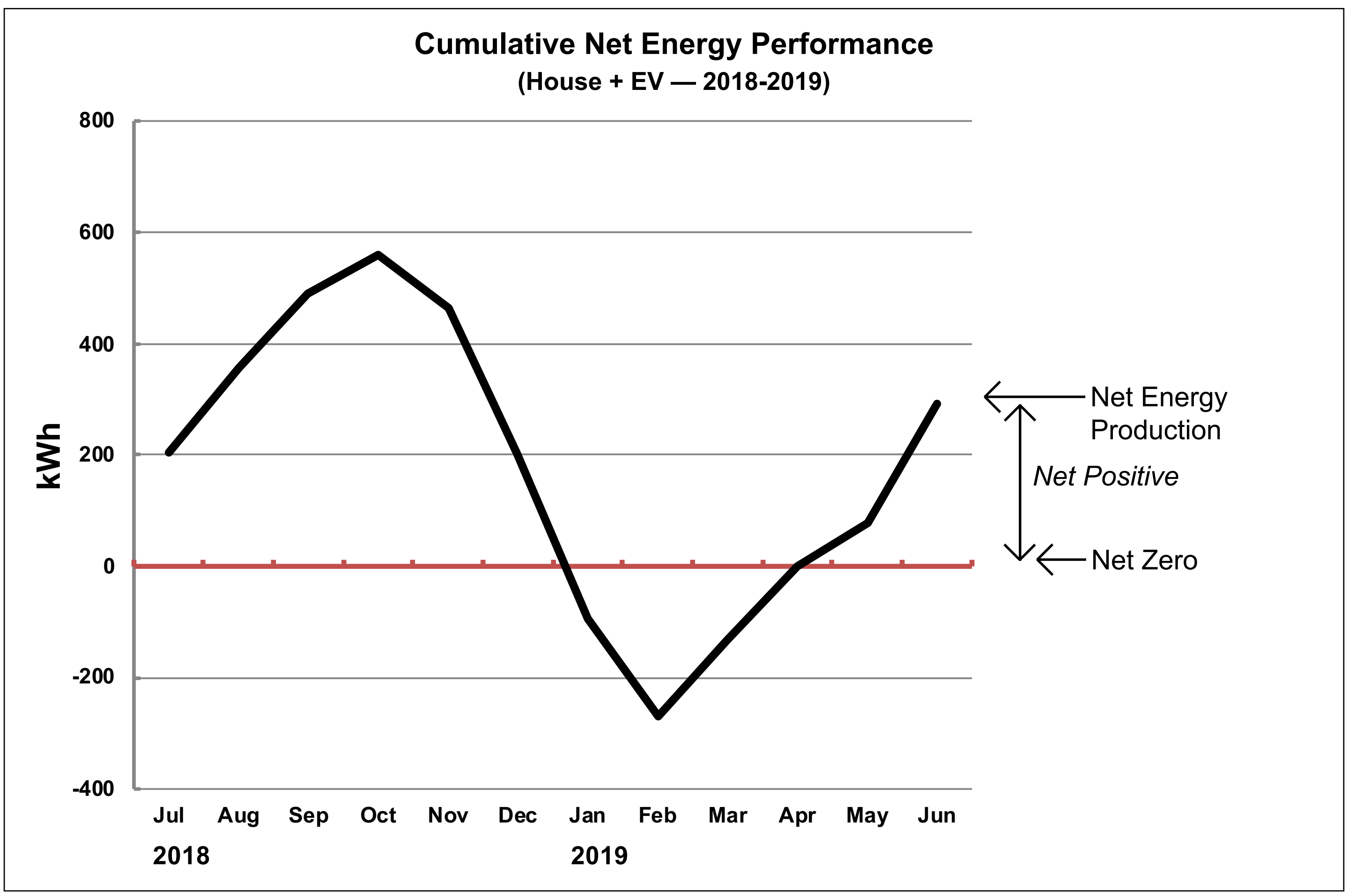
[4] The PHPP is a spreadsheet form of energy use calculation by category of load. See: https://passipedia.org/planning/calculating_energy_efficiency/phpp_-_the_passive_house_planning_package.

[5] Note that the Passive House certification process requires that the project be verified by the PHPP and several other document submittals. The only onsite inspection required is the *Blower Door* test, which has to be done by a Passive House certified consultant. When the pressure test meets the standard, this consultant writes the report on the test results for certification.


Modeled Monthly Energy Use
(From PHPP)
5,900 kWh/year
Modeled EUI = 9.5
kBtu/sq.ft.
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Lighting, Plug Load, DHW
Cooling
Heating


Measured Monthly Energy Use
(2018 - 2019)
7,461 kWh/year
Measured EUI = 12.0
kBtu/sq.ft.
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2018
2019


Solar Photovoltaic System Performance
(2018 - 2019)
kWh
1,200
1,000
800
600
400
200
0
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2018
2019
Energy Use (House + EV)
Energy Use (House)
Energy Production (PV System)


Cumulative Net Energy Performance
(House + EV — 2018-2019)
kWh
800
600
400
200
0
-200
-400
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2018
2019
Net Energy Production
Net Positive
Net Zero

Post-Occupancy: Observations and Conclusions

The house consumes more energy than calculated by the PHPP, similar to the Passive House of Case Study No. 6, but as noted above it is still net positive by some amount. More cooking activity than originally calculated appears to be the principal difference in the measured data.

The solar PV system is relatively small (<6 kW) and is capable of providing the energy to make house *plus* electric vehicle (EV) together ZNE.

In 2019, the Perlita Passive House was certified as a "Petal Certified Renovation" by the International Living Future Institute (ILFI), which is one of the few certifications for ZNE buildings. To obtain such a certification from ILFI, the building is required to be all-electric as well (no carbon based energy sources such as natural gas).

The Perlita Passive House is expected to receive certification as *Passive House Plus*[6], which requires a greater energy-efficiency and generation of a minimum amount of renewable energy.

Since there are always "lessons learned" in any building project, there are issues to note for consideration in future projects. This is particularly true in these case study homes, which are on the leading edge of design and construction innovation and therefore unfamiliar to most in the the building trades and to many designers.

As an example of such experiences, one of the owners observed that the choice of a custom-designed HVAC system as described above was effective for himself, as a trained mechanical engineer, but a standard approach using an HRV with a mini-split heating/cooling system would be a preferred choice for another type of client.

As with Case Study No. 6, the owners of Perlita Passive House now think that a kitchen exhaust fan that exhausts air directly outside via a simple wall penetration is preferable to a recirculating kitchen hood. The indoor air quality is noticeably different to the owner-occupants.

The airtightness membrane, selected as a method to air-seal the framing gaps and openings, proved to be difficult to work with and too fragile. The result was that the builders experienced many tears and material breakdowns that had to be sealed by various means, including the use of tapes and caulking. The Blower Door test as a result proved difficult to do, with leak patching of the membrane requiring much time and effort. The owner's conclusion is to rely on proven techniques and an airtightness system listed by *Passive House*[7].

[6] A building built to *Passive House Plus* is more efficient — it may not consume more than 45 kWh/m^2 per year of renewable primary energy. It must also *generate* at least 60 kWh/m^2 per year of energy in relation to the area covered by the building (building footprint). (Note: for Perlita Passive House, this renewable energy generation total was 97.6 kWh/m^2 for the measured year, more than 50% above the required amount.)

[7] https://database.passivehouse.com/en/components/list/airtightness_system

CASE STUDY NO. 8

Stratton-Lee DIY House

PHOTO: LAWRENCE ANDERSON

Stratton-Lee DIY House

Case Study No. 8

Data Summary

Building Type:
Single-Family (Renovation)

Location: Temple City, CA

Gross Floor Area:
1,323 gross sq. ft. (additional 515 sq. ft. unconditioned garage)

Occupied: Continuous

Work Start Date: 2016

Substantial Completion: 2019

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

On-Site Storage Battery
None – Planned but not yet installed

Measured On-Site Energy Production:
5,200 kWh per year (2019)
13.5 kBtu/sq.ft. per year

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

Measured EUI (Site):
15.5 kBtu/sq.ft. per year (data period overlaps on-going renovation work)

Owner/Client
Chris Stratton
Wen Lee

Project Team

Architect / Designer:
Chris Stratton

Mechanical Engineer:
Chris Stratton

Structural Engineer:
Mark Acciani, P.E., Running Hills, CA

HERS Rater:
Dav Camras of HERSRater-LA, Los Angeles, CA

Landscape Designer:
Wen Lee

General Contractor:
Chris Stratton

The large inventory of existing post-WWII single-family houses represent a significant potential for residential construction projects consisting of renovations and additions, especially given the current cost of new construction in California. A large portion of these renovation projects will incorporate zero-net-energy (ZNE) and zero-carbon features in response to the societal goals that have been set in California by government representatives, as well as to the mandates now set into the current building code.

In some cases, these features involve substantial design changes to the original home to achieve ZNE and zero-carbon performance, such as Case Study No. 7 (Perlita Passive House in this Volume 2) and Case Study No. 2 (Fortunato House in Volume 1). These particular case studies retained only concrete foundations and some raw framing; the result in each case was a completely different house in appearance when completed. Generally, these renovation projects are similar to entirely new houses, involving building contractors and start-to-finish construction in a year.

Other renovations may achieve the same type of ZNE and zero-carbon performance through less visible changes that are in actuality no less substantial in nature. This case study is such a house.

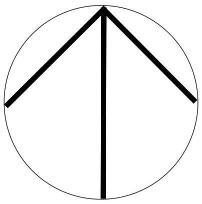
An additional part of the story of this case study home, and one of the reasons it was selected for inclusion in this book, is that it was largely designed and built by the owners over an extended period of time—a kind of ambitious "Do-It-Yourself" (DIY) project. This general approach to home renovation is quite common, emphasizing effective low-budget solutions with most of the labor provided by the owner-builder with varying practical skill sets. In this case, the result was a verified zero-carbon, ZNE retrofit of a single-family suburban house that essentially looks the same while having a very different energy performance than the original structure.

Background

The background for this case study project is personal: Wen Lee and Chris Stratton, owners of this case study house, are a couple that met during their studies at the *Environmental Studies Program* at the University of Oregon and were married in 2014. It is their personal background

(Above) The original house, built in 1963, as viewed from the street. (Photo: Wen Lee)

Stratton-Lee DIY House - General Vicinity Plan



(Opposite page, top) Work area on the north side of the house. *(Opposite page, bottom)* Front lawn transformed into a neighborhood vegetable garden.

and experience that gave them the initial idea for this project and the motivation and knowledge to execute it.

Wen Lee was Communications Director at *Alliance for Climate Education* and subsequently Engagement Director at republicEN.org part of the *Energy & Enterprise Initiative* at George Mason University. The well-documented and "well-followed" internet blog[1] on the experience of the rehabilitation of this house project for a zero-carbon footprint was a natural application of her skills and interests.

Chris Stratton worked as a building science researcher in the *Residential Building Systems Group* at Lawrence Berkeley National Laboratory (LBNL) and at the same time was technical editor for *Home Energy Magazine*. Therefore, he was well-informed about the current technical state-of-the-art of residential design and construction, as well as cutting-edge technologies making their way into that market.

The house is the childhood home of Wen Lee, who grew up in the neighborhood east of Pasadena and attended the local school. She moved out of the area, living in Oregon while attending the university and in the San Francisco Bay Area with Chris for several years after that. Wen's mother continued to live in the house during that time. When her mother passed away in 2015, Wen decided to return to Southern California and live near her extended family, moving into the house that she had inherited.

Chris agreed with the idea, though it meant leaving his position at LBNL. But it also presented the opportunity, which he welcomed, of putting into practice all that he had learned about residential energy systems and a zero-carbon lifestyle. It would become the ultimate DIY project.

Both Wen and Chris enthusiastically embarked on a very public process of DIY-renovating the house and recording the entire experience on the internet blog, "frugalhappy.org"[2]. Through text and video, every task is discussed and recorded so that the detailed experience is uncompromisingly shared with the public. They manage to communicate that this path to a ZNE and zero-carbon house is both affordable and possible—DIY for the ambitious homeowner or certainly feasible with professional contractor help.

The construction activity began in September, 2016, and they originally targeted one year to complete everything. Work proceeded at a reasonable pace for a DIY project, but eventually the realization took hold that the completion time of every scope item would be much longer than planned. The new target date for completion was set at mid-October, 2019, marked by the arrival date of their first child.

This case study discussion describes this three-year process and its successful outcome.

Project Process

Building Program

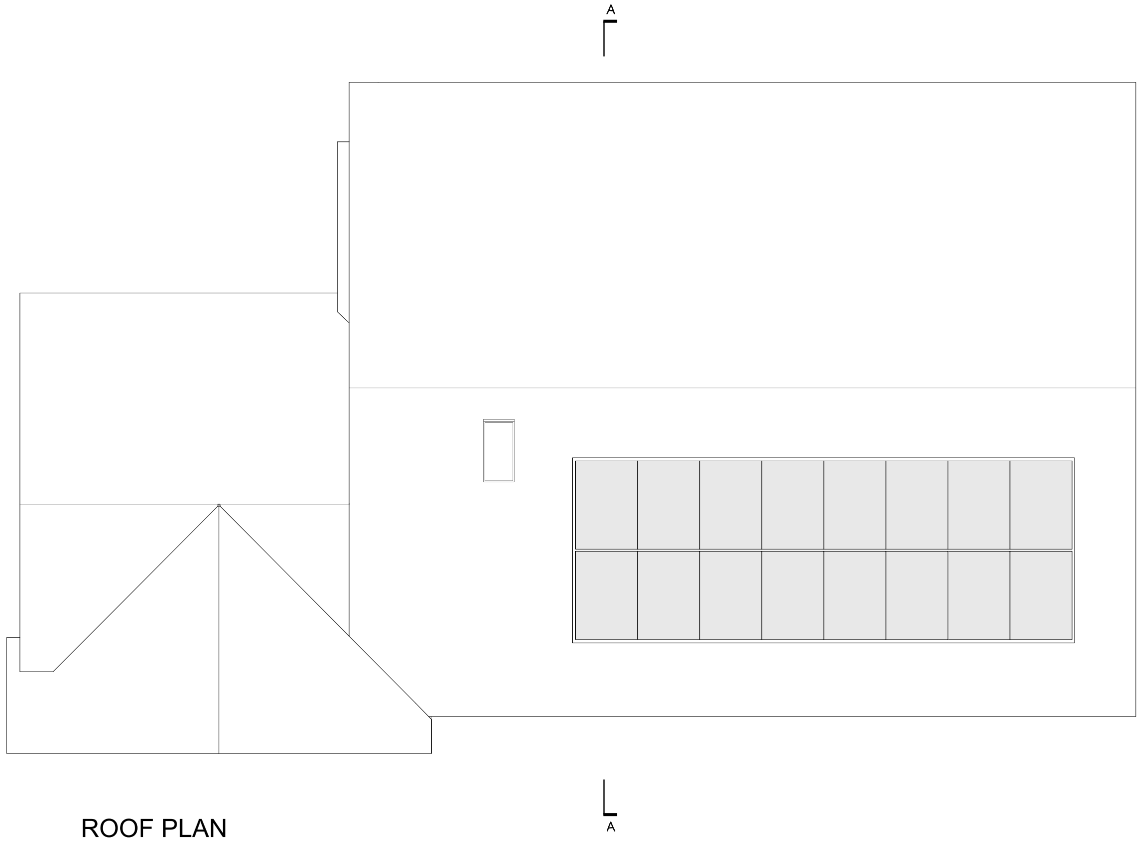
Planning began in January, 2016, with drawings and specifications developed by Chris for different phases of the work to be done. Since Wen and Chris were going to remain in the house throughout construction, they developed a phasing plan to allow this to happen. The original plan called for completion in one year and a preliminary budget of $50,000. Chris decided to take the year off to complete the ambitious work plan.

[1] http://www.frugalhappy.org/archive

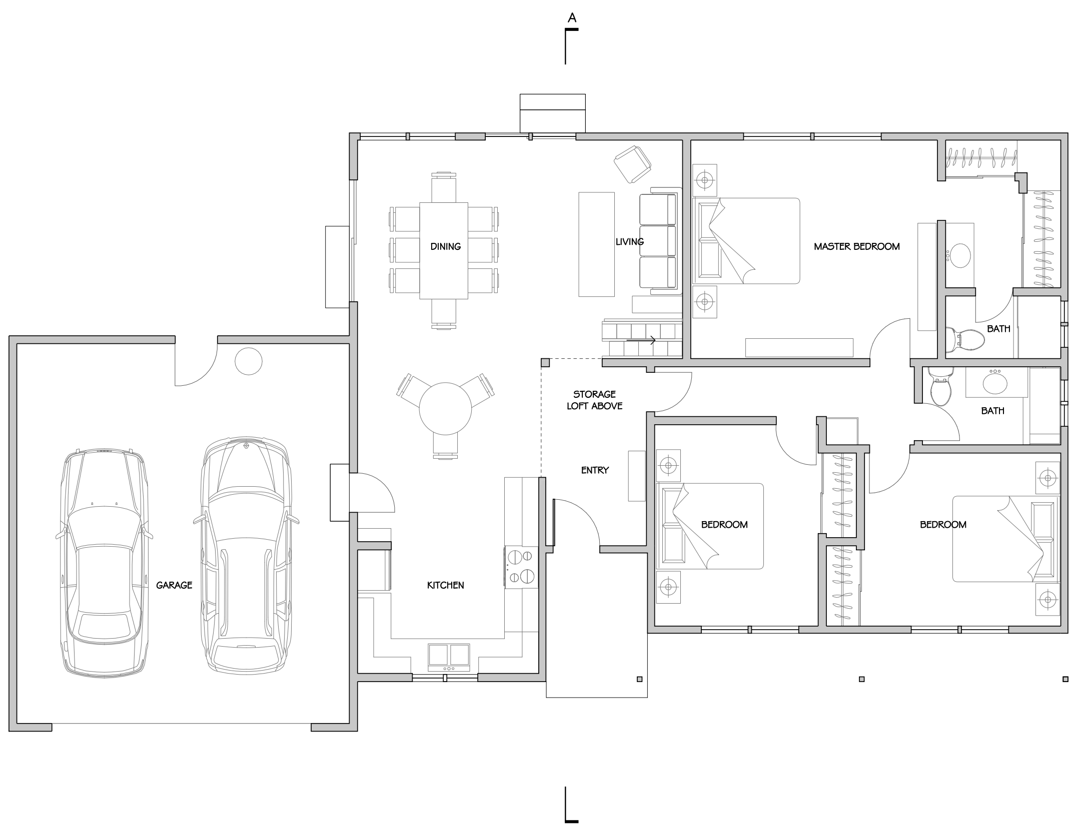
[2] Ibid.

PHOTO: LAWRENCE ANDERSON

PHOTO: LAWRENCE ANDERSON

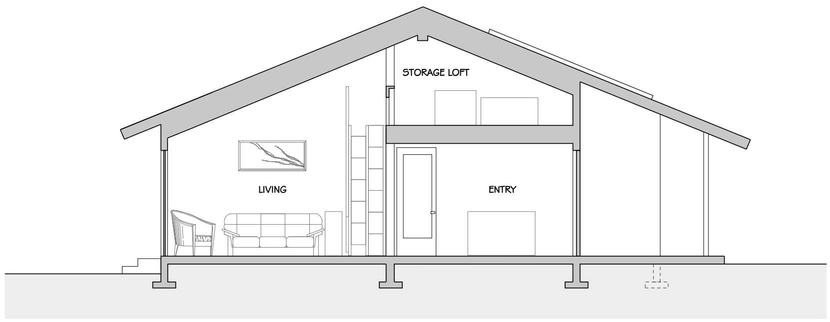


ROOF PLAN

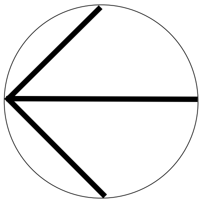


FLOOR PLAN

0 1 2 4 8 FT



TRANSVERSE (CROSS) SECTION



STRATTON-LEE DIY HOUSE: FLOOR PLANS AND BUILDING SECTION

The house was to remain the same in appearance and floor plan layout—one-story and all rooms within the existing exterior walls. The renovated house has the same number of bedrooms and bathrooms as the original. The living spaces were combined into one large loft-like space, to reflect modern living preferences, with some of the existing attic space above removed and combined to enlarge the volume of that common area. A small storage loft above the entry foyer was created.

The opening of the living area into one volume was the only major aesthetic decision of the renovation, with all other new features involving the zero-carbon goals of the project. Basically, the building program changes involved only the energy-related systems. The house retains essentially the same appearance as it had pre-renovation, but it is radically different in its makeup of materials and systems.

Site Constraints

All work was internal to the existing building envelope, so there were no site constraints.

Low Energy Design Strategies

A principal characteristic of the DIY approach is phasing of the work and adjusting the living arrangements to that phasing. There were two main phases, one for each half of the house. Phase 1 (the north half of the house) included the kitchen and living spaces, followed by Phase 2 (the south half of the house), which included the bedrooms and bathrooms.

During Phase 1, a temporary kitchen was located on the covered patio in the rear yard, a workable arrangement only because of the benign climate of the northern suburbs of Los Angeles. As a temporary aspect of the project phasing, this was acceptable (similar to trailer camping).

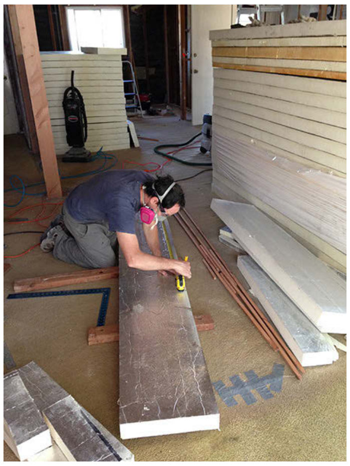
Building Envelope — Insulation and Windows

The original house was built in 1963 without any wall insulation and only minimal insulation in the attic. With the priority of very low cost determining many design decisions, as much of the

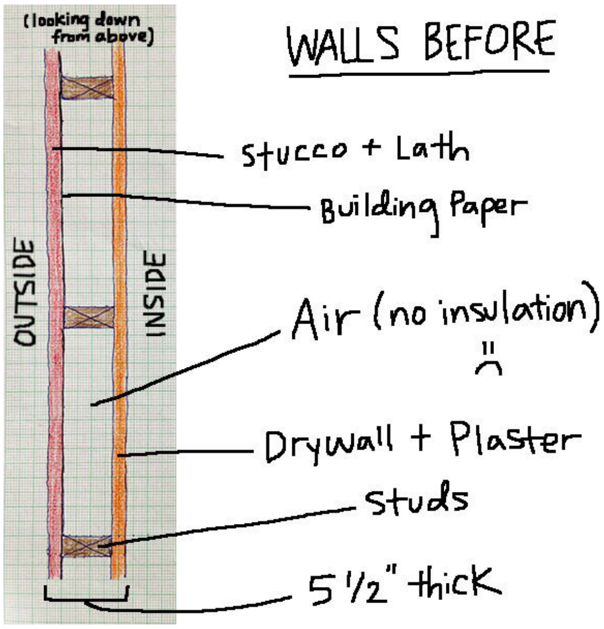
(Above) The renovated house, completed in 2019, as viewed from the street.

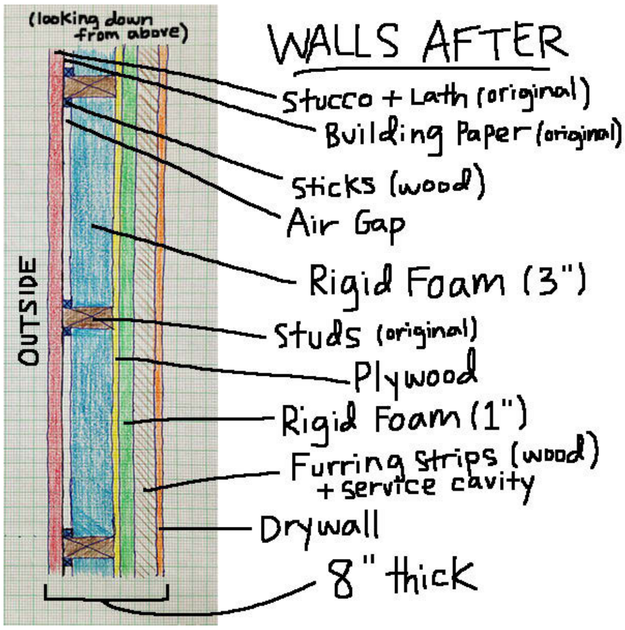
original assemblies as possible were retained. For the exterior walls, the exterior cement plaster finis, weather-resistant barrier and existing 2X4 framing were retained. No additional framing was added to the interior of the walls to make space for more insulation, but 3” of dense (R = 6 per inch) polyisocyanurate insulation was installed in the existing 3” stud space, leaving ½” air gap to the weather-barrier.

Each phase involved stripping the interior finish off the exterior walls, installing the insulation, then adding ½” plywood for structural strengthening and 1” of rigid polyisocyanurate insulation to reduce thermal bridging and to increase the total wall R-value to R = 26. (See sketch below.)



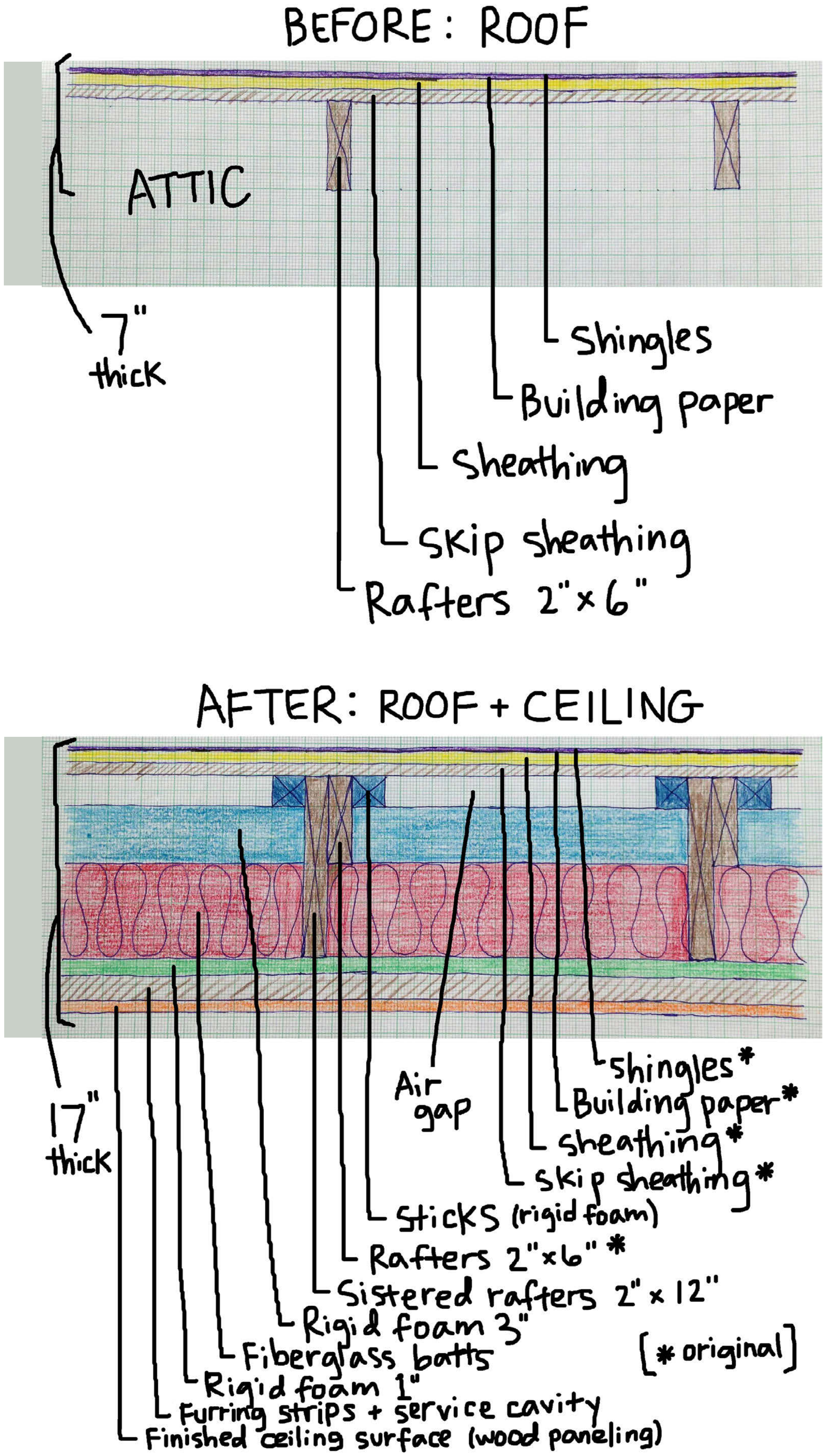
(Above) Work on insulating the walls with 3” polyisocyanurate foam layer. (Photo by Wen Lee)





(Left) Diagram of the wall structure in Phases 1 and 2, before and after the retrofit construction work.

(Right) Diagram of the roof/ceiling structure in Phase 1, before and after the retrofit construction work.



A slightly different approach was taken with the roof structure, whose rafters were made only with 2X6 framing members. In the living space (Phase 1), since the attic was removed to create a larger volume, 2X12 lumber was attached to each 2X6 as part of strengthening the structure. This also allowed the insulation value of the roof to be raised substantially by providing space to add more insulation. The same 3" of dense polyisocyanurate insulation was installed adjacent to the exterior sheathing and roofing, and 6" of fiberglass insulation filled the rest of the enlarged cavity before applying the 1" of rigid polyisocyanurate insulation board. The net result was a total roof R-value of R = 46. (See sketch on the opposite page.)

In the bedroom area (Phase 2), since the attic space was retained, the owners opted for a conventional ventilated attic design. The ceiling of this area was well-insulated by adding 14" of blown fiberglass insulation on the floor of the attic, and good ventilation of the attic space was achieved by installing rafter bay vents and a continuous ridge vent.

The original windows had already been replaced some years before with double-glazed vinyl windows. The owners decided that changing all the windows would only be marginally effective and, in the interest of maintaining very low cost to the improvements and to save time in the DIY work schedule, the owners opted to leave the windows in place.

Building Envelope — Airtightness

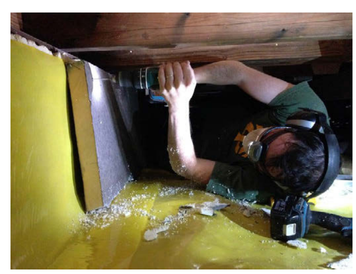
Airtightness is a key design strategy for any home targeting ZNE and zero-carbon performance. For this project, the air-sealing had to be done from the inside and without the advantage provided by reframing. It was, therefore, a painstaking effort. Spray-foam or acoustical caulking was used to seal gaps between the insulation and the studs.

The blower door test was done several times during the final stages of construction. Preliminary tests yielded 18.3 ACH50 before sealing anything and 8 ACH50 after Phase 1 was completed. The entire house achieved 4.1 ACH50 in the final blower door test.

The crawl space was encapsulated. With the encapsulated crawl space, usually it is wise to use either a supply duct from the air conditioning system or a humidity-controlled exhaust fan to keep the humidity within desirable limits to prevent excessive moisture levels. Chris installed a relative humidity recording device to see if either was necessary. It was recorded that the relative humidity never got as high as 60% so neither action was taken.

Heating, Ventilating and Cooling Systems – Domestic Hot Water

The house was retrofitted with a completely new heating and cooling system. The system is comprised of a heat pump mini-split system and an energy recovery ventilator (ERV)[3]. There are two mini-splits, one in each of the two parts of the house, with an exterior compressor. Each mini-split system is rated at 1.0 tons and the wall units are rated at SEER 26.1[4]. The mini-split serving the Phase 1 living area is ductless, but the second mini-split has a supply duct to each of the bedrooms. The exterior compressor for both mini-splits is 1.8 tons.

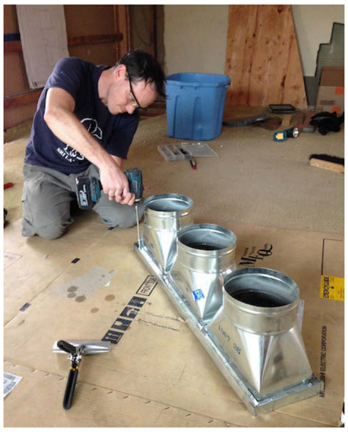


(Above, top) Insulating the roof in Phase 1 living area with the 6" fiberglass batts.
(Above, middle) Sealing the gaps with caulking to make the house airtight.
(Above, bottom) Encapsulating the crawl space.
(Photos by Wen Lee)

[3] See M. Holladay, "HRV or ERV", Green Building Advisor, (Jan., 2010), https://www.greenbuildingadvisor.com/article/hrv-or-erv; see also D. Boyer, "Choosing between an HRV and an ERV", Ecohome, (Feb., 2014), https://www.ecohome.net/guides/2276/choosing-between-an-hrv-and-an-erv/

[4] "Seasonal Energy Efficiency Ratio" or SEER is the ratio of the cooling output of a heat pump in Btu over a typical cooling season divided by the energy consumed in watt-hours. The higher the SEER ratio, then the higher the energy efficiency of the system.

(Opposite page) View of the interior of the completed Phase 1 living area.



(Above) Making the sheet metal ductwork for the mini-split system serving the Phase 2 bedroom area. (Photo by Wen Lee)

An ERV was selected instead of an HRV because of the sizable cooling demand in this location and the possible need for moisture control of the exterior air. (The climate of this area, however, is quite dry, so an HRV would have been a good choice also.) The ERV provides fresh air to all the spaces via separate 6" rigid steel supply ductwork and has continuous exhaust at the bathrooms via ductwork back to the heat exchanger at the ERV unit.

The kitchen exhaust fan in the range hood vents directly to the outside. A low-power unit (150 cfm) was selected to avoid excessive exhausting of inside conditioned air and to reduce the fan load. The unit selected has high capture efficiency at rlatively low airflows. The performance has been good at this level of air flow speed. The owners preferred not to have a recirculating fan unit for air quality reasons in an airtight house.

Domestic hot water was supplied by a gas water heater until August, 2019, when it was replaced by an electric 50-gallon heat-pump water heater. At that point, the house became fully electric and zero-carbon. (The house was already performing at ZNE including the energy used by the gas water heater. See the discussion below in the section, *Energy Use—Post Occupancy Measurement*.)

Lighting and Plug Loads

All lighting is done with high-efficiency LED sources and all appliances are Energy Star®. A venting skylight with remote control was added to the newly enlarged volume in the living spaces in order to bring daylight to the interior, which previously required electric lighting even on bright days.

Since the house is designed to be all-electric, the cooking is done by induction cooktop and electric oven. The owners had to use portable induction units when the temporary kitchen was set up on the back patio, so they developed a familiarity with the techniques of cooking on such units. The final plans called for an induction cooktop for a zero-carbon house, but the practice experienced in the temporary kitchen was useful to have.

The clothes dryer is a conventional electric dryer located in the unconditioned garage.

Control Systems

For cost reasons, the owners chose not to have any "smart technologies" other than the energy monitoring device to record energy consumption at each point of use. An on-demand recirculation pump was installed in all the bathrooms, activated by a simple button, to conserve water use.

Construction

The construction period was initially planned to be one year, but extended to two years and eight months, reaching a conclusion in October, 2019. (See the blog postings on "FrugalHappy" for a complete history of the work from start to finish.) While Chris largely worked alone and usually full-time, he was often assisted by relatives and neighbors.

Structural modifications required an upgrade of the foundation footings. For this design and construction task, the owners decided to hire a structural engineer and a foundation subcontractor. This was one part of the project that they concluded would be better accomplished with experienced help. This occurred a second time in the fall of 2019 when only finishing work remained to be done in the Phase 2 bedroom spaces and the owners' first child was due.


PHOTO: LAWRENCE ANDERSON

Renewable On-Site Energy Supply

There are sixteen (16) panels in the solar PV array, which is rated at 4 kW (DC). The 250-watt Trina panels[5] were installed in 2016 before any construction work began. The roof is a simple gable with the slopes facing west and east; the western sloping side was selected for the panel location because there would likely be more clear skies in the afternoon and because there would be a higher cooling load at that time of day. Since the slope is relatively shallow, there is not a large penalty in performance compared to an ideal south orientation.

The owners do not currently have a battery for energy storage. They are planning to install one so that the energy collected by the solar PV system during the day can be used at the time of their peak load in the evening.

Energy Performance

Energy Modeling and Post-Occupancy Measurement

Energy Use—Modeling

Preconstruction energy modeling was done by the owners using BEopt (Version 2.8) software[6], developed by the National Renewable Energy Laboratory (NREL) for residential projects. The results are shown in the chart on the opposite page, which displays the modeled monthly energy use of the house over the course of a typical year.

Energy Use—Post Occupancy Measurement

The owners decided to meter the energy consumption in some detail as construction was underway in order to see the effects of the retrofit process as they were being put in place. They used a commercially available electrical monitoring system[7] that measures the energy use of each identified appliance or device and transmits that information via Wifi to a phone or tablet over the internet. The owners were in fact able to see the effect of completed work when energy use trended downward as work proceeded.

The data recorded during the final year of construction (November, 2018, through October, 2019) serves as the closest approximation for the actual energy performance for the house at the completion of construction. The owners purchased an electric vehicle (EV) in December, 2018, and the data includes the energy used in charging the car during the year. This energy was not metered, but was estimated by the owner as follows:

> "We keep track of how many miles we drive whenever we use a car. I looked up all the miles traveled in the EV since we got it in December of last year. I subtracted any trips where we didn't charge at home. I took the total number of miles traveled each month and divided it by the power efficiency of our vehicle, which is 4.9 miles/kWh."

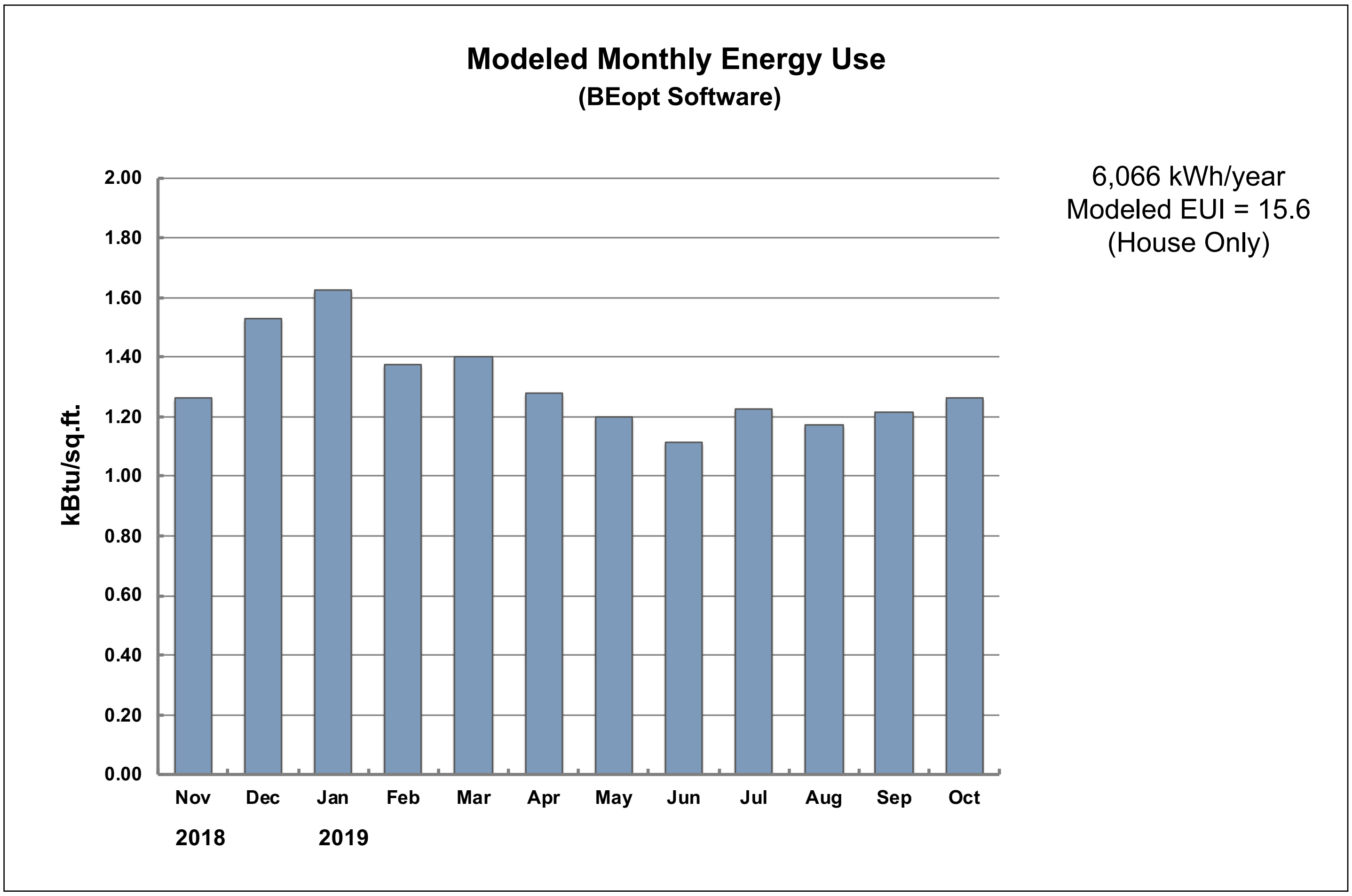
This yielded an estimate of the monthly energy used to charge the EV, which can be subtracted from the total metered amount to give the monthly energy used by the house alone.

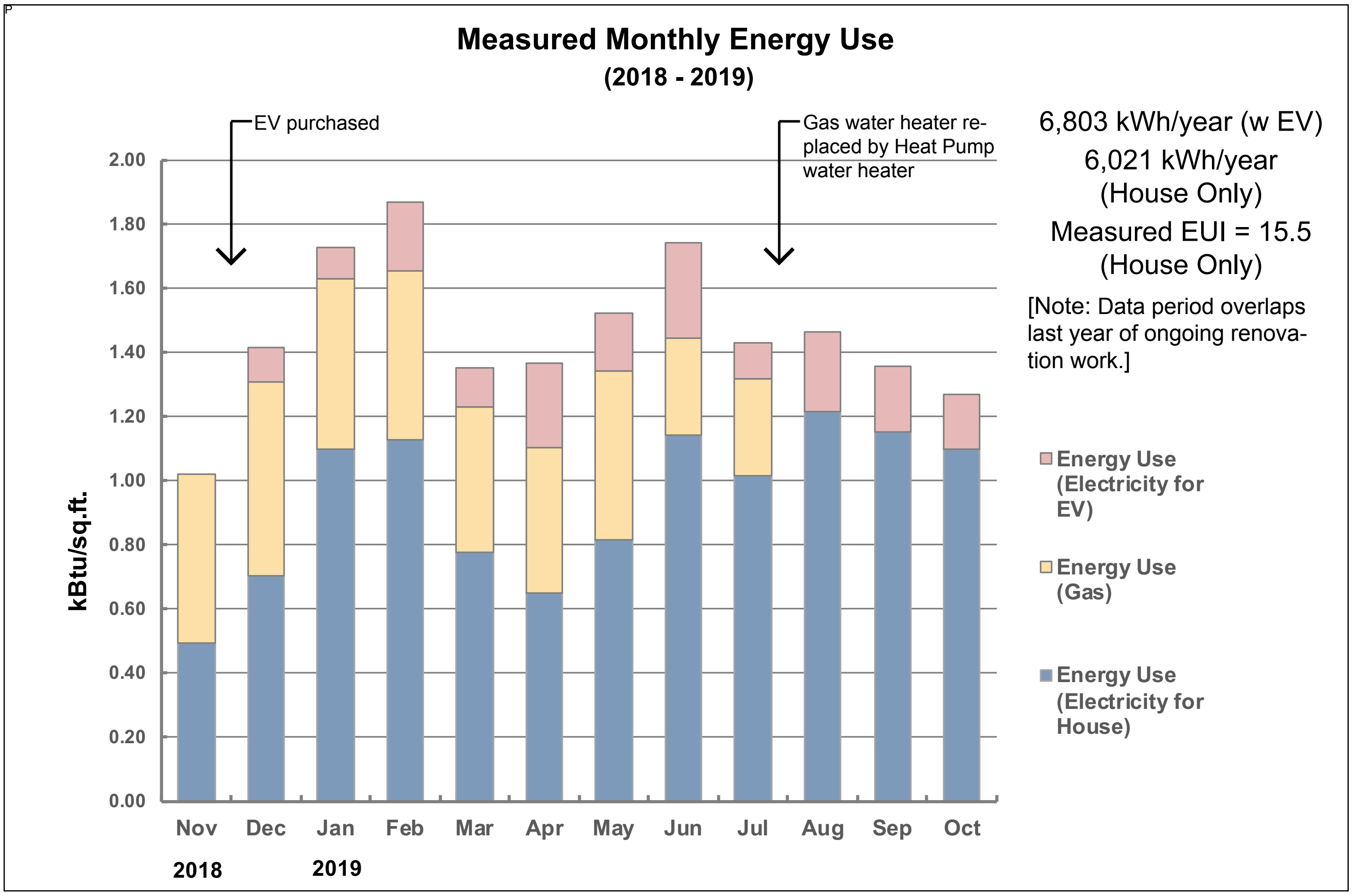
The chart on the opposite page shows the measured monthly energy use for this period (November, 2018, through October, 2019), including the energy used in charging the EV. Note also the

[5] https://www.trinasolar.com/us

[6] https://beopt.nrel.gov/home

[7] Sense Energy Monitor. See: https://sense.com/product


Modeled Monthly Energy Use
(BEopt Software)
6,066 kWh/year
Modeled EUI = 15.6
(House Only)
kBtu/sq.ft.
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
2018
2019


Measured Monthly Energy Use
(2018 - 2019)
EV purchased
Gas water heater replaced by Heat Pump water heater
6,803 kWh/year (w EV)
6,021 kWh/year
(House Only)
Measured EUI = 15.5
(House Only)
[Note: Data period overlaps last year of ongoing renovation work.]
Energy Use (Electricity for EV)
Energy Use (Gas)
Energy Use (Electricity for House)
kBtu/sq.ft.
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
2018
2019

energy used by the gas water heater, which ended in August, 2019, when it was replaced by the heat pump water heater.

As the owners report, this energy use will be even lower in 2020 since the attic above the Phase 2 bedroom area was just recently insulated and sealed in 10/2019. The data in both charts reflects the condition of an uninsulated attic space and the space conditioning loads are higher than what is expected in 2020.

Energy Production versus Energy Use: Zero Net Energy Performance

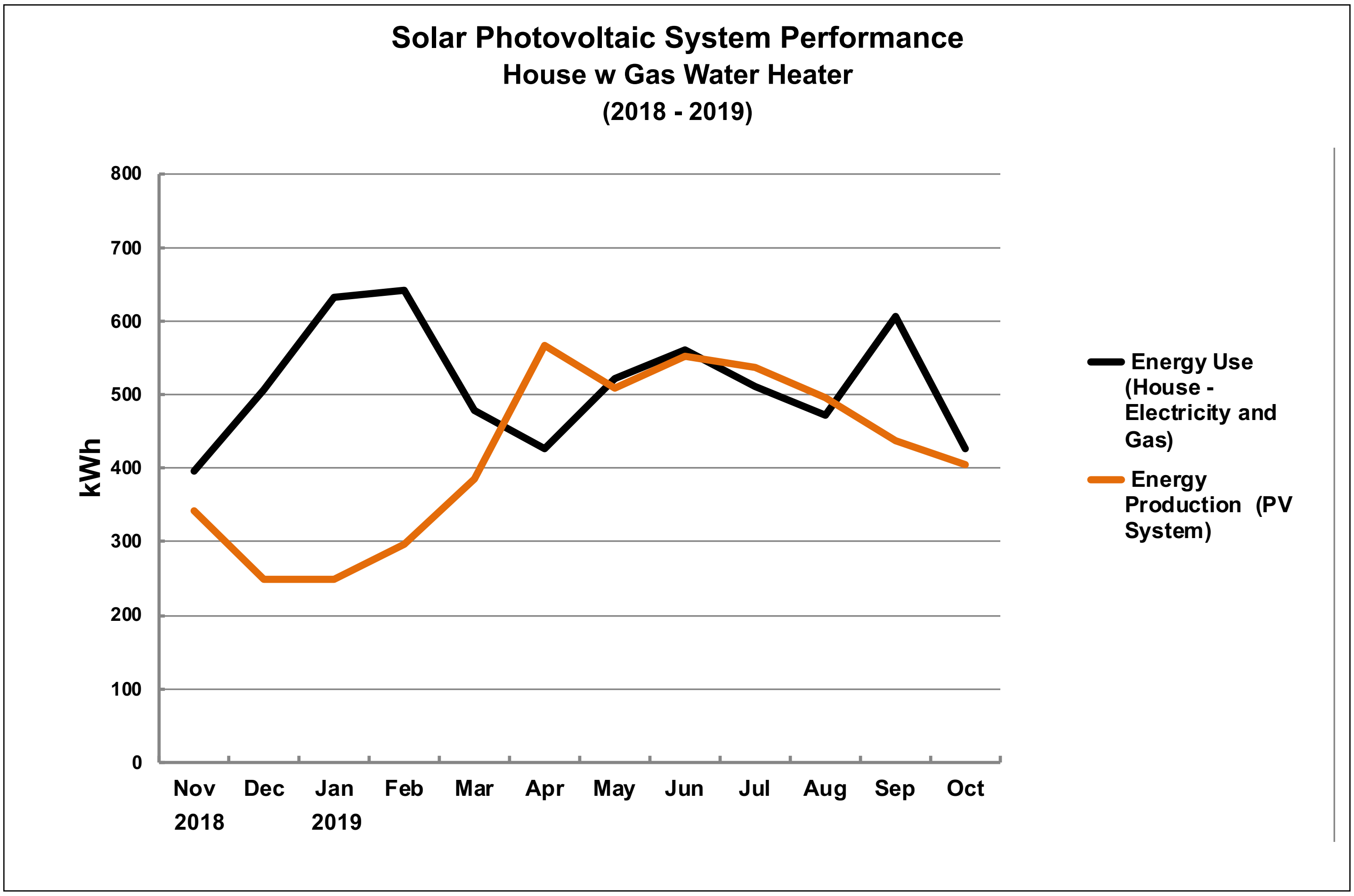
The charts on the following pages show the solar PV system performance over the course of the year starting in November, 2018. The charts of solar energy production versus energy use include the monthly energy use data for the house alone, making the adjustment to the recorded data by removing the estimated energy use for charging the EV. Two charts are shown: one shows the actual energy use with the gas water heater in use until August, 2019, when it was replaced by the more efficient heat pump water heater, The second one shows the hypothetical situation where that heat pump water heater is assumed installed throughout the period of data recording.

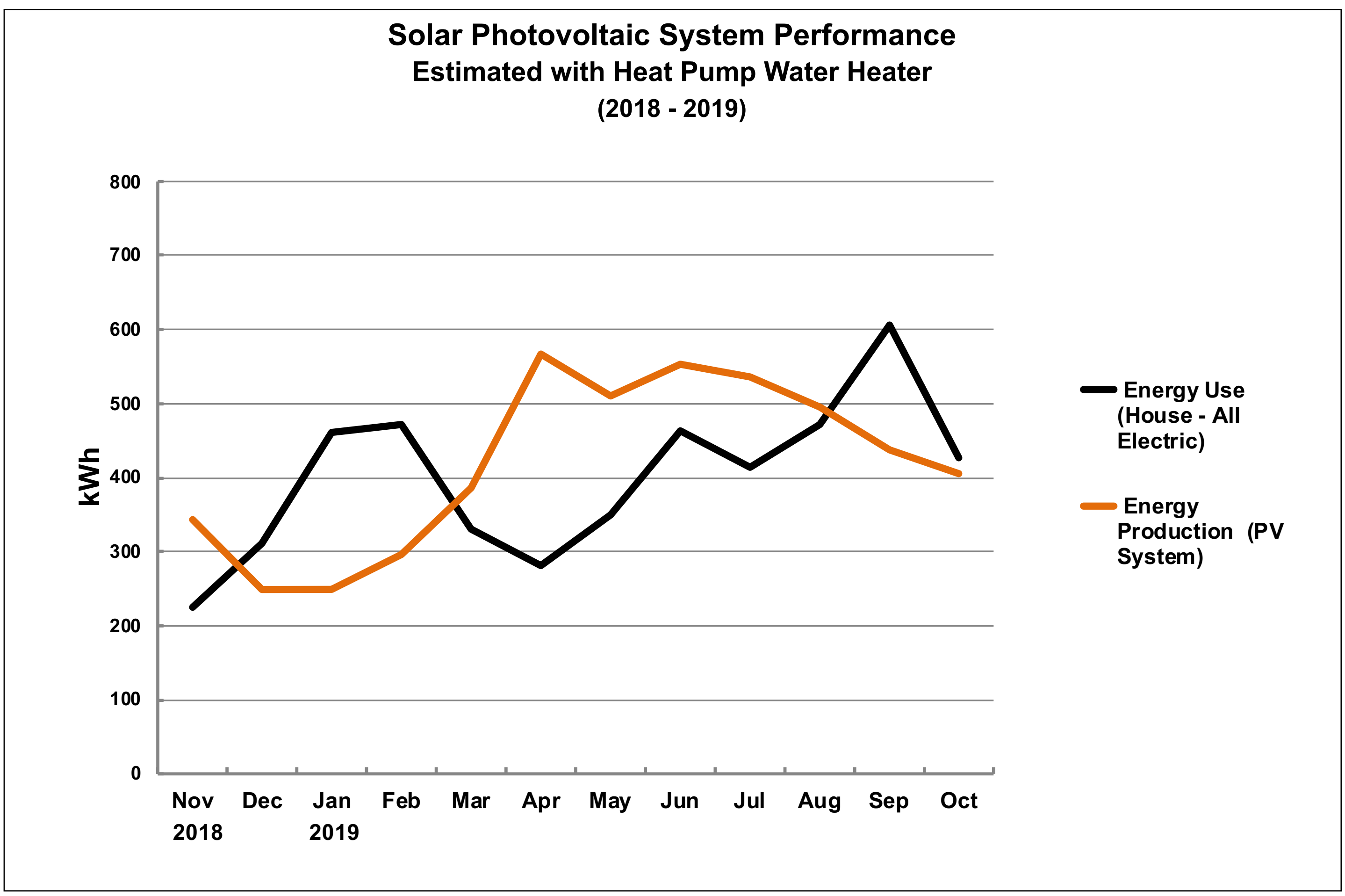
The second chart illustrates the effect of the water heater replacement on the overall energy performance of the house. The heat pump water heater is six times more efficient in producing hot water than the gas water heater (and produces no carbon on the site). Taking this efficiency ratio and applying it to the energy use data recorded for the gas water heater from 11/2018 through 7/2019, yields the expected energy use for the heat pump water heater were it in service during that period.

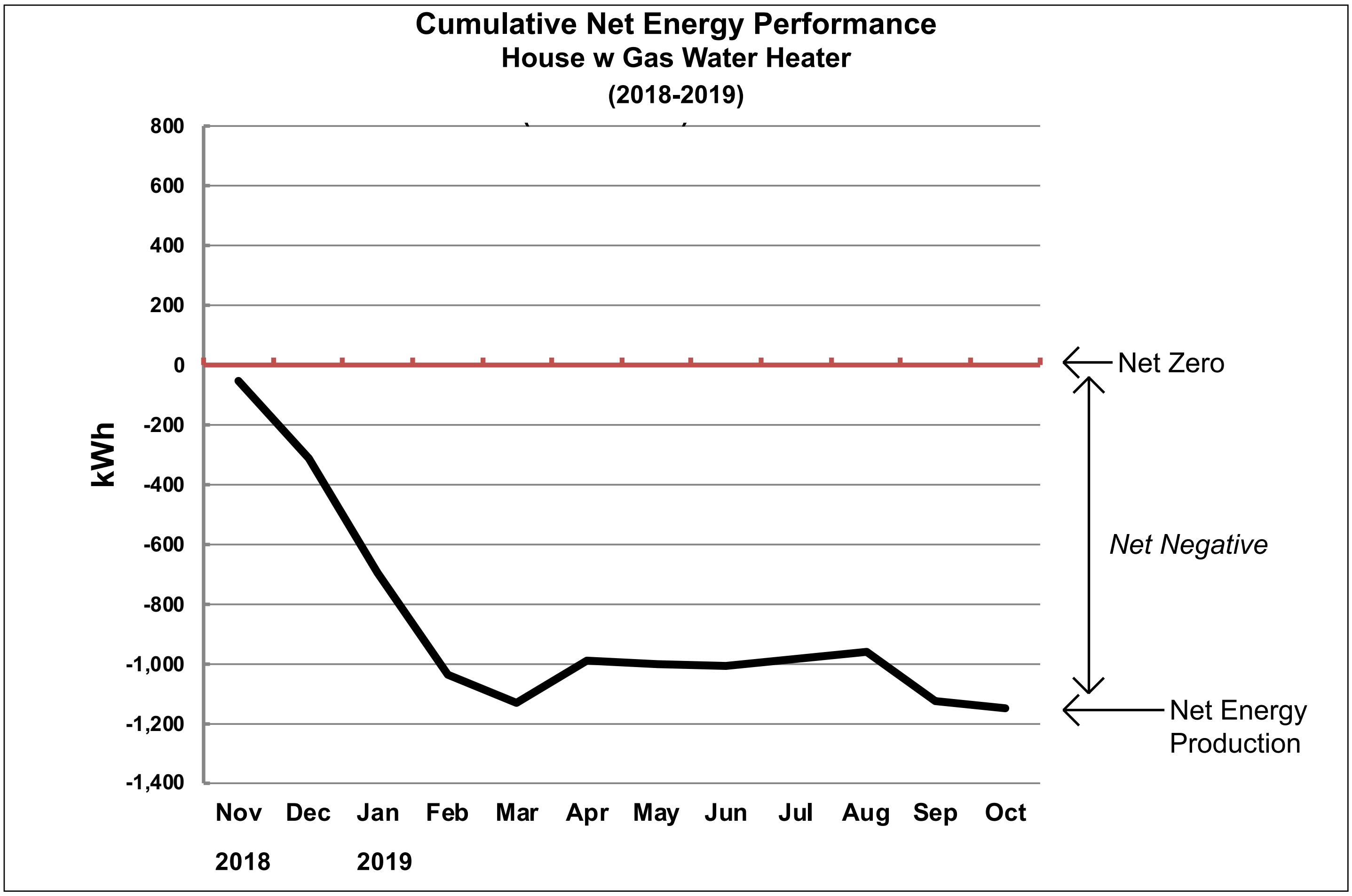
Basically, the DIY project falls short of ZNE performance in 10/2019 with the gas water heater but achieves ZNE if the owners had replaced this with the heat pump water heater in 11/2018, the start of the one-year of data recording. This is illustrated by the respective charts for the *cumulative net energy production* on page 56.

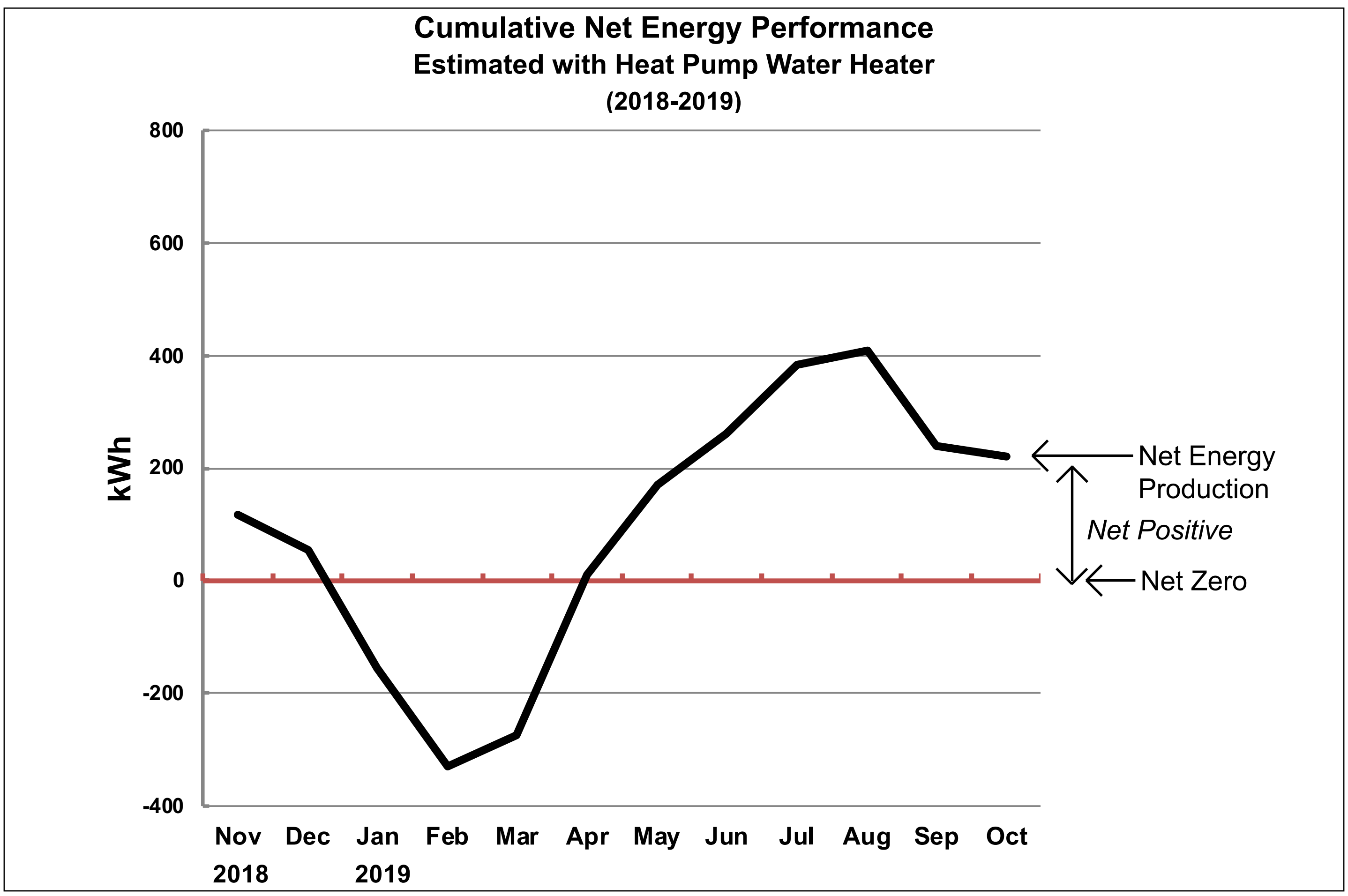
The *cumulative net energy production* is a chart that essentially shows the progression of the energy performance toward ZNE by adding each month's net energy performance to the previous month's total—if, at the end of the 12-month period, the curve remains on the positive side of the zero axis, then the building is indeed performing better than ZNE, i.e., *Net Positive*. For this case study, there are two charts—one representing the actual recorded data including gas water heater and the second representing the hypothetical performance of the house at construction completion, derived from the recorded data and substituting the heat pump water heater for the gas water heater for the entire period.

The second chart shows that the house is expected to be ZNE with the heat pump water heater instead of the gas water heater. As the first chart shows, the energy performance falls short of ZNE with the gas water heater in operation.


Solar Photovoltaic System Performance
House w Gas Water Heater
(2018 - 2019)
kWh
800
700
600
500
400
300
200
100
0
Nov 2018
Dec
Jan 2019
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Energy Use (House - Electricity and Gas)
Energy Production (PV System)


Solar Photovoltaic System Performance
Estimated with Heat Pump Water Heater
(2018 - 2019)
kWh
800
700
600
500
400
300
200
100
0
Nov 2018
Dec
Jan 2019
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Energy Use (House - All Electric)
Energy Production (PV System)


Cumulative Net Energy Performance
House w Gas Water Heater
(2018-2019)
800
600
400
200
0
-200
-400
-600
-800
-1,000
-1,200
-1,400
kWh
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
2018
2019
Net Zero
Net Negative
Net Energy Production


Cumulative Net Energy Performance
Estimated with Heat Pump Water Heater
(2018-2019)
800
600
400
200
0
-200
-400
kWh
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
2018
2019
Net Energy Production
Net Positive
Net Zero

Post-Occupancy: Observations and Conclusions

The owners are not seeking any certifications for this all-electric house, in spite of the verification of ZNE performance expected in 2020 after a year of operation after completion of construction. This is in keeping with the cost consciousness of the process employed from the beginning.

The timeline of the DIY process was much longer than planned or anticipated: almost three years rather than only one. The owners expressed the opinion that they were naively optimistic. In hindsight, they would hire more professional builders and tradespeople to carry out certain tasks. The owners kept a record of their time: the labor for the owners totaled 4,800 hours, averaging 25 hours per week or the equivalent of roughly three days at 8 hours per day. The owners estimate that if they had hired subcontractors selectively, then they could have reduced this DIY labor to weekend work, which would have been more tolerable over that period of time and traditional for a DIY project.

The cost was also underestimated: originally planned at $50,000, the total came to about $120,000, or ($90 per sq. ft.), without charging anything for the owners' labor. Still, this is a very small fraction of the current cost of residential construction in California.

The general assessment by the owners is that despite the differences in work process that they would plan differently, there are no significant changes that they would make to the actual scope of work carried out. The work plan and choices made are judged to be sound and they achieved their objectives.

One observation about the heating/cooling system is that two mini-split units were required to keep the two isolated halves of the house habitable while work proceeded in each of the two phases of the work. They were sized for this condition, but when the construction was completed, the two areas were joined together, rendering the two mini-splits slightly over-sized for the whole house (a combined 3.8 tons for 1,323 sq. ft.).

CASE STUDY NO. 9

Silver Star Apartments

PHOTO: NATALIA KNEZEVIC

Silver Star Apartments

Case Study No. 9

Data Summary

Building Type: Multifamily – Low-Rise (New Construction)
Location: Los Angeles, CA
Gross Floor Area: 33,923 gross sq. ft.
Occupied: June 2017

On-Site Renewable Energy System Installed:
127 kW (DC) Solar PV
26 Panels Solar Thermal Syst.
On-Site Storage Battery
None (Planned but not installed)
Measured On-Site Energy Production:
138,200 kWh per year
13.9 kBtu/sq.ft. per year
Modeled EUI (Site):
18.8 kBtu/sq.ft. per year
Measured EUI (Site):
18.7 kBtu/sq.ft. per year

Owner/Client
A Community of Friends (ACOF), Los Angeles, CA

Project Team

Architect:
FSY Architects, Los Angeles, CA
Energy and Sustainability Consultant:
Green Dinosaur, Culver City, CA
Solar PV System:
Promise Energy, Culver City, CA
Mechanical and Plumbing Engineering:
JaycoCal Engineering, Pasadena, CA
Electrical Engineering:
Electrical Building Systems, Mission Hills, CA
Landscape Architect:
Yael Lir Landscape Architects, South Pasadena, CA

General Contractor:
Dreyfuss Construction, Los Angeles, CA

In Volume 1 of *Zero Net Energy Case Study Homes*, a mixed-use project that incorporates affordable multifamily housing rental units[1] is included partly because of the recognized need for this type of housing but also since, as the case study points out,

> "…the process of achieving the ZNE performance goal within the institutional structures of financing, approvals, design and construction for such a project is as informative as the technical features."

The same is true for a similar type of multifamily housing, namely affordable housing for homeless individuals and families. The current societal problem of homelessness for a sizable part of the population in California has resulted in the initiation of government programs to provide incentives of various kinds to build this type of housing. With these projects, there is a need to keep operating cost as low as possible for the future financial well-being of the operator and the tenants, so a ZNE design is a natural part of any program of such a project—more so than with conventional multifamily housing development where the financial factors are very different.

Background

The project was initiated by the Housing Authority of the City of Los Angeles (HACLA) and funded by a local bond measure and various tax credits (the low-income housing tax credit program administered by U.S. Department of Housing and Urban Development (HUD) and the renewable energy investment tax credit). The purpose of the bond measure was to provide affordable housing for the homeless population of Los Angeles. The project was awarded to ACOF (A Committee of Friends), a private, non-profit organization whose mission is to provide affordable housing, with an eye toward the homeless population of Southern California, particularly those with mental illness[2]. ACOF also describes its mission as:

> "Our focus is to build housing for people who have less than 30% of area median income (AMI) and have a mental, physical or developmental disability, with a primary focus on AMI[3]."

This project is intended in particular to provide housing for military veterans who are homeless and living with disabilities, including mental illness, substance abuse and other chronic illnesses, as well as those veterans with income at or below 30% of AMI. Supportive services for these tenants are provided on-site.

ACOF engages in project development to build such housing, property management for those developments and supportive services for their tenants. The ACOF mission statement also includes the statement that,

> "The Living Building Challenge, LEED® Certification and NetZero are green building programs that…are an integral part of ACOF's housing development strategy."

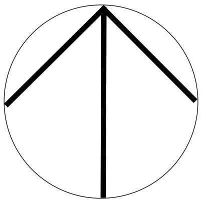
Commitment to ZNE performance of this housing project is therefore explicitly prescribed as a goal for this developer, who also is a partner in managing the property and providing support services. This commitment is partly practical in nature since the developer is required to maintain

[1] Case Study No. 5 – Colonial House Multifamily Housing.

[2] See: https://www.acof.org/

[3] "Target AMI of 30%", definition: The *median income* for all cities across the country is defined each year for each city by U.S. Department of Housing and Urban Development (HUD). The *AMI* is the "area median income" and that number is by definition 100% AMI. So, 30% AMI is a targeted income level at or below which applicants must qualify.

Silver Star Apartments - General Vicinity Plan



(Opposite page) Interior courtyard at Silver Star Apartments.

the project as affordable housing for 55 years, so minimizing operating cost is basic to this long term requirement.

ACOF assembled the project team and successfully made a proposal to build a project that would produce 105% of the energy used by the buildings over the course of a year, rendering it "net positive".

Project Process

Building Program

The project program was set specifically for military veterans who are homeless, with a fraction that need on-site support services of various kinds. The core requirement was for 48 one-bedroom units and one two-bedroom unit for the resident manager. There are a number of shared spaces, including a large community room, a computer room, studio, laundry, lounge and management offices. There are three EV-charging parking spaces for staff and visitors. The program also called for the ZNE design goal as well as no use of natural gas.

Site Constraints

The site was previously occupied by light industrial structures, which were demolished to make a clean site for this project. No trees or nearby built objects affect solar access to the site.

Low Energy Design Strategies[4]

The energy performance goal was set at 105% for the ratio of the annual renewable on-site energy generation to the annual energy use by all the buildings, or just a slight margin above ZNE for the year as a "cushion" for the as-built performance. The design team realized that this goal would be a challenge within the cost constraints since the project would consist of three-story buildings on the small urban site. The area limitation of the roof would naturally limit the solar energy that could be collected, setting the maximum energy use that could be used by the buildings.

In addition to this ZNE design goal, the project was also seeking Platinum certification from the *LEED for Homes* program[5] and Energy Star® for Residential New Construction[6].

Building Envelope — Insulation and Windows

The project is wood-frame construction using *advanced framing*[7] techniques for economy of construction and to maximize the wall area filed with insulation. For all three buildings, the walls (framed with 2X6) and roofs (framed with 12" truss-joists) are insulated to a level higher than required by code, with R-21 for the walls and R-30 for the roofs. Because of the extra cost, continuous insulation in the form of rigid board was not applied to the outside of the wall studs to eliminated thermal bridging. The concrete floor slab is uninsulated because of the mild climate and the low heating and cooling loads

---

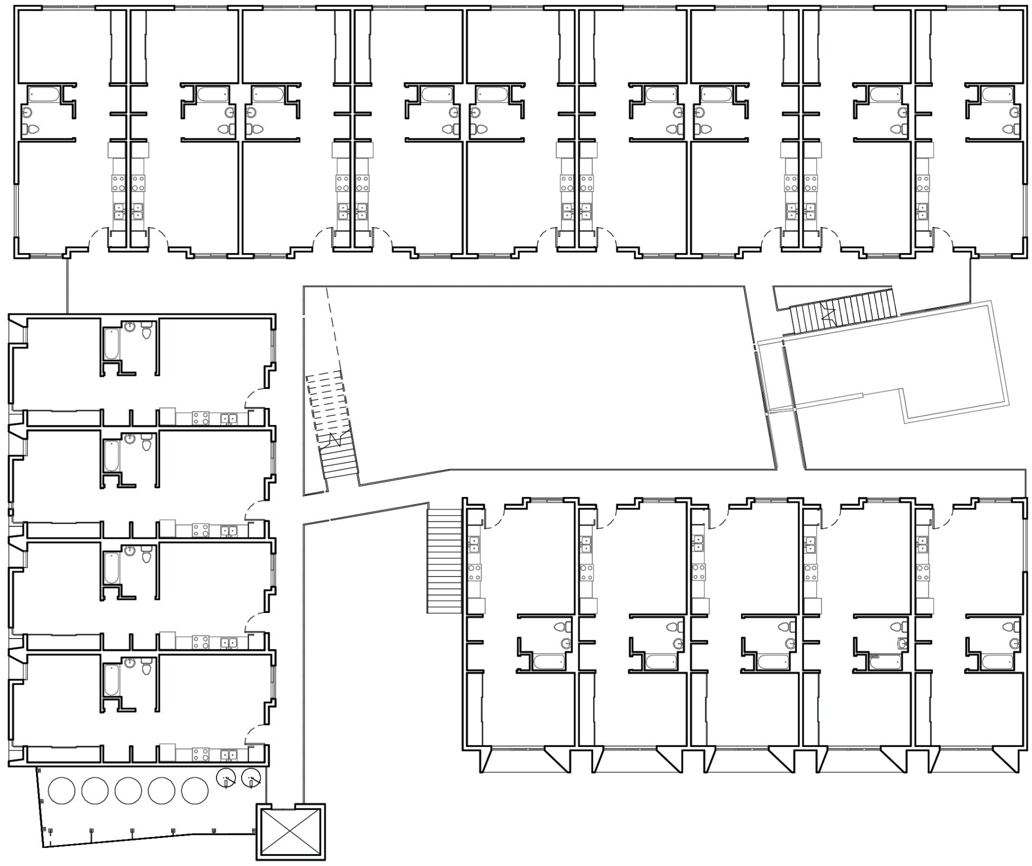
[4] The energy-related design strategies employed in this case study project are described in this section (below). There is also a series of short videos about some of these topics available online, which were created by the energy and sustainability consultant on this project. See: https://www.greendinosaur.org/video-series-zne-playlist/

[5] https://new.usgbc.org/cert-guide/homes

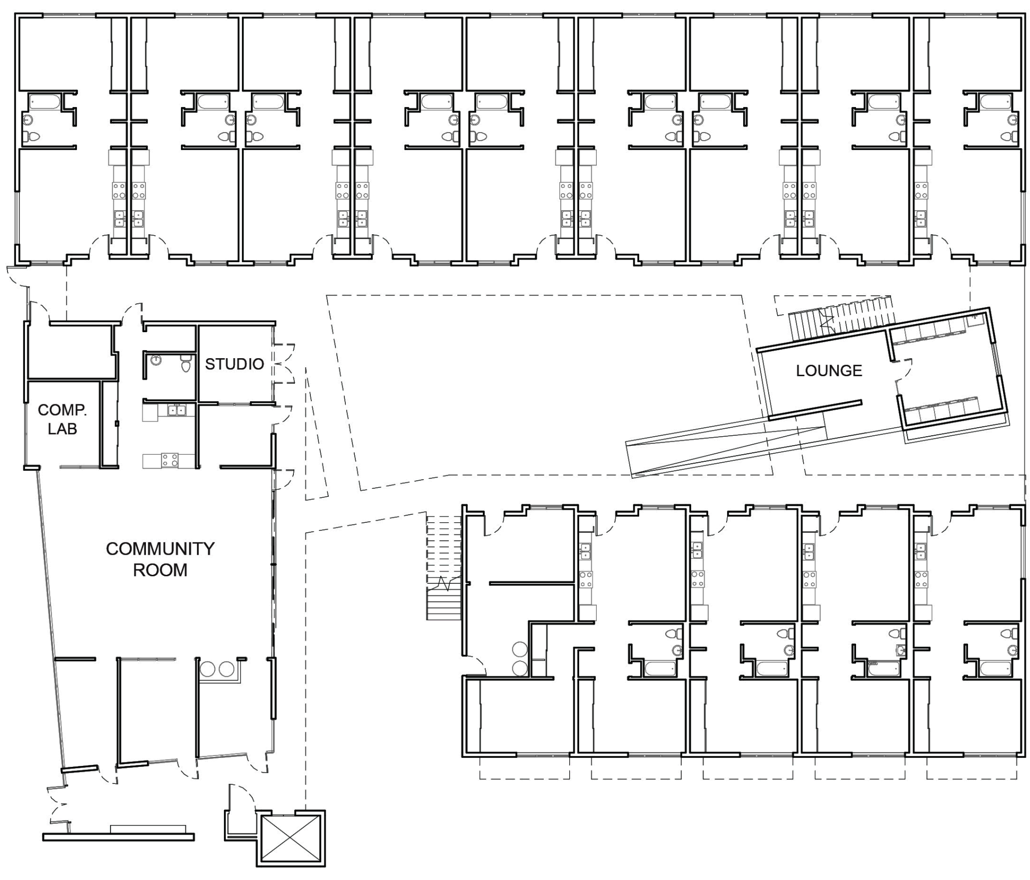
[6] https://www.energystar.gov/partner_resources/residential_new/about

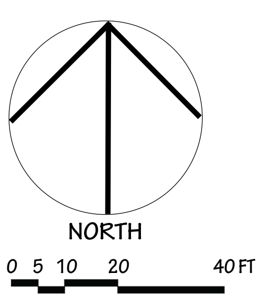
[7] See for example: https://www.apawood.org/advanced-framing

PHOTO: NATALIA KNEZEVIĆ



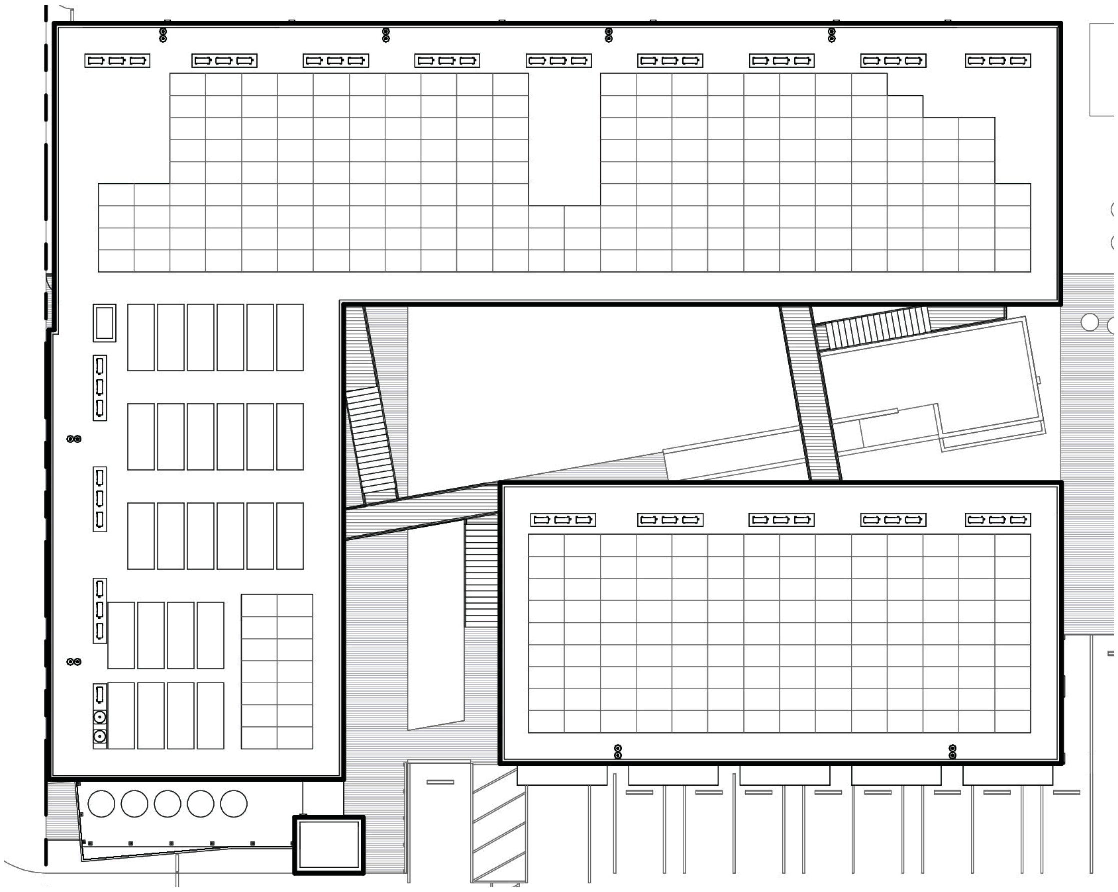
SECOND FLOOR PLAN



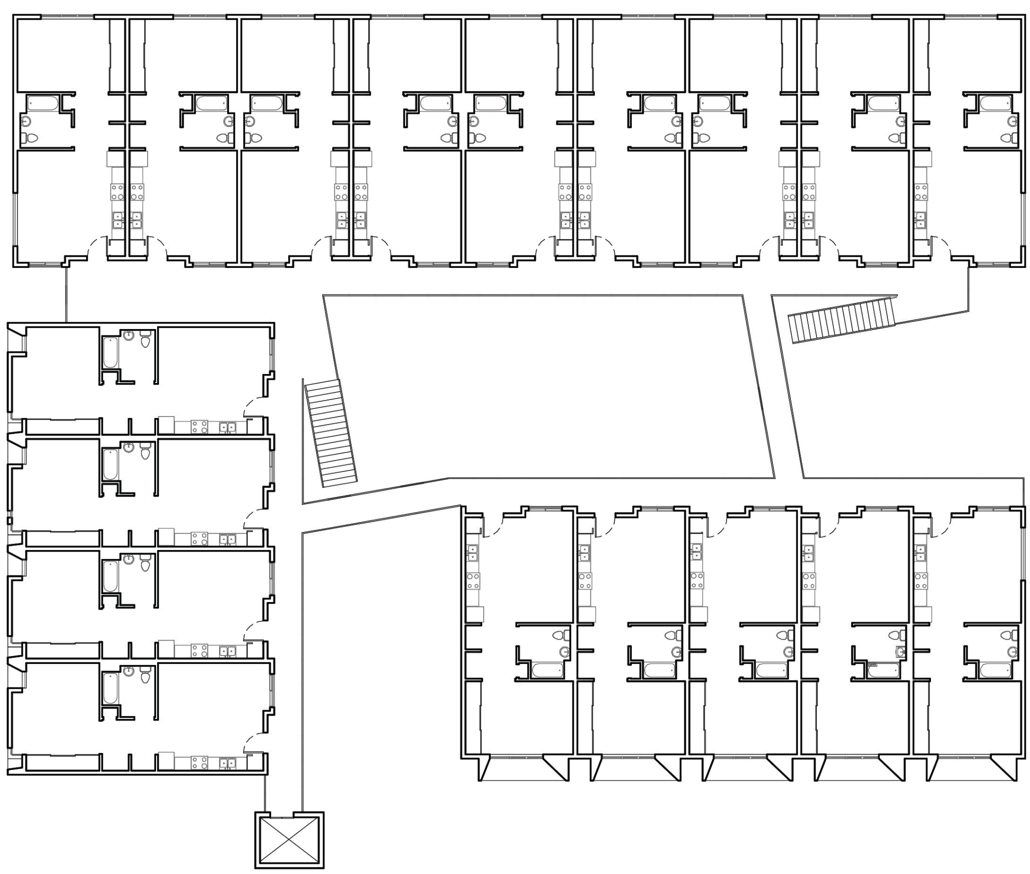


GROUND FLOOR PLAN

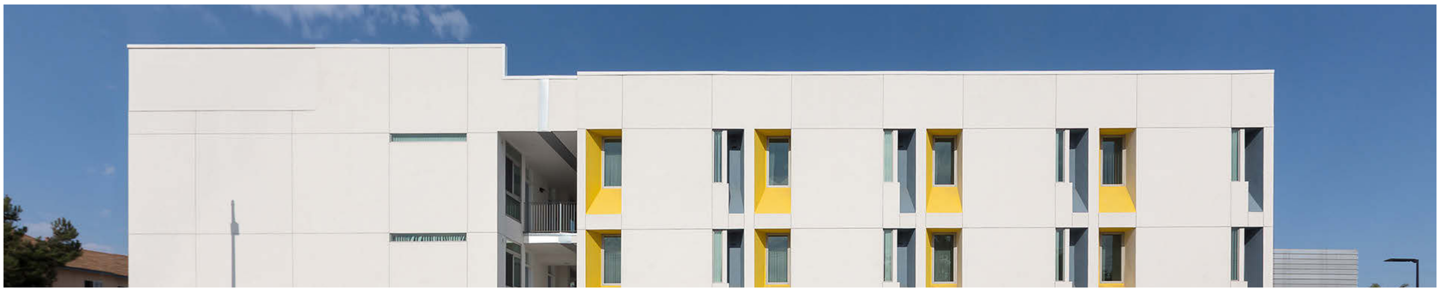
SILVER STAR APARTMENTS: FLOOR PLANS AND BUILDING SECTIONS

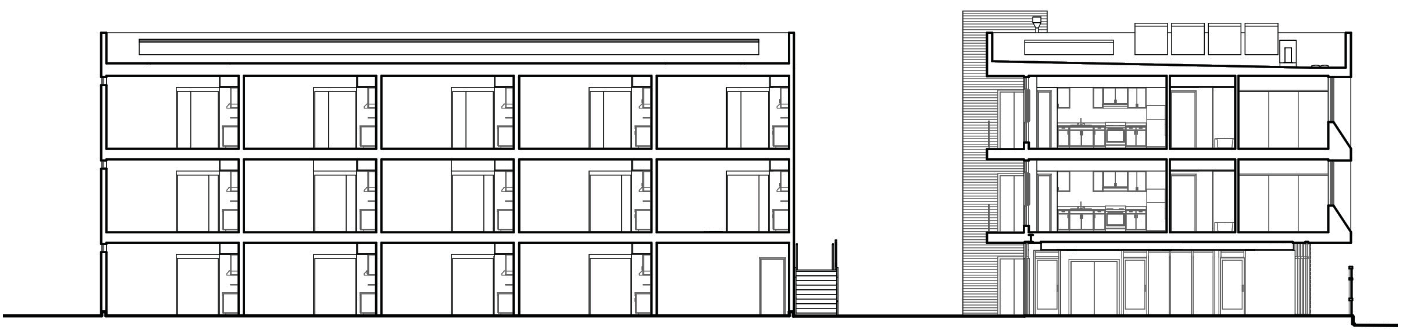


ROOF PLAN

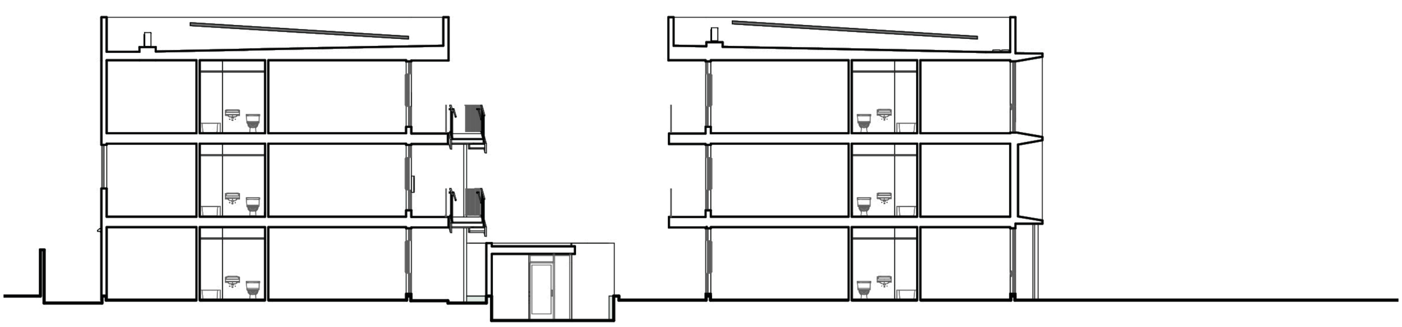


THIRD FLOOR PLAN





SECTION A-A



SECTION B-B

Phase change material[8] is placed inside the south wall to reduce the indoor temperature swing and to provide some passive heating in winter evenings by delaying the daytime heat gain. The phase change material is estimated to reduce the seasonal heating and cooling loads by 30%.

Windows are manufactured, vinyl-framed, double-glazed with a low-e coating. The assembly is R-3 and has a solar heat gain coefficient (SHGC) = 0.25.

Building Envelope — Airtightness

Airtightness was designed and built into the exterior wall and roofs of three buildings using a continuous air barrier, as well as gasket and sealant products, as listed as approved by the California Energy Commission[9]. *LEED for Homes* (low-rise) and Energy Star® requirements are met through HERS-verified air sealing and insulation installation inspections. These inspections confirmed that the building' envelopes of all three structures meet *QII (Quality Insulation Installation)* HERS performance specifications for air-sealing as required by the California energy code[10].

A *Blower Door* was not performed on the project. (Tests have shown that California code requirements result in an airtightness of approximately 5 ACH50.)

Heating, Ventilating and Cooling Systems

A ¾-ton ducted mini-split system is installed in each unit and the manager's office. Larger units serve each of the manager's apartment and the large community room. These systems are rated at SEER-19 (seasonal energy efficiency ratio). The condenser units for each are located on the roof.

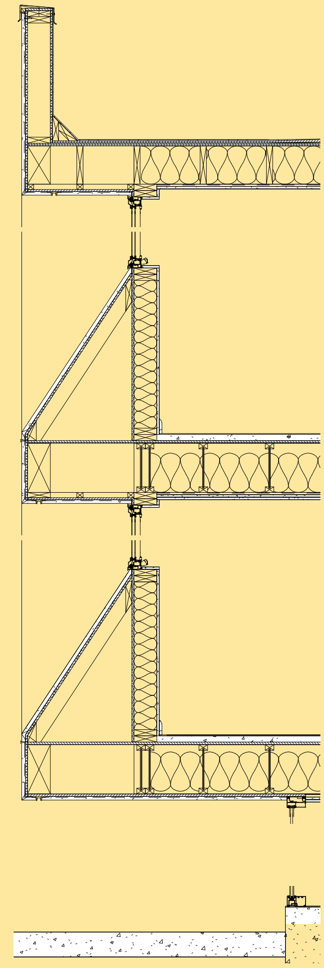
Ceiling fans are installed in the major rooms of each apartment to increase occupant comfort at higher indoor air temperatures and thereby reduce the use of the mini-split systems.

Lighting and Plug Loads

LED lighting was specified throughout the project. In addition, the daylight levels were raised in the unit by creating a higher floor-to-floor height. This allowed the windows to be taller than normal, which gave deeper penetration of daylight to the unit interior. The advanced framing method allowed the window headers to be placed even higher, therefore further increasing the daylight penetration. The overall effect is to increase the likelihood that the occupant will not reflexively use the electric lights because of the ample amount of daylight in the unit.

Control Systems

Standard thermostats are used to control air temperature in each unit and the separate common areas. Other than basic light switches, there are no other user-controls or automatic controls such as occupancy sensors. No system is in place for monitoring the energy use of the individual units. One utility meter measures the net energy use for the entire complex.



(Above) Section through the south wall at the Community Room.

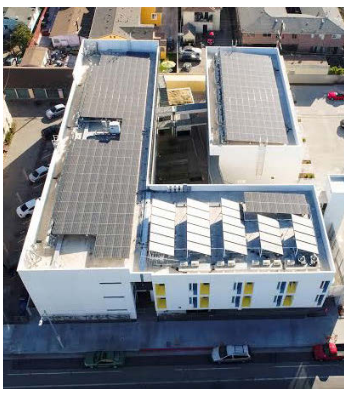
[8] A. Wilson, "Storing Heat in Walls with Phase Change Materials", Green Building Advisor, (Nov., 2009), https://www.greenbuildingadvisor.com/article/storing-heat-in-walls-with-phase-change-materials; See also: M. Reynolds, "Phase Change Building Materials – Natural Heat Storage in Buildings", Ecohome, (Jan., 2017), https://www.ecohome.net/guides/2205/phase-change-building-materials-natural-heat-storage-in-buildings/

[9] https://ww2.energy.ca.gov/HERS/documents/QII_Air_Sealing.pdf

[10] Ibid

(Opposite, top) Interior view of Community Room.
(Opposite, bottom) Interior view typical one bedroom apartment.

(Photo on following overleaf, p.70-71) South facade of the Silver Star Apartments.



(Above) View of roof with solar PV arrays and, in foreground, the angled solar thermal panels. (Photo courtesy of FSY Architects)

Domestic Hot Water – The Solar Thermal System

There are twenty-six (26) panels making up the solar thermal system that essentially preheats the domestic hot water (DHW) before delivering it to four storage tanks with heat pumps attached. The temperature is boosted there by the heat pumps, ready for use throughout the project.

Because of the moderate climate and relatively low heating and cooling loads, the energy demand for water heating is often a dominant part of the total energy demand in these types of buildings—estimated at one-third of the total. The designers therefore paid particular attention to the efficiency of the system design for this load.

The project program prescribed that use of natural gas at the site was not an option. This meant that a natural gas supply infrastructure at the site and buildings did not have to be built. The design team chose a solar thermal system over one that was simply more solar PV panels combined with heat pump water heaters. Solar thermal systems are 80% efficient in converting solar energy to hot water whereas solar PV is only about 18% efficient converting solar energy to electrical energy. Therefore, it was determined that the solar thermal system makes more efficient use of roof space and that it would use the renewable energy more effectively.

The solar thermal system provides enough energy to offset 80% of that required for all the DHW of the project. The heat pump water heaters, which are used to raise the water temperature to that required for use, therefore consume only 20% of the electric energy normally required for all the water heating. (See the pie chart on p. 73, where DHW represents only 5% of the modeled energy use for the entire complex.)

Construction

A contractor was a member of the design team for cost-estimating and constructability consulting. Costs were estimated for certain design alternatives, which brought cost-effectiveness criteria into the decision-making process at a detailed level. This produced a cost-efficient integrated design.

The project was a traditional design-bid-build process. In the end, the consulting contractor was the successful bidder and proceeded with the actual construction.

Renewable On-Site Energy Supply

ACOF engaged the solar PV system consultant at the very beginning of the design process to collaborate with the project team in reaching the balance between energy-efficiency measures and the design of the solar PV system to achieve the target of 105% offset of site energy use (slightly net positive). The challenge was principally to fit as many solar PV panels on the roof as possible, given the additional space requirements for fire-department access, rooftop mechanical equipment and the solar thermal system.

To have space for enough solar panels, the roof was extended over the area between two of the three buildings and exterior walkways. It was not deemed cost feasible to place the panels on canopies over parking or vertically on the building. However, some PV panels were placed vertically against the south-facing building parapets for a boost in output. The result was the placement of a near horizontal array (tilted at 5°, facing due south) that is rated at 107 kW (DC) and a vertical array at the parapets (tilted at 90°, facing due south) that is reated at 20 kW (DC).

A battery storage system was designed as part of the on-site renewable energy system to allow load shifting and some measure of resiliency to the operation of the buildings during power out-


PHOTO: NATALIA KNEZEVIC


PHOTO: NATALIA KNEZEVIC

PHOTO: NATALIA KNEZEVIC

ages on the grid. Closets and wiring are ready for the batteries to be installed, which is planned once additional funding is secured. A cost factor is that projects of this size that include elevators require 3-phase batteries and most are single-phase for the single-family residential market; typically the 208V 3-phase batteries are significantly higher cost.

Energy Performance
Energy Modeling and Post-Occupancy Measurement

Energy Use—Modeling

Energy modeling was done during the design phase in 2013 for the purposes of code compliance. Since the project was seeking LEED Platinum certification, the model was run again in June, 2017, which was the “as-built” condition at the completion of construction. The California energy code compliance software was used in both cases for the modeling analysis, *EnergyPro* (version 6 for the final modeling).

The annual total amount of energy used was modeled to be 186,500 kWh, or an EUI of 18.8 (kBtu/sq.ft. per year). No breakdown into monthly energy use is available. The pie chart on the opposite page shows the annual energy use by category of use.

Energy Use—Post Occupancy Measurement

Energy use data was calculated from the single utility net meter for the project and the solar generation data as recorded by the PV system. Since the latter data was found to be faulty prior to March, 2019, (see discussion in the next section below), the reliable energy use data corresponds only to March through October of 2019. For the remainder of the full year of data, from November, 2019, through February, 2020, the energy use data has to be estimated. A simple method, given the uniformity of the energy use profile in this mild climate, is to estimate the monthly energy use for the four months as the same as the average for the previous eight months. This estimated energy use is showed dashed in the chart on the opposite page.

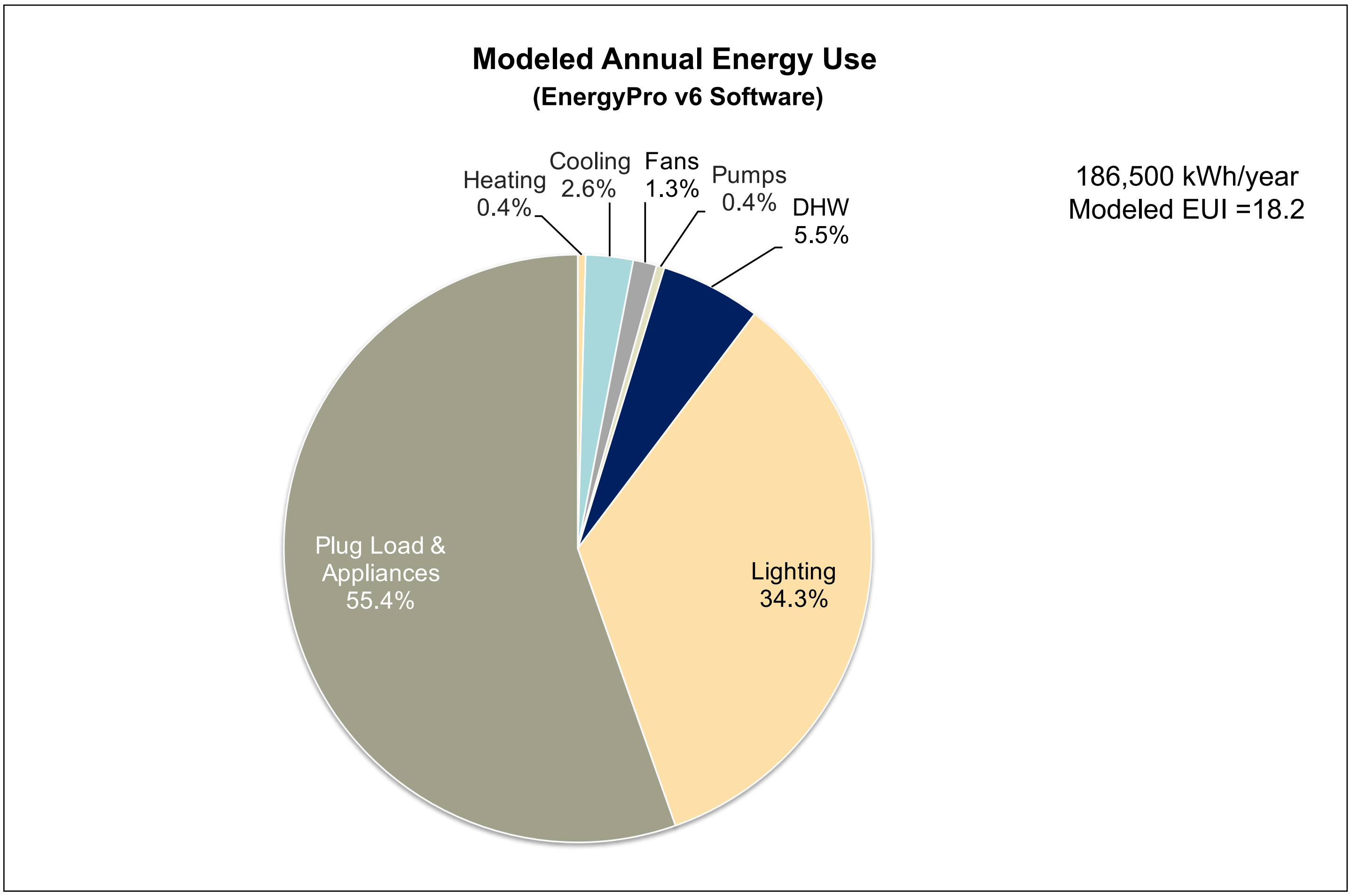
The total annual measured (and partially estimated) energy use is 185,850 kWh or 18.7 kBtu/sq.ft. This number compares well to the modeled total of 18.8 kBtu/sq.ft. Achieving the project ZNE goal depends on the solar energy production at the site and whether it can reach this level for the year, namely approximately 186,000 kWh/year. This is discussed in the next section.

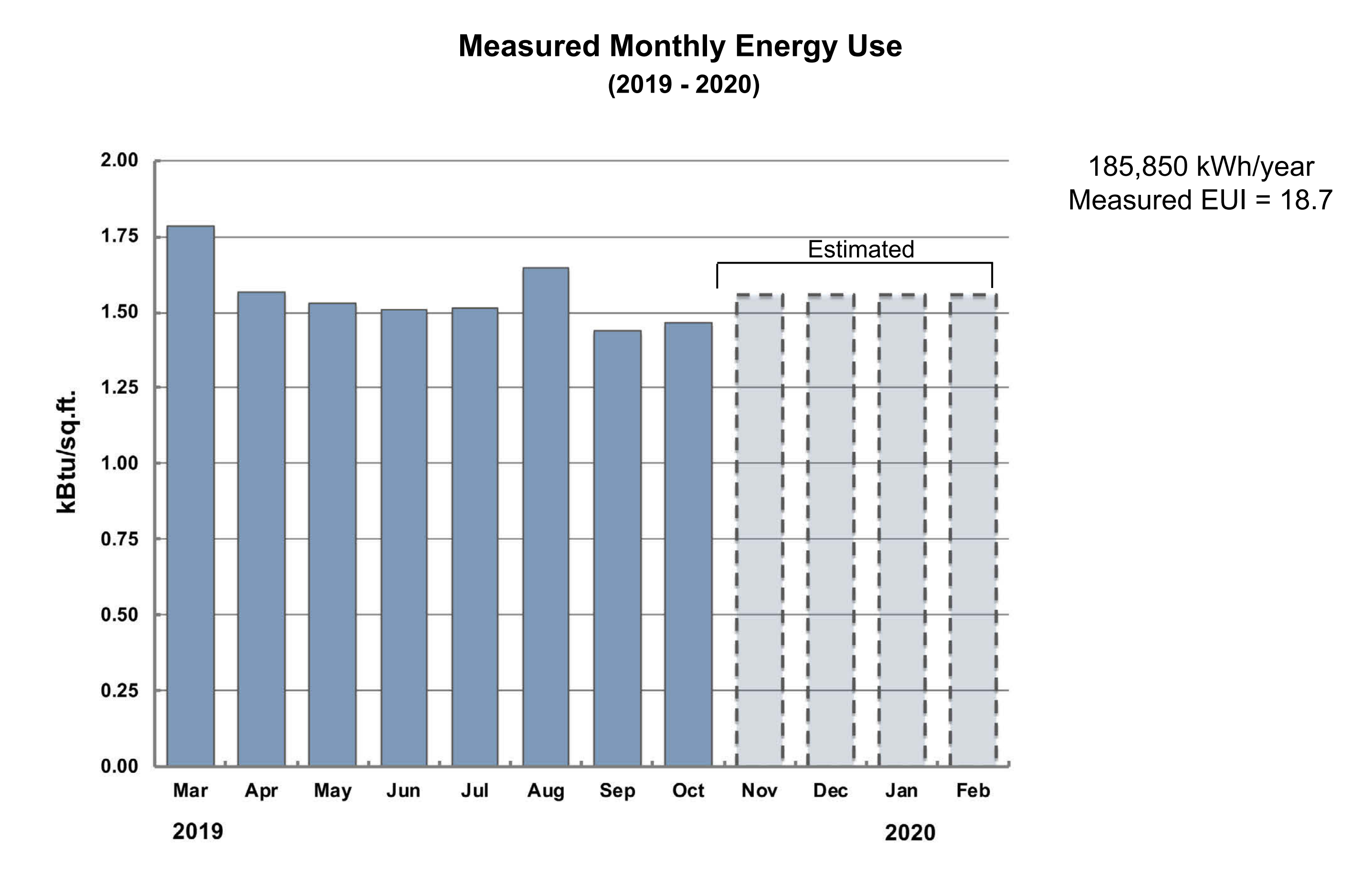
Energy Production versus Energy Use: Zero Net Energy Performance

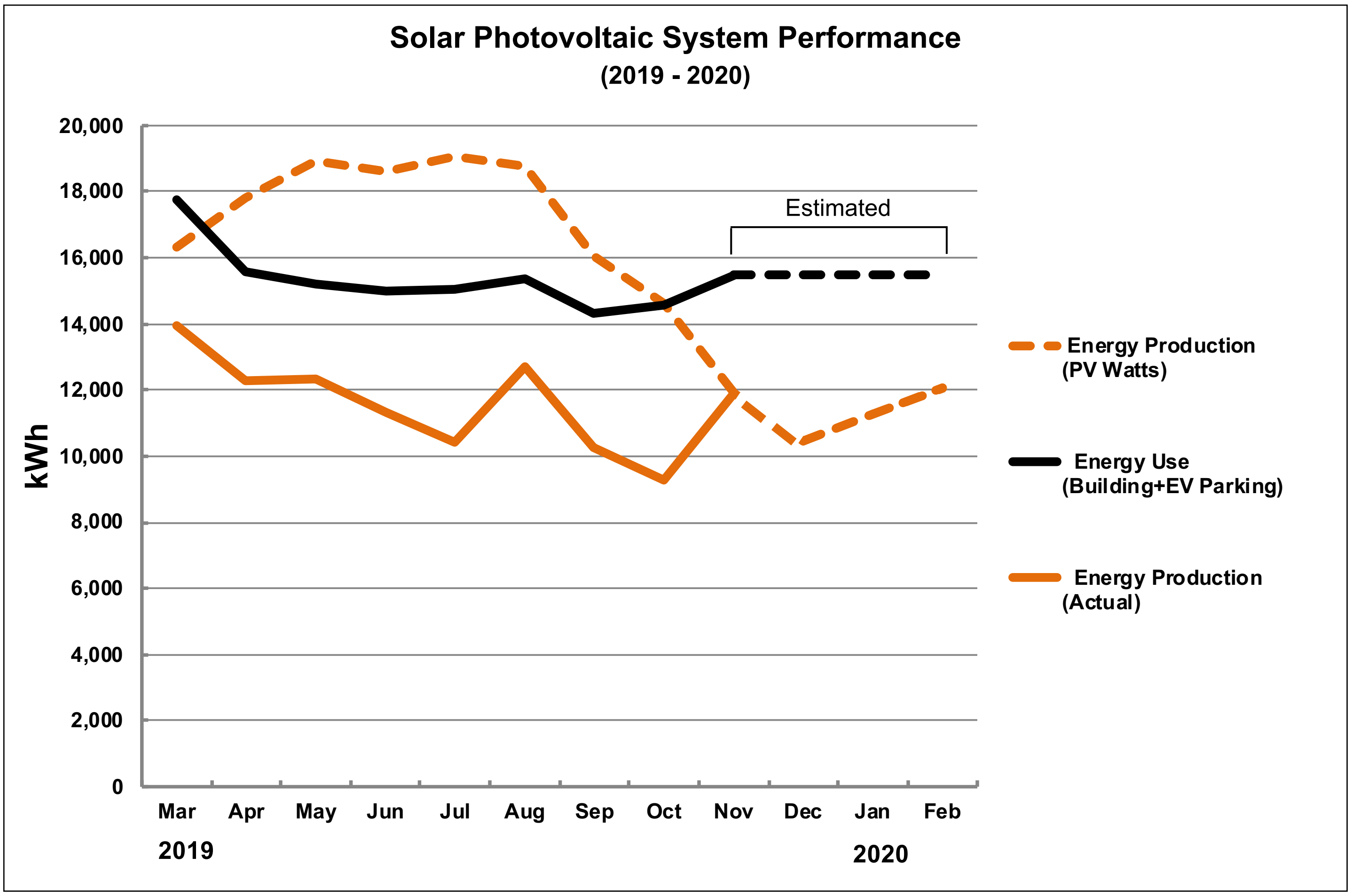
There are six inverters on this project, which should be monitored regularly for indications of malfunction or failure. If one inverter fails, then the production from those panels is lost. The property owner and manager have not instituted a service agreement for monitoring or maintenance of the solar PV system (or solar thermal system).

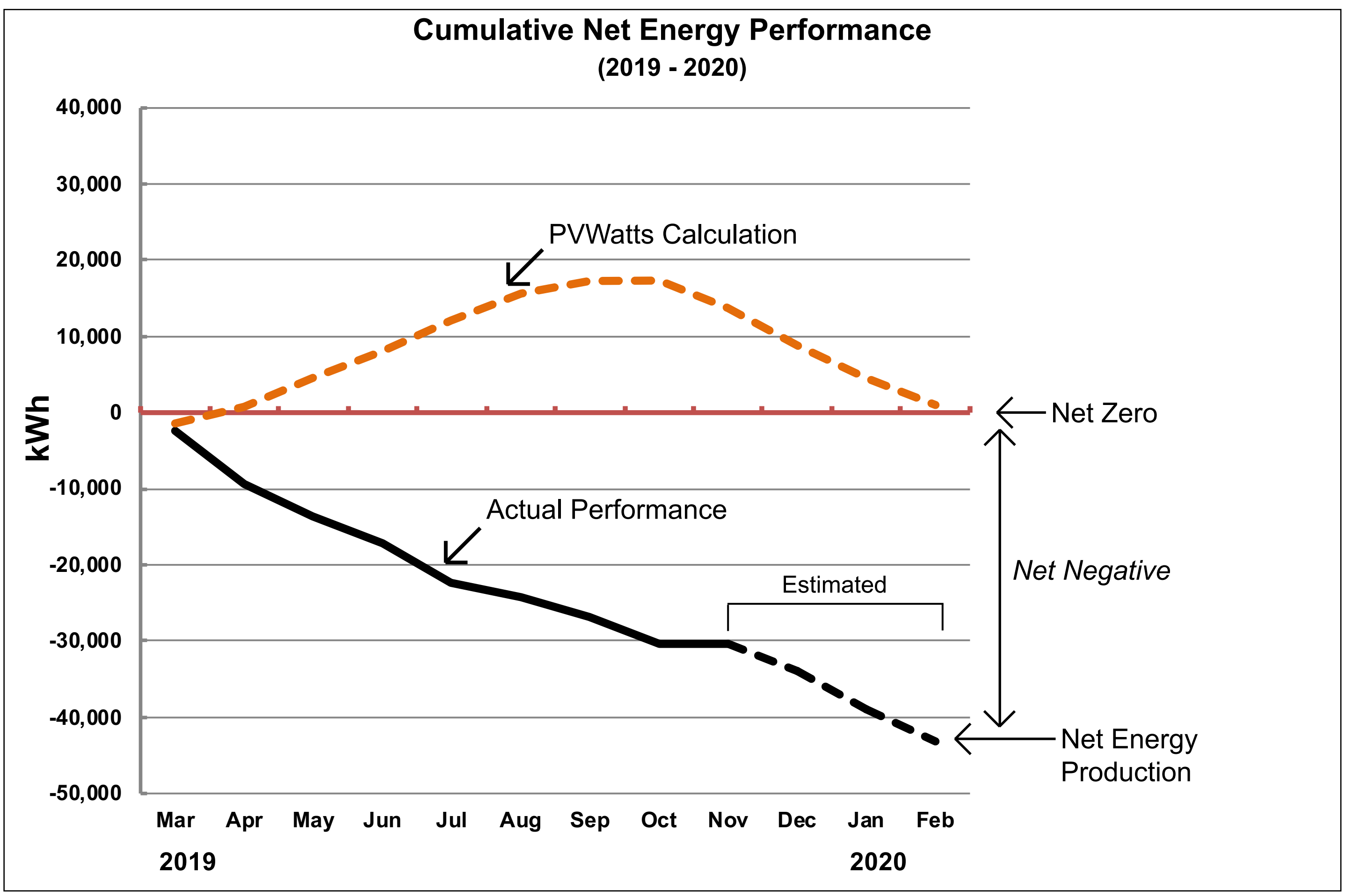
The solar PV contractor has occasionally checked on the operation of the installed system as a professional responsibility. In a recent check, the contractor discovered that one inverter had failed and that a major portion of the system output had been lost prior to March, 2019. After advising the owner, the inverter was replaced and the system was restored to its full capacity.

As a result of this experience, the solar PV contractor has continued to monitor system performance, though still not under any service agreement, and has performed site inspections as well. The solar production data has been monitored and recorded since March, with some additional power drops caused by local power outages and failure of some inverters to turn back on.


Modeled Annual Energy Use
(EnergyPro v6 Software)
Heating 0.4%
Cooling 2.6%
Fans 1.3%
Pumps 0.4%
DHW 5.5%
Lighting 34.3%
Plug Load & Appliances 55.4%
186,500 kWh/year
Modeled EUI =18.2


Measured Monthly Energy Use
(2019 - 2020)
185,850 kWh/year
Measured EUI = 18.7
Estimated
kBtu/sq.ft.
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
2019
2020


Solar Photovoltaic System Performance
(2019 - 2020)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
kWh
Estimated
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
2019
2020
Energy Production (PV Watts)
Energy Use (Building+EV Parking)
Energy Production (Actual)


Cumulative Net Energy Performance
(2019 - 2020)
40,000
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
-40,000
-50,000
kWh
PVWatts Calculation
Actual Performance
Estimated
Net Zero
Net Negative
Net Energy Production
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
2019
2020

(Left) Photo of particulate film coating the PV panels. Its degree of opacity suggests significant effect on the power production of the panels. (Photo courtesy of Green Dinosaur.)

The solar generation data since March, 2019, has been corrected with estimated data of these three short periods of production drop-off by taking the data from the adjacent period of time that has full operation. In addition, the solar data for November, 2019, through February, 2020, is simply estimated by that predicted by *PVWatts*[11] for the system as designed and located at the site in Inglewood, CA. This actual performance data, the corrected data gaps and the estimated performance for the remaining four months, are shown in the chart on the opposite page, *Solar Photovoltaic System Performance*.

The chart also displays the monthly energy use totals for the project and, for illustration purposes, the *PVWatts* prediction for the system as desigmed for the entire year.

The chart clearly shows that the system is performing at a level of about 35% less than designed and less than the project goal. After some investigation and site inspection, the cause remains somewhat unclear, but the probable cause is inadequate cleaning of the solar panels. (See photo above.) The site experiences a high level of air-borne particulate pollutants that can form a sun-blocking film on the PV panels. The effect can be substantial if allowed to build up, perhaps as much as shown in the reduction of the energy output data. There may also be continuing issues with the inverters, which is being investigated.

As with the other case studies, The *Cumulative Net Energy Production*, the bottom chart on the opposite page, essentially shows the progression of the energy performance toward ZNE by adding each month's net energy performance to the previous month's total—if, at the end of the 12-month period, the curve returns exactly to the zero-axis, the project is performaing at *Net Zero* (ZNE).

This chart clearly shows the impact of the operational issues with the solar PV system on this project. The ideal system performance is given by the curve that represents that predicted by *PVWatts* for the system as designed, which just achieves ZNE at the end of the year, The actual system performance, however, falls significantly short of ZNE .

Post-Occupancy: Observations and Conclusions

The most noteworthy observation is the obvious need for a regular maintenance program for the solar PV system. The system is performing substantially lower than its capability and causing the project to fall short of its ZNE goal, which is a principal concern for client and design team.

Real-time monitoring and recording of the performance of the system is being done, which enables the facility manager to be informed about any failures of system components or underproduction that needs to be investigated. Nevertheless, putting a regular service agreement in place would help to ensure prompt response to any performance issues and to maintain optimal operation of the system.

On the energy-use side, the occupants of the Silver Star Apartments are a unique population in that they do not pay utility bills. Therefore, they have no motivation to consider energy efficiency in the operation of the units based on the normal feedback that is given by an energy bill. Monitoring the individual unit's energy use and communicating the information to the occupant may influence user behavior to lower energy use. It would be useful in any event for management to have this information. The energy modeling done prior to construction using EnergyPro is based in part on patterns of use for a standard population, as required by code. There may be a benefit in general of knowing patterns of energy use for this population in order to plan more efficient affordable housing of this type in the future.

[11] See: https://pvwatts.nrel.gov/pvwatts.php

CASE STUDY NO. 10

Cottages at Cypress

PHOTO: RYAN FILGAS

Cottages at Cypress

Case Study No. 10

Data Summary

Building Type: Multifamily – Low Income Senior Housing (New Construction)

Location: Fort Bragg, CA

Gross Floor Area: 17,260 gross sq. ft.

Occupied: 2014

On-Site Renewable Energy System Installed:
131 kW (DC) Solar PV – total
1BR unit: 4 kW (DC)
2BR unit: 5 kW (DC)
Communal Bldgs: 20 kW(DC)

On-Site Storage Battery: None

Measured On-Site Energy Production:
1BR unit (#26): 6,440 kWh/yr
39.9 kBtu/sq.ft. per year
2BR unit (#23): 7,315 kWh/yr
31.5 kBtu/sq.ft. per year

Modeled EUI (Site):
1BR unit:
27.8 kBtu/sq.ft. per year
2BR unit:
24.3 kBtu/sq.ft. per year

Measured EUI (Site):
1BR unit (Unit #26):
17.4 kBtu/sq.ft. per year
2BR unit (Unit #23):
13.9 kBtu/sq.ft. per year

Owner/Client
Danco Group, Arcata, CA

Project Team

Architect:
K. Boodjeh Architects, Eureka, CA

Structural Engineer:
Branch Engineering, Inc., Springfield, OR

Energy and Sustainability Consultant:
Redwood Energy, Arcata, CA

Solar PV System Design & Installation:
Roger, Arcata, CA

General Contractor:
Danco Builders Northwest, Arcata, CA

"Affordable housing" is a recognized urgency for many subsets of the population, each with its special needs and aspects. For some, this subset is low-income families or the homeless with support service needs, as in two previous case study projects in this series of books, *Zero Net Energy Case Study Homes*. This case study is yet another group for which affordable housing has become an urgent issue: low-income seniors.

What is common to all housing currently under development for these populations is the desirable aspect of zero-net-energy (ZNE) performance for the completed project for the simple reason that future energy costs for the tenant or building operator are minimal. Indeed, the award of the contract for the design and construction of an affordable housing project often depends on this feature being included in the proposal. The financing arrangements for the project are structured so that ZNE is a natural method of keeping future operating costs low and predictable.

The form of the building program and project design are also quite different, depending on the social group and location. The ZNE design strategies are therefore different as well. This case study, a project for low-income seniors in a semi-rural area, is a case in point. In a location on the California coast where the decline in fishing and timber industries has led to a decline in moderate incomes, seniors now comprise most of the low-income population. Their lifelong familiarity with and preference for individual homes rather than larger complexes of adjacent units led to the concept of the neighborhood of small houses, or individual "cottages". The ZNE design strategies therefore involve smaller independent systems and envelope-dominated design of small buildings rather than other types of design approaches better suited to larger buildings.

Background

The initiator of this project, Danco Group, is an affordable housing, for-profit developer that was looking to initiate a project in the Fort Bragg area on the Northern California coast. Affordable housing for seniors in one of a portfolio of types of affordable housing pursued by Danco Group in addition to low-income family and supportive-services types. Most of their projects are initiated by the company rather than packaged in response to a specific RFP. The company has a construction division and a property management division, which are involved in their projects at various times.

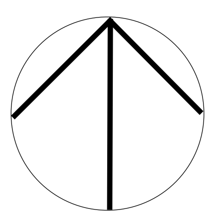
Their methodology is that they proactively seek such projects in their geographic area, Northern California between San Francisco and the Oregon border, and the company puts together proposal packages to interest local governments who want to create affordable housing for their constituents. If there is interest, Danco Group forms a limited partnership for the project, arranges the financial packages and then acts as the design-build entity to construct the final product. There is a non-profit partner within that limited partnership (LLC) that is the "managing general partner", while Dance Group is the "administrative general partner". A limited partner to provide financing and to buy the tax credits is the third member of the LLC.

Danco Group chose the City of Fort Bragg as a good candidate for their strategic plan to develop affordable housing and approached the city with a proposal for a project for low-income seniors, the local population with the highest need for this type of housing. The city accepted the idea. The company sought and received federal tax credits for the project through a program of the U.S. Department of Agriculture (USDA), which had a requirement at the time that funding required that the project be ZNE. Thus, ZNE was integral to the program, as described above.

> "It does not cost an affordable housing project any more money to go net zero."
> —Chris Dart, President of Danco Group.

The project site was found after three years of searching and Danco Group, upon final agreement with the city, purchased the land and began the project.

Cottages at Cypress - General Vicinity Plan



(Opposite page) Site Plan for The Cottages at Cypress.

(Left) View of the project from Cypress Street. (Photo by Ryan Filgas.)

Project Process

Building Program

The program reflects the strong desire of the target population to continue living in separate homes as they have been doing throughout their lives while raising families and working in the local industries. They were not inclined to be forced to live in the close quarters of the unfamiliar housing type of an apartment building or other clusters of units. The developer therefore elected to build small individual homes of the type that were familiar to most local people.

As planned and built, the project consists of eighteen (18) one-bedroom cottages, six (6) two-bedroom cottages and one manager's cottage, for a total of 25 small houses on the two-acre site. There are also two communal buildings: the community center and the shared laundry facility.

The cottages are quite small: between 550 sq. ft. and 582 sq. ft. for the one-bedroom units and between 782 sq. ft. and 821 sq. ft. in the two-bedroom units. The shared community building, with the large open room for meetings, a kitchen and a manager's office, is 1,200 sq. ft. The separate common laundry facility is 470 sq. ft. All the buildings total 17,260 sq. ft.

The site includes a designated "coastal wetland area" that was to be enhanced and restored as part of the development. This included a significant portion of the southwest corner of the site. (See the landscape site plan on the opposite page.)

The project was also programmed as an all-electric development in order to keep the carbon footprint minimal.

Site Constraints

Large cypress trees at the northeast corner of the site cast a significant amount of shade on that corner of the site. Because of the limited size of the site and the number of houses planned, units would have to be located in that shaded area.

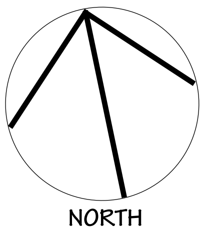
Solar shade analysis showed that two of the house building sites would be negatively affected, namely units #8 and #12. (See the landscape plan on the opposite page.) The solar PV systems planned for those units would not be productive, so their PV panels were placed elsewhere on the site where sunlight exposure was good, namely on the roof of the communal buildings. (See the discussion below in *Renewable On-Site Energy Supply*.)

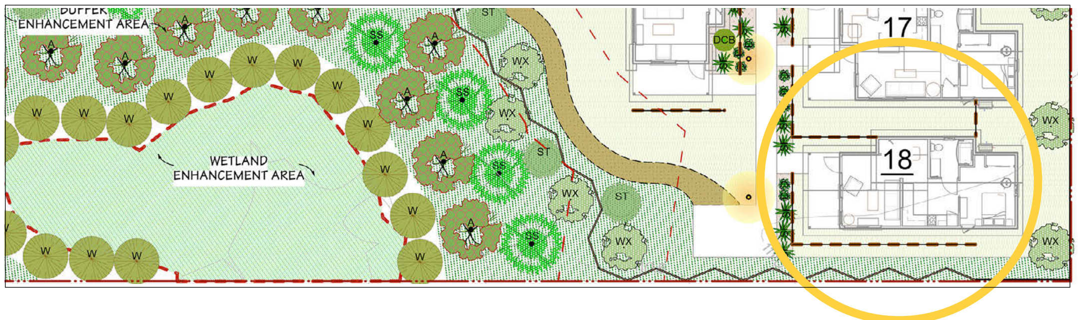
Low Energy Design Strategies

As with the affordable housing Case Study No. 9, the Silver Star Apartments, ZNE performance was part of the program brief, so the solar PV systems were sized to cover slightly more than the annual energy demand of the houses and an allowance for charging an EV, in this case 110%. The one-bedroom units have very similar floor plans and orientations, so this energy demand is much the same for each unit of this type and the same system could be specified for each one. The same is true for the two-bedroom units.

Many of the house plans are repeated for both the one-bedroom and two-bedroom units, but are rotated in orientation to make the site plan work. Since the solar panels must face south, this resulted in a different roof orientation and design for the same floor plan.

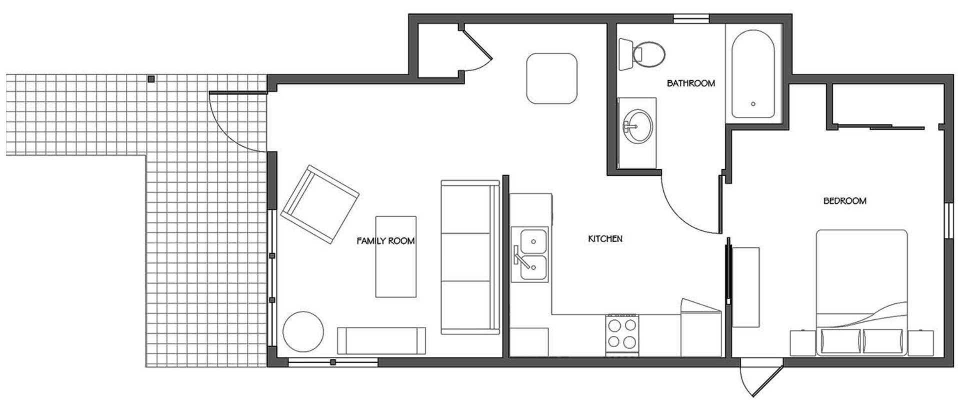

CYPRESS STREET
SHORTER PLANTINGS FOR SAFE VISIBILITY AT DRIVEWAY
ENTRY SIGN
(E) SIDEWALK
WALKWAY BOLLARD LIGHT, CFL LAMP, DARK-SKY COMPLIANT, REFER TO ELECTRICAL, TYP.
RECYCLED PLASTIC BENDER BOARD AT ALL LAWN TO MULCH TRANSITIONS, TYP.
TALLER PLANTINGS SCREEN PARKING & BACKFLOW PREVENTER
ALL HEAT PUMP UNITS AND UTILITIES ARE LOCATED OUT OF VIEW AND/OR SCREENED BY LANDSCAPING
OPEN GRADED PERMEABLE PAVING, REFER TO SITE GRADING & DRAINAGE PLAN
HYDROSEED LAWN @ GRASSPAVE2 PARKING STALLS
GRASS SWALE
BRIDGE
AGGREGATE PATH
LAWN
SPLIT RAIL FENCE
WOOD FENCE 6 FT TALL. INSTALL MAN GATE(S) AS REQUIRED BY FORT BRAGG FIRE DEPT.
LED POLE LIGHT, 20 FT TALL, DARK SKY COMPLIANT, REFER TO ELECTRICAL, TYP.
EXT. LIGHTS ATTACHED TO BUILDINGS ARE NOT SHOWN HERE, SEE BLDG ELECTRICAL PLANS, TYP.
NATURE TRAIL INTERPRETIVE SIGN
50 FT BUFFER
30 FT BUFFER
BUFFER ENHANCEMENT AREA
WETLAND ENHANCEMENT AREA





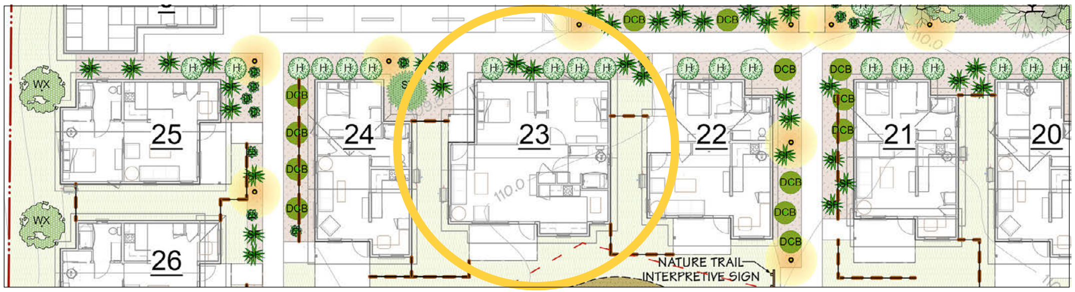
COTTAGE #18
1 BR UNIT

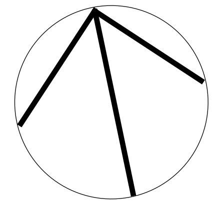
ROOF PLAN



COTTAGES AT CYPRESS — FLOOR PLANS AND SECTIONS

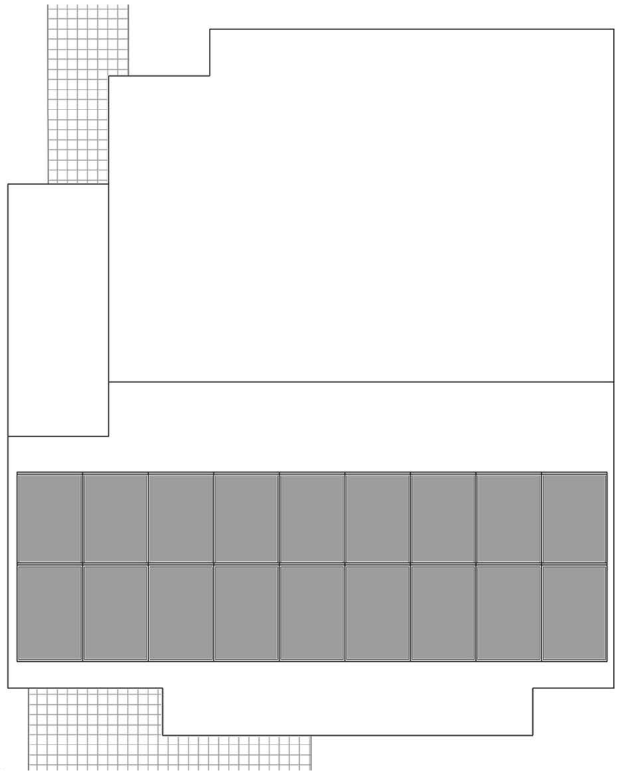
FLOOR PLAN



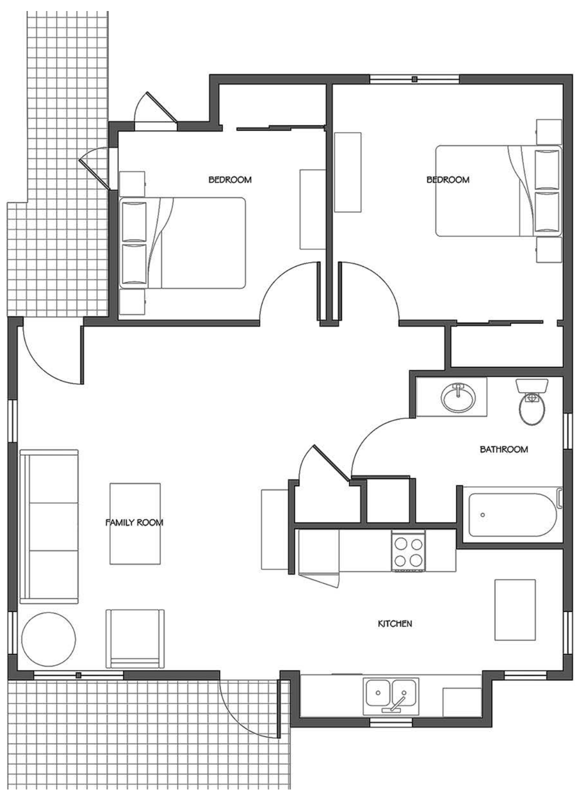


NORTH

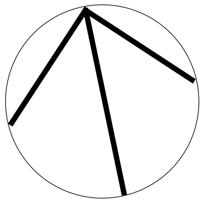
COTTAGE #23
2 BR UNIT



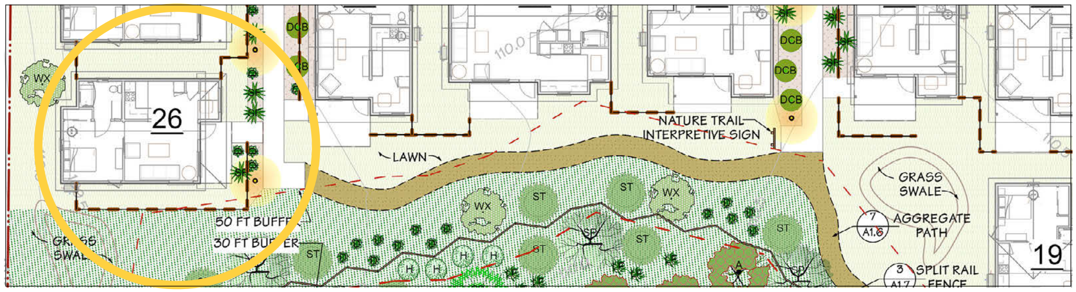
ROOF PLAN



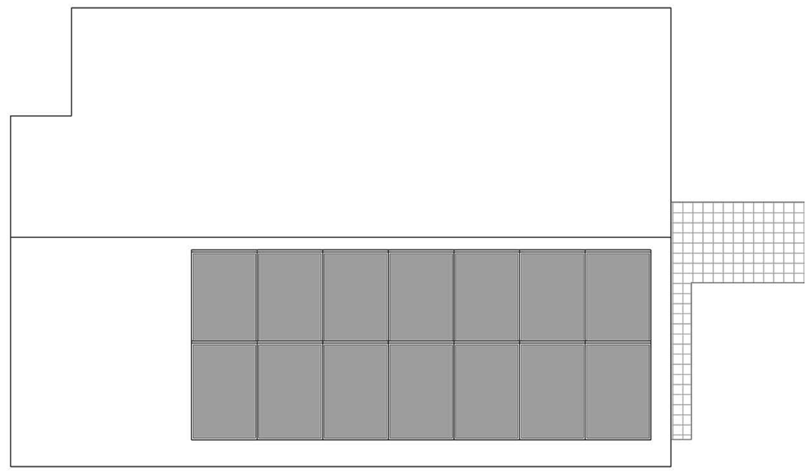
FLOOR PLAN



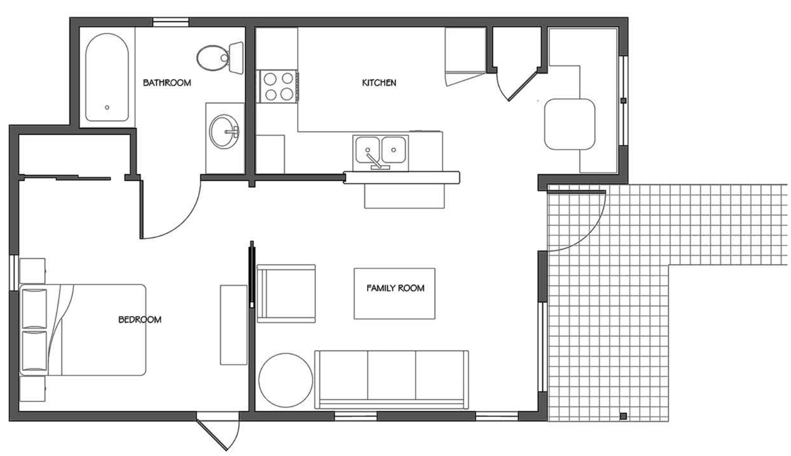
NORTH



COTTAGE #26
1 BR UNIT



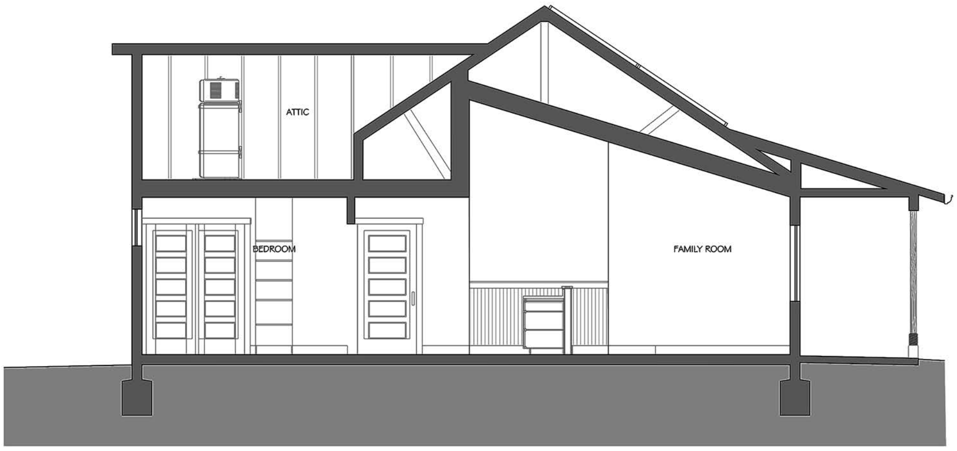
ROOF PLAN

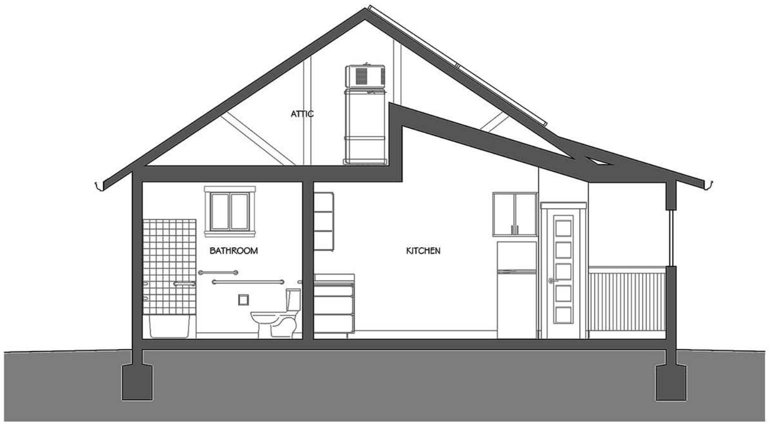


COTTAGES AT CYPRESS — FLOOR PLANS AND SECTIONS

FLOOR PLAN

STANDARD SECTIONS
ALL UNITS





Building Envelope — Insulation and Windows

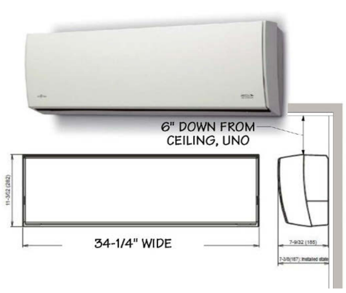
The windows are double-glazed, but do not have the low-e coatings, which are conventionally used in most climate zones of California to reduce the cooling load produced by solar gains. This location in the mild climate of the Northern California coast generally has little or no cooling load. The seasonally large heating load, on the other hand, is reduced in these houses by the passive solar heat gains that are obtained by omitting the low-e coating.

Insulation levels were designed to California energy code only, which required R-21 walls and R-35 roofs. No rigid insulation was installed on the outside of the studs to prevent solar bridging because of the cost premium, not appropriate for tightly budgeted affordable housing.

Building Envelope — Airtightness

Measures were taken to air-seal the homes and meet the requirements of the *Energy Star® for Homes* program. These included gaskets under the sill plates as well as complete inspection and sealants in all the gaps in the house walls and roofs.

Each house was tested using the Blower Door Test and every house in the final test measured 3.0 ACH50 or better, as required by *Energy Star® for Homes*.



(Above) Ductless mini-split heat pump unit: outdoor compressor unit *(top)* and indoor heating/cooling unit *(bottom)*.

Heating, Ventilating and Cooling Systems

The houses are heated and cooled with high-efficiency ductless mini-split heat pumps[1]. Only one mini-split wall unit is required since the cottages are small.

The mildness of the marine climate allows natural ventilation with operable windows for the entire year so no HRV units were specified for fresh air ventilation and the heat exchange between outgoing and incoming air. Normally, they would be recommended for climate zones with larger heating and cooling loads and very airtight houses.

The kitchen fans exhaust directly to the outside and meet *Energy Star®* standards for power demand, air flow rates and sound level. Recirculating fan units were deemed to be unsatisfactory for their effect on indoor air quality.

Lighting and Plug Loads

All lighting is provided by LED sources for maximum efficiency.

Electric coil ranges were selected were specified for the kitchens for their affordability compared to electric smooth-top type. Electric induction cooktops were considered too costly to specify despite advantages in terms of energy use.

Domestic Hot Water

Each house has a 50-gallon heat pump water heater[2]. When the energy modeling for the houses showed that domestic hot water would be a major part of the total energy use, the project team decided to specify heat pump water heaters as an energy efficiency measure. Since this type of water heater requires a comparatively large closet size and the floor plans had already been completed, the water heaters were placed in the attic space to avoid taking up some of the usable floor space.

Construction

Since the individual houses were simple in design and conventionally detailed with standard products, the construction process was straightforward.

[1] 25-SEER Fujitsu 9RLQ with a heating seasonal performance factor of 12.

[2] GE GeoSpring™ Heat Pump Water Heater

Renewable On-Site Energy Supply

The solar PV system size for each unit is designed to supply the annual energy demand of that unit's household electrical needs plus an allowance for the electrical energy required to recharge one electric vehicle driven 5,000 miles in a year.

This design criterion resulting in the sizing of the individual systems as follows: each one-bedroom cottage is equipped with a 4 kW (DC) system and each two-bedroom cottage has a 5 kW system, for a total of 102 kW for all the houses in the development. There is also a 20 kW system for the shared buildings and their energy demand. Each small system is independent and separately metered by the utility, then billed to the occupants.

Because two of the houses in the northwest corner of the site are in the shade of the tall cypress trees, their systems are located at the communal buildings, tied into the communal system for practical operation purposes. So the total system at the communal buildings is nominally 29 kW and the utility allocates the appropriate share of the net-metered credit from this total system to the two units that are without any solar PV systems on the roof (units #8 and #12),

Three electric car charging stations are provided in the communal parking lot near the community center for staff and visitors.

(Below) Two-bedroom.cottages with 5 kW solar PV arrays. (Photo by Ryan Filgas.)


PHOTO: RYAN FILGAS

PHOTO: RYAN FILGAS

(Left) View of a typical ZNE cottage for low-income seniors.

Energy Performance
Energy Modeling and Post-Occupancy Measurement

Energy Use—Modeling

Energy modeling was done for representative one-bedroom and two-bedroom houses in order to determine their energy use profiles and to support the application for *Low Income Housing Tax Credits (LIHTCs)*[3] essential to the project.

This modeling was done using the *California Utility Allowance Calculator (CUAC)*. The CUAC software allows energy consultants working for affordable housing developers to provide a more accurate estimate of what tenants will pay for utilities, taking into account the energy affecting features of the proposed building, the solar PV system designed for it, and the applicable tariff. (The CUAC is intended for use with new construction projects.)

The CUAC results for the annual energy use for each system for the typical one-bedroom and two-bedroom units appear in the charts on the next page.

Energy Use—Post Occupancy Measurement

The actual energy use by each house has been monitored by the solar PV system contractor using recorded data metered at the individual inverters. Since the floor plans are repetitive, the energy use of three houses were selected as representative of the individual houses of the project as a whole:

- House #18, a one-bedroom unit with the typical linear plan
- House #26, a one-bedroom unit with the typical square plan
- House #23, a two-bedroom unit with the common plan for all six

See the Landscape/Site Plan on p. 81 for the location of these houses on the site. See also the individual floor plans and sections of these houses on pp. 82-85.

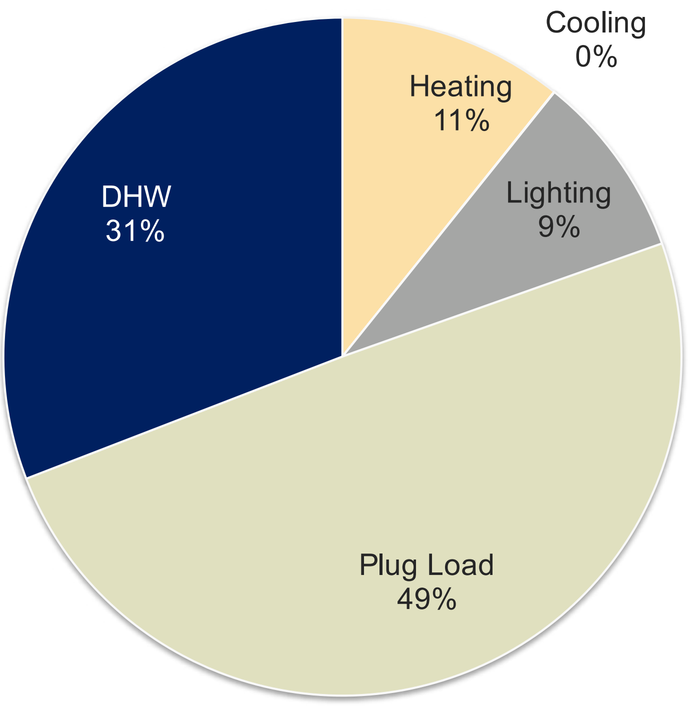
The measured monthly energy use for each of these three houses during one particular year is shown in the charts on pp. 93-94. (A different year was selected for each house based on the data availability). For comparison with the CUAC modeling results for a house of the same type, the CUAC-modeled monthly energy use predicted for the same month is integrated with the measured energy use in these charts.

The modeled and measured energy use are reasonably close in certain months but deviate sharply in May - October. The differences during those periods may be attributed the occupants natural frugality with regard to the cooling system operation, or in some cases may simply be periods of non-occupancy for a variety of reasons. Another possible explanation is that the CUAC software does not accurately model the user behavior of this group of occupants, namely seniors in benign mild coastal climate.

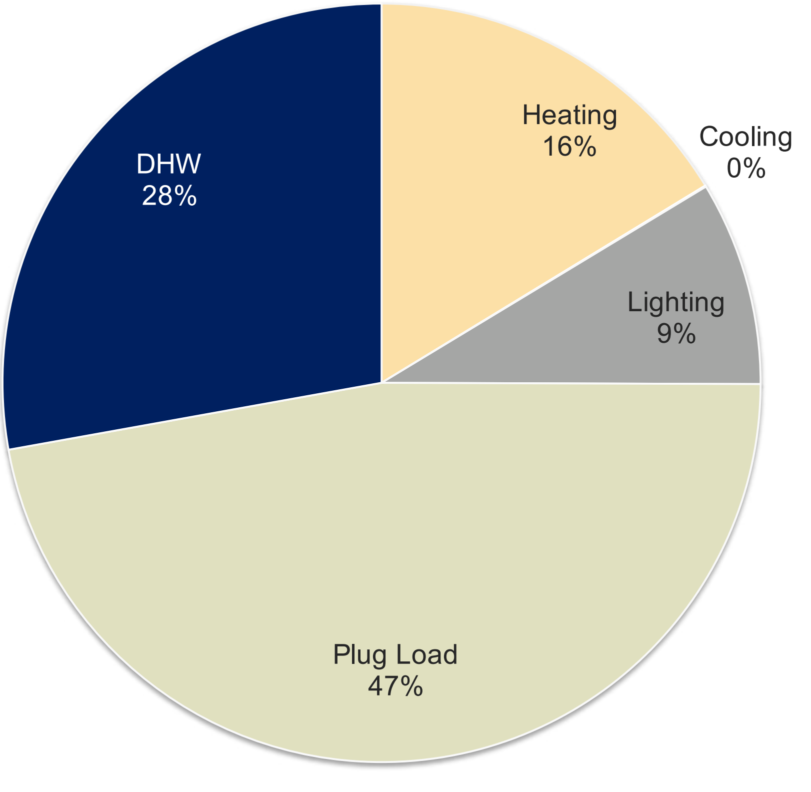
---

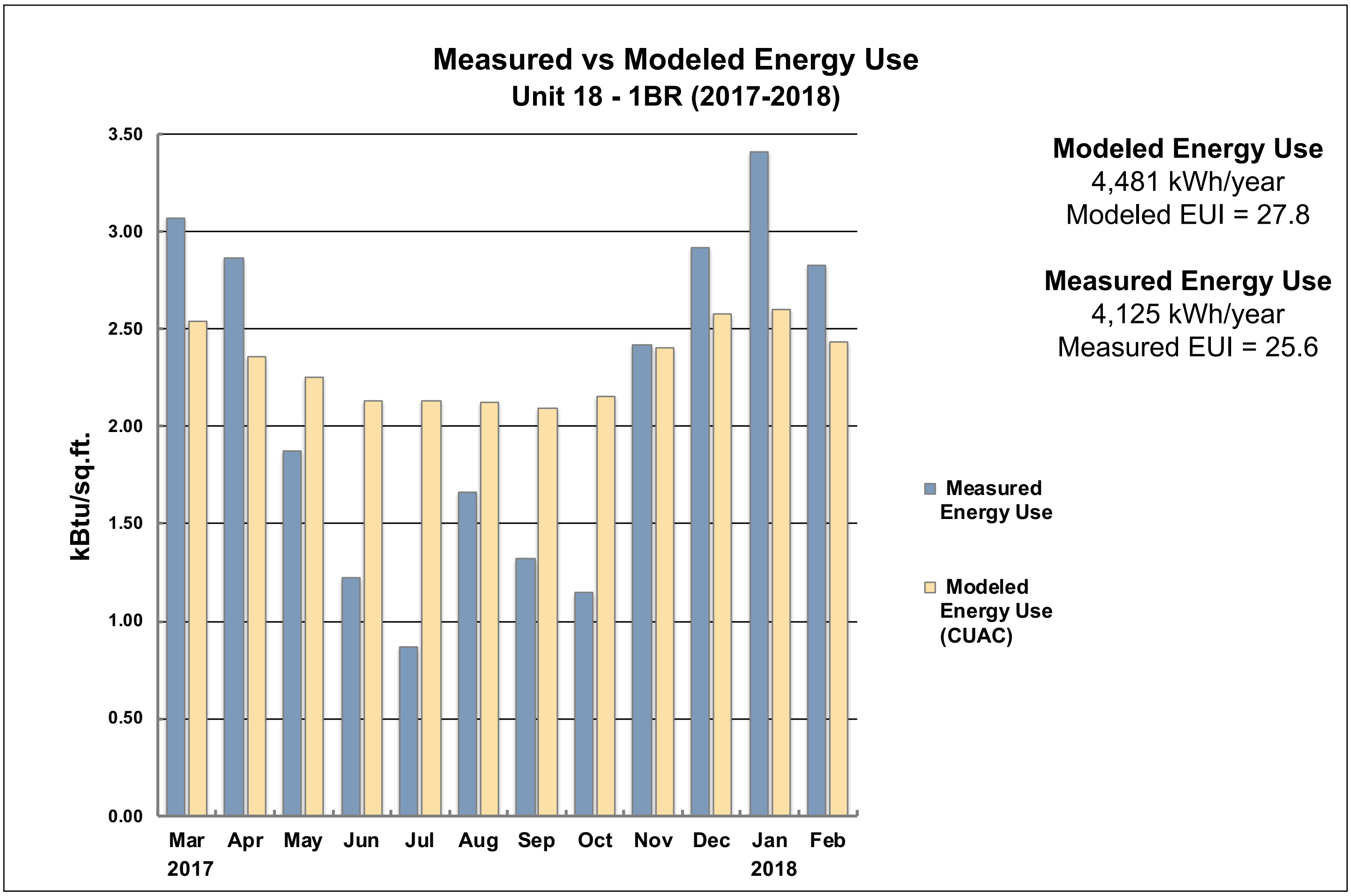
[3] The California Tax Credit Allocation Committee (TCAC) is the state agency that allocates these federal and state tax credits in support of affordable housing. Applicants for LIHTCs must estimate the monthly income and expenses for proposed projects. As part of the calculation, applicants need to provide an estimate of the utility costs tenants will face. Historically, the most common source of the utility cost estimate was local public housing authorities' utility allowance schedules. Those schedules generally overestimate what tenants' utility costs will be. In 2008, the California Energy Commission worked with the affordable housing community and TCAC to create a more accurate tool for estimating tenants' utility costs: the *California Utility Allowance Calculator, or CUAC*.

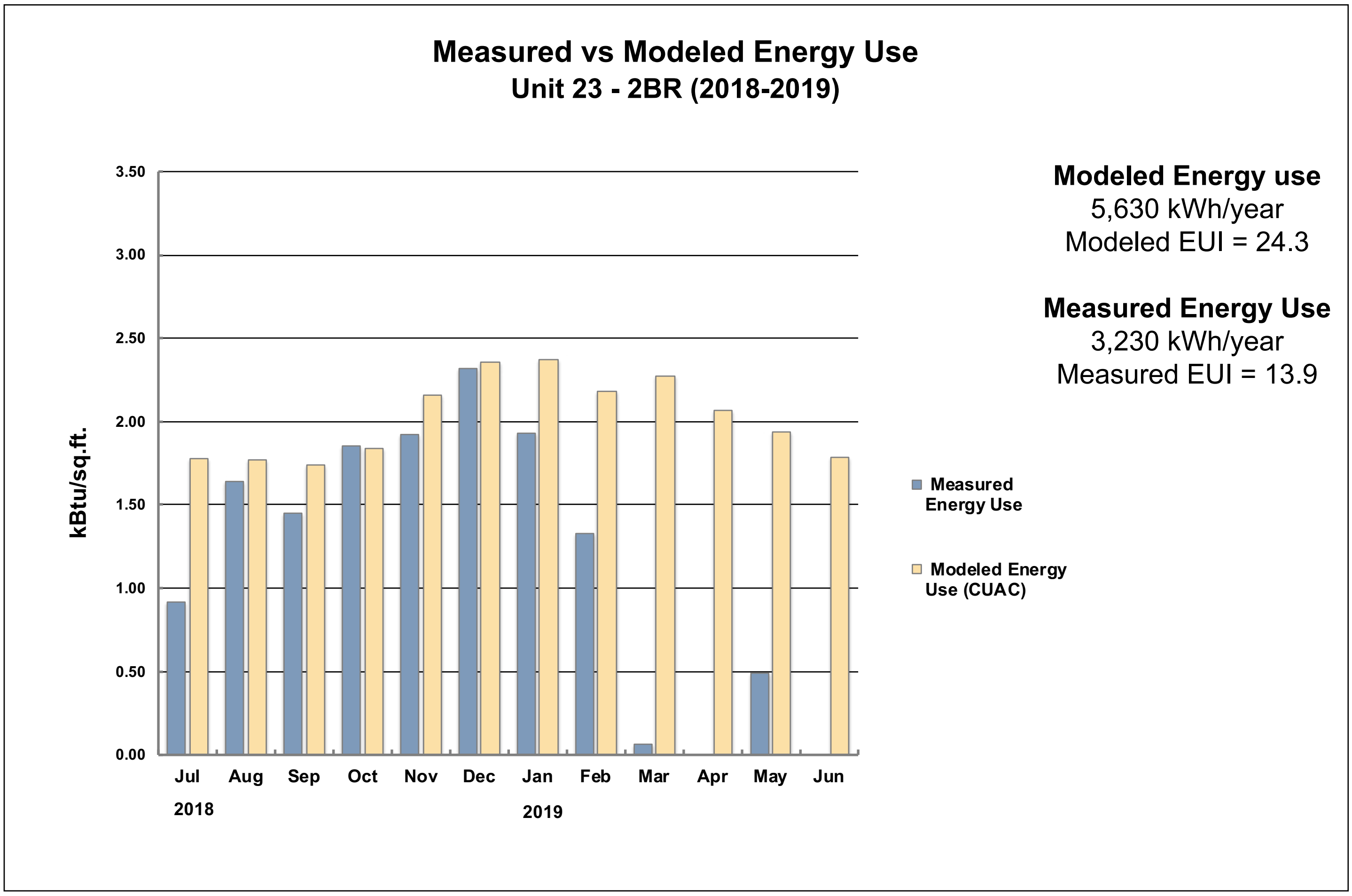
Modeled Annual Energy Use (CUAC)
1 BR Unit

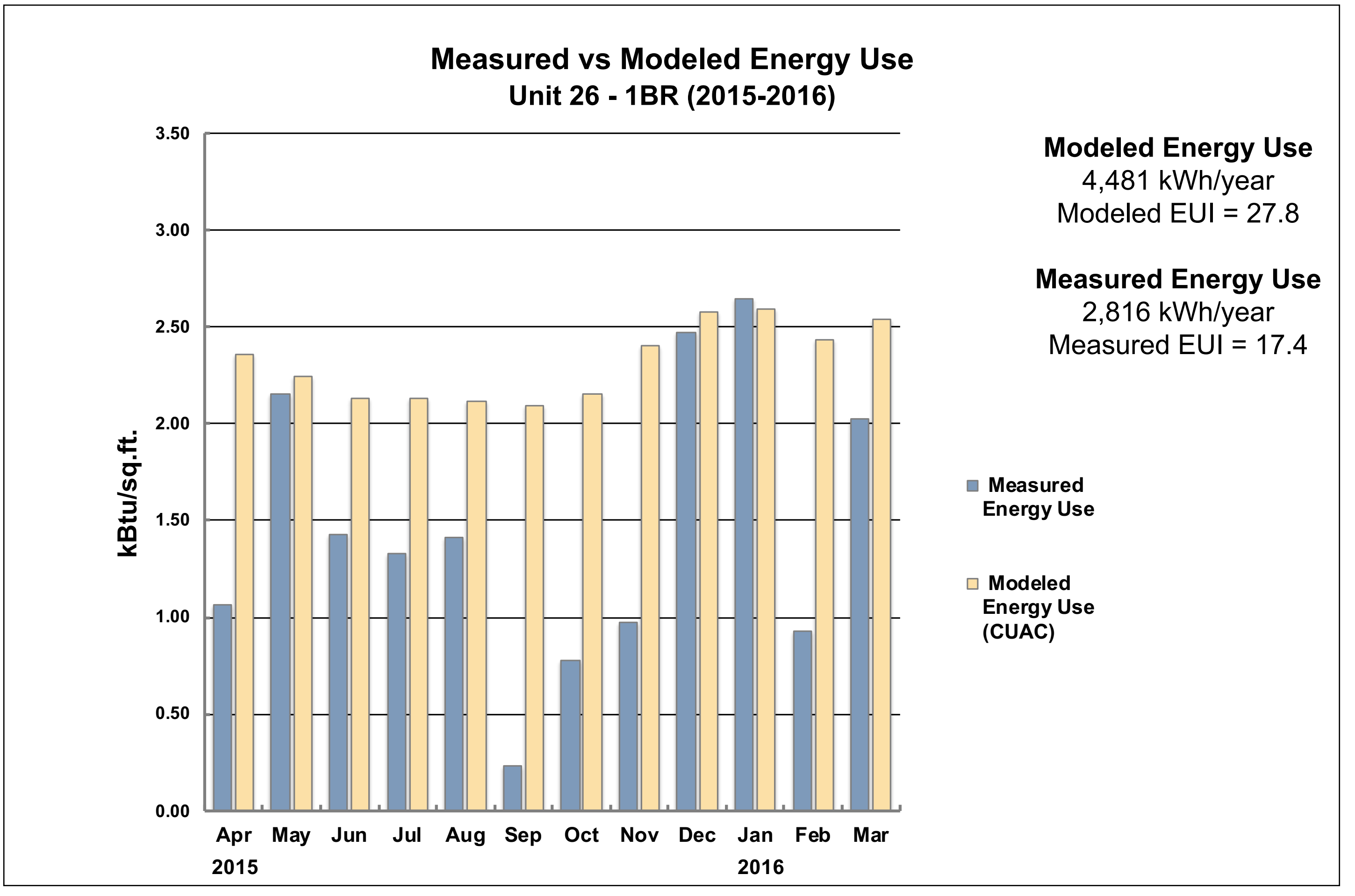


Modeled Annual Energy Use (CUAC)
2 BR Unit




Measured vs Modeled Energy Use
Unit 18 - 1BR (2017-2018)
kBtu/sq.ft.
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
2017
2018
Modeled Energy Use
4,481 kWh/year
Modeled EUI = 27.8
Measured Energy Use
4,125 kWh/year
Measured EUI = 25.6
Measured Energy Use
Modeled Energy Use (CUAC)


Measured vs Modeled Energy Use
Unit 23 - 2BR (2018-2019)
kBtu/sq.ft.
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2018
2019
Modeled Energy use
5,630 kWh/year
Modeled EUI = 24.3
Measured Energy Use
3,230 kWh/year
Measured EUI = 13.9
Measured Energy Use
Modeled Energy Use (CUAC)



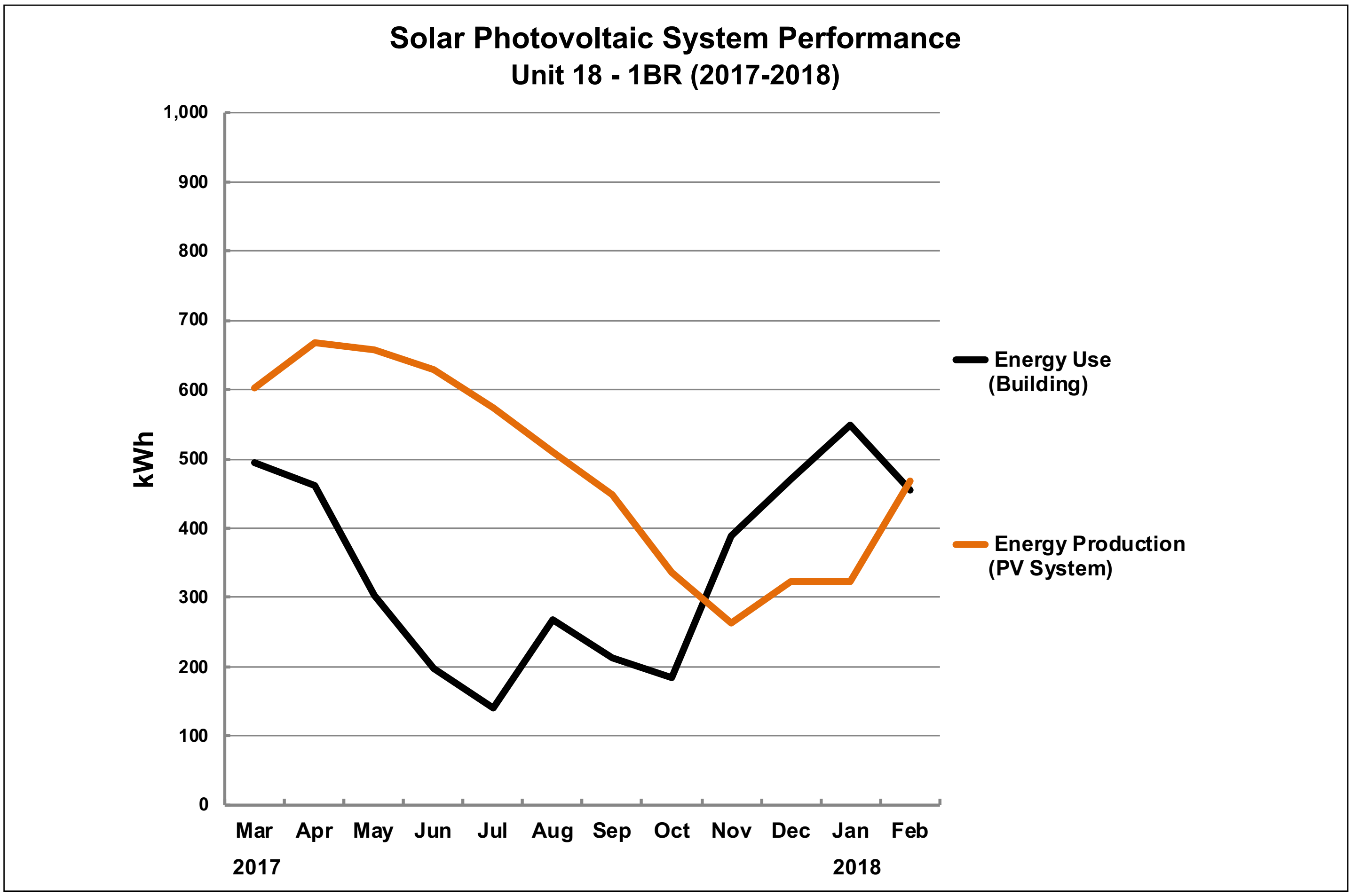
What is remarkable about the ZNE performance characteristics as shown by the data is the variability in energy use patterns. The houses are very similar in design, yet have very different energy consumption totals and distribution according to the season.

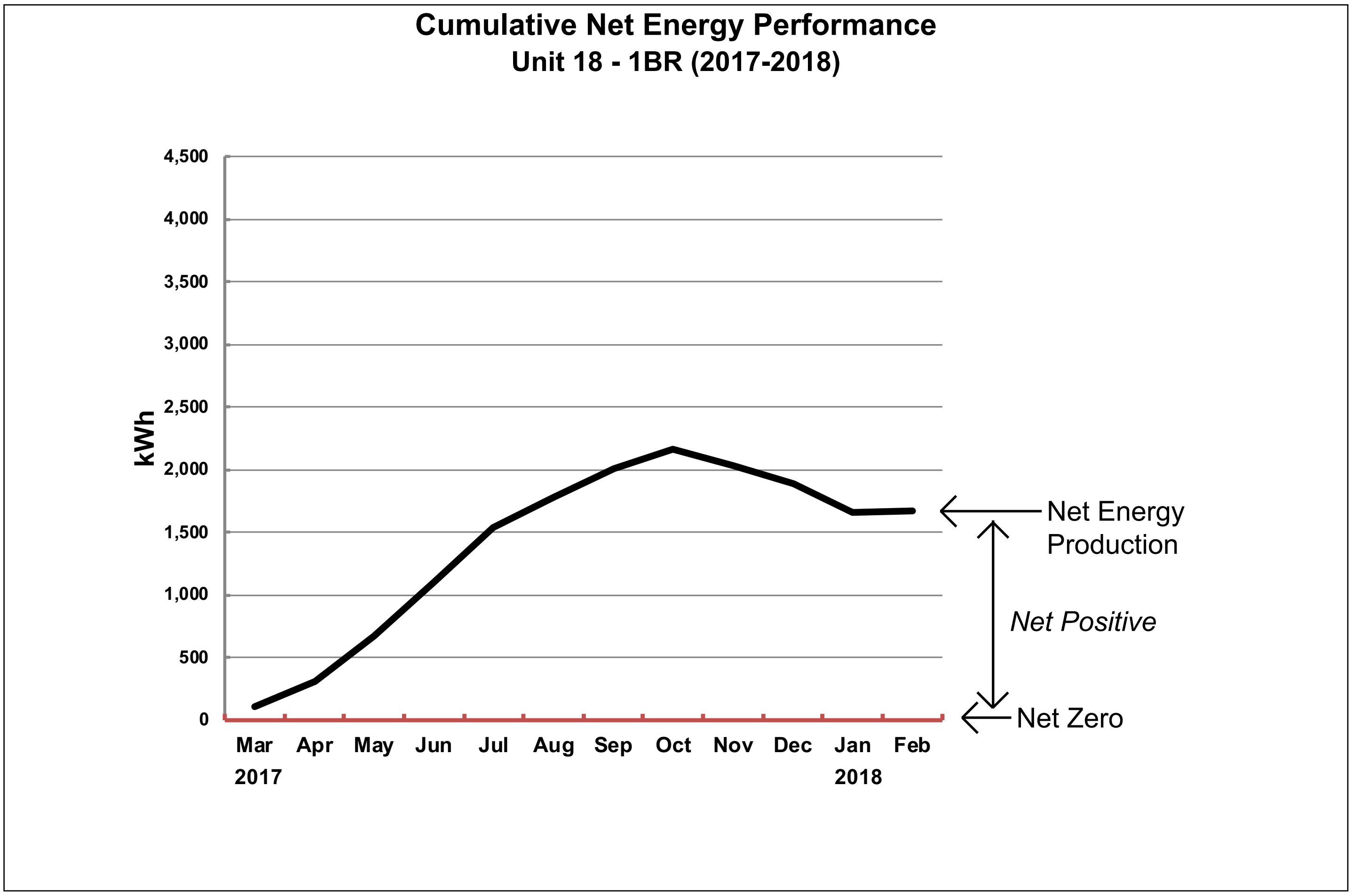
Energy Production versus Energy Use: Zero Net Energy Performance

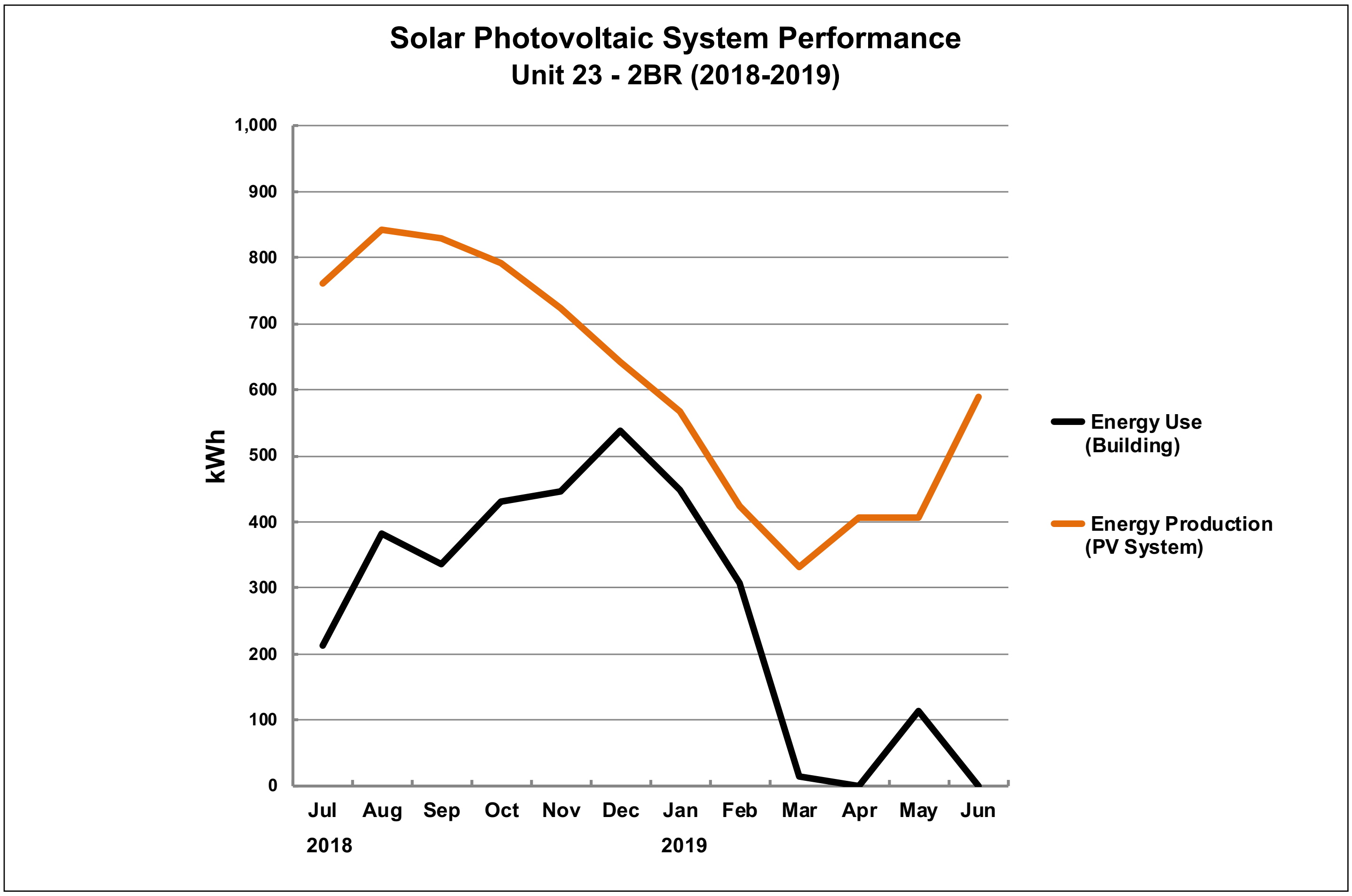
The charts on pp. 95-97 show the solar PV systems' energy production during the same periods of use for the three houses. It is clear from these representative performance charts that the systems are providing more energy than is used in the houses.

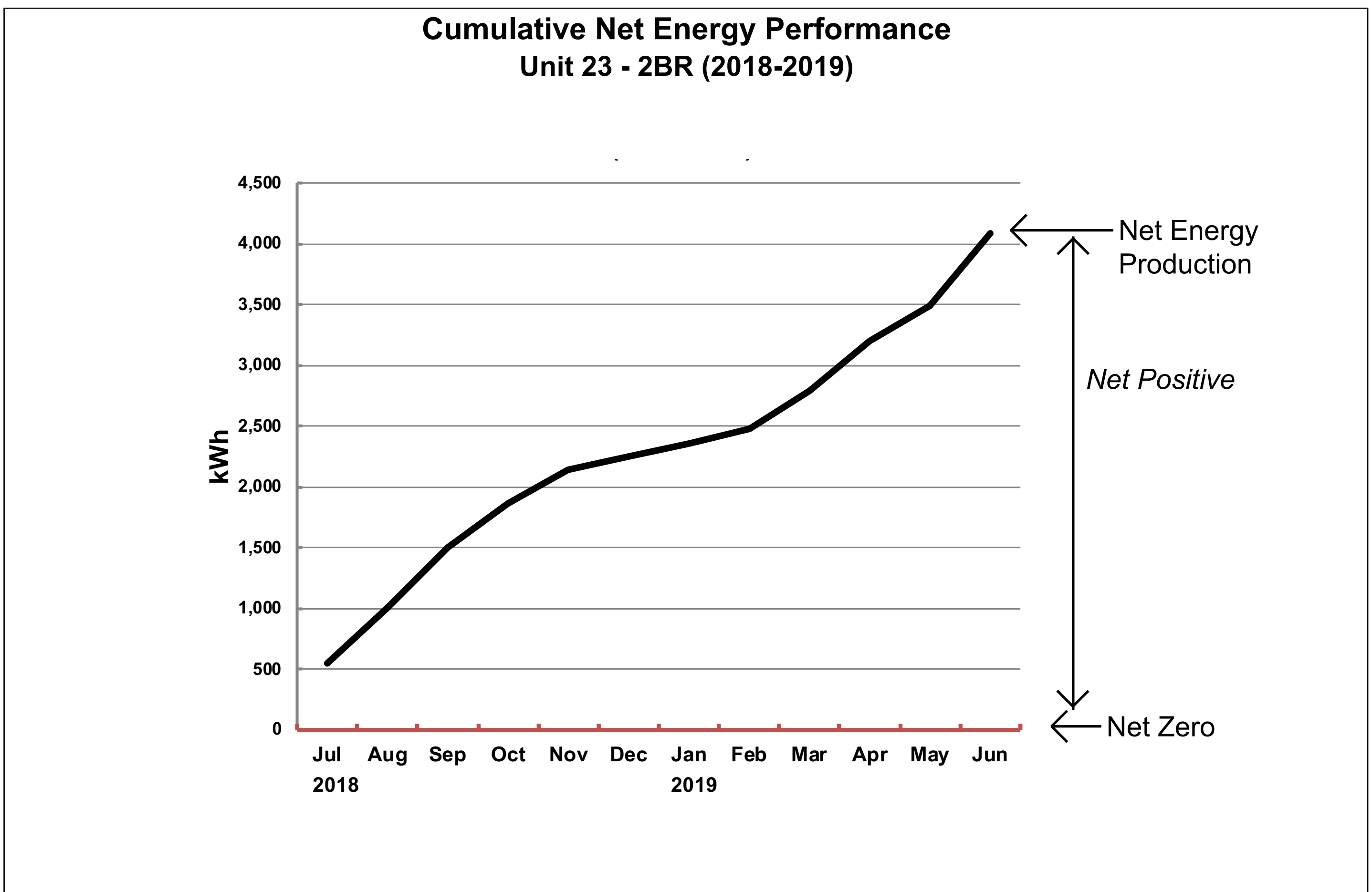
Similarly, when the *cumulative energy production*[4] for each house is charted from this data, the houses can be seen to be strongly *net positive* performers. The solar PV system installer, who also carries out performance maintenance on the system and records the monthly net meter and the energy production data, has reported that all units in the development have shown net positive performance for the periods covered in the charts, although exhibiting a wide range of energy use patterns. The net positive performance for all units indicate that the PV systems may have been oversized, in his opinion, at least for this initial period when none of the residents own an EV.

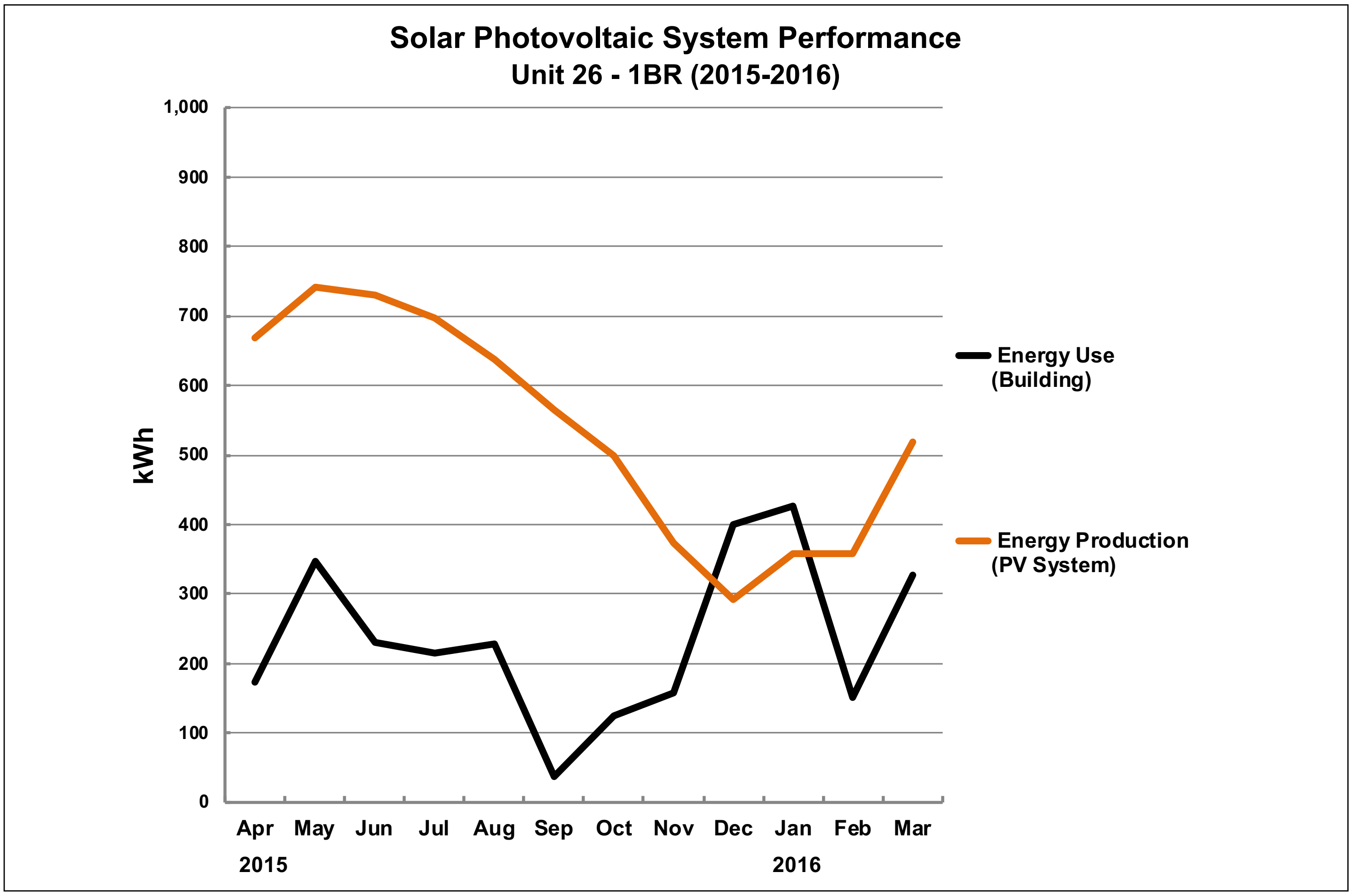
[4] The *cumulative net energy production* is a chart that essentially shows the progression of the energy performance toward ZNE by adding each month's net energy performance to the previous month's total—if, at the end of the 12-month period, the curve remains on the positive side of the zero axis, then the building in performing better than ZNE, i.e., *Net Positive*. If the curve exactly returns to the zero-axis, then the building is exactly *Net Zero* (that is, ZNE).

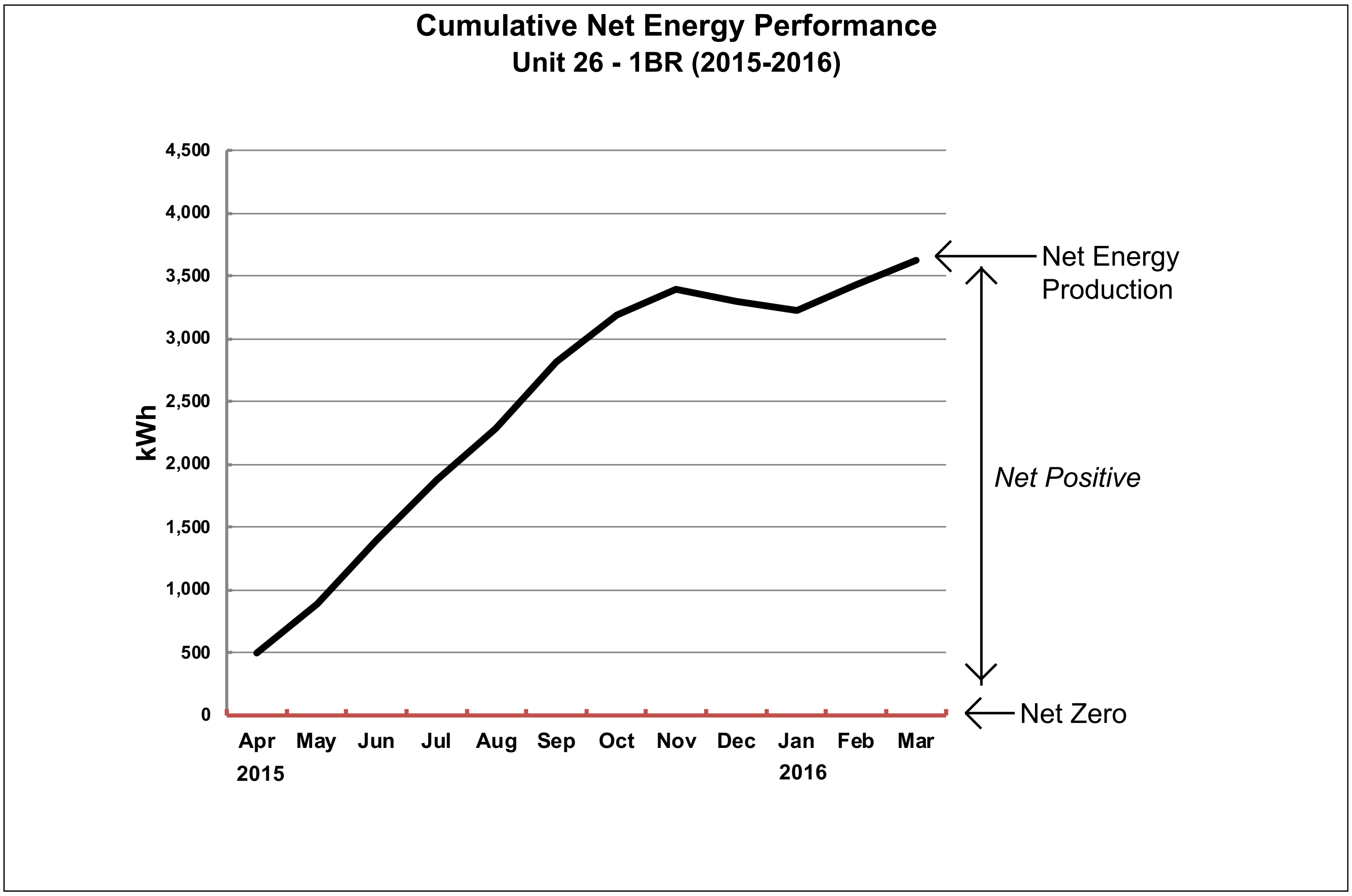

Solar Photovoltaic System Performance
Unit 18 - 1BR (2017-2018)
kWh
1,000
900
800
700
600
500
400
300
200
100
0
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
2017
2018
Energy Use (Building)
Energy Production (PV System)


Cumulative Net Energy Performance
Unit 18 - 1BR (2017-2018)
kWh
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
2017
2018
Net Energy Production
Net Positive
Net Zero


Solar Photovoltaic System Performance
Unit 23 - 2BR (2018-2019)
kWh
1,000
900
800
700
600
500
400
300
200
100
0
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2018
2019
Energy Use (Building)
Energy Production (PV System)


Cumulative Net Energy Performance
Unit 23 - 2BR (2018-2019)
kWh
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2018
2019
Net Energy Production
Net Positive
Net Zero


Solar Photovoltaic System Performance
Unit 26 - 1BR (2015-2016)
kWh
1,000
900
800
700
600
500
400
300
200
100
0
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
2015
2016
Energy Use (Building)
Energy Production (PV System)


Cumulative Net Energy Performance
Unit 26 - 1BR (2015-2016)
kWh
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
2015
2016
Net Energy Production
Net Positive
Net Zero

(Right) View from the Community Center deck.

Post-Occupancy: Observations and Conclusions

The City of Fort Bragg, the developer, the design team and, most importantly, the resident seniors occupying the houses expressed great satisfaction with all aspects of the project when interviewed for this case study. The occupants interviewed noted how particularly happy they were to receive a check from the utility rather than a bill, especially since they were on a fixed income. In addition, they were thermally comfortable at all times and were not required to consider reductions in their comfort levels because of a high utility bill.

The project team described only one aspect of the design that would be done differently in a future project: the location of the heat pump water heater in the attic space. This location has several practical drawbacks. The primary one is that the heavy vertical tank is overhead rather than at the floor level, a concern in the event of an earthquake. Another is the relative difficulty of access for service or adjustment of control settings. The original location saved on assignable floor area, which was seen as an added cost factor in the initial budgeting for the project.

The project team also reported that on-site commissioning and construction inspection are important to schedule. Even in relatively simple projects such as the subject of this case study, commissioning should be a priority to ensure that energy systems are functioning properly. Likewise, a rigorous construction inspection program should be a basic part of the construction phase. A noticeable example in this project was the failure of the bathroom exhaust systems, where 22 out of 26 units failed initially, largely due to installation errors.

PHOTO: RYAN FILGAS

CASE STUDY NO. 11

Sol Lux Alpha


PHOTO: MATT ABRAMS, WWW.SKYHIAERIAL.COM

Sol Lux Alpha

Case Study No. 11

Data Summary

Building Type: Multifamily – Mid-Rise (New Construction)
Location: San Francisco, CA
Gross Floor Area: 12,225 gsf
Occupied:
Unit A: 2016; Unit B: 2016
Unit C: 2019; Unit D: 2018

On-Site Renewable Energy System Installed:
Each Unit: 10 kW (DC)

On-Site Storage Battery
Each Unit: 3 Tesla Power-Walls, 40.5 kWh

Measured On-Site Energy Production:
Unit A: 11,686 kWh per year
17.3 kBtu/sq.ft. per year
Unit B: 11,077 kWh per year
16.37 kBtu/sq.ft. per year
Unit D: 11,417 kWh per year
16.88 kBtu/sq.ft. per year

Pre-Occupancy Calculated EUI (Site):
Whole Building: 8.05 kBtu/sq.ft. per year

Measured EUI (Site):
Unit A: 14.66 kBtu/sq.ft. per yr
Unit B: 15.57 kBtu/sq.ft. per yr
Unit D: 13.25 kBtu/sq.ft. per yr

Owner/Client
Sol Lux Alpha LLC,
San Francisco, CA

Project Team

Architect:
RG-Architecture,
San Francisco, CA

Mechanical Engineer Design:
Neumann Energy Design,
San Francisco, CA

Electrical Engineer:
Zeiger Engineers, Oakland, CA

Certified Passive House Consultants:
Graham Irwin, San Anselmo, CA

Air-Sealing Consultant:
Terry Nordbye, Inverness, CA

General Contractor:
Sarter Construction & Design,
San Rafael, CA

There is another type of multifamily housing commonly built in California urban areas, which has proved challenging to the production of projects with zero-net-energy (ZNE) performance. This is the developer-initiated *luxury condominium* project. With the recent inflation of the cost of construction in California, the financing of these projects and the resulting sale prices required to maintain adequate profit margins have affected the market size. The market is still a healthy one, however, especially in urban areas where high housing demand is a factor.

A for-profit developer of these types of projects is certainly inspired to undertake a ZNE project by a personal commitment to the general social goal of energy-efficient building and the consequent reduction of carbon emissions. But there are also profit-related advantages such as marketing and likely quick sale to buyers that are attracted to such a project. Another advantage that affects the bottom line is an expedited approvals process and favorable zoning interpretations by city agencies that consider ZNE projects desirable. This latter can result in a large reduction in the time to secure the necessary entitlements and project approvals—a great incentive for all developers. This case study is an example of such a project.

Finally, the *Sol Lux Alpha* project is instructive as a case study because it is an example of a mid-rise multifamily residential project that meets the *Passive House Standards.* As the third Passive House in this Volume 2, it employs the highly energy-efficient techniques required for Passive House certification[1], while at the same time achieves ZNE performance and meets the financial objectives of the project.

Background

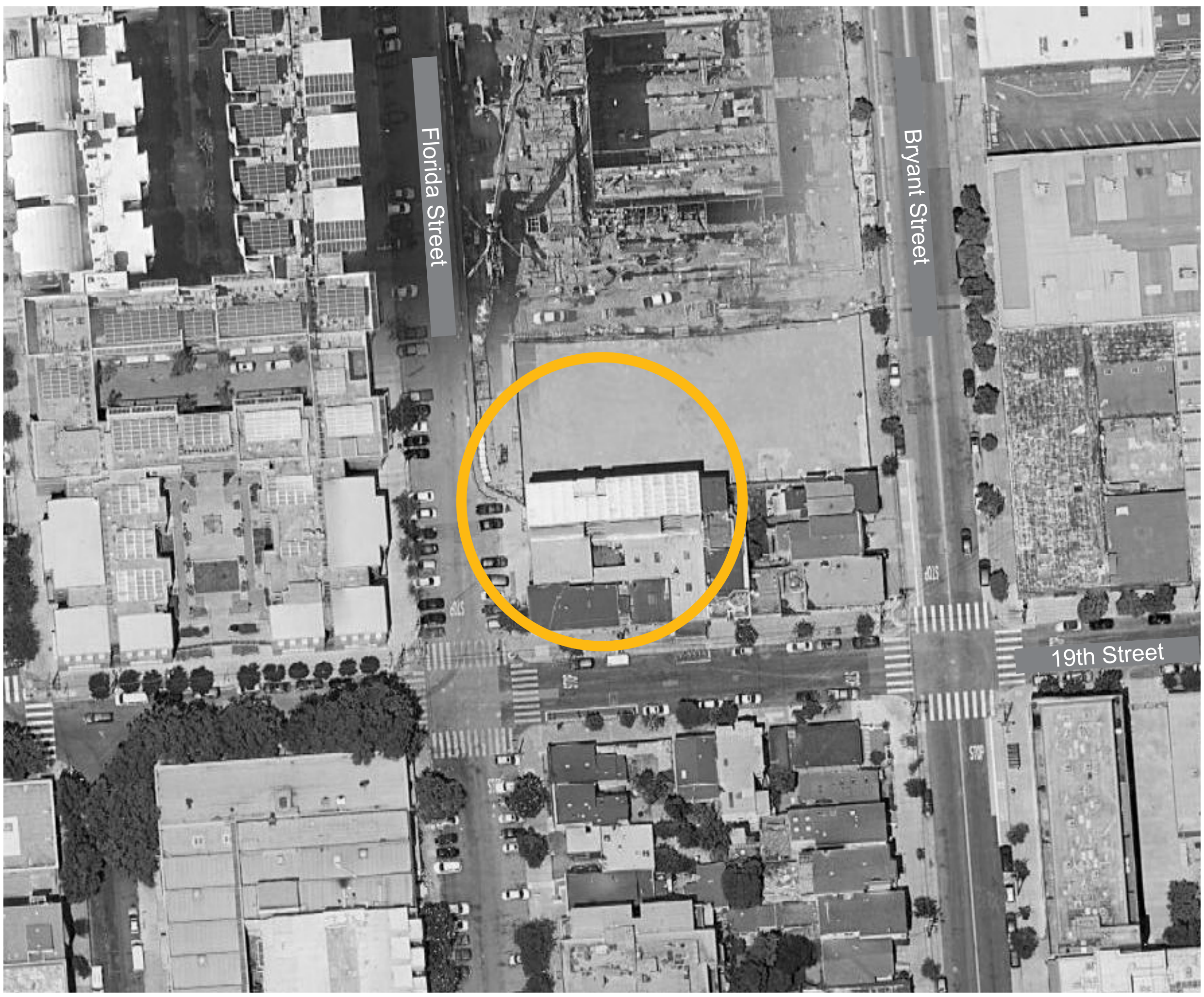
One of the developers was inspired to attempt a residential project that combined together the energy-efficiency building of the *Passive Building Standard – North America*[2] with the latest renewable energy technologies, including enough additional on-site electric energy generation and battery storage to charge an electric vehicle (EV). This ambitious program goal was undertaken in a neighborhood just south of downtown San Francisco, which was expected to have the seller's market and city agencies that would be favorable to such a project. Adding to the attractive location factors was the high purchase rate paid by CleanPowerSF for energy sent to the utility grid, $.089/kWh.

Besides these good marketing factors, the project would have one more attractive feature for both buyers and the public utility; namely, enough energy storage that would give the project a resiliency in the event of utility power shutdowns, either planned or unplanned. The individual living units would be able to function without any power interruption for an extended period of time, depending on capacity of the battery system in each unit. In the three years since the condominiums were placed on the market, this has proved to be a prescient design feature to have incorporated.

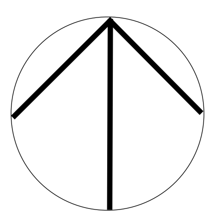
Once these guiding goals were established, a candidate project site in the locale was evaluated for the related factors of acquisition, program fit and financials. The site potentially available was a small empty residential lot (25 feet by 100 feet), which was privately owned but being used informally as a community garden. The owner of the property, hearing about the nature of the

[1] For a description of the Standards for Passive House certification, see: https://www.passivehouse-international.org/index.php?page_id=150.

[2] The project was certified by Passive House Institute US (PHIUS) in 2016. https://www.phius.org/phius-2015-new-passive-building-standard-summary. It also received certification by the DOE Zero Energy Ready Home program. These certifications allowed the project to comply with San Francisco's rigorous Green Building Code using the "alternate path of compliance", saving additional time and expense. A LEED certification was not pursued.



Sol Lux Alpha - General Vicinity Plan



(Right) Wall section detail with manufactured wall panels, showing framing size and insulation location.

project, decided to invest in it. The two people formed a limited liability partnership, *Sol Lux Alpha LLC*, to develop the project and realize the cutting-edge goals. (Name derivation: “Sol” means “solar-powered”, “Lux” means “luxury apartments” and “Alpha” means “the first of its kind”.)

Project Process

Building Program

The financial analysis set the program at four condominium apartments of 1,800 gross square feet each, the maximum size for a single-story unit on this site. With the ground floor level given over to parking and vertical circulation, and a deck at roof level, the building as realized is six stories high, a mid-rise development and at scale with this neighborhood. The floor plate of each level also contains the two required exit stairs and an elevator that provides direct access to each apartment with an electronic access card.

Each condominium unit consists of three bedrooms, two bathrooms, an alcove office and a general living area. The kitchen uses an induction cooktop and electric ovens.

Site Constraints

The small size of the lot in the urban environment was an obvious constraint on the planning, and the setback requirements in this part of the city would have made the project infeasible. Specifically, zoning required a rear yard setback of twenty feet and side yard setbacks of zero feet on each side. The developer requested a simple “exception” to this aspect of the zoning ordinance rather than a “variance”, which would have required a public hearing process to build to “zero lot line”. This was granted by the city zoning administrator because of the project’s innovative energy features and ZNE design. After these were discussed at a community public meeting, there were no objections to the project as proposed.

Low Energy Design Strategies

Obtaining the *Passive House* certification set the approaches to the features and systems for the building, as discussed below. Various options were evaluated for their impact on cost and schedule as well as energy efficiency, as is usual for speculative building projects.

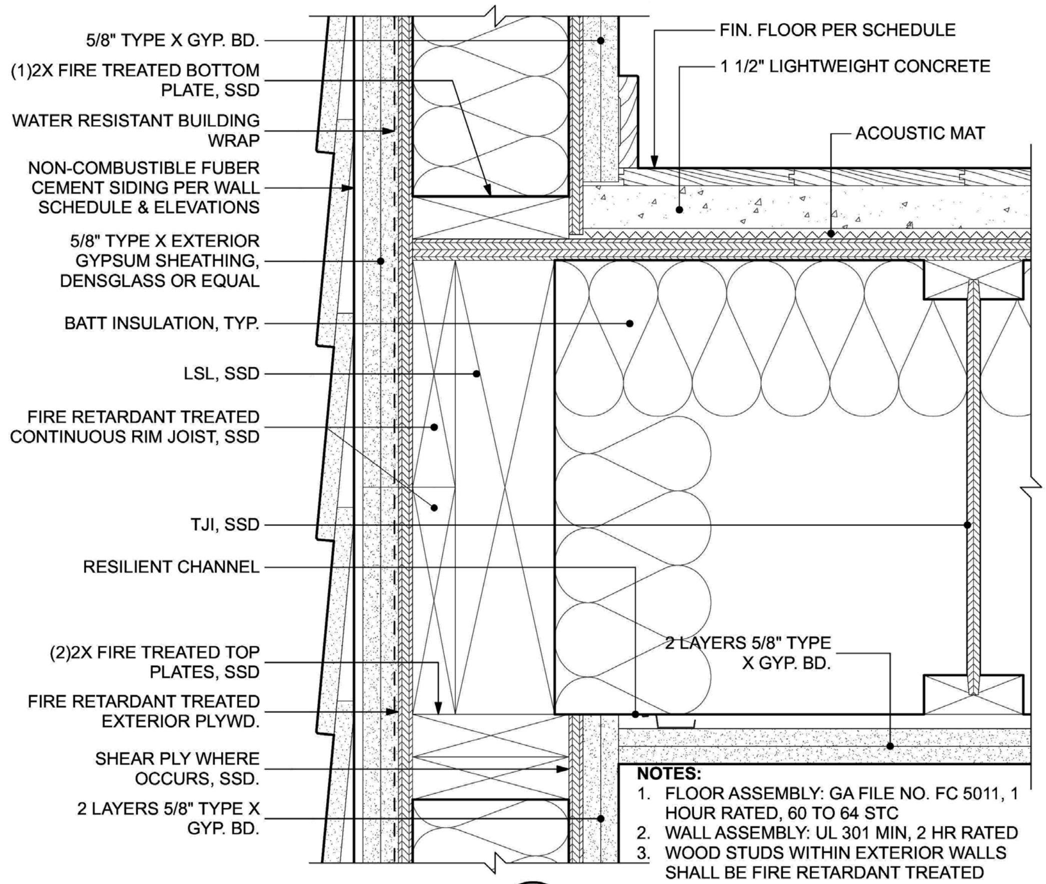
Building Envelope — Insulation and Windows

The developer, facing a cost/profit issue with regard to construction time on a site with limited access, opted to use a manufactured wall panel system. These panels could be pre-made with the thick insulation levels required for Passive House certification. Given the strict airtightness limits required of the building skin (0.6 ACH50), which could be pre-tested at the factory, the wall panels also offered an opportunity to save time during the testing phase.

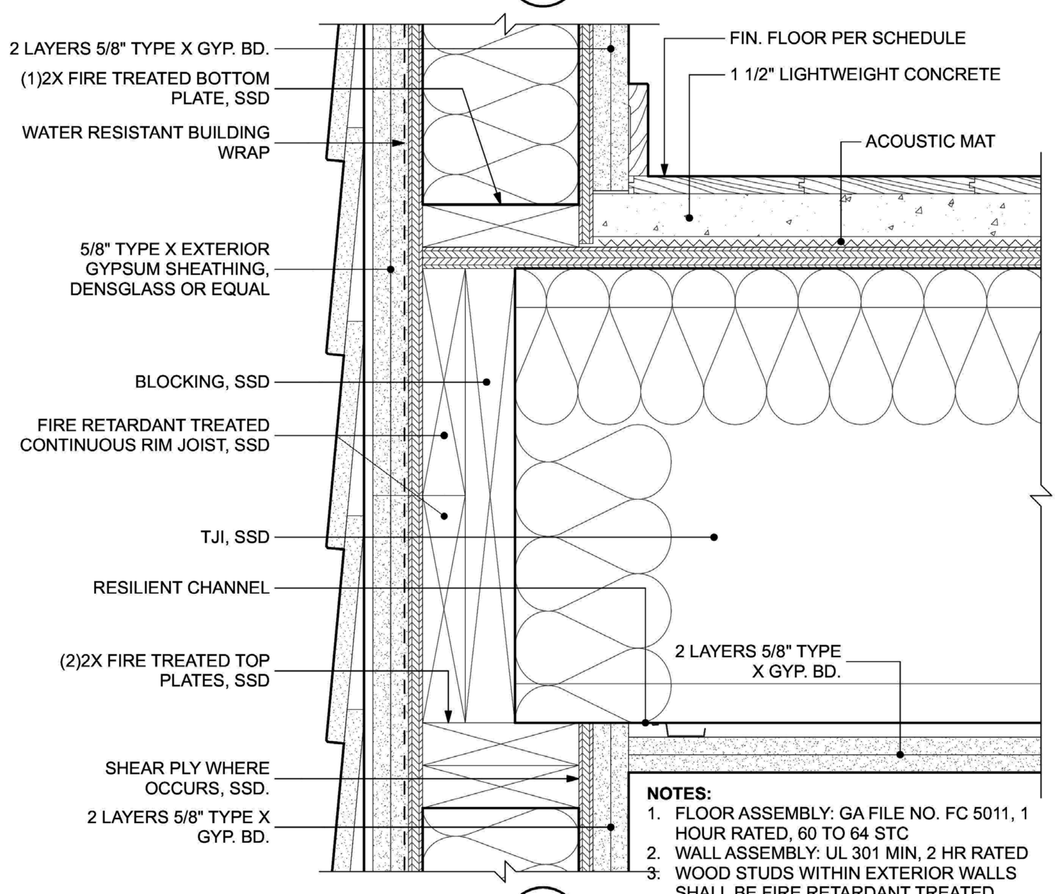
The final advantage of this manufactured wall panel approach was in building the many layers of the wall assembly required for the 2-hour fire rating. (See wall detail on the opposite page.) It was deemed to be faster and easier to assemble these layers in the controlled environment of the factory than on site where the access and weather conditions would be difficult.

These expectations were not fully realized during construction; see the *Building Envelope — Airtightness* and the *Observations* sections (below) for a discussion of the issues.

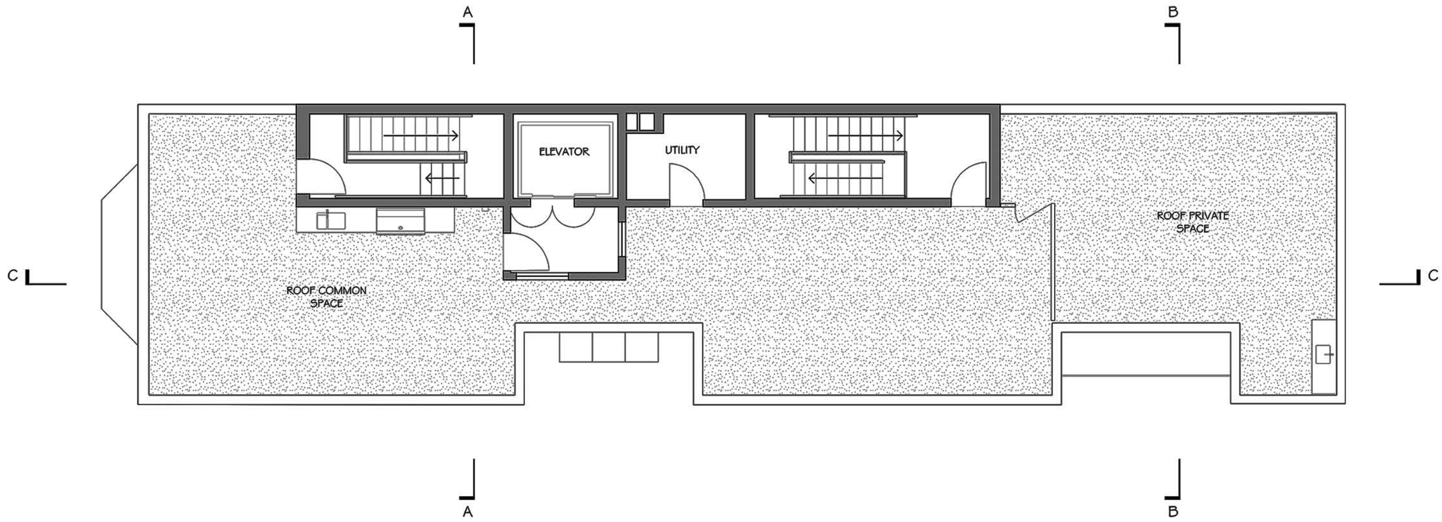
The manufactured wall is insulated with 5.5” blown fiberglass and four layers of fiberglass mat gypsum board for a total R-value of R=27. The unvented attic utilizes open-cell spray foam plus 11” dense-packed fiberglass to achieve a very high R=82. The wall does not employ a layer of exterior insulation board over the 2X6 studs as a method of reducing thermal bridging. An analy-



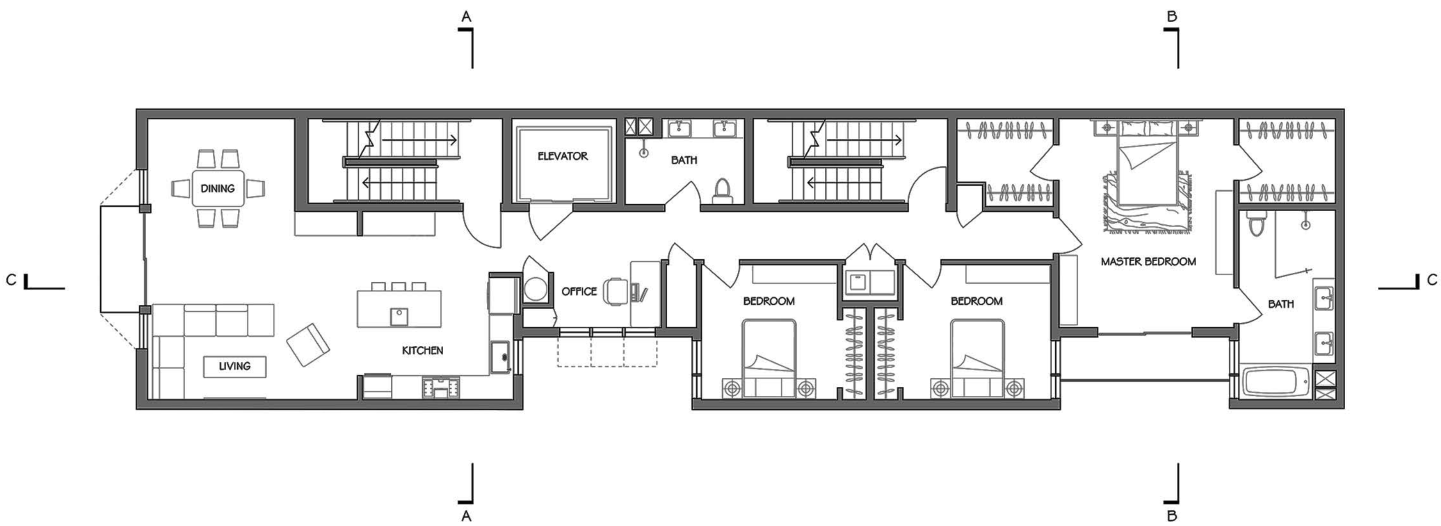
EXT. WALL/FLOOR INTERSECTION: JOISTS PARALLEL TO WALL
SCALE: 3" = 1'-0"
19



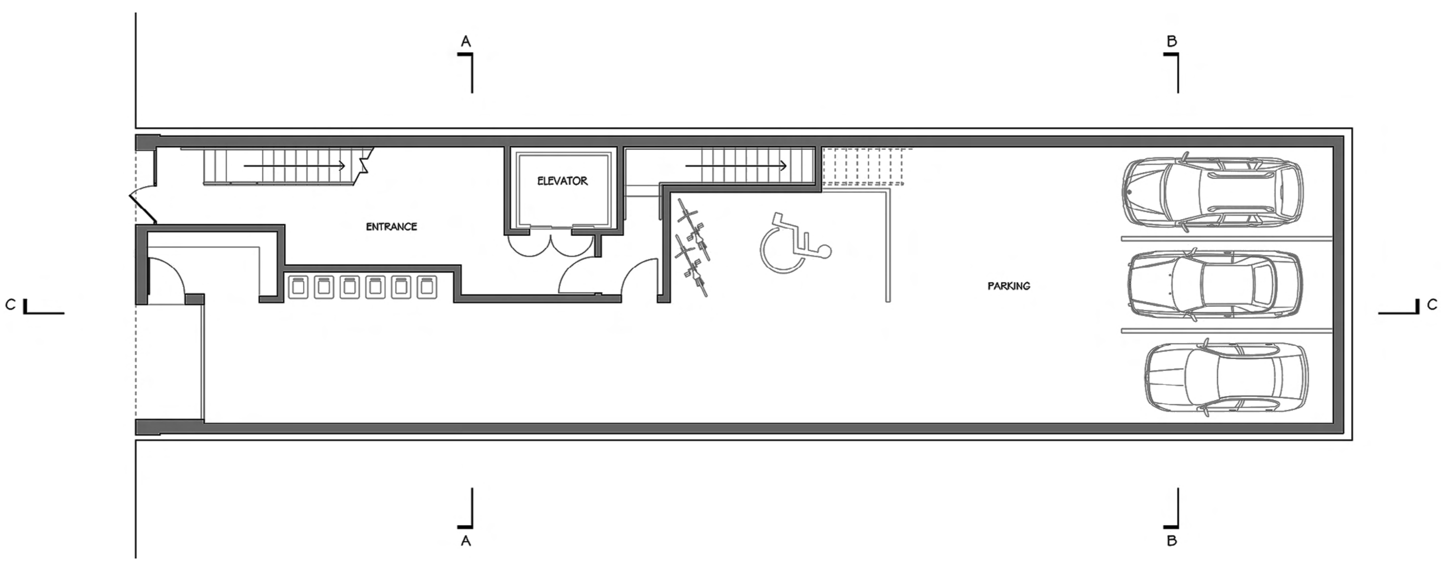
EXT. WALL/FLOOR INTERSECTION: JOISTS PERPENDICULAR TO WALL
SCALE: 3" = 1'-0"
18



FLOOR PLAN; ROOF DECK



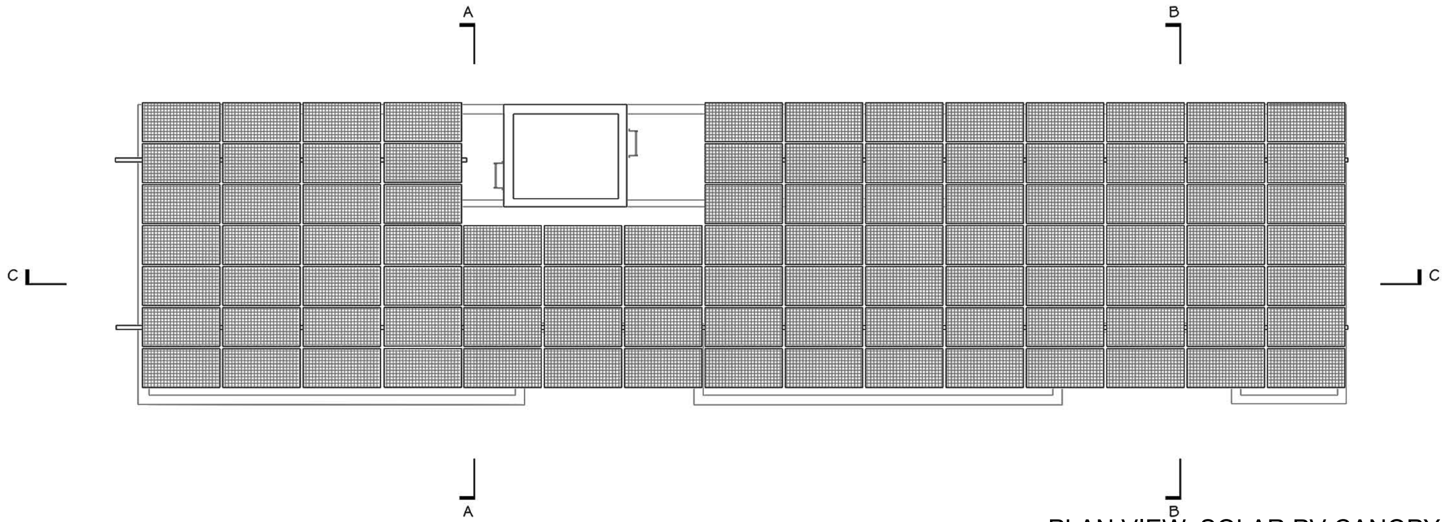
FLOOR PLAN; LEVELS 2-5



GROUND FLOOR PLAN

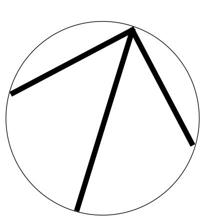
SOL LUX ALPHA: FLOOR PLANS AND BUILDING SECTIONS

0 2 4 8 16 FT

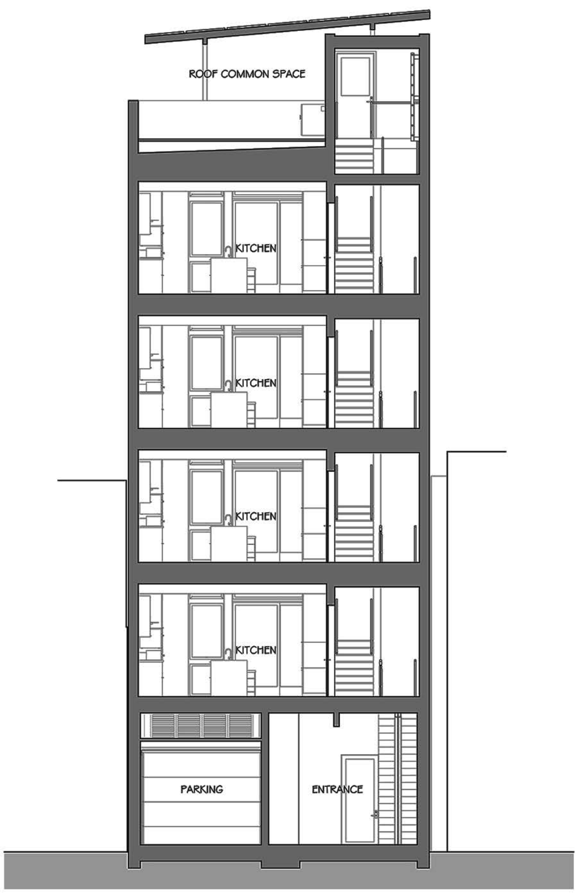


PLAN VIEW: SOLAR PV CANOPY

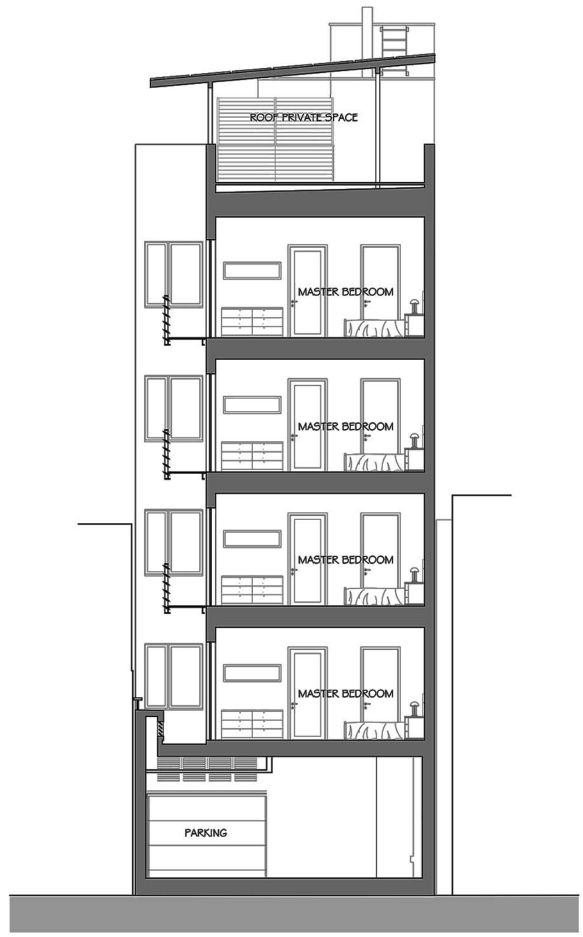
LONGITUDINAL SECTION C



NORTH



TRANSVERSE SECTION A



TRANSVERSE SECTION B

SOL LUX ALPHA: FLOOR PLANS AND BUILDING SECTIONS

0 2 4 8 16 FT

(Following pp. 106-107)
View of roof deck and solar PV canopy.

sis showed that the stacked units had a small exterior envelope area compared to a one- or two-level house and that it met the Passive House standard without the extra insulation. Windows and doors are double-glazed products[3] imported from Ireland and certified by the Passive House Institute (PHI).

Building Envelope — Airtightness

The manufactured wall panels, thought sufficiently airtight with their internal construction, proved to be difficult to air seal when assembled together on site and joined to the site-built structural frame. Silicone gaskets were placed under the bottom plates and vertically between the panels. However, building and assembling prefabricated panels with the small tolerances that were specified proved to be challenging. Likewise, the concrete floor slabs were not sufficiently flat to prevent small gaps between the slabs and the bottom of the wall panels. With the weight of these panels approaching 1½ tons, the placement task was difficult to execute.

Viscous liquid sealant eventually resolved these issues and the difficulty eased for the wall panels that were put into place at the upper floors as panel tolerances improved at the factory due to a quality control effort. The uniform flatness of the concrete slab was less of an issue at the higher floors also.

Smoke tests were done to pre-test the air sealing at each level and specifically to locate any of the possible gaps described above. Finally, the *Blower Door Test* at each individual floor demonstrated that the strict airtightness standard for Passive House certification had been achieved, namely less than 0.6 ACH50. The average value of each floor was 0.57 ACH50.

Heating, Ventilating and Cooling Systems

A ducted mini-split two-zone system provides primarily heating in each unit in this cool climate, though it has the capability of operating in a cooling mode for the rare periods of relatively high temperature. The tight air seal that was eventually achieved makes it necessary to have a controlled fresh air supply, so an ERV unit is designed into the system of each unit. Therefore, there are two systems of ducting air to each room, one for conditioned air and one for fresh air.

The kitchen exhaust fan directs air via a kitchen vent to the ERV and then to the outside. This maintains indoor air quality while still recovering heating or cooling energy from within the unit.

Lighting and Plug Loads; Control Systems

All LED lighting is used throughout the entire building. No motion detectors were installed for light shut-off. However, occupancy sensors are located in the bedrooms to reduce plug loads and eliminate “vampire” loads. One continuously electrical outlet not on the occupancy sensor is provided for phone charging.

Domestic Hot Water

The domestic hot water is supplied by a heat pump water heater[4], which is separated into an outdoor equiipment component, the heat pump, and an indoor equipment component, the storage tank. This arrangement was selected so that the indoor enclosure would not be undesirably cooled.

---

[3] Klearwall, https://klearwall.com/

[4] The Sanden CO_2 water heater, which uses CO_2 as a refrigerant and has much less impact on the atmosphere than commonly-used refrigerants if the gas happens to leak from the equipment. https://www.sandenwaterheater.com/.

PHOTO: JOSEPH SCHELL

(Right) View of bifacial solar PV canopy above the sixth floor roof deck.
(Photo: Matt Abrams, SkyHi Aerial Photography, www.skyhiaerial.com)

Construction

The most unusual phase of the construction process was the arrival and placement of the manufactured wall panels on the six levels of the structural frame. Since there was no site access from any of the sides, the heavy panels could only be lifted by crane from the street side of the narrow site. The builder had to obtain a city permit to block the street for specified periods of time when the crane was in use.

Renewable On-Site Energy Supply

On-Site Solar Photovoltaic System

The solar PV system was limited to the roof level because of the potential for new building development at all sides of the lot, thus blocking access to the sun for any vertical solar facades. To allow for a usable roof deck area, the solar panels were made into an overhead canopy which covers the entire roof deck and common service areas.

Usually, solar PV arrays at the roof level are required to have a 3’-0” setback for roof access, but this requirement was waived because the array was placed on the raised canopy. This allowed for a larger system and the corresponding higher solar energy production. Even with this maximum area of solar PV array, equal to the lot footprint area of 2,500 square feet, there would have to be enough energy generated to meet the project goals for ZNE performance of building and electric vehicles over the course of a year for all four condominium units and the common space. With high energy-efficiency designed into the building using the Passive House standards, it remained to choose the solar PV panels with a high power production to meet the calculated loads.

A “bifacial” solar PV panel[5] was selected to maximize output per unit area of the PV array. (A bifacial panel harvests solar energy from the backside of the panel, making it highly productive when used as a canopy—about a 20% boost in power output.)

The total PV array then consists of 96 panels forming the roof canopy, divided into 21 panels for each of the four condominium units and 12 panels for the common spaces and elevator. The output of each bifacial panel is approximately 450-500 watts, so the total output of the system assigned to each condominium unit is about 10 kW and the remaining 6 kW is assigned to the common area. The maximum power production of the total system is approximately 46 kW.

On-Site Energy Storage: Battery Component

For each condominium unit, there are three Tesla Powerwall batteries that total 41.5 kWh of available energy storage when fully charged. For the condominium unit alone, this is enough energy for two to three days without recharging the batteries—ample resiliency for any utility power outage. The sun continues to shine, automatically providing periods of re-charge, so the condominium unit could potentially operate normally off-the-grid indefinitely.

The EV charging presents a different set of conditions. Its battery has a relatively high storage capacity (75kWh for a Tesla) and the car alone can drain the house battery array completely in a short time by fully recharging. So, if the car charging occurs at night, then the house battery could be drained by morning, which may not be the best schedule for battery use in terms of utility rates and time-of-day use.

(Opposite page, top) View of wall-mounted inverters at roof deck;
(Opposite page, bottom) Wall-mounted battery units located in the ground-level garage.

[5] Sunpreme Maxima GxB 380, http://sunpreme.com/products-main/


PHOTO: JOSEPH SCHELL

PHOTO: JOSEPH SCHELL

The developer provided a practical solution for the owner: set the default operation of the system so that the EV is charged at night directly from the utility grid, not the house batteries. This is best for the utility's demand profile and the cost to the owner, since utility rates are typically lowest at night. Another advantage of this operational design is that a 240V charging station can be used with the utility power connection, whereas charging from the Tesla Powerwall is limited to 120V power, which provides a much slower rate of charge.

Therefore, as designed and installed, under normal operating conditions the house batteries are only used in conjunction with the house energy demands and can be scheduled accordingly. However, if the power from the grid is interrupted for an extended period of time, the EV can be charged from the house batteries, though only at "level 1" rate of charge to prevent excessive battery drain.

Battery storage for common areas and the elevator is an entirely different system. The elevator requires battery equipment that produces 208V and 3-phase power. The system selected was a lithium ferrous phosphate ($LiFePO_4$) *Blue Ion*[6] battery to provide the necessary voltage capability, combined with three Schneider inverters[7] to produce the 3-phase power.

Energy Performance
Energy Modeling and Post-Occupancy Measurement

Energy Use—Modeling

In order to receive the *Passive House Institute US (PHIUS)* certification, the developer was required to submit the completed *Passive House Planning Package (PHPP)* to document that all required standards for certification were met. The resulting energy use "model" represents an ideal performance for the conditioned space of the building (the four identical condominium units). The chart on the opposite page shows the monthly energy use per square foot as calculated by the PHPP.

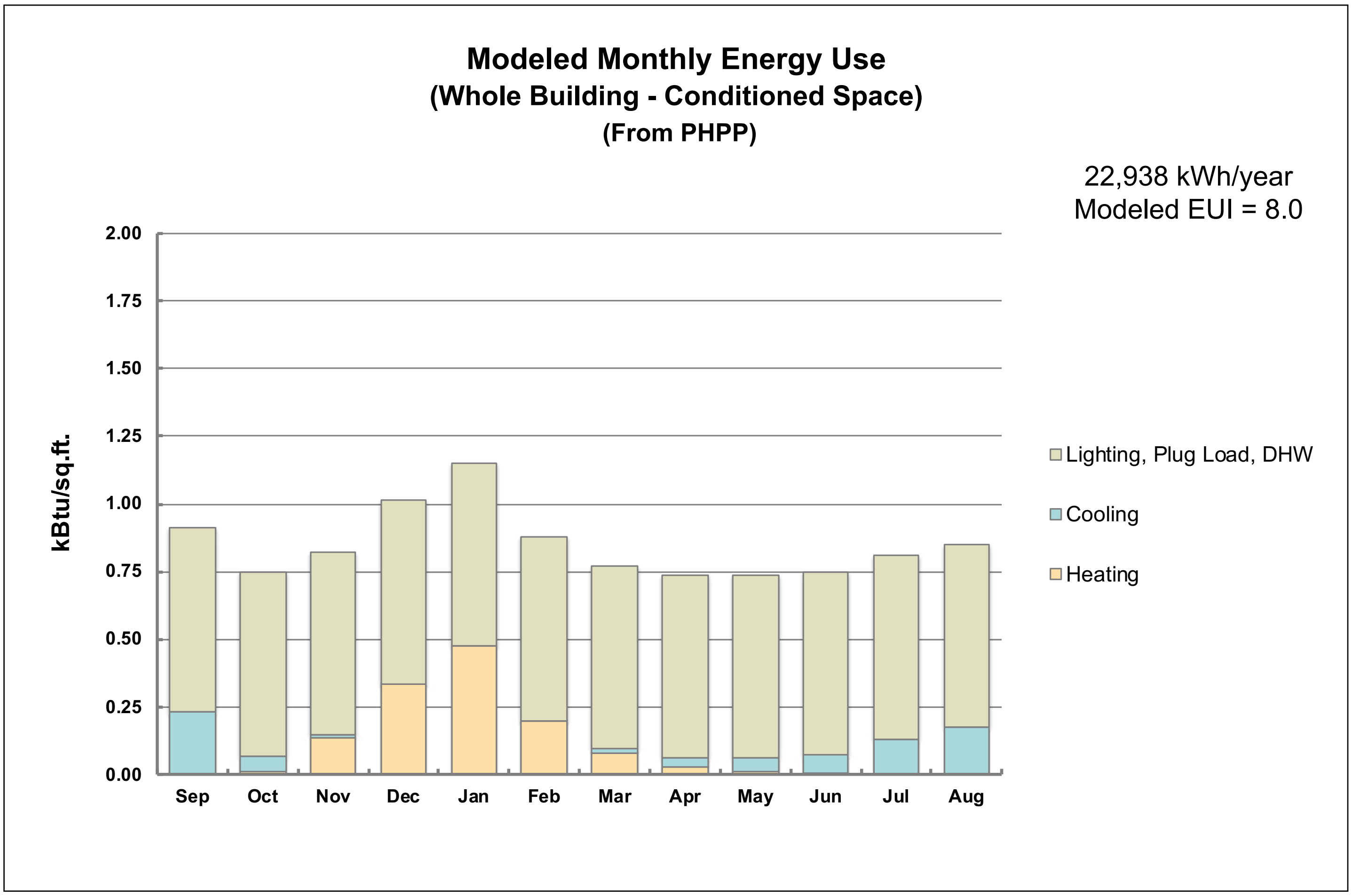
Energy Use—Post Occupancy Measurement

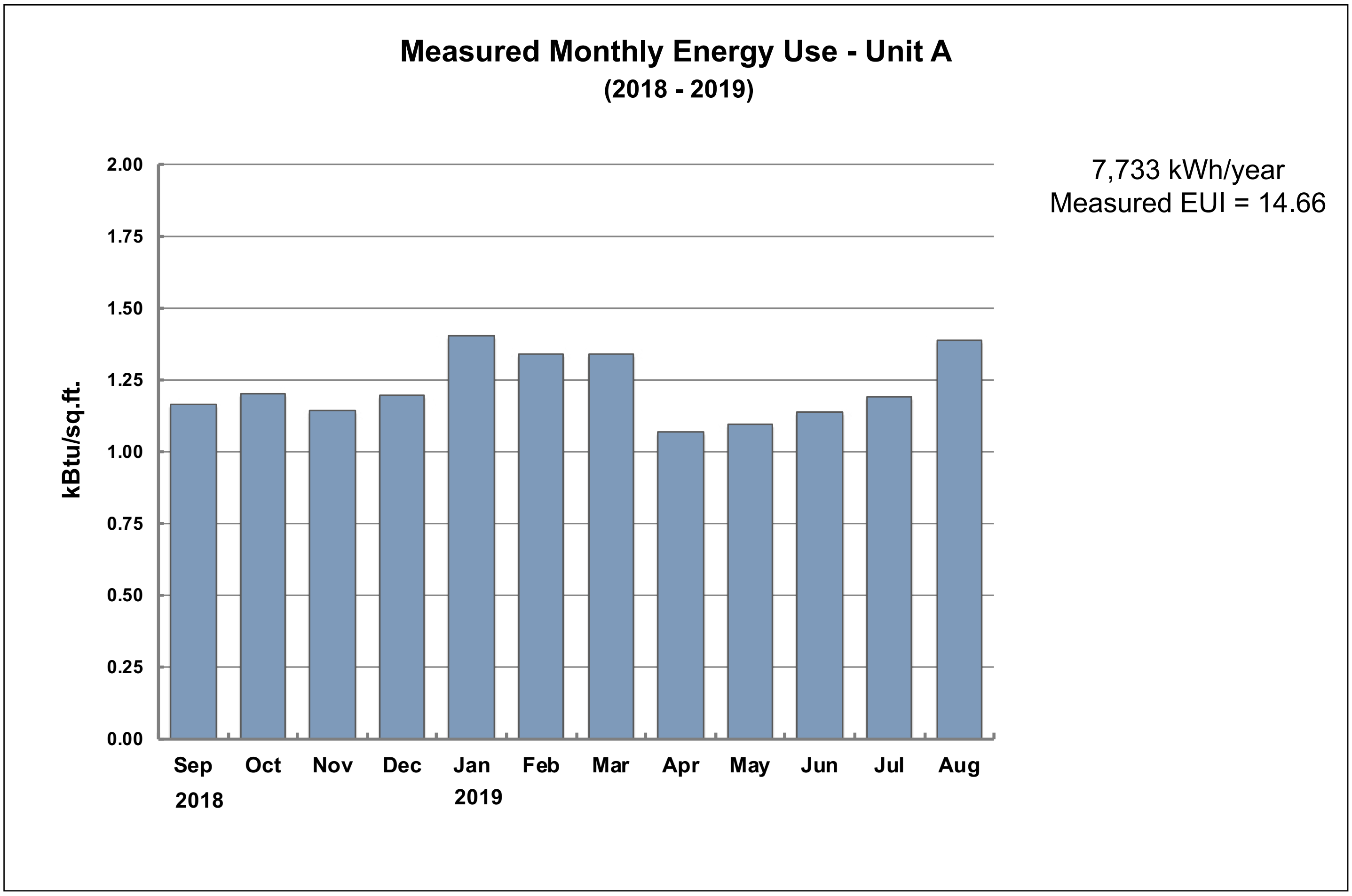
Data on the energy use and production for each unit and its assigned solar PV system is routinely recorded on the Tesla Powerwall and can be accessed using the system's software (its app). This was done for the three units that were purchased in 2016 and 2018, for which there is more than 12 months of recorded data. (The third unit, Condominium Unit C, is recently purchased and does not yet have one full year of recorded data.)

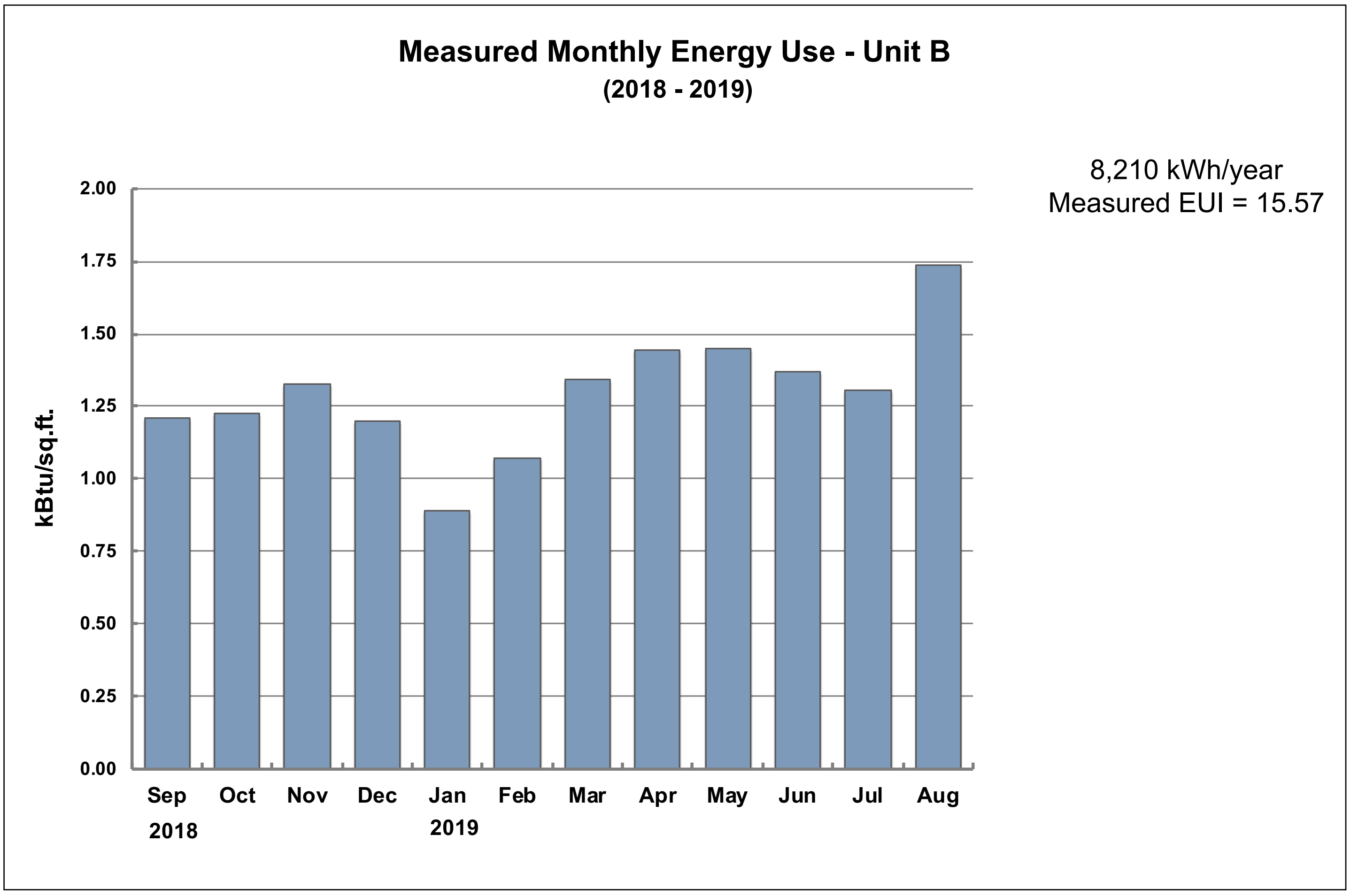
The charts on pp. 111-112 show the actual measured monthly energy use for Units A, B and D, the identical units located on the second, third and fifth floors. During this period of time, only the occupants of Unit A owned an EV. As described above, the EV charging occurs directly from the utility grid; it is not included in the data monitoring of the Tesla Powerwall, so the chart of measured monthly energy use for Unit A does *not* include the monthly energy use data for the EV. It is useful to compare these to the "modeled" energy use for the "ideal" unit, which shows the variation caused by the different behavior patterns of the occupants.

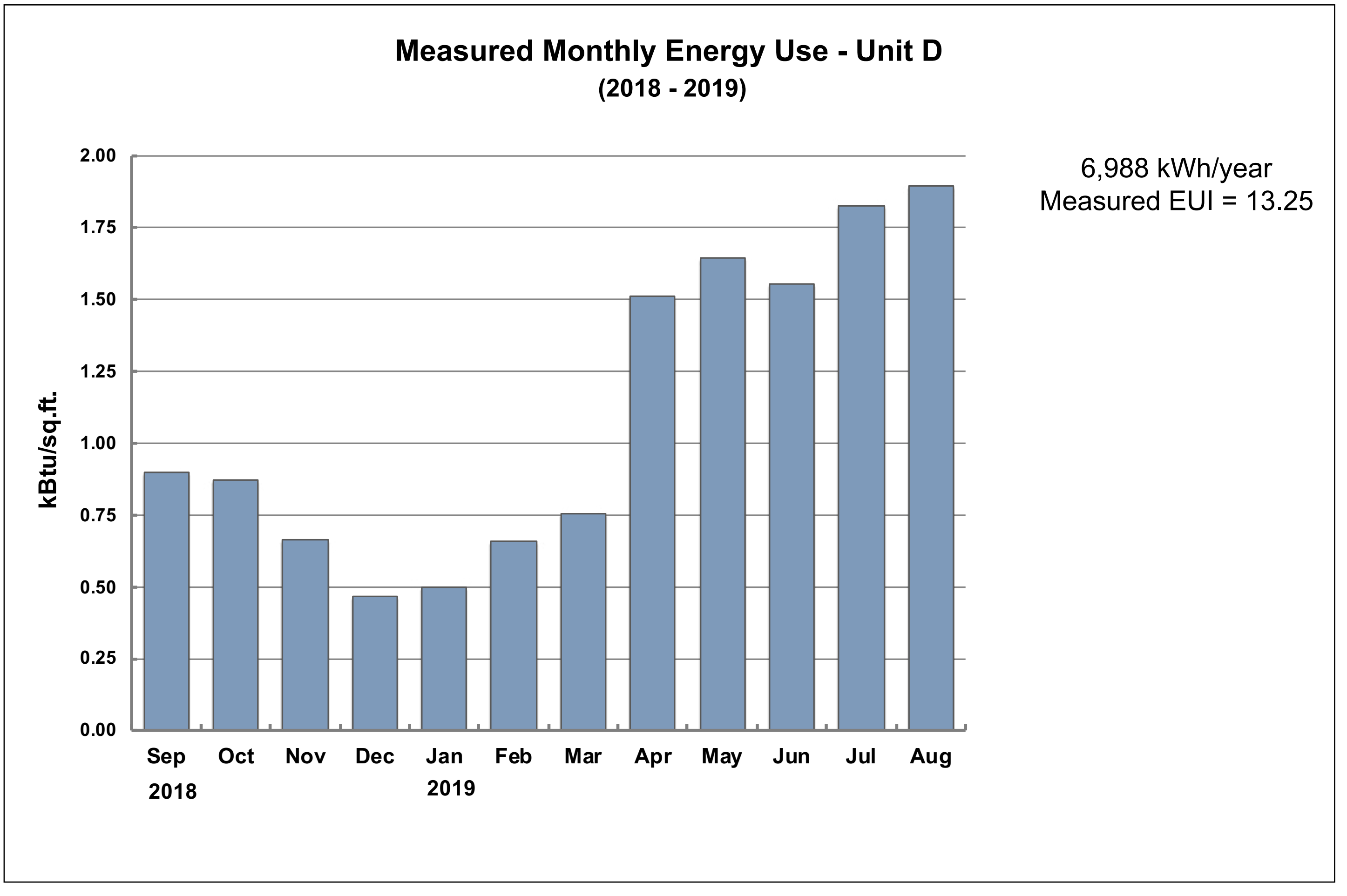
[6] See Blue Planet Energy, https://blueplanetenergy.com/products/blue-ion2.

[7] See https://solar.schneider-electric.com/product/conext-cl/


Modeled Monthly Energy Use
(Whole Building - Conditioned Space)
(From PHPP)
22,938 kWh/year
Modeled EUI = 8.0
kBtu/sq.ft.
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Lighting, Plug Load, DHW
Cooling
Heating


Measured Monthly Energy Use - Unit A
(2018 - 2019)
7,733 kWh/year
Measured EUI = 14.66
kBtu/sq.ft.
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2018
2019


Measured Monthly Energy Use - Unit B
(2018 - 2019)
8,210 kWh/year
Measured EUI = 15.57
kBtu/sq.ft.
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2018
2019


Measured Monthly Energy Use - Unit D
(2018 - 2019)
6,988 kWh/year
Measured EUI = 13.25
kBtu/sq.ft.
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2018
2019

PHOTOS: JOSEPH SCHELL

Energy Production versus Energy Use: Zero Net Energy Performance

The charts on pp. 115-117 show the solar PV system performance over the course of a year for each condominium unit compared to the monthly measured energy use for that same period. The excess solar energy production in each case indicates how much energy would be available theoretically for EV charging or is simply exported to the utility grid for additional revenue.

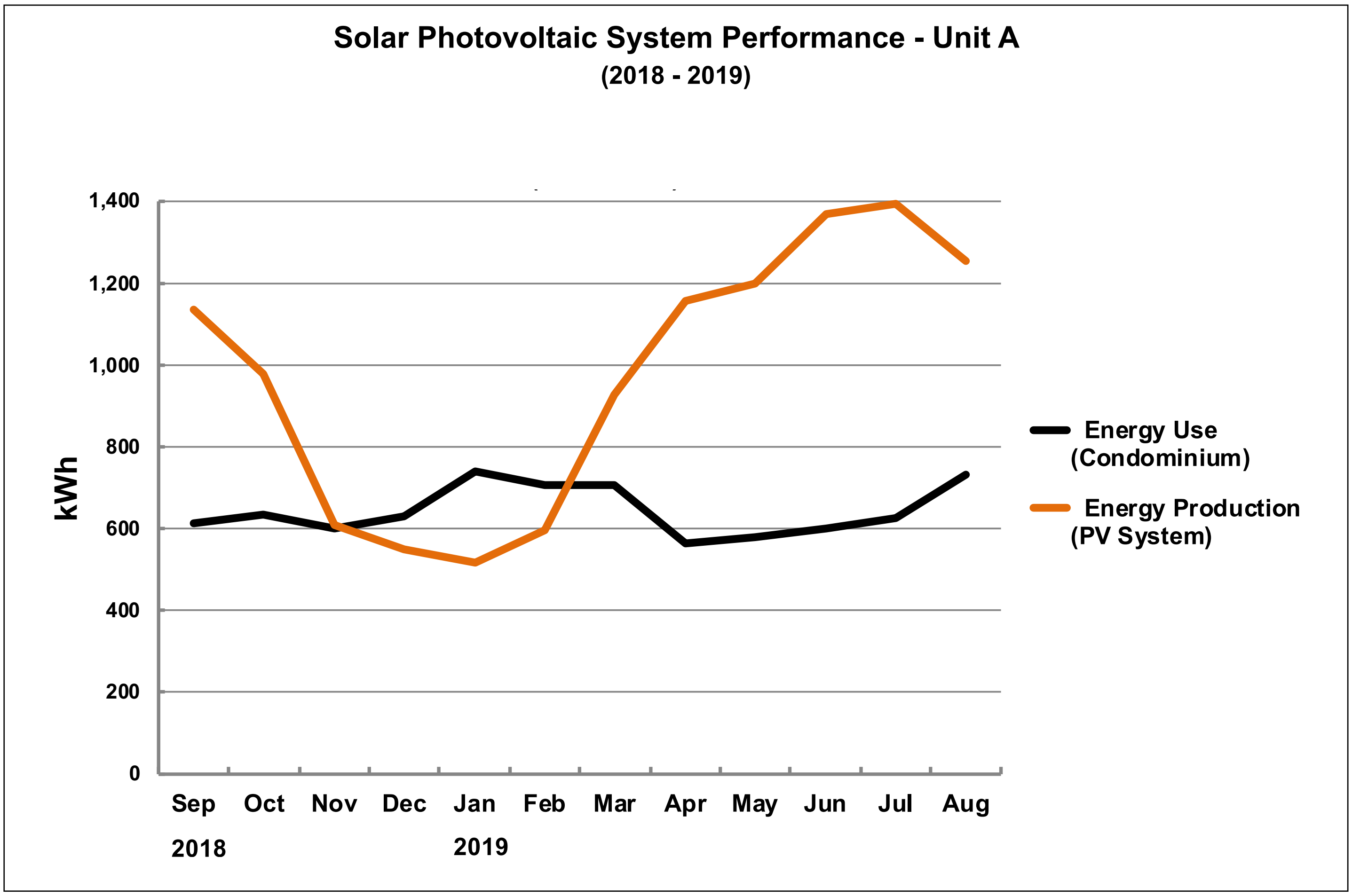
The *cumulative net energy production* is a chart that essentially shows the progression of the energy performance toward ZNE by adding each month's net energy performance to the previous month's total—if, at the end of the 12-month period, the curve remains on the positive side of the zero axis, then the building is indeed performing better than ZNE, i.e., *Net Positive*.

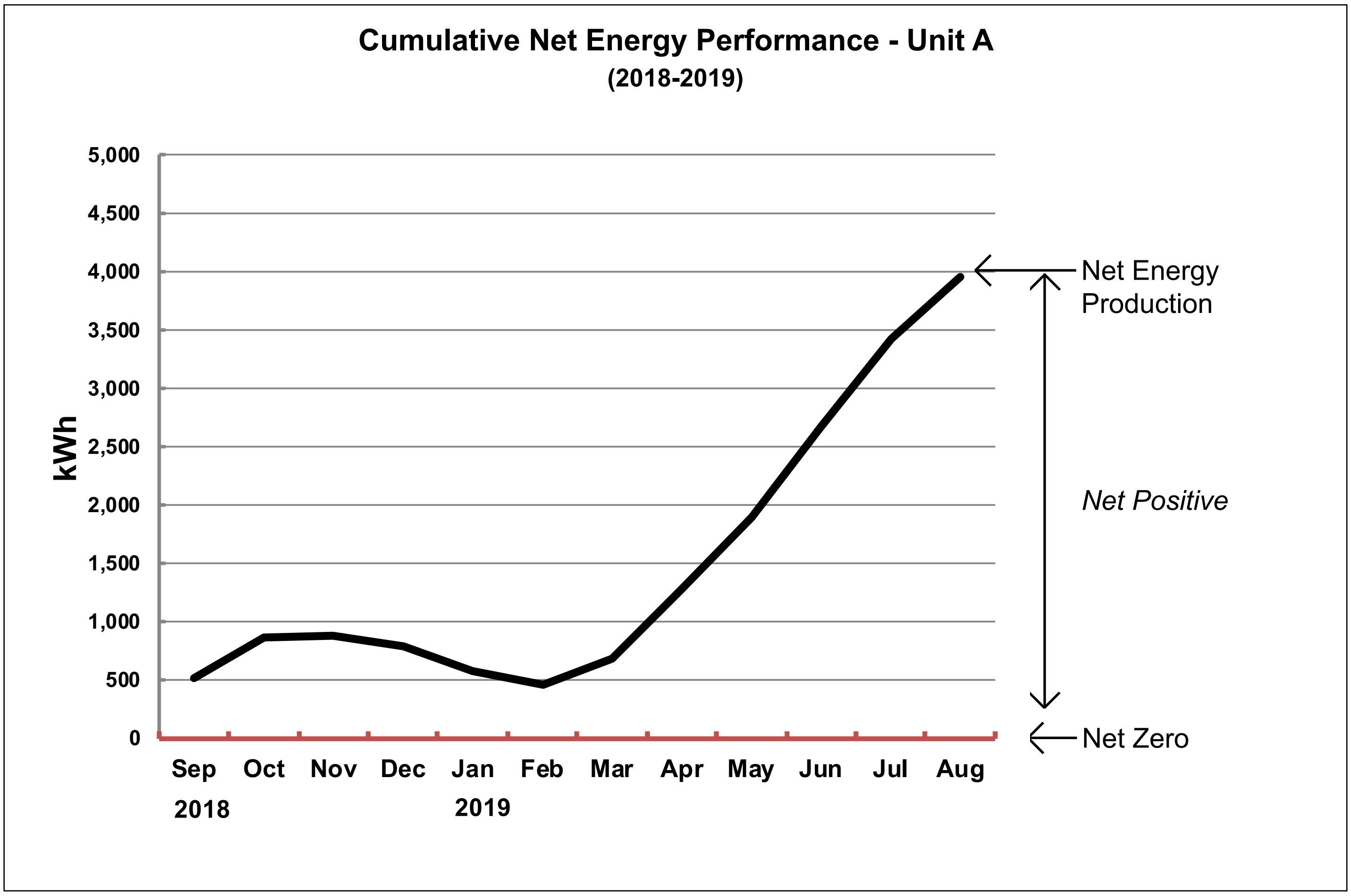
Because each condominium unit's system is currently wired so that the EV-charging energy always comes from the grid and cannot come from the PV system or battery, there is an excess of production by each solar PV system, which was originally designed to include some EV charging. Were this circuiting to be changed in the future, the EV-owners would know roughly how much of the battery could be used at night and still remain at ZNE for house and EV. Alternatively, if personal schedules permit, the EV could be charged at home during the day directly from the solar PV panels after the batteries had been charged.

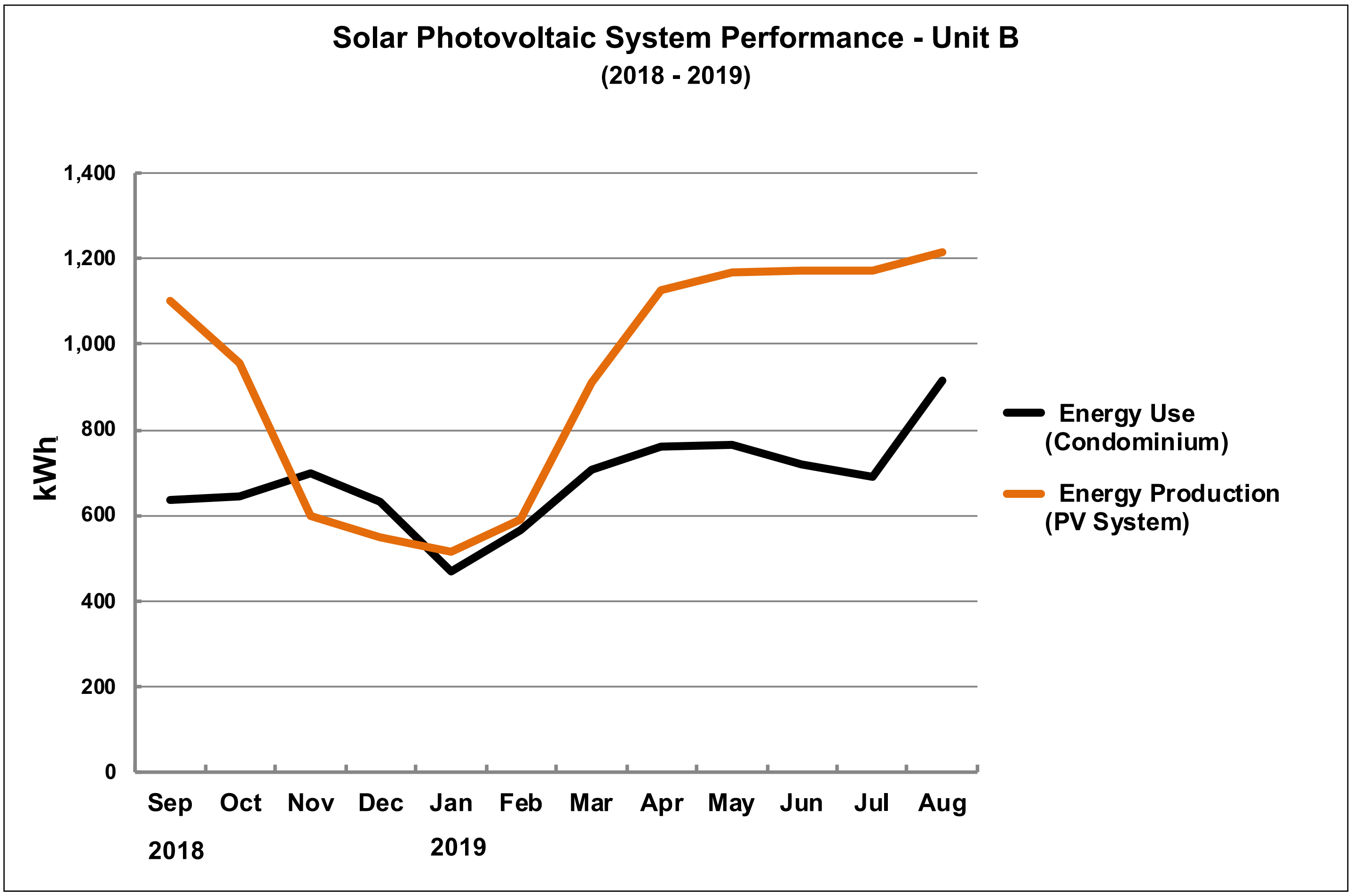
Post-Occupancy: Observations and Conclusions

The manufactured wall panels had perceived advantages in theory but proved to have too many practical difficulties to warrant using the same approach on future similar projects with greatly restricted crane access. The process of assembly on site from only one of the short sides of a long narrow site, street closures, large crane rental required for necessary "reach", and positioning the heavy panels at the attachment points, were together sufficient to bring the developer to this conclusion in retrospect. The added requirement of meeting the strict airtightness standard for Passive House certification was particularly difficult to achieve because of these site logisitics. The airtightness standard was finally achieved, but not until much time and effort had been expended—a discouraging result for any developer.

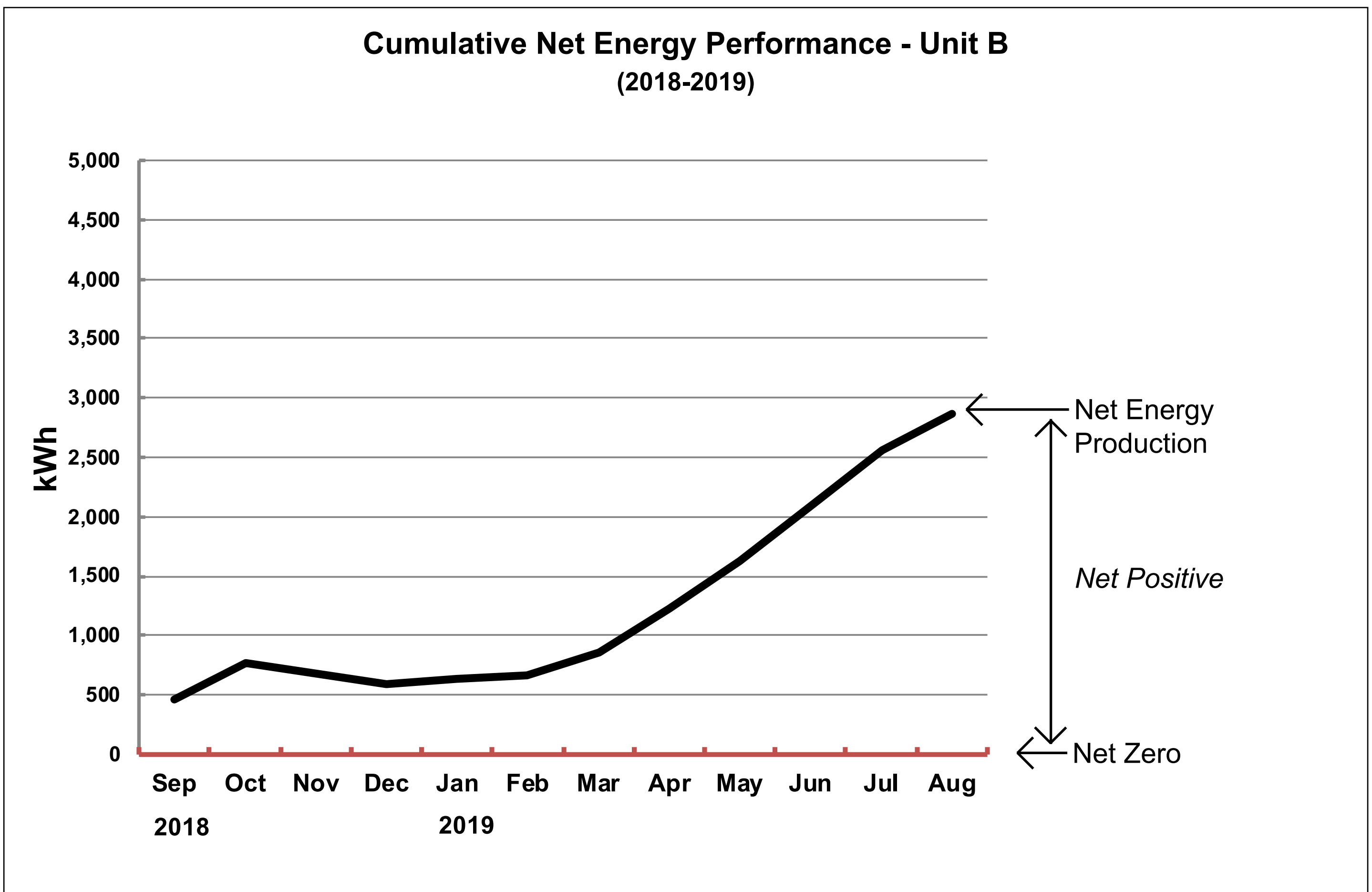
The developer is nevertheless not dissuaded from using manufactured housing components on a more accessible site, where prefabrication can save cost, construction time and result in a highly energy-efficient product meeting Passive House standards.


Solar Photovoltaic System Performance - Unit A
(2018 - 2019)
kWh
1,400
1,200
1,000
800
600
400
200
0
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2018
2019
Energy Use (Condominium)
Energy Production (PV System)

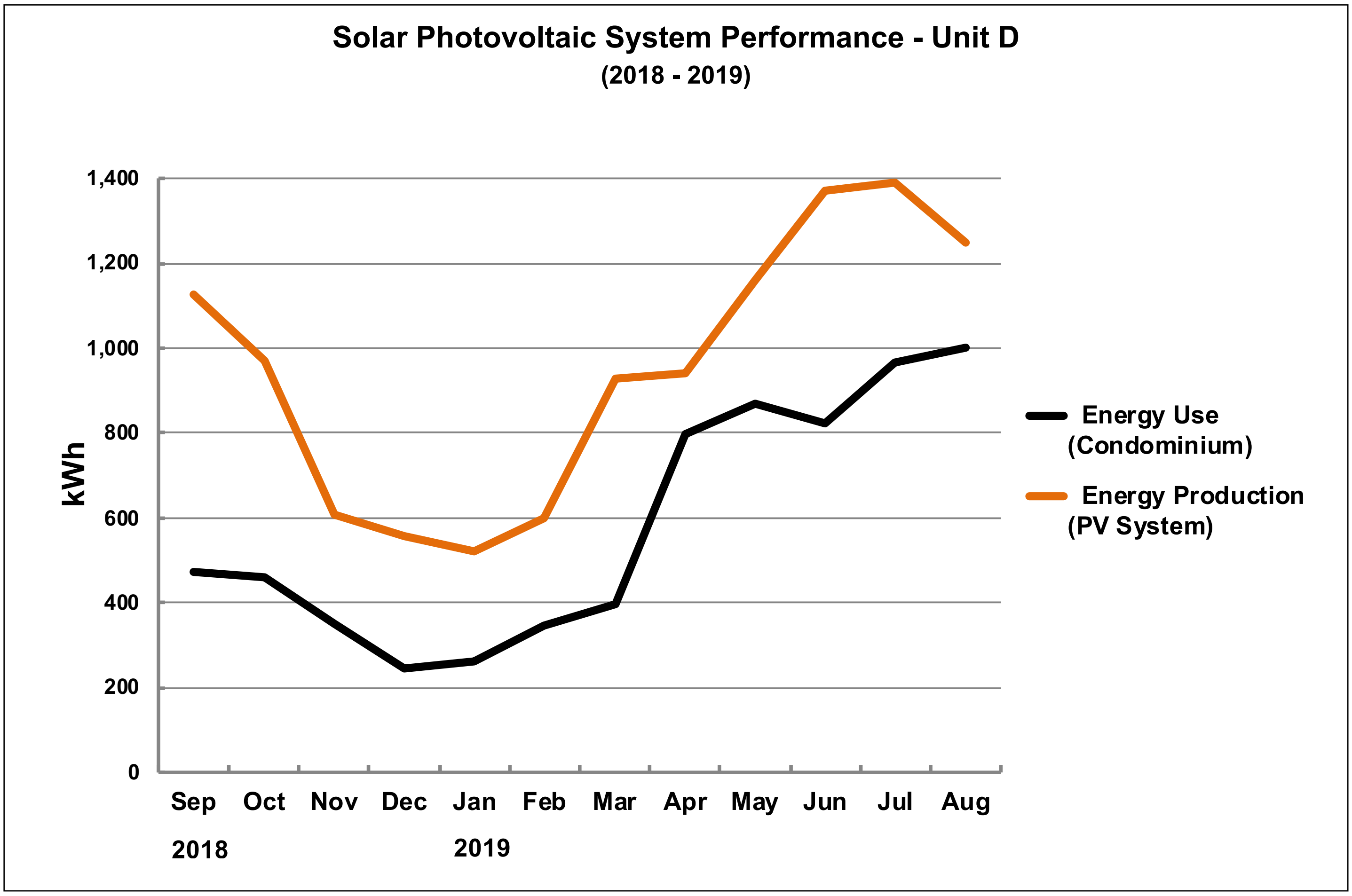

Cumulative Net Energy Performance - Unit A
(2018-2019)
kWh
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2018
2019
Net Energy Production
Net Positive
Net Zero

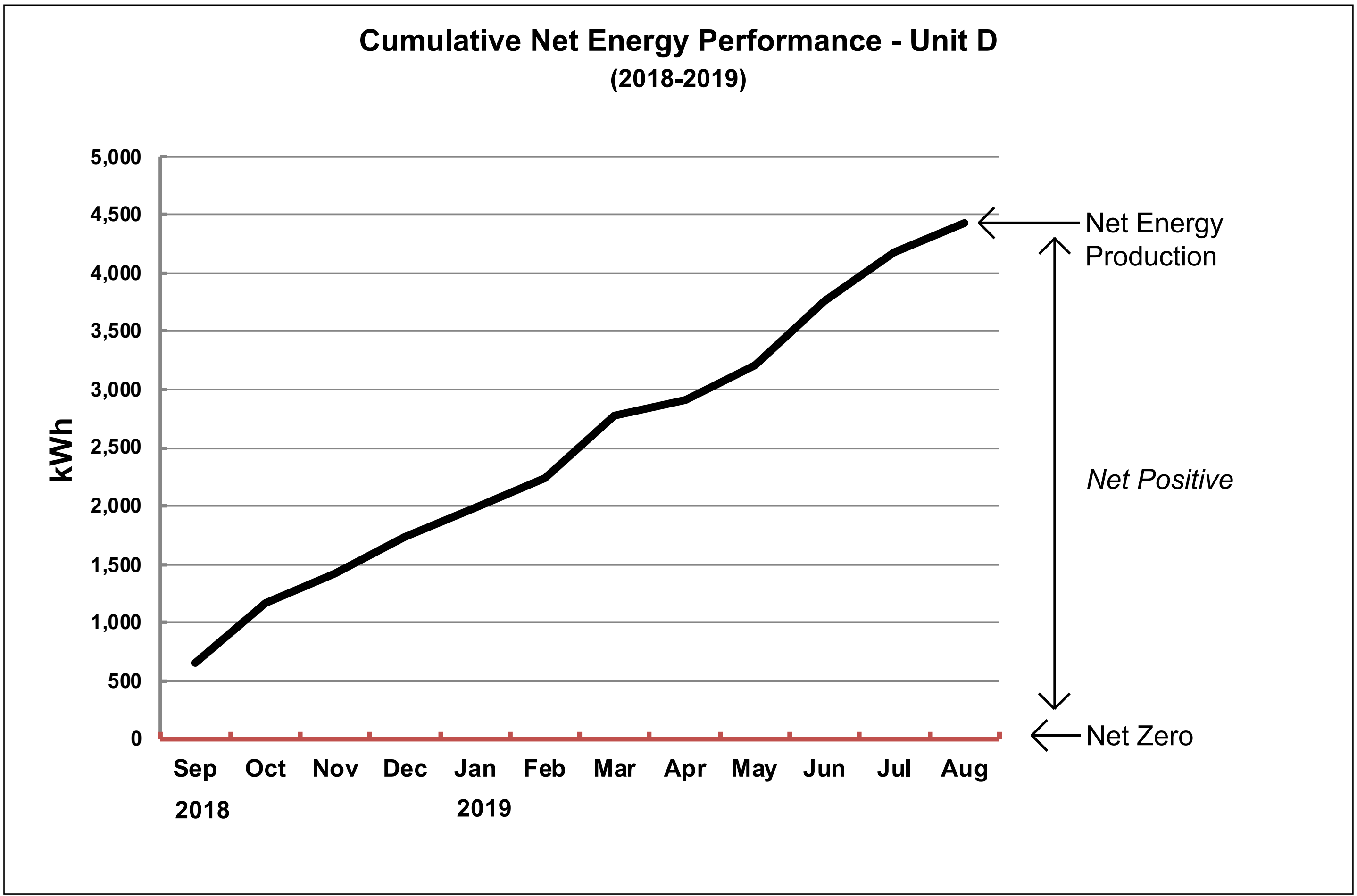


Solar Photovoltaic System Performance - Unit B
(2018 - 2019)
1,400
1,200
1,000
800
600
400
200
0
kWh
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2018
2019
Energy Use
(Condominium)
Energy Production
(PV System)



Cumulative Net Energy Performance - Unit B
(2018-2019)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
kWh
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2018
2019
Net Energy
Production
Net Positive
Net Zero


Solar Photovoltaic System Performance - Unit D
(2018 - 2019)
kWh
1,400
1,200
1,000
800
600
400
200
0
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2018
2019
Energy Use (Condominium)
Energy Production (PV System)


Cumulative Net Energy Performance - Unit D
(2018-2019)
kWh
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
2018
2019
Net Energy Production
Net Positive
Net Zero

(Above) View of entrance and lobby interior.

Conclusion ▷

Observations

It has been only one year since the publication of Volume 1 of *Zero Net Energy Case Study Homes*, yet the context of the design and construction of these types of buildings has shifted significantly. Interestingly, the case study projects in this Volume 2 incorporate the new features that are now being recognized as currently important even though they were completed well before this awareness was widespread.

One issue, discussed in the Introduction, is the need for load shifting in the California power grid to prevent the exacerbation of the *Duck Curve* and the effect on carbon emissions. (This issue was discussed also at the end of Volume 1 as an emerging "new design issue".) But perhaps the most significant new issue, at least to the California consumer, is the phenomenon of grid power outages, both planned (to inhibit the chance of wildfires) and unplanned. Both issues have given rise again to the discussion of *battery storage* connected to the solar PV systems. Where this was always a system feature for off-the-grid housing, it is now a design strategy to be considered for all grid-connected ZNE homes.

Remarkably, of the six case study projects presented in this Volume 2, three utilize this design strategy and a fourth is slated to add a battery storage system in the near future. The remaining two case studies, as *affordable* housing projects, understandably could not adopt such a design feature from the primary cost perspective. These six case studies therefore prove to be quite timely in providing attention to the practical issues and experiences with these particular systems and how they have an impact on the project design decisions.

In addition to the new battery storage feature, the six case studies continue to show the common ZNE design strategies employed to create a very low energy use, as measured by the EUI, so that the on-site solar PV systems can provide the annual balance of this amount of energy. Yet there are within these strategies differences in approach that are informative for future ZNE residential projects, as can be seen in the detailed descriptions of the individual case studies.

Observations from the Case Studies in Volume 2

As in the case studies of Volume 1, the principal advanced design strategies used for the projects of Volume 2, beyond the basic ZNE design measures of insulation values higher than code for the entire building envelope and energy-efficient lighting and equipment, were the following:

- Airtight construction to a standard of very low air leakage, which was tested and measured in five of the six case study projects by a *Blower Door* test.

  Since two of these projects are certified *Passive Houses*, the airtightness achieved was required to be even lower than usual. The concept of airtight construction, and verifying the level achieved via testing and measurement, is now standard practice for almost all ZNE homes. (In the case of projects like the Silver Star Apartments, airtightness is an important design strategy, but inspection by the HERS rater is required in lieu of the testing and measurement.)

- Use of heat pump heating and cooling systems for maintaining comfortable indoor space conditions, either ducted or ductless systems.

- Heat pump water heater.

  All the case study projects utilize this type of water heating equipment, which is now the cost effective non-carbon choice for ZNE homes.

- Use of a heat recovery ventilator (HRV) or energy recovery ventilator (ERV).

All three single-family homes and the multifamily project in Case Study No. 11 utilize this equipment to guarantee controlled fresh-air ventilation in these homes built with air-sealing techniques.

- Induction cooktops and electric ovens.

  These same four projects have kitchens with induction cooktops. The remaining two case study projects, the two multifamily affordable housing projects, selected electric cooktops to maintain the non-carbon nature of the selected equipment and appliances.

This list of advanced design features common to these case study projects indicates that these are now accepted practice in the design of ZNE homes. When the electric utility grid achieves a zero-carbon power mix in 2045, these all-electric ZNE case study homes will become zero-carbon homes as well.

Continuing Observation: Modeling and Measurement

Ordinarily, energy monitoring equipment is not usually installed for cost reasons and the owner has to rely on the monthly performance as reported by the utility net meter data. This data represents the difference between the energy used and the energy generated on-site by the solar PV system for the reporting period. More useful information identifying patterns of energy use or possible equipment failure or inefficient operation is desirable, but usually not obtainable unless some kind of monitoring equipment is installed.

As discussed in the multifamily affordable housing case studies of this Volume 2, this aspect is particularly helpful with regard to controlling operating costs during the life of the building and keeping the solar PV systems at maximum efficiency through good maintenance.

Recent battery technology improvements with regard to built-in data recording and accessibility via portable computer devices have led to a convenient method of reporting energy use, energy production and storage. This is yet another advantage of including a basic battery component as part of the solar PV system.

Looking Ahead

With the official adoption of the 2020 California Building Code, the general stock of new residential housing will move closer to ZNE design and performance, as the pre-permit calculation of annual electric energy used will be required to be offset by the energy generated by a solar PV system. This is still not ZNE in general, nor zero-carbon, but it is another step in that direction.

Rebates for solar PV systems are phasing out but California rebates for battery storage components are continuing until 2025. As noted in these Volume 2 case studies, energy storage in the form of batteries is becoming more prevalent in the design of ZNE homes, partly because of the incentive but also as a hedge against the anticipated power outages during “wildfire season” in California.

Design strategies for ZNE homes are likely to remain as listed above, especially as costs come down as the market matures. The impact of the growth of the number of electric vehicles, however, and how their energy systems interact with home design may prove to be impactful in the future. As noted at the end of Volume 1, future case study residential projects are likely to involve issues beyond design for annual ZNE performance to include the *grid harmonization* of solar electric power generation and also *energy storage* (batteries) to optimize both grid performance and the cost of energy to the residential consumer via time-of-day rate structures.

Acknowledgments

Many thanks to the following clients, users and designers of these ZNE residential projects who gave generously of their time to provide all of the information and insights into various aspects of their design and performance. They share an obvious pride in their work and a commitment to the goal of a future of sustainably designed buildings.

Christian Kienapfel, Architect/Owner of the Passive House L.A. (PHLA+), Case Study No.6.
For the detailed information and response to many questions about the design and techniques of construction of PHLA+, including complete performance data.

Xavier Gaucher, Owner and Certified Passive House Consultant for the Perlita Passive House, Case Study No. 7.
For all the information and patient correspondence concerning the design and operation of the case study house.

Chris Stratton and Wen Lee, the energetic designers of the DIY project that is their home and the subject of Case Study No. 8.
For the tireless responses and complete information about the DIY process as applied to this ZNE home.

Andy Mannle, Vice President of Strategic Development, Promise Energy, solar PV system designer and installer for the Silver Star Apartments, Case Study No. 9.
For providing the background information and performance data for this project, and for fielding the many questions about the system.

Arturo Yanez, Partner, FSY Architects, design lead of the project team for Silver Star Apartments, Case Study No. 9.
For all the technical information and photographs of this project.

Sean Armstrong, Redwood Energy, ZNE consultant for Cottages at Cypress, Case Study No. 10.
For continued support in providing detailed explanations of the design and performance of this type of affordable senior housing.

John Sarter, head of Sol Lux Alpha LLC, developer of the Sol Lux Alpha condominium project, Case Study No. 11.
For the detailed description of the project and tireless response to the many questions about the design, construction, systems and performance of this building.

In addition, I would like to thank the professionals who provided valuable additional information and reference documents for the case study buildings, invaluable for this publication:

Roger and his “Merry Band of Solar Installers”, Arcata (Cottages at Cypress, Case Study No. 10).

Sylvia Wallis, Certified Passive House Consultant, Los Angeles (PHLA+, Case Study No. 6)

Chris Dart, President
Latasha Talamantes, V.P. Property Management
Marcie Deniz, on-site Manager
Danco Communities, Arcata (Cottages at Cypress, Case Study No. 10).

Kash Boodjeh, Architect, K. Boodjeh Architects, Eureka (Cottages at Cypress, Case Study No. 10).

Riyad Ghannam, RG-Architecture, San Francisco (Sol Lux Alpha Condominiums, Case Study No. 10).

Jason Lorcher, P.E., Principal, Green Dinosaur, Inc., Green Building Consulting, Los Angeles (Silver Star Apartments, Case Study No. 9).

Finally, I would like to thank the team at Southern California Edison (SCE) for originating and supporting this series of publications on ZNE case study homes; mainly Will Vicent, Kevin Chan, Ryan McFadyen, Jude Schneider and Michelle Thomas.

--Edward Dean, FAIA, Bernheim + Dean, Inc.

This book is dedicated to Kevin G. Wood, who will be retiring from SCE this year. Over the course of her illustrious career, Kevin dedicated herself to improving the lives of many. Having led large scale demand side management portfolios, she helped Southern Californians save countless dollars and kilowatt-hours. Kevin is also the mastermind responsible for establishing SCE's building electrification organization, which will now be indefinitely committed to addressing the climate crisis by diminishing the use of fossil fuels in homes and businesses. She will be incredibly missed, but her contributions will remain indelible and universally respected. Thank you, Kevin!

SOUTHERN CALIFORNIA EDISON®

An EDISON INTERNATIONAL® Company

This publication is funded by California utility customers and administered by SCE under the auspices of the California Public Utilities Commission.