Zero Net Energy Production Builder Demonstration

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ABBREVIATIONS AND ACRONYMS

ACH_{50}	Air changes per hour at 50 Pascals
AFUE	Annual fuel utilization efficiency
AMY	Actual meteorological year
CHISPA	Community Housing Improvement Systems and Planning Association, Inc.
DHW	Domestic hot water
EER	Energy efficiency ratio
EF	Energy factor
EUI	Energy use intensity
HSPF	Heating seasonal performance factor
HVAC	Heating, ventilating, and air conditioning
PG&E	Pacific Gas and Electric Company
PV	Photovoltaics
SEER	Seasonal energy efficiency ratio
SF	Square foot
SJC Habitat	Habitat for Humanity of San Joaquin Valley
T	Ton
TDV	Time dependent valuation
TMY	Typical meteorological year
ZNE	Zero net energy

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EXECUTIVE SUMMARY

Pacific Gas and Electric Company (PG&E) implemented a Zero Net Energy (ZNE) Production Builder Demonstration that supported six builders in California in designing and monitoring a ZNE house. Each builder received technical support from start to finish to upgrade one of their existing prototypes to ZNE while preserving their look and feel. The ultimate goal was to achieve a ZNE home that the builder could replicate to begin to build ZNE homes at scale. For each builder, the design consultants recommended energy efficiency measures for the builder's standard design based on performance modeling and substantial past experience with ZNE and energy-efficient homes. As part of this offering, PG&E reimbursed up to $15,000 in incremental cost of the energy efficiency measures; experience shows that the incremental costs will drop in subsequent projects. Finally, the monitoring consultants tracked the end-use energy consumption of the completed home for a year after occupancy to determine whether the ZNE home is performing as designed and to diagnose any operational issues.

Although the participating projects are in both marine and hot dry climates and built for low income and market rate occupants, there were several common design features. At least four used 2x6, 24" on center wood framing, located their ducts in semi-conditioned or conditioned space, provided heat pumps for space conditioning, installed condensing gas water heaters, and installed 100% LED lighting. The modeled energy use intensities (EUIs) of the ZNE designs vary from 15 to 27 kBtu/sf/yr, representing a reduction of 3-55% below the builder's standard practice.

The measured energy consumption data was compared to energy models using typical and actual weather for the location. The measured consumption was greater than predicted in all cases based on actual weather condition and in five of six cases using typical weather. The measured energy consumption data shows that California energy code has effectively reduced HVAC energy through tightening building envelope requirements so that hot water was the biggest end use in most cases. The combination of appliances and plug loads, which are not be regulated by California building energy codes, accounted for 30-47% of measured consumption. One of the most effective efficiency measures that is available to builders is supplying highly efficient appliances since occupants may otherwise choose inefficient models.

The ZNE homes built as a part of this effort provide a base for each builder to iterate on as they refine their strategies and processes and increase the efficiency of their homes.

The body of this report describes the overall demonstration, the design and monitored performance of the houses, and some lessons learned. The appendices contain detailed design and monitoring case studies of five of the builder projects.

INTRODUCTION

MOTIVATION

In California's 2008 Long Term Energy Efficiency Strategic Plan, the California Public Utility Commission defined four "Big Bold Energy Efficiency Strategies." One key goal was that all new residential construction in California be Zero Net Energy (ZNE) by 2020.[1] Starting in 2014, Pacific Gas and Electric Company (PG&E) ran a ZNE Production Builder Demonstration to support these ZNE goals as well as to support builders in preparing for the 2016 building code.

The demonstration was designed to provide valuable information to both builders and PG&E. Builder benefits of the demonstration included

- ZNE prototype development ahead of competition and code
- Demonstrate proof of concept of ZNE in a production builder environment
- Test market acceptance
- In depth design team training on ZNE design
- Construction inspections together with education of tradespeople
- Assistance with incremental cost of ZNE prototype construction
- Feedback on performance of occupied prototype
- Assistance with cost reduction techniques and practices
- Publicity through case studies and public events

PG&E benefits and goals included

- Moving toward a building code that supports the State's ZNE goals
- Demonstrate proof of concept of ZNE in a production builder environment
- Develop relationships with proactive, cutting edge builders
- Gather information on any challenges on building to a ZNE level
- Gather information about the current incremental cost of ZNE for builders, the cost of ZNE homes, and where these costs can be driven down
- Gather information about the performance of occupied ZNE homes
- Develop case studies for builder education

DEMONSTRATION STRUCTURE

The high-touch demonstration effort was organized into four main components:

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[1] http://www.cpuc.ca.gov/General.aspx?id=4125

- *Design Development*. Beginning with a target of ZNE, the design consultants and builder team tailored the prototype based on parameters like climate zone, customer base, and builder supply chain. Design consultants performed energy modeling to determine final building systems and equipment for inclusion in the prototype and to estimate energy performance. Design consultants also worked with the builder team to ensure the prototype preserved the look, feel, characteristics and amenities of the builder product type for the development or sub-division.
- *Construction and Construction Inspections*. Design consultants worked with the builder team and subcontractors as needed to ensure careful installation of energy efficient and ZNE systems and equipment.
- *Equipment and System "Buy Down."* PG&E negotiated with the builder and covered the incremental costs of energy efficiency measures which go beyond the builder's current practice (up to $15,000). This "buy down" did not include the cost of solar photovoltaic (PV) systems.
- *Ongoing Performance Monitoring*. Monitoring consultants worked with the builder team and the design consultants to ensure the integration of monitoring equipment from the early stages of design. Once construction was completed, the monitoring team tracked ongoing energy performance over the course of a year to evaluate the overall energy performance and energy consumption of end uses to determine whether the occupied prototype was performing as designed and to diagnose needed corrections, as necessary.

The design teams facilitated an iterative design process with each builder. The builder's plans for one of their standard models were used as a starting point. From there, the design teams proposed possible measures based on professional experience. The measures that the builder team was interested in were modeled for energy performance and evaluated for cost impacts.

There were four consultant groups involved:

- Resource Refocus LLC – demonstration development, oversight, coordination, and energy modeling
- Design AVEnues[2] – design & technical assistance
- BIRAenergy – design & technical assistance, energy modeling
- Frontier Energy (formerly Davis Energy Group) – performance monitoring

METRICS

Two types of energy were used for modeling and performance evaluation in the Demonstration: site energy and time dependent valuation of energy (TDV).

[2] Team includes Ann Edminster, Rick Chitwood, and Steve Easley.

- Site energy is simply the amount of energy that is delivered to the site. It can be directly measured and is shown on utility bills (kWh of electricity and therms of natural gas).
- TDV is the basis of the California Building Energy Efficiency Standards (Title 24, Part 6). The TDV metric assigns a societal value of energy based on where in California it is being used, what hour it is being used, and whether it is electricity, natural gas, or propane. It is a modeling metric calculated by multiplying hourly climate-dependent factors with hourly site energy performance simulation data.

In this demonstration, the ZNE design goal was defined using TDV to align with California building energy code. However TDV is purely a modeling metric. It cannot be used to assess measured ZNE performance because the TDV multipliers are tied to specific weather, grid, and economic projections and assumptions that will not be met exactly over the course of an actual year (Pande et al. 2016). Therefore measured ZNE performance was evaluated based on site energy. The final design models that predicted zero net TDV also output site energy predictions, and these values were compared to the measured site energy to assess measured ZNE performance.

Homes modeled as TDV zero are not expected to achieve site zero performance. Because "peak" electricity during hot summer afternoons is the most costly energy for the grid operators to produce, procure and deliver, it is weighted the most heavily in the TDV multipliers, up to 20 times more than the values for 95% of the time.[3] Those are precisely the hours with high electricity production from photovoltaic (PV) panels, so electricity production from the same array can offset a higher proportion of TDV consumption than site energy consumption. This means that a smaller array is needed to reach TDV zero than site zero.

PARTICIPATING BUILDERS

Six builders participated in the Demonstration:

- Blu Homes
- Community Housing Improvement Systems and Planning Association, Inc. (CHISPA)
- De Young Properties
- Habitat for Humanity of San Joaquin County, Inc. (SJC Habitat)
- Meritage Homes
- PulteGroup

These builders vary in size, targeted market segment, and process. De Young, Meritage, and Pulte all build market rate homes, but Meritage and Pulte are national while De Young is a regional builder in the Fresno area. Blu Homes builds custom homes made of modules in their factory before trucking them to the site. SJC Habitat and CHISPA both serve lower income populations. Habitat for Humanity has affiliates all over the world that use volunteer labor and often donated materials, while CHISPA builds in the Salinas area using a more

[3] TDV factors are updated with every energy code cycle. This description specifically applies to the 2013 code.

standard process. PG&E and the consultants tailored their approach during the development of the ZNE prototype to fit the process and circumstances of each builder.

Four of six projects are located in hot-dry climates (CA Climate Zones 12 & 13), and two are in marine climates (CA Climate Zones 3 & 4) (Figure 1, Table 1). They range in size from 1,167 to 2,359 sf. Four of six have 3 bedrooms, one has 4 bedrooms, and one has 5. One home is all electric; the other five have at least one natural gas end use.

FIGURE 1. PARTICIPATING BUILDERS AND HOME LOCATIONS

TABLE 1. PROJECT CHARACTERISTICS

BUILDER	LOCATION	CA CLIMATE ZONE	FLOOR AREA (SF)	BEDROOMS, BATHS	OCCUPANCY
Pulte	Brentwood	12	2,359	4, 2.5	May 2016
Meritage	Hayward	3	2,047	5, 2.5	May 2017
Blu Homes	Loomis	12	1,877	3, 2	Aug 2016
De Young	Clovis	13	2,024	3, 2	Oct 2017
CHISPA	Greenfield	4	1,167	3, 2	Apr 2017
SJC Habitat	Stockton	12	1,229	3, 2	May 2016

Participation in the Demonstration was a long term commitment for both PG&E and the builder. Between the design consultations, time to build the homes, and 12 months of post-occupancy monitoring, engagement lasted about three years for each project.

DESIGN

DESIGN PROCESS

The Demonstration team engaged with each builder on a specific project that was under design. Through discussions with the builder team, the design team identified potential energy efficiency interventions and used a combination of extensive past experience supplemented by energy modeling to make recommendations. This was an iterative process that underwent multiple cycles for each builder before coming to a final design package that worked within the builder's existing process and could be replicated beyond the Demonstration.

DRIVERS OF DECISION MAKING

ENERGY PERFORMANCE

The ultimate goal of each design was to have modeled TDV consumption and production net to zero. Most builders also considered energy use intensity (EUI) to understand the energy performance of their homes, because it is a site energy metric and therefore directly related to the kWh and therm values on utility bills.

COST

Cost was a driver of decision making in many different contexts: material and labor costs, utility and other incentives, lifecycle paybacks, and ultimate home value. For example,

- Meritage stayed with open cell spray foam insulation because going to closed cell would be more expensive to install.
- De Young found it much easier to use LEDs in their houses when the California Advanced Homes Program (CAHP) changed its rules to allow screw-in LEDs because standard fixtures that accept screw-in lamps are cheaper than specialized ones.
- SJC Habitat does not install tubular skylights in their houses because they have a very long cost payback compared to 100% LED lighting.
- In order to maximize living space, homes often extend all the way to the zoning setbacks. Changes as small as increasing the thickness of exterior walls by 2-4" take away from that living space and can be an obstacle to building high performance walls.

As the cost of PV continues to fall and Title 24 becomes more stringent, the incentive for building above-code envelopes is shifting from cost effectiveness of balancing consumption and production from ZNE to occupant comfort and effective useful life. A better sealed and insulated home remains comfortable longer without electricity, and these envelope measures last longer than equipment upgrades and PV panels.

SUPPLY CHAIN

Products have to be available for to be able to builders to put them in the houses they build. This includes availability in the market in general, at a large enough scale, and from suppliers that a builder has an established relationship with. For example, Rick Chitwood often recommends heat pumps because houses that are very well insulated in mild climates tend to have such low heating loads that none of the furnaces on the market are small enough. Pulte was worried that there would not be enough contractors to install spray foam in attics if they works with Owens Corning and therefore preferred the box netting system to a spray foam solution for implementing a high performance attic.

SYNERGIES

Some efficiency measures have cascading beneficial effects to make them more impactful than they appear to be at first glance. SJC Habitat is very careful with house layout and construction techniques to simultaneously increase comfort and energy efficiency while decreasing cost, installation complexity, and materials usage. Sizing and positioning windows in response to the 24" framing module and code requirements around shear strength reduced the lumber required by 60%, avoided an expensive, specialized shear system, and left wall cavities open for easy insulation installation. Grouping all the points of hot water use in the center of the house allowed the longest pipe run to be only 12', saving water, energy, and material as well as reducing wait times for hot water. These kinds of synergistic designs are possible only through close collaboration between the trades but can have outsized impacts.

CHISPA simplified their roof from multi-plane hip plan to a less steep gable plan, mostly to provide more space for PV, but also to simplify the construction and make air sealing less challenging.

HOMEOWNERS

Most builders are very concerned about the preferences of potential homeowners because ultimately they have to sell what they build. They believe that homebuyers strongly prefer gas over electric cooking and therefore are in general unwilling to consider all electric construction despite potential cost savings opportunities.[4]

Blu Homes, on the other hand, builds custom homes and know the preferences of the specific homeowner during design. The client for their ZNE house wanted radiant floor heating and so that was included in the house without considering other factors. One of the reasons this works is that Blu Homes can pass the extra cost onto that client, while a spec builder would be more likely to have to absorb that cost.

The builders wanted to make sure that they marketed their ZNE homes carefully in order to get a premium when they are sold but also to not be misleading. Explaining ZNE to potential homebuyers can be difficult; a survey of 62 homeowners of energy efficient homes found that less than 40% could accurately define ZNE.[5] This is exacerbated when the definition is based on TDV instead of on measurable energy units. All of the builders asked for assistance in how to explain the definition, and De Young decided to add extra PV in order to meet Source ZNE[6] because it would be easier to explain and therefore market.

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[4] Mahone, Amber; Charles Li; Zack Subin; et al. (2019), Residential Building Electrification in California: Consumer economics, greenhouse gases and grid impacts. https://www.ethree.com/wp-content/uploads/2019/04/E3_Residential_Building_Electrification_in_California_April_2019.pdf

[5] Pande, Abhijeet; Marian Goebes; Stephanie Berkland; et al. (2015), Residential ZNE Market Characterization. Submitted to: Pacific Gas and Electric Company. http://www.calmac.org/publications/TRC_Res_ZNE_MC_Final_Report_CALMAC_PGE0351.01.pdf

[6] Source energy takes into account the losses between the primary energy source and what arrives on the building site. For example not all of the energy of the fuel burned at the power plant is converted into electricity, and not all of that electricity arrives at the site because of transmission and distribution losses.

CODES

One of the reasons that builders participated in the demonstration was to prepare for the 2016 code, particularly to get experience building high performance walls and attics. Pulte was also interested passing information about required roof area for PV back to their architectural team to make sure that future designs will accommodate that. At the same time, multiple builders had problems getting some of the high efficiency features through local code review. SJC Habitat attaches the copies of the relevant pages of the code when submitting for permits to avoid going back and forth with the plan checker.

Because many of the developments were already permitted before the builders joined the demonstration program, builders did not want to implement measures that would require them to resubmit. For example, Pulte was careful to avoid changing the equipment in the house in order not to have to redo Title 24 compliance. Similarly, Meritage was not interested in exploring drainwater heat recovery because it would require resubmitting for permits. This will not be as much of a concern in future projects that are ZNE from the beginning.

COMMON MEASURES

Although all six builders chose a package of efficiency measures that fit in their process and supply chain, there are a few similarities between them.

ENVELOPE

Four of the homes have walls with 2x6 studs 24" on center (Table 2). With U-values ranging from 0.043-0.048, these walls would meet the 2016 code requirement of U≤0.05 although the two with 2x4 walls would not.[7]

TABLE 2. ENVELOPE SPECS

BUILDER	CLIMATE ZONE	WALL CONSTRUCTION	WALL U-VALUE	ATTIC
Pulte	12	R-15+5, 16" oc	0.055	R-38 fiberglass, boxed netting under roof deck, unvented
Meritage	4	R-13+4, 16" oc	0.067	R-30 foam under roof deck, unvented
Blu Homes	11	R-19+5, 24" oc	0.048	R-38 SIPs, unvented
De Young	13	R-21+4, 24" oc	0.048	R-38 fiberglass wired and glued under roof deck, unvented
CHISPA	3	R-22+5, 24" oc	0.044	R-49 fiberglass at attic floor, vented
SJC Habitat	12	R-19+5, 24" oc, 13% framing factor	0.043	R-42 fiberglass at attic floor, vented

All six of the ZNE homes have ducts in semi-conditioned or conditioned space, but they achieved it in five different ways (Table 2). CHISPA and SJC Habitat have the insulation on

[7] CEC (California Energy Commission) (2015), Building Energy Efficiency Standard for Residential and Nonresidential Buildings: For the 2016 Energy Efficiency Standards. http://energycodeace.com/content/reference-ace-2016-tool

the attic floor and ducts in dropped ceilings below that. The equipment itself is in mechanical closets, so nothing is in the attic. The other four builders have the insulation at the roof deck and the ducts in the attic, which is then semi-conditioned, unvented space. Blu Homes uses structural insulated panels (SIPs), and Meritage uses spray foam. De Young glued and wired fiberglass batts to the bottom of the roof deck. Pulte used boxed netting to make enclosed cavities under the roof deck and blew in fiberglass insulation.

SPACE CONDITIONING

Four of the homes have heat pumps for space conditioning (Table 3).[8] Because heat pumps move heat from one space to another instead of producing it, they have efficiencies greater than one and switching from a furnace to a heat pump reduces EUI. Even though electricity is weighted more heavily in terms of TDV than gas, the switch to a heat pump still saves TDV energy because heating does not occur during the peak TDV periods.

WATER HEATING

Four of the homes have condensing gas water heaters, three of which are tankless, and have efficiency factors of at least 0.95. Of the remaining homes, one has a heat pump and the other has a less efficient gas tankless unit.

TABLE 3. EQUIPMENT SPECS

BUILDER	HVAC	WATER HEATING
Pulte	Heat pump: 19 SEER, 9.2 HSPF, 3T	Condensing gas: tankless, 0.96 EF
Meritage	AC: 17 SEER/ 12.8 EER, 2 speed Furnace: 96% AFUE	Condensing gas: tankless, 0.95 EF
Blu Homes	Heat pump: 16 SEER, 8.5 HSPF 2-speed, 2T	Heat pump: 50 gal, 2.9 COP
De Young	AC: 19 SEER / 14 EER, 2.5T Furnace: 96% AFUE	Condensing gas: tankless, 0.96 EF
CHISPA	Ducted mini-split: 15 SEER, 9 HSPF, 1.5T	Condensing gas: 50 gal, 0.95 EF
SJC Habitat	Ducted mini-split: 24.5 SEER, 12.5 HSPF, 0.75T	Gas: tankless, 0.82 EF

LIGHTING

All of the homes have 100% LED lighting.

APPLIANCES

All of the builders installed at least some EnergyStar appliances, and most installed all EnergyStar. However standard practice is typically to offer various levels of appliance packages as add-ons to the home, so customers are able to choose more or less efficient appliances.

[8] The Blu home has an air source heat pump for back up heating; the primary heating is provided by a heat pump water heater and radiant floor distribution.

Half of the builders installed gas stoves and the other half used electric; the same for clothes dryers.

Photovoltaics

The PV arrays on the homes vary in size from 3.36 to 5.58 kW (Table 4). Although zero net TDV was the official goal for the Demonstration, not all of the builders sized their PV based on that metric.

Table 4. PV Sizes

Builder	PV Size (kW)
Pulte	4.62
Meritage	4.05
Blu Homes	4.58
De Young	5.58
CHISPA	4.48
SJC Habitat	3.36

Energy Performance

Modeling

Modeling Methodology

Two principle energy performance models were made for each builder: one with their standard practice and one with the final ZNE package. The modeling was done with BEopt v2.3 running the EnergyPlus simulation engine. The weather files and TDV factors for the 2013 version of Title 24 were used for the appropriate climate zone.

Modeled Performance

Figure 2 shows the modeled energy consumption of each builder's baseline[9] and ZNE packages compared with ZNE "exemplar" houses developed by Arup as a proof of the technical feasibility of ZNE design (Arup 2012). The EUIs of the ZNE designs vary from 15 to 27 kBtu/sf/yr. This represents a reduction of 3-55% below the builder's standard practice.

[9] Because Blu Homes builds custom homes for individual owners, they do not have a standard practice as such, so only a ZNE model was built.

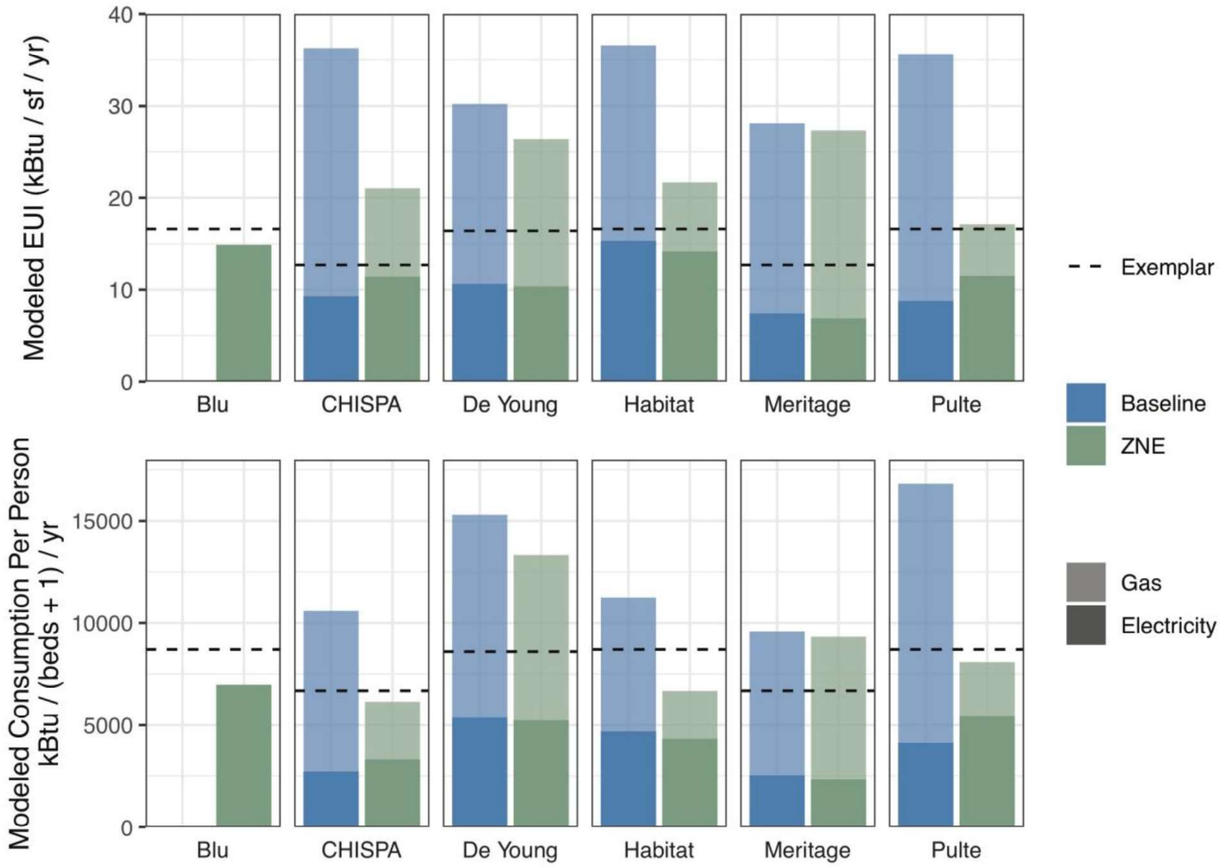

FIGURE 2. MODELED ENERGY CONSUMPTION OF BASELINE AND ZNE PACKAGES PER FLOOR AREA AND PER PERSON[10]

In terms of site EUI, the single measure with the greatest impact was replacing a gas furnace with a heat pump: 55% of total savings came from heating in the CHISPA home and 75% for the Pulte home. Some of this savings is related to envelope measures and moving ducts to conditioned space, but replacing the furnace brings the efficiency of the heating source from less than one to more than three. Increased water heating efficiencies were also significant contributors to EUI savings.

EUI is one of the standard metrics of building energy performance because it allows comparison across different building sizes. However it privileges large homes because the energy consumption is normalized by conditioned floor area. While some end uses, notably space heating and cooling depend heavily on floor area, others, such as hot water, appliances, and plug loads depend principally on the number of occupants. This means that comparing the EUI of the small houses built by low-income builders to the EUI of larger houses with the same number of bedrooms gives a misleading picture of their relative efficiency. The number of bedrooms plus one is a common proxy for the number of occupants. Their modeled energy performance is shown below for comparison. While CHISPA and SJC Habitat have higher EUIs than their corresponding exemplars, they have

[10] "Exemplar" performance shown for the same or similar CA climate zone as the modeled home (Arup 2012). These homes have 3 bedrooms and 2100 sf.

lower consumption per occupant. The change in relative efficiency is dramatic when comparing the builders across the two metrics.

END USE BREAKDOWNS

Figure 3 shows the share of site energy consumption due to each end use. The importance of HVAC consumption varies substantially depending on the heating source (electricity vs. gas) and size of the house: it makes up about 20% of the consumption of the large houses with electric heating (Pulte, Blu), less than 10% for the small houses (CHISPA, SJC Habitat), and almost half for the houses with gas heating (De Young, Meritage). Lighting is the smallest end use, and the other end uses account for similar shares of total consumption. A lot of design team focus is put on improving the efficiency of HVAC, but the breakdown shows that other end uses need to become an increasing focus.

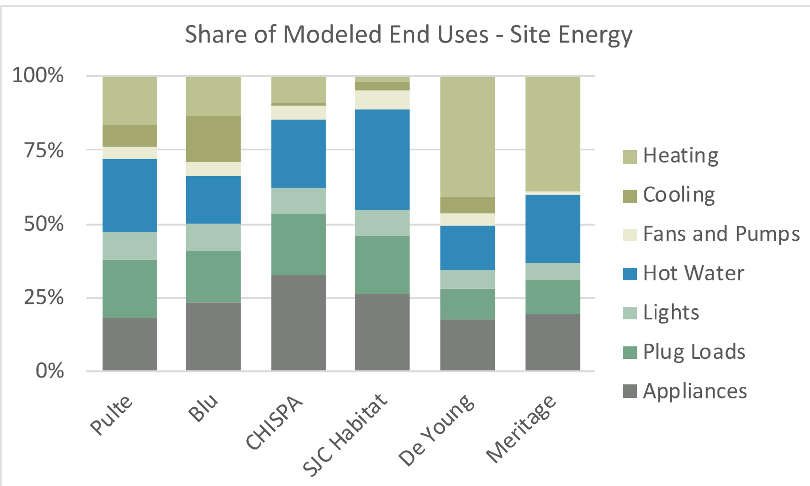

FIGURE 3. SHARE OF MODELED ENERGY BY END USE – SITE ENERGY

MONITORING

MONITORING METHODOLOGY

The one year of post occupancy energy monitoring was accomplished using a Powerwise SiteSage monitor. Current transducers, gas meters, thermostats, and relative humidity sensors were connected to the monitor, which logged data at 1 minute intervals and uploaded hourly sums and averages to a cloud-based service. The occupants could track this information through an online dashboard. In order for all the end uses to be measured separately, the monitoring team made sure that all end uses were put on their own circuits, including lighting and plug loads.

OVERALL TRENDS

The measured energy consumption data shows that California energy code has done a good job reducing HVAC energy through tightening building envelope requirements. In most cases hot water, rather than HVAC, was the largest end use (Table 5). The combination of appliances and plug loads, which cannot be regulated by California, accounted for 30-47% of measured consumption.

BUILDER	HVAC	HOT WATER	APPLIANCES	PLUG LOADS	HARDWIRED LIGHTS	NOTES
Blu	24%	49%	16%	15%	4%	"Hot Water" includes DHW and radiant floor heating
CHISPA	12%	35%	29%	15%	9%	
De Young	36%	30%	14%	20%	0%	
Habitat	22%	28%	20%	27%	3%	
Meritage	3%	44%	23%	24%	6%	Electric space heaters were used by occupant instead of the furnace.
Pulte	29%	18%	18%	24%	10%	

TABLE 5. END USE DISTRIBUTION OF MEASURED CONSUMPTION

COMPARISON TO MODEL

The measured energy consumption was compared against two modeled baselines – one using typical meteorological year (TMY) weather data and one using actual meteorological year (AMY) weather data. As shown in Table 6 and Figure 4, measured EUI was more than modeled with AMY weather data in all cases. Measured EUI was less than modeled with TMY weather data only for Meritage.

BUILDER	MEASURED	MODELED (TMY)	MODELED (AMY)
Blu	18.3	14.9	14.2
CHISPA	32.8	21.1	20.9
De Young	30.6	26.3	21.3
Habitat	28.1	21.7	22.1
Meritage	26.2	27.3	23.6
Pulte	22.4	17.1	16.1

TABLE 6. MEASURED AND MODELED ANNUAL ENERGY CONSUMPTION (KBTU/SF/YR)

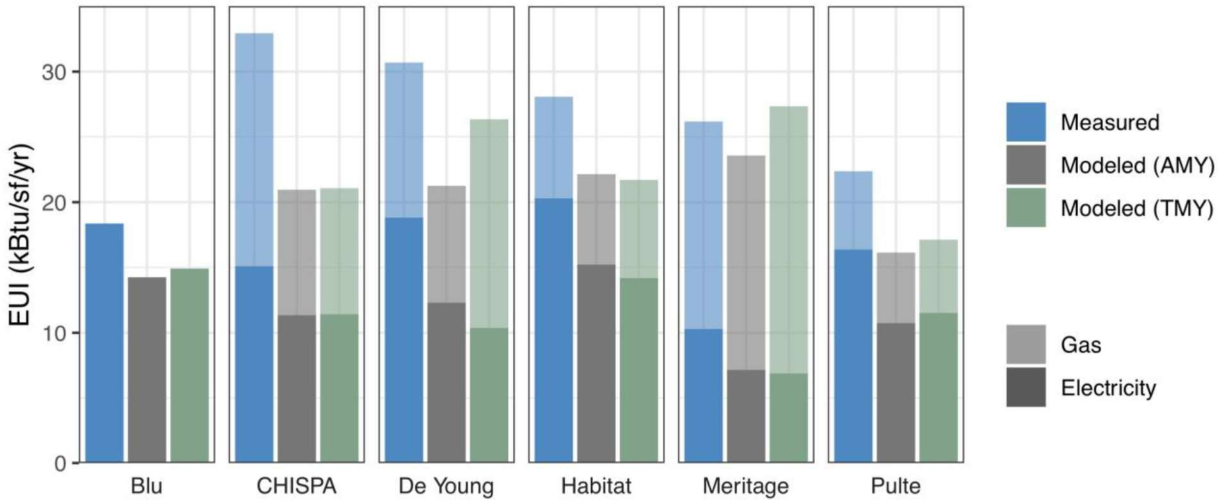

FIGURE 4. MEASURED AND MODELED ANNUAL ENERGY CONSUMPTION

Measured PV production was greater than predicted in all cases, likely because the production was simulated with an assumed 12% derate factor to account for performance degradation and dust buildup, so the first year's production would be higher than modeled.

ZNE PERFORMANCE

The ZNE target was based on TDV, which is purely a modeling metric and cannot be calculated for measured data. It also results in undersized PV compared to what would be required to offset total site energy consumption, so it is not expected that solar production will meet or exceed consumption for these houses. To assess ZNE performance[11], the percentage of site energy consumption that was offset by PV production was compared between the measured data and modeled predictions. For the De Young, Habitat, and Meritage houses, the measured offset was commensurate with what was modeled, so they can be said to have achieved measured ZNE performance.[12] The Blu, CHISPA, and Pulte homes consumed more than modeled with TMY or AMY weather data, but PV production was also more than modeled. However the ratio of the additional consumption to the additional production meant that they did not achieve their initial ZNE performance targets.

[11] All of the houses achieved ZNE design.

[12] Despite urging from the builder and project teams, the owners of the Meritage house elected not to activate their PV array. Therefore, the "measured" PV was calculated using AMY data.

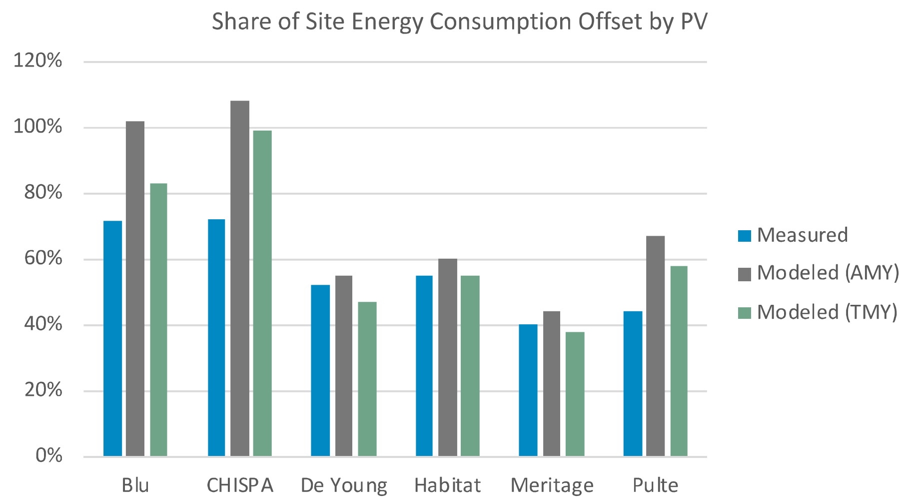

FIGURE 5. MEASURED AND MODELED ZNE PERFORMANCE[11]

LESSONS LEARNED

CONSTRUCTION

The air sealing targets were difficult to achieve. Pulte had a goal of 3.5 ACH_{50} and used a conservative estimate of 4 ACH_{50} in the energy modeling. However, the final blower door test showed an infiltration rate of 4.96 ACH_{50}, the same as their standard practice. With some site assistance, the CHISPA team met their 2 ACH_{50} air sealing goal, tightening the building significantly from the initial blower door test showing 3.5 ACH_{50}. The initial test was done when the walls were already closed, which made the additional sealing more difficult because of the leaks being less accessible.

The ZNE measures being installed had wider implications for construction than the immediate piece of equipment. Switching from a gas furnace to an electric heat pump meant that the Pulte ZNE home did not need a gas line to the attic but it has one anyway. Similarly, the insulation contractor for the CHISPA house put in the baffles for the low eave vents that are typically there, even though they were removed for the ZNE house design. The baffles were stuccoed over during air sealing. This unnecessary work was caused in part by the ZNE homes being different from the others in the subdivision; the workers just did the same installation as for all the other houses next to them. If all the homes had the same upgraded features these issues would be less likely to occur.

SJC Habitat shows what can happen with seamless communication. George Koertzen is not only the construction manager but also the lead for all the trades. As the insulation contractor, he knows that the more regular the wall cavities are the easier they are to insulate. So as the primary designer he can place and size walls, windows, and doors to maintain regular wall cavities. As the electrical contractor, he knows where the wires need to be pulled from and to, so as the framer he can save work for the electrical and insulation contractors by drilling holes at the bottom of the wall studs to act as a conduit for the wires.

FINANCIAL

The Demonstration offered an incremental cost buydown of up to $15,000 for energy efficiency measures, and most of the builders came in with incremental costs below that threshold. The exception was for redrawing plans to accommodate wider walls and a higher top plate. However that design work is reusable in a production building context, so the cost can be distributed among all the homes that employ the new drawings.

There is often speculation about the home price impact of "going ZNE". The incremental cost associated with the ZNE package for the Pulte ZNE home totaled less than 3% of the sale price. The home was sold using a bid process, resulting in a final price that more than covered the incremental cost of the efficiency upgrades.

More detailed information is available for CHISPA (Edminster and Chitwood 2018; Appendix A) and SJC Habitat (Edminster and Chitwood 2017; Appenix C).

ITERATION

Optimizing a package of measures and their implementation to meet ZNE is an iterative process. It took George Koertzen of SJC Habitat several iterations to develop the advanced framing and air sealing details for his very low framing factor and infiltration rates. The contractors that CHISPA uses now have some hands on training about air sealing and will be able to implement the process more quickly next time. Pulte learned that sequencing the trades for the boxed netting attic solution is complicated, and it may take another iteration or two to optimize. In fact, the benefits of iteration are one of the reasons that pushing builders to pursue ZNE is important – starting earlier allows more time for iteration.

SUBSEQUENT PROJECTS

Now that these builders have built a ZNE home, there are ways that future ZNE homes will be easier.

REUSABLE DESIGN AND SOURCING WORK

Some of the design work that was done for these projects can be reused in future ones. Blu Homes has confirmed with their structural engineers that 24" oc framing is strong enough to be transported on the trucks. CHISPA has already redesigned the roof to be gable instead of hip, raised the top plate to 9', and revised and the framing plan to use 2x6 24" oc. Revisions requiring architects and engineers can be quite costly, but they are precisely the kind of work that is reusable.

Finding an appropriate product to implement an efficiency measure can sometimes be a hurdle. De Young found LED replacements for their standard lamps and fixtures; in some cases it was extremely difficult. But now that they have a schedule of the replacements they can use it easily in their future projects.

Some efficiency measures can be hard to get through design review. The De Young project was delayed in plan check because of requests for extra documentation. The plan checker was concerned about securing the stone veneer to 24" oc instead of 16" oc walls and requested that De Young submit the installation instructions from the stone manufacturer. Also, De Young consolidated two of the required vents for the HVAC system into a single penetration using a concentric vent/fan kit in order to reduce roof penetrations and make insulating the roof easier. The plan checker requested supplemental testing and verification documents about this kit beyond what is typically required. Because the equipment is not ANSI certified, De Young could not provide that documentation and had to get the HVAC contractor involved to resolve the situation, further pushing back the approval timeline.

SJC Habitat has learned that including the relevant sections of the building code with their submission can speed up the process.

GREATER FAMILIARITY

In order to install the boxed netting insulation under the roof deck in the Pulte home, the insulation contractor had to be certified for using this new product. The product and installation technique were so new that representatives of Owens Corning's technical marketing team were on site during the installation. Now that the workers have done the installation once, they will be able to do it more confidently and quickly in the future.

The onsite training about air sealing that some of CHISPA's contractors received was crucial for achieving the infiltration goal for this particular project but more importantly will enable the workers to do better air sealing in their future projects.

Improving a building's envelope can mean that the HVAC equipment required to meet the load is unbelievably small for engineers and contractors who have been installing large equipment for many years. Many people do not believe that SJC Habitat's ¾ ton heat pump is large enough to meet the load. CHISPA's mechanical engineer wanted to install a 2 ton heat pump and was uncomfortable with the Design AVEnues team's recommendation of a 1 ton heat pump. CHISPA installed a 1.5 ton unit as a compromise.

RECOMMENDATIONS

FOR BUILDERS

One of the ways that production builders lower their costs is using their large purchasing volume to bargain for special prices. If builders install energy efficient features, such as heat pumps, in all or a large portion of their homes, they will lower the incremental cost of ZNE.

FOR EFFORTS TO ENCOURAGE ZNE

While the demonstration was focused on helping builders and PG&E, it has also helped some manufacturers. Owens Corning and Johns Manville both have new attic insulation products that will help builders comply with the code requirement of ducts in conditioned space. Pulte and De Young provided them with demonstration projects and real world examples to work out some of the kinks of installation.

The earlier in the process the design consultants become involved the more measures are available to the builder. A builder is less likely to consider a measure that will require redoing drawings, resubmitting for permit, or construction delays, because of the unnecessary costs that are incurred. Earlier in the process, it is easier to talk about synergistic strategies such as advanced framing and major changes that might be required to get ducts in conditioned space.

BUILDING DECARBONIZATION

The ZNE Builder Demonstration was conceived in 2014 in preparation for the 2016 code coming into effect. ZNE is in 2019 code for single family homes and much of what the builders tried for the first time in the Demo has to be their standard practice. Now the California state agencies are focusing increasingly on decarbonization and greenhouse gas reductions instead of ZNE. Although decarbonization does not necessarily mean electrification, it is one critical strategy (Mahone et al. 2018). If we were conducting a Builder Demo now in 2019 we would be encouraging builders to try electrification strategies such as heat pumps and heat pump water heaters.

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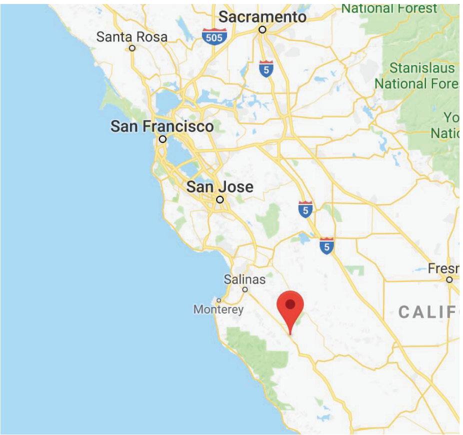
APPENDIX A: CHISPA CASE STUDIES

Zero Net Energy Demonstration Home Community Housing Improvement Systems and Planning Association (CHISPA)

Design Case Study

Source: CHISPA



PROJECT OVERVIEW

Floor Area: 1,167 sf

Bedrooms: 3

Location: Greenfield, CA

CA Climate Zone: 4

Completion: December 2016

Modeled EUI: 21.1 kBtu/sf/yr

PV Array: 4.48 kW

Community Housing Improvement Systems and Planning Association, Inc. (CHISPA) completed a zero net energy (ZNE) demonstration house with support from Pacific Gas and Electric Company (PG&E) and its consultant team. The non-profit housing developer has a core mission of increasing housing affordability by reducing utility costs for tenants and homebuyers alike, making them an ideal participant in the ZNE demonstration. The project team was able to reduce the modeled site energy consumption by 42% compared to CHISPA's standard practice, mainly through increasing water heating efficiency, improving the building envelope, and replacing the gas furnace with a mini-split heat pump. CHISPA plans to include several energy efficiency measures piloted in this demonstration in future projects, including cool roofing, increased attic insulation (R-38), improved air sealing, and 100% LED lighting.

PG&E ZNE Production Builder Demonstration

The State of California has a goal that all new residential buildings be zero net energy (ZNE) by 2020.[1] To support builders in designing and constructing ZNE homes, PG&E offered support through a ZNE Production Builder Demonstration. Participating builders received technical support from start to finish to upgrade one of their existing prototypes to ZNE while preserving their look and feel, and in a way that works for their team. The ultimate goal was to achieve a ZNE home that the builder could replicate to begin to build ZNE homes at scale. For each builder, the design consultants recommended energy efficiency measures for the builder's standard design based on performance modeling and substantial past experience with zero net energy and energy-efficient homes. They also visited the site during construction to ensure that the measures were being properly installed. As part of this offering, PG&E reimbursed up to $15,000 in incremental cost of the energy efficiency measures; experience shows that the incremental costs will drop in subsequent projects. Finally, the monitoring consultants tracked the end-use energy consumption of the completed home for a year after occupancy to determine whether the ZNE home is performing as designed and to diagnose any operational issues.

[1] CPUC (2017) "Energy Efficiency Strategic Plan" http://www.cpuc.ca.gov/General.aspx?id=4125

ZNE Goal and Project Approach

The ZNE goal for the project was based on Time Dependent Valuation (TDV) to align with California building energy code.[2] Site energy was also modeled to understand the energy efficiency of the home.

The CHISPA team approached the project through the lens of their core value, to increase housing affordability through reducing utility costs for tenants and homeowners in Monterey, San Benito, and Santa Cruz Counties. Efficiency upgrades were chosen in a framework that considered end-user cost. Furthermore, this builder team approached the demo as a wholehearted learning experience and displayed an enthusiastic willingness to adjust many areas of the design. This resulted in more discussion with the consulting team and upgrades such as an improved water heater and HVAC system.

CHISPA Zero Net Energy Package

CHISPA made large changes to every system in the house to improve energy efficiency and to reduce the modeled site energy consumption of the house by 42%:

- Wall framing changed from 2x4 at 16” on center to 2x6 at 24” on center to increase cavity insulation from R-13 to R-23
- Non-batt insulation substituted in the walls to be less prone to installation defects
- R-6 continuous exterior wall insulation added
- Improved window specifications to 0.28 U, 0.23 SHGC
- Top plate raised from 8’ to 9’ to allow a dropped ceiling to contain the ducts entirely in conditioned space
- Air sealing focus increased, with envelope leakage rate reduced by half to 2.3 ACH_{50}
- Gas furnace replaced by a 1.5-ton mini-split heat pump
- Standard gas tank water heater (0.65 EF) replaced with condensing gas tankless (0.95 EF)
- Lighting improved from 90% CFL fixtures to 100% LED fixtures and 3 tubular skylights

[2] TDV values energy differently based on its source and on when and where it is consumed or produced. Because “peak” electricity during hot summer afternoons is the most costly energy for the grid operators to produce, procure and deliver, it is weighted the most heavily by TDV.

Detailed Specifications and Costs

		Baseline	ZNE	Cost Diff.
Envelope				**$ 5,154**
Exterior Walls	cavity R value, insulation type	R-13 fiberglass	**R-23 fiberglass**	
	framing type, spacing	2x4 @ 16" oc	**2x6 @ 24"oc**	
	continuous insulation	none	**R-6 foil-faced foam**	
Glazing	U / SHGC	0.3 U / 0.3 SHGC	**0.28 U / 0.23 SHGC**	
	WWR	**15% WWR**		
	shading	1' eaves	**1.5' eaves**	
	skylights	none	**3 solar tubes**	
Roof	insulation type, R value	R-30	**R-38**	
	insulation location	**attic floor**		
	vented/unvented attic	**vented attic**		
	radiant barrier	none	**radiant barrier**	
	cool roof	none	**reflectance 0.22 / emittance 0.92**	
Foundation	type	**slab**		
	insulation	**none**		
Air Leakage	ACH50	4 ACH50	**2.3 ACH50**	
HVAC System				**$ 6,510**
Ventilation	type	exhaust	**ducted outdoor air**	
Heating & Cooling	heating system type	gas furnace	**1.5-ton ducted mini split**	
	heating efficiency	0.9 AFUE	**9 HSPF**	
	heating capacity			
	cooling system type	none		
	cooling efficiency		**15.3 SEER**	
	cooling capacity		**1.5-ton ducted mini split**	
	equipment location	attic	**cond. space (hall soffit)**	
Ducts	location	attic	**cond. space (dropped ceiling)**	
	insulation	**R-6**		
	leakage	7.50%	**6.50%**	
Water Heating				**$ 3,810**
Water Heater	water heater type, efficiency	gas tank, 0.67 EF	**gas tankless, 0.95 EF**	
	tank size	50 gal	**NA**	
	equipment location	**garage**		
DHW Distribution	insulation, pipe material	R-2, copper	**R-4, PEX**	
	recirculation system	none	**timer recirculation**	
	low flow fixtures		**low flow fixtures**	
Electric Loads				
Lighting	type	90% CFL, 10% LED	**100% LED**	$ 350
	controls		**occupancy sensors**	$ 370
Appliances	fridge	**ENERGY STAR**		$ 520
	cooking	**gas cooking**		
	dishwasher	**ENERGY STAR**		
	washer	not provided	**ENERGY STAR**	$ 696
	dryer	not provided	**gas dryer**	$ 588
Architectural, Structural, Mechanical, Electrical				**$ 18,672**
Redesign	roof framing, plate height	8' plate height, hipped roof	**9' plate height, gabled roof**	
	walls	2x4, no exterior insulation	**2x6 + exterior insulation**	
	hall ceiling	standard	**dropped soffit**	
	wiring	standard	**separated for monitoring**	
	mechanical	furnace, vent fan, hood fan	**heat pump, vent fan, hood fan, fresh air intake**	
Total				
				$ 36,670

Note: a blank cell indicates no change, bold indicates final package

Highlight: Air Sealing

The homes built in CHISPA's standard practice have an air leakage rate of about 4 ACH_{50}. This project team aimed to reduce this rate to 2.0 ACH_{50} to improve thermal comfort and reduce energy consumption. A blower door test during a post-drywall site visit revealed a leakage rate of 4.5 ACH_{50} so additional sealing was undertaken by an air sealing specialist. The team focused on typical leakage sites such as the seam where the drywall meets the top plate. Additional sites were identified using smoke-testing and sealed as well as possible. While an effort was made to seal major leaks throughout the construction process, ineffective products and installation required them to be sealed when the walls were closed and they were less accessible. This increased the difficulty and time required to substantially lower the air leakage. The finished product measured 2.3 ACH_{50}.

Source: PG&E Currents

Highlight: Ducts in Conditioned Space

In order to get ahead of the anticipated code requirement that ducts be in conditioned space, CHISPA moved the ducts in the ZNE home from the attic to a dropped ceiling in the hallway. They raised the top plate from 8' to 9' to accommodate this and kept the insulation on the attic floor. The final ducts measured 6.5% interior leakage and zero exterior leakage.

Measures Considered But Not Implemented

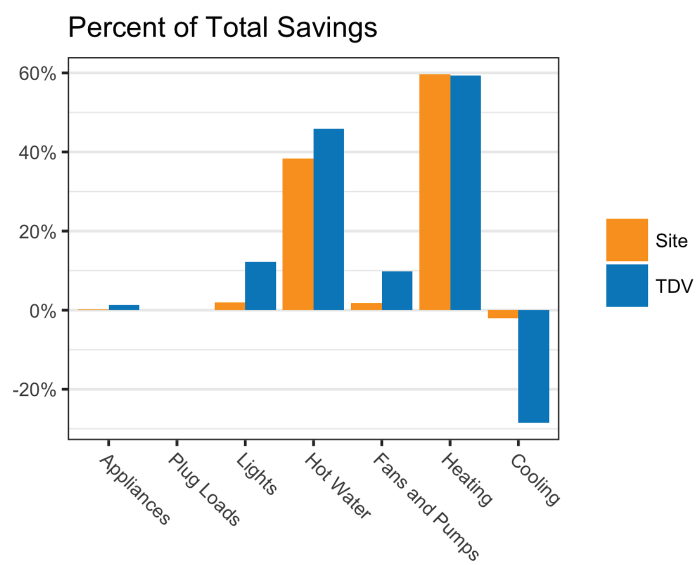
The mechanical engineer of record adjusted the consultants' recommendation of a 1 ton heat pump to a 1.5 ton unit. This was the engineer's first use of a heat pump system, and as the responsible party he wanted to ensure thermal comfort throughout the home. Time and budget constraints also prevented further HVAC system upgrades, including doubling the size of the return air duct grille and adjustments for dry climate air flow (550 CFM/ton).

In order to provide hot water at the fixtures quickly and without wasting water, CHISPA specified a recirculation loop. The consultant team recommended using a push button control system so that the pump would only operate when there was a demand for hot water, but CHISPA went with a timer system.

Other measures that were considered but not implemented include slab edge insulation, which modeling showed to not be very impactful, and some specific advanced framing techniques.

Modeled Energy Performance

The energy savings impact of the implemented energy efficiency measures was evaluated using both site energy and TDV metrics to weigh their impact on the overall modeled energy performance. Because TDV is weighted seasonally and hourly, the modeled energy savings are different in each metric. The final package reduced the modeled site energy consumption by 42% and the modeled TDV energy by 14%, compared to standard practice for the same home model.[3]



As seen to the left, efficiency improvements affecting heating had the most significant impact on both modeled site energy and TDV savings. These improvements include both envelope upgrades and replacing the furnace with a mini-split heat pump. Reductions in water heating energy were the next most impactful for both metrics. In the base case, this house does not have cooling. While adding cooling did not have a major impact on site energy consumption, it introduced a substantial new load in terms of TDV. At the same time, though, it improves thermal comfort.

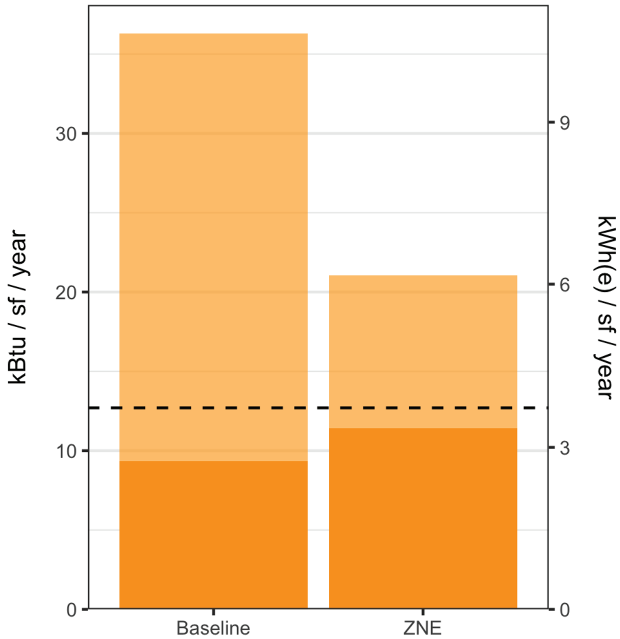
As seen on the next page, the modeled monthly energy consumption shows a U-shape for site energy, reflecting the low summer cooling load. However, because TDV multipliers for electricity are the highest in July through September and affect all end uses, the analogous TDV graph shows a W-shape.

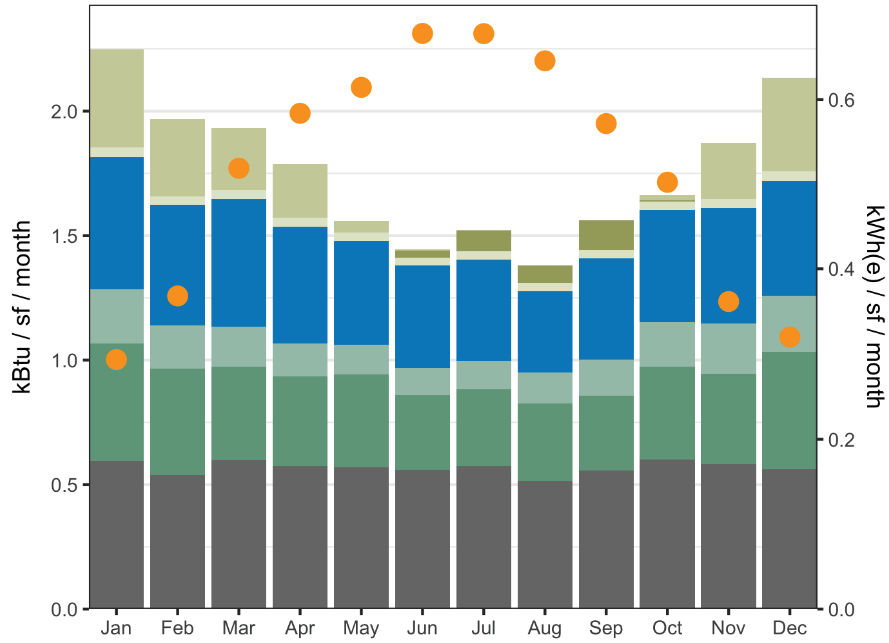
For both site energy and TDV energy, PV production follows an inverted U-shape, with production peaking in the summer months. However the ratio of summer to winter production is very different for the two metrics: for site energy it is only 2.5 times as much, while for TDV it is 5 times as much because of the way that TDV weights summer electricity.

In order to place the site energy modeling results in a larger context, the CHISPA ZNE home modeling results were compared to the performance of an exemplar, based on project results from *The Technical Feasibility of Zero Net Energy Buildings in California*.[4] The CHISPA ZNE package's modeled EUI, 21.1 kBtu/sf/yr, was about 60% higher than the EUI of the exemplar in Climate Zone 3, the closest one considered in the report. However the EUI metric privileges large buildings because major loads such as water heating and appliances scale by the number bedrooms instead of floor area. The exemplar building is 2,100 sf, 40% bigger than the CHISPA house, and they both have 3 bedrooms. Comparing to the performance of the exemplar using the number of bedrooms plus one as a proxy for number of occupants, the ZNE package is modeled as using 8% less energy per person than the exemplar.

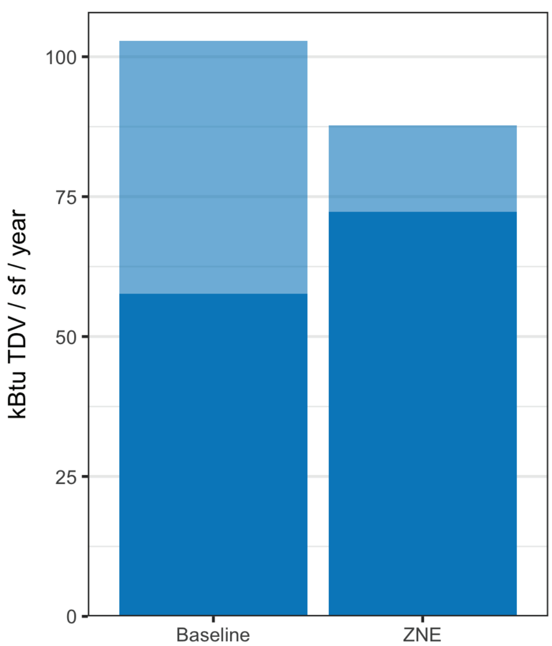
[3] Energy modeling was done with BEopt 2.3 using the 2013 CEC weather file for California climate zone 4.
[4] http://www.calmac.org/publications/California_ZNE_Technical_Feasibility_Report_CALMAC_PGE0326.01.pdf

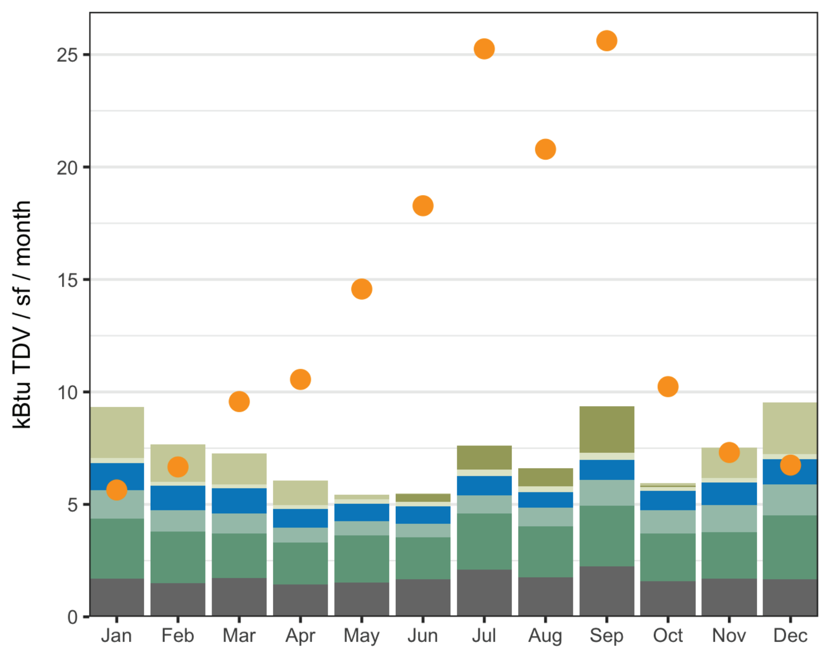
Modeled Site Energy





Modeled TDV Energy





Lessons Learned

Timeline Management

Timing barriers were responsible for many changes that resulted in cost increases, both in architectural fees and in actual construction. The Demonstration targeted projects that were already in the construction pipeline, which meant changes such as switching to 2x6 exterior walls, changing the roof shape, and raising the top plate required redesign. For a project starting from scratch, this would be baked into the original costs and not represent additional work.

On the construction side, reaching the air sealing target of 2 ACH_{50} was also made more difficult and costly due to timing. Air leakage tests and adjustments were made after drywall was installed, making access to the leakage sites challenging. Moving forward, projects should be tested for air leakage after the rough plumbing and electrical are completed, just before insulation is installed, so that it will be easier to find and seal most air leaks.

Financial Findings

The total incremental cost associated with the ZNE package was about $36.7k. Approximately $18.7k of incremental cost was spent on design work that can be reused in future projects, meaning future ZNE homes built by CHISPA should have much lower incremental cost once design is finalized. Equipment, material and installation incremental costs included $6.5k in HVAC improvements, $5.2k for envelope changes, $3.8k in water heating system upgrades, and $1.8k for appliances. Incremental labor cost is expected to decrease in future projects as the contractor learning curve improves.

Source: CHISPA

Completion and Next Steps

CHISPA will continue to implement some of the measures they piloted in this ZNE demonstration house during home construction of the Cambria Park subdivision:

- Condensing water heater
- 100% LED lighting
- Improved air sealing
- Increased attic insulation (R-38)
- Radiant barrier roof sheathing
- Cool roofing
- Non-batt insulation, which is more immune to installation defects

In addition, this project has changed how CHISPA thinks about their buildings; they now use a table like the one in this case study to explicitly consider energy efficiency measures.

PROJECT TEAM

Builder Team:

Community Housing Improvement Systems and Planning Association, Inc. (CHISPA)

ZNE Team:

PG&E

Design AVEnues LLC

Chitwood Energy Management, Inc.

Stave Easley & Associates, Inc.

Resource Refocus LLC

Frontier Energy, Inc.

This case study was written by Resource Refocus LLC based on consultant reports and project analysis.

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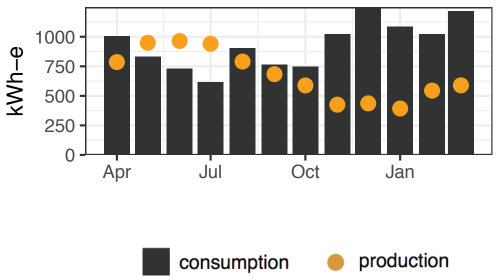
Community Housing Improvement Systems and Planning Association, Inc. (CHISPA) *Monitoring Case Study*

Measured Site Energy: Monthly Consumption and Production



Energy Overview	Mod.	Meas.
EUI kBtu/sf/yr	21.1	32.8
PV Production kBtu/sf/yr	20.9	23.6
Offset % Site Energy	99%	72%

PROJECT OVERVIEW

Floor Area: 1,167 sf

Bedrooms: 3

Location: Greenfield, CA

CA Climate Zone: 4

Completion: February 2016

Monitoring Dates: April 2017 - March 2018 (after occupancy)

PV Array: 4.48 kW

Under the auspices of Pacific Gas and Electric Company's (PG&E) Zero Net Energy (ZNE) Production Builder Demonstration, Community Housing Improvement Systems and Planning Association, Inc. (CHISPA) built a ZNE home with an upgraded envelope, a 1.5-ton ducted mini-split heat pump in a hall soffit, a condensing gas tankless water heater, and 3 tubular skylights. The 4.48 kW PV array has an expected generation sufficient to offset the modeled TDV energy consumption. During the year of monitoring, the solar energy produced by the PV array offset 72% of annual site energy consumption, less than the 99% predicted by the energy modeling. Heating, ventilation, and air conditioning (HVAC) loads were reduced enough that water heating and appliances were the two largest end uses; together they accounted for 67% of the consumption.[1]

Measured Energy Performance

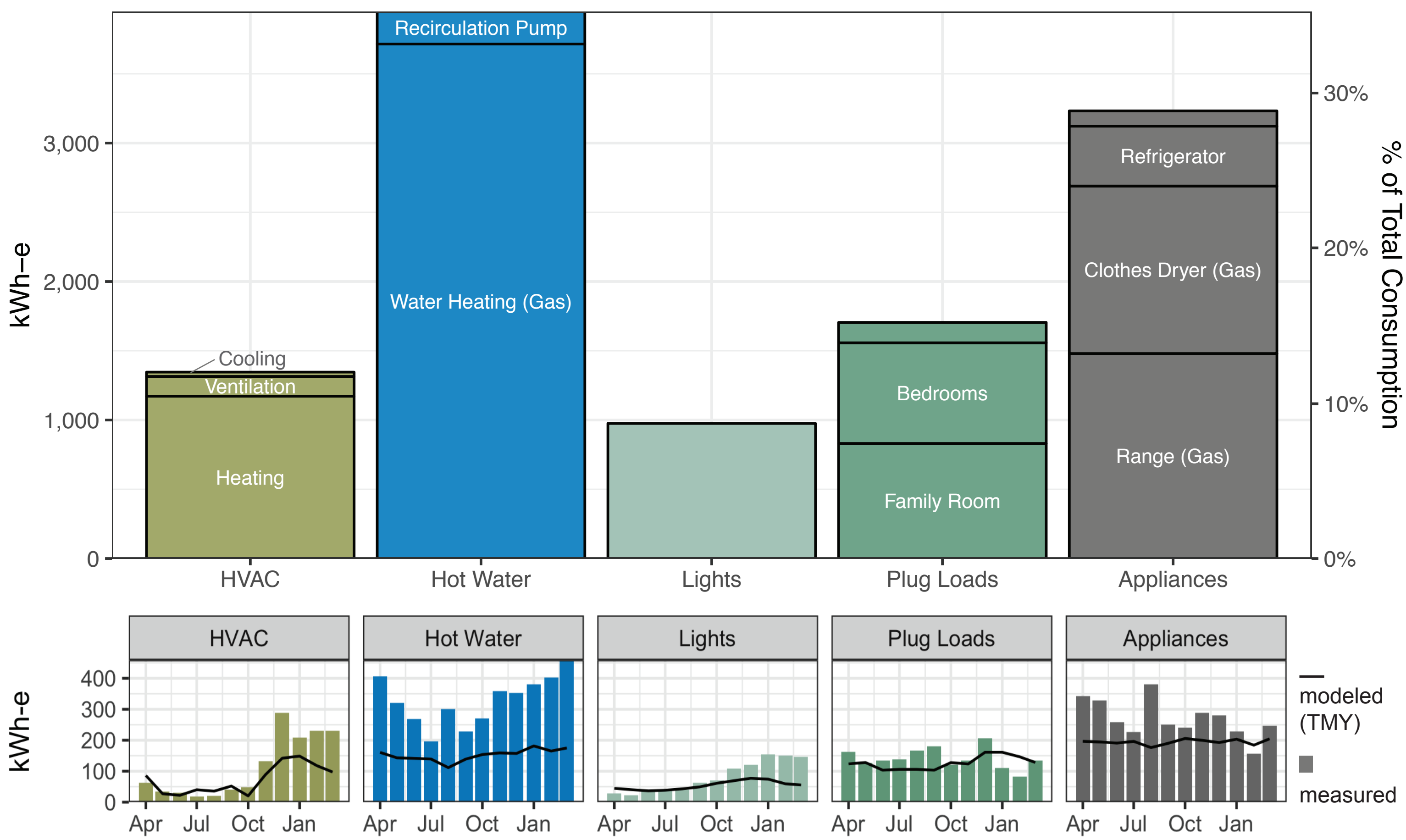
The energy consumption of specific end uses was monitored for a year to understand the house's performance while occupied.

To align with California building energy code, the ZNE goal for this project was based on Time Dependent Valuation (TDV). Because TDV is a modeling metric that cannot be accurately assessed for measured energy performance data,[2] ZNE performance was evaluated using the site energy performance predictions of the TDV model. The measured data showed that the PV production offset only 72% of site energy consumption, substantially less than the 99% predicted by the model, so the performance was not in line with the home's ZNE design.[3]

Site energy production was 13% more than modeled, but consumption was 56% more than modeled. Half of the increase in consumption was due to hot water, and the other half was primarily due to appliances and space heating.

[1] "End use" refers to the final work that the energy did. For example, electricity might be ultimately used to run appliances, and natural gas might be used to heat water.
[2] TDV multipliers are tied to specific weather, grid, and economic projections and assumptions that will not be met exactly over the course of a year, so it is not appropriate to apply them to measured data.
[3] See design case study for information about building specs and design decisions.

Measured Site Energy



The figures above show the measured energy consumption broken down by end use for the entire year of monitoring and by month. On the facing page, the charts compare modeled and measured energy consumption and outdoor temperature.

HVAC

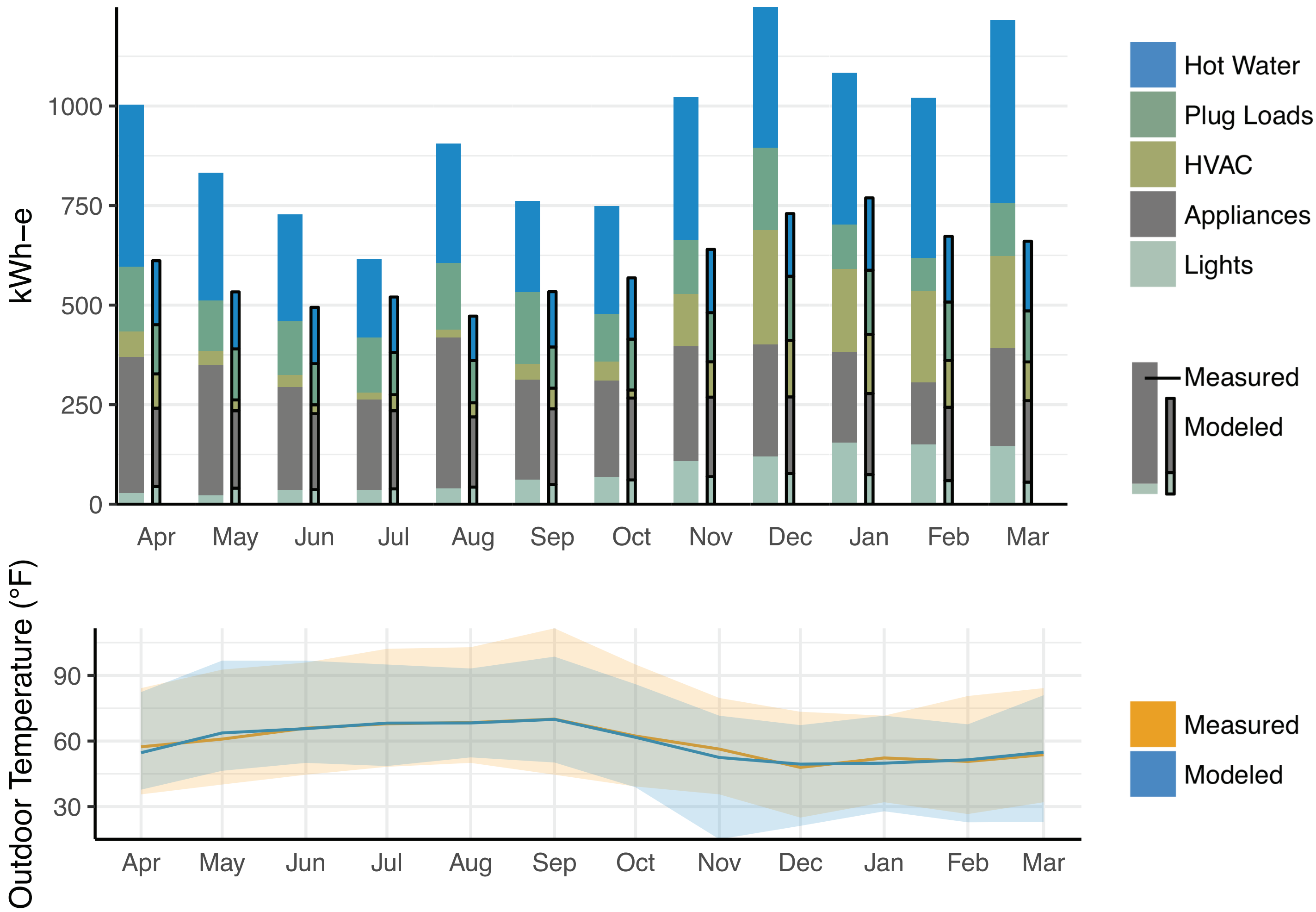
Heating consumption was not quite twice as much as was predicted. The energy model was run twice – once with the Typical Meteorological Year (TMY) weather file that is used for code compliance and once with the Actual Meteorological Year (AMY) weather file that corresponds to the real weather during the monitoring period.[4] Heating was 83% more than what was predicted using TMY weather and 100% more than using AMY weather. Despite this large increase over the model, heating was only 10% of total consumption. On the other hand, the occupants almost did not use the air conditioning. Cooling consumed 70-75% less than modeled, only 31 kWh in the entire year. None of the other homes constructed in the same development have air conditioning; perhaps this low use is related.

Hot Water

Domestic hot water was the single biggest end use, accounting for 35% of the total consumption. This includes both the gas consumption by the water heater itself and the electricity of the recirculation pump. The recirculation is discussed in more detail on the back page of this case study.

[4] Elsewhere in the case study, modeled numbers refer to the TMY data.

Energy and Temperature Comparisons: Modeled vs Measured



Lights
The energy consumption for hard-wired lighting accounted for 9% of overall consumption and was 50% more than modeled even without including plug-in lamps.

Plug Loads
Plug loads accounted for 15% of the total consumption. The family room by itself accounted for almost half of the plug load consumption and 7% of the household consumption. In all, plug load consumption was 12% more than modeled.

Appliances
Appliances were the second largest end use, accounting for 29% of the measured energy consumption. This was dominated by the gas stove (46%) and gas dryer (37%); each were responsible for at least as much energy consumption as space heating.

Source: Resource Refocus LLC

Highlight: Hot Water Recirculation

This house has a hot water recirculation loop to reduce the time it takes for hot water to arrive at a fixture. The ZNE design team recommended push button controls so that the recirculation pump would only run when an occupant requests hot water, but the installed controls are based on a timer. Recirculation pumps do reduce the amount of water that is wasted while waiting for it to get hot, but they can also significantly increase heat loss through the pipes. Without one, the hot water remaining in the pipes after use cools off once, but with a timer-based pump the lost heat is being replenished almost constantly. Various simulation and field studies estimate that timer-based systems can have anywhere from a marginal decrease to a 60% increase in water heating energy, depending on assumptions and occupant behavior.[5] In this case, the measured gas consumption from the water heater was more than twice as much as modeled. It is hard to pinpoint how much of this difference was due to occupant behavior compared to equipment issues and the recirculation loop without measuring the hot water use (gallons) in addition to the energy to heat it, but the recirculation definitely played a role.

Lessons Learned

Over the course of the first year of occupancy, the occupied house consumed more than 50% more energy than modeled, principally because of hot water. The three pieces of gas equipment – water heater, cooking range, dryer – accounted for 59% of the total measured site energy consumption.

Especially in ZNE homes, where HVAC has been carefully designed to be energy efficient, the unregulated end uses of plug loads, appliances, and lighting make up a large portion of the total energy consumption; 53% in this case. The dryer and the range each consumed as much site energy as the HVAC did. Although homeowners are typically responsible for buying their own appliances, builders can have a big impact on energy consumption by supplying efficient appliances.

[5] California Building Energy Code Compliance 2019 Residential Standards compliance software. Gas Technology Institute, 2015. "Evaluation of Residential Recirculation Pumps" https://www.etcc-ca.com/reports/evaluation-residential-recirculation-pumps.

PROJECT TEAM

Builder Team:

Community Housing Improvement Systems and Planning Association, Inc. (CHISPA)

Monitoring Team:

Frontier Energy, Inc.

ZNE Team:

PG&E

Design AVEnues LLC

Chitwood Energy Management, Inc.

Steve Easley & Associates, Inc.

Resource Refocus LLC

This case study was written by Resource Refocus LLC based on consultant reports and project analysis.

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

APPENDIX B: DE YOUNG CASE STUDIES

Zero Net Energy Demonstration Home
De Young Properties
Design Case Study

Source: Frontier Energy, Inc.

PROJECT OVERVIEW

Floor Area: 2,024 sf

Bedrooms: 3

Location: Clovis, CA

CA Climate Zone: 13

Completion: May 2017

Modeled EUI: 26.8 kBtu/sf/yr

PV Array: 5.58 kW

De Young Properties completed their second zero net energy (ZNE) demonstration house with support from Pacific Gas and Electric Company (PG&E) and its consultant team. De Young is a family-owned single-family home construction company, with core commitment to energy efficiency and smart home development. This demonstration project further refined their existing building efficiency practices. The project team was able to reduce the modeled site energy consumption by 11% compared to their standard practice at the time, mainly by going from 2x4 to 2x6 walls, moving the attic insulation directly under the roof deck, and installing a higher efficiency air conditioner. Since this project, De Young has been working on a community of 36 ZNE homes.

PG&E ZNE Production Builder Demonstration

The State of California has a goal that all new residential buildings be zero net energy (ZNE) by 2020.[1] To support builders in designing and constructing ZNE homes, PG&E offered support through a ZNE Production Builder Demonstration. Participating builders received technical support from start to finish to upgrade one of their existing prototypes to ZNE while preserving their look and feel, and in a way that works for their team. The ultimate goal was to achieve a ZNE home that the builder could replicate to begin to build ZNE homes at scale. For each builder, the design consultants recommended energy efficiency measures for the builder's standard design based on performance modeling and substantial past experience with zero net energy and energy-efficient homes. They also visited the site during construction to ensure that the measures were being properly installed. As part of this offering, PG&E reimbursed up to $15,000 in incremental cost of the energy efficiency measures; experience shows that the incremental costs will drop in subsequent projects. Finally, the monitoring consultants tracked the end-use energy consumption of the completed home for a year after occupancy to determine whether the ZNE home is performing as designed and to diagnose any operational issues.

[1] CPUC (2017) "Energy Efficiency Strategic Plan"
http://www.cpuc.ca.gov/General.aspx?id=4125

ZNE Goal and Project Approach

The ZNE goal for the Production Builder Demonstration as a whole was zero net TDV to align with California building energy code, which incorporates Time Dependent Valuation (TDV).[2] However, De Young chose zero net source energy for this particular project because they believe that it is the ZNE definition most easily understood by homeowners.

De Young has been experimenting with high performance building products and techniques since 2010 and continues to do so. The focus of this project was the high performance attic that brought ducts into semi-conditioned space.

De Young Zero Net Energy Package

Broadly, De Young implemented four energy efficiency measures beyond their standard practice to reduce the modeled site energy consumption of the house by 11%:

- Advanced framed walls with 2x6, 24" oc to reduce thermal bridging and improve wall insulation, increasing the cavity insulation from R-17 to R-21 total
- Raising the attic insulation to directly under the roof deck to bring the ducts into semi-conditioned space
- Increasing the efficiency of the air conditioner from 16 to 19 SEER
- Using 100% LEDs

Upgrading the water heater is a typical energy efficiency measure. De Young's standard practice is already a gas tankless condensing water heater with EF=0.96, so it was left unchanged in the ZNE package. The home was modeled to meet its source ZNE design goal with a 5.58 kW PV array.

[2] TDV values energy differently based on its source and on when and where it is consumed or produced. Because "peak" electricity during hot summer afternoons is the most costly energy for the grid operators to produce, procure and deliver, it is weighted the most heavily by TDV.

"The De Young ZE Home supports the California Long Term Energy Efficiency Strategic Plan that will eventually require all new homes in California to be Zero Net Energy, and it sets an example for new home construction for years to come" ***-De Young Advertisement***

Detailed Specifications and Costs

		Baseline	ZNE
Envelope			
Exterior Walls	cavity R value, insulation type	R-15 fiberglass	**R-21 fiberglass**
	framing type, spacing	2x4 16" oc	**2x6, 24" oc**
	continuous insulation	**R-4 EPS**	
Glazing	U / SHGC	**0.28 U / 0.23 SHGC**	
	WWR	**20% WWR**	
	shading		
	skylights	**no skylights**	
Roof	insulation type, R value	R-49 fiberglass	**R-38 fiberglass**
	insulation location	attic floor	**under roof deck**
	vented/unvented attic	vented attic	**unvented attic**
	radiant barrier	radiant barrier	**no radiant barrier**
Foundation	type	**slab**	
	insulation	**none**	
Air Leakage	ACH50	4.4 ACH50	**4 ACH50**
HVAC System			
Ventilation	type	**balanced**	
Heating & Cooling	heating system type	**gas furnace, 2 stage**	
	heating efficiency	**96%**	
	cooling system type	**split system a/c**	
	cooling efficiency	16 SEER	**19 SEER, 14 EER**
	cooling capacity	3 tons	**2.5 tons**
	equipment location	unconditioned attic	**semi-conditioned attic**
	thermostat	code-compliant setback	**smart thermostat**
Ducts	location	unconditioned attic	**semi-conditioned attic**
	insulation	**R-8**	
	change in duct length		**none**
Water Heating			
Water Heater	water heater type, efficiency	**tankless gas condensing, 0.96 EF**	
	equipment location	**garage**	
DHW Distribution	insulation, pipe material	**R-2 PEX**	
	recirculation	none	**installed**
	low flow fixtures		
Electric Loads			
Lighting	type	80% LED, 20% CFL	**100% LED**
Appliances	fridge	fridge	**ENERGY STAR fridge**
	cooking	**gas cooking**	
	dishwasher, washer	**ENERGY STAR**	
	dryer	**electric dryer**	
Other		**gas fireplace**	

Note: a blank cell indicates no change, bold indicates final package

Highlight: Ducts in Semi-Conditioned Space

The project team considered several methods shifting attic insulation to directly under the roof deck to bring the attic into the thermal envelope. Without any venting or active conditioning, the attic becomes a semi-conditioned space, so the ducts can remain there without the large efficiency penalty that typically comes with putting ducts in the attic.

Ultimately they chose to use a Johns Manville solution of gluing fiberglass batts under the roof deck with wire underneath as a backup. This approach was a couple of days slower but half the incremental cost of the Owens Corning boxed netting approach that they installed in another house.[3]

One common concern with sealed attics is that moisture will build up and create a mold problem. De Young worked with a team at Lawrence Berkeley National Laboratory to assess the risk of mold. Based on detailed simulation and heavy instrumentation of a similar installation, the team concluded that mold is not an issue in sealed attics in the dry Fresno climate.[4]

Source: BIRAenergy

Measures Considered But Not Implemented

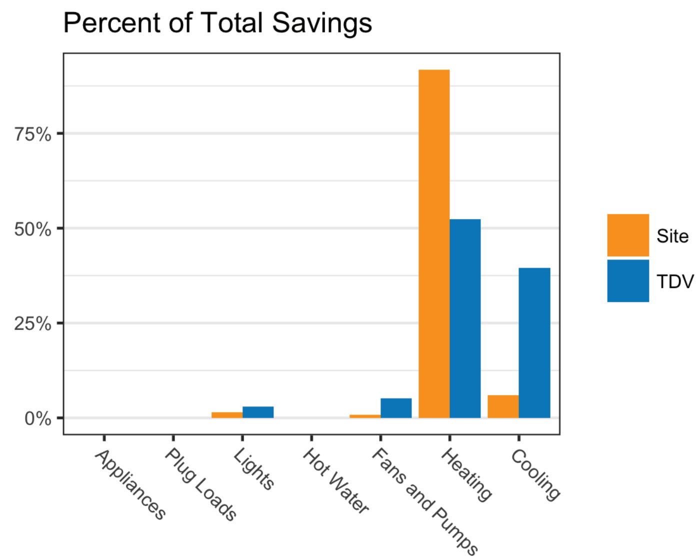
In line with their tendency to try new products and systems, De Young considered a combined heat recovery and greywater system that would save both energy and water for irrigation. It recovers heat from the greywater from the showers and clothes washer before sending that water out to irrigate the yard. They decided against the system because of cost, the possibility that homeowners would not use appropriate biodegradable soaps or maintain it properly, and concerns about its acceptability to local jurisdictions when permitting.

They also considered installing a heat pump water heater (HPWH) instead of a gas condensing tankless water heater. Their main metric for the decision was cost to the homeowner. Because they were making the choice during a time of historically low prices for natural gas, they calculated that the HPWH would have the same operating cost only if it were used in conjunction with the heat recovery system. Other factors that went into the decision to not install a HPWH were the higher first cost, lack of information about the expected lifespan of the equipment, and lower-than-expected performance observed in other homes.

[3] See the PulteGroup design case study for more information on this approach.
[4] Less, B et al. 2018. Measured Thermal and Moisture Performance of an Air Sealed and Insulated Attic with Porous Insulation. ACEEE Summer Study in Buildings. https://aceee.org/files/proceedings/2018/assets/attachments/0194_0286_000235.pdf

Modeled Energy Performance

The implemented energy efficiency measures reduced modeled site energy consumption by 11% and modeled TDV energy consumption by 9% compared to De Young's standard practice. In terms of site energy, 90% of the modeled savings were from heating and 6% from cooling. Although they were also the top two sources of savings in terms of TDV energy, cooling had a proportionally larger impact: 52% from heating, 40% from cooling. This is because of how TDV weighs electricity, particularly electricity during peak summer times, much more heavily than gas.



Modeled monthly energy consumption is mostly U-shaped for site energy but W-shaped for TDV energy. This difference is because of how much more heavily TDV weighs electricity compared to gas. The seasonal dependence of TDV can also be seen in the higher appliance consumption in July through September compared to the rest of the year.

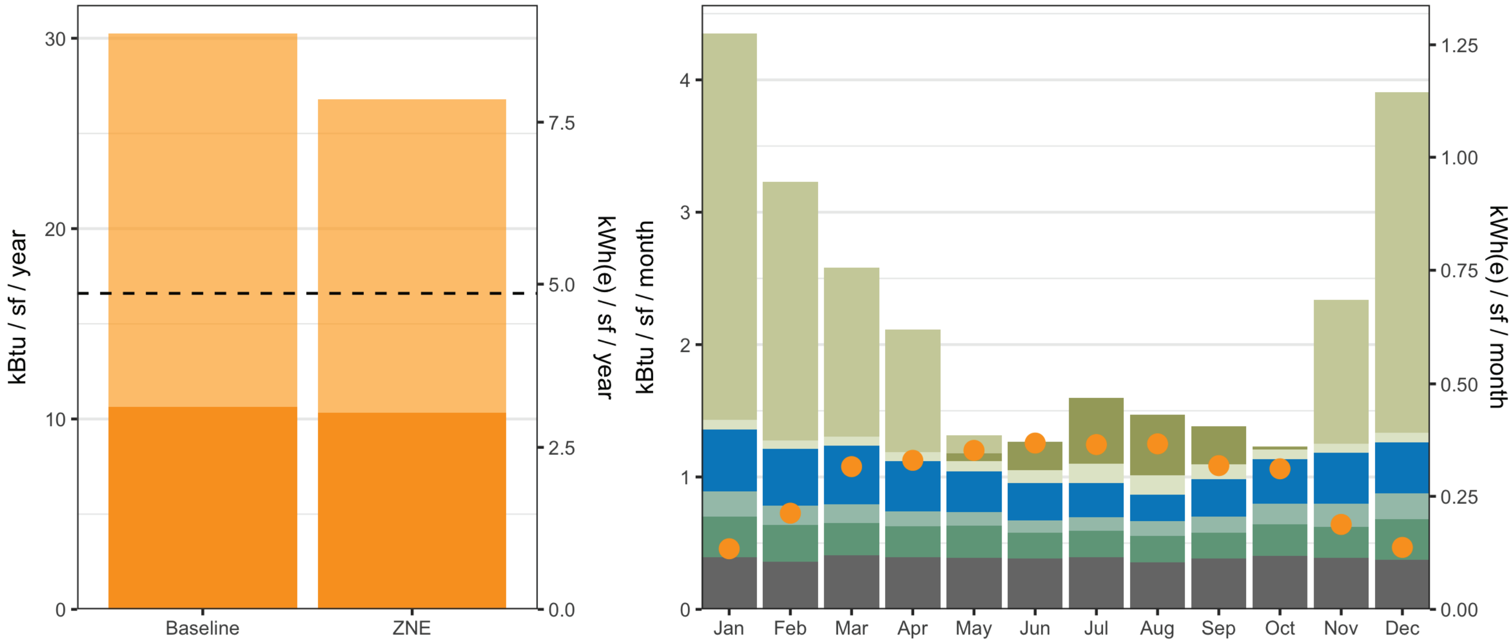
For both site and TDV energy, PV production follows an inverted U-shape, with production peaking in the summer months. However, the TDV peak is much more extreme than the site peak because afternoon electricity in the summer, when solar panels are producing the most solar electricity, is so valuable in terms of TDV.

In order to place the site energy modeling results in a larger context, they were compared to the performance of an exemplar, as reported in *The Technical Feasibility of Zero Net Energy Buildings in California*.[5] The De Young ZNE package's modeled EUI, 26.8 kBtu/sf/yr, was much higher than the 16.4 kBtu/sf/yr EUI as the exemplar in the same climate zone. This gap is primarily due to the gas furnace. When modeling, some loads, such as heating and cooling, vary depending on floor area, but others, such as water heating, appliances, and plug loads, vary mostly based on the number of occupants. However, because this home is virtually identical in size and makeup to the exemplar home used for the modeling, the comparison of the two packages is the same when examining per person and per square foot metrics.

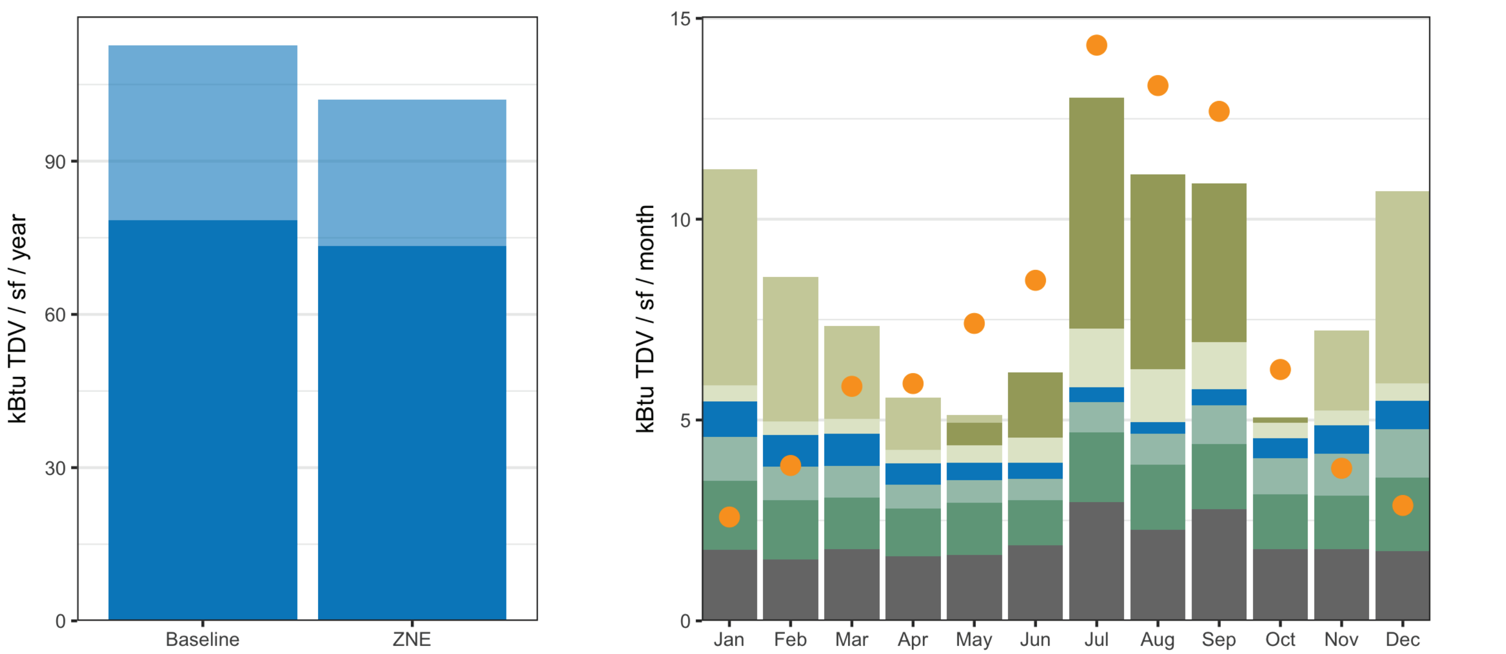
[5] http://www.calmac.org/publications/California_ZNE_Technical_Feasibility_Report_CALMAC_PGE0326.01.pdf

"We are committed to leading-edge, energy-efficient building science and technology to ensure our customers are living in state-of-the-art homes that are more affordable, healthier to live in, and better for the environment." ***-De Young Advertisement***

Modeled Site Energy



Modeled TDV Energy



Lessons Learned

Wall Framing

While participating in the Demonstration, De Young was in the middle of converting all of their plans from 2x4 into 2x6 walls. This was a significant investment, but they wanted to have their plans adjusted well ahead of the 2019 code requirements. The largest component of the incremental cost was actually redrawing the plans, especially because they all then needed review by the management team, but the lumber and labor for framing also contributed to the cost increase. Because they build their homes right up against the setbacks, increasing the width of the walls marginally decreased the conditioned floor area, which affects their sales and marketing teams.

Air Sealing

Because the attic was brought into the thermal envelope by moving the insulation from the attic floor to directly under the roof deck, the air barrier also needed to move to encompass the attic. However a site walk during construction before the walls were closed showed a large hole from an overhang into the attic, a hole cut for a ventilation fan in the attic, and other gaps. These would be fine in a house with a vented attic, like all the rest of the homes in the subdivision, but would undermine the performance of the sealed attic. Because of the site walk, these holes were able to be sealed relatively easily. This is an example of how changes in one component of a home need to be communicated through to all the trades because usually more than one is affected by any given change.

ZNE Metric and Natural Gas

The energy metric used to calculate ZNE for this project was source energy. Although it was chosen for marketing reasons, namely to be more easily understood by homeowners, it also has an effect on design decisions. In particular, the three common energy metrics in California – site, source, and TDV – vary considerably in the relative influence on total energy consumption of natural gas compared to electricity. Natural gas consumption has a large impact on total site energy consumption, but it has a much smaller impact using the TDV or source energy metrics. For this house, gas is about 60% of the modeled site consumption and only about 30% of the modeled TDV and source energy consumption. This means that electrifying end uses such as space and water heating is a high priority for reducing site energy consumption but not for reducing TDV or source energy consumption.

"This breakthrough makes purchasing a Zero Energy Home financially feasible for homebuyers here in the Central Valley today and is a momentous step towards what is coming next in today's housing market-zero energy homes for the public at large."

-Brandon De Young, De Young Properties

Source: Resource Refocus LLC

Completion and Next Steps

The De Young ZNE home was completed in May 2017 and occupied in October 2017.

De Young has completely embraced ZNE; while working on this project they updated their standard practice to include virtually all of the efficiency features present in this house. But they have not stopped there. They are currently working with the Electric Power Research Institute (EPRI), PG&E, and BIRAenergy to build a whole community of 36 ZNE homes at EnVision in Clovis, CA as well as several model homes.[6] They are continuing to try out new products and specifications, such as heat pumps for space heating and clothes drying, reflective exterior paint, and multiple methods for building sealed attics with insulation directly under the roof deck.

[6] https://deyoungproperties.com/blog/just-announced-de-young-properties-unveils-largest-grid-connected-zero-energy-community-state/

PROJECT TEAM

Builder Team:

De Young Properties

ZNE Team:

PG&E

BIRAenergy

Frontier Energy, Inc.

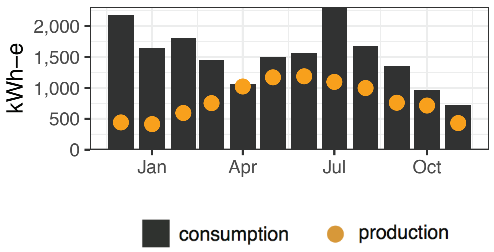
Resource Refocus LLC

This case study was written by Resource Refocus LLC based on consultant reports and project analysis.

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

De Young Properties
Monitoring Case Study

Measured Site Energy: Monthly Consumption and Production



Energy Overview	Mod.	Meas.
EUI kBtu/sf/yr	26.3	30.6
PV Production kBtu/sf/yr	12.3	16.1
Offset % Site Energy	47%	53%

PROJECT OVERVIEW

Floor Area: 2,024 sf

Bedrooms: 3

Location: Clovis, CA

CA Climate Zone: 13

Completion: May 2017

Monitoring Dates: December 2017 - November 2018 (after occupancy)

PV Array: 5.58 kW

Under the auspices of Pacific Gas and Electric Company's (PG&E) Zero Net Energy (ZNE) Production Builder Demonstration, De Young Properties built a ZNE home with increased wall insulation, ducts in semi-conditioned space, and a high efficiency air conditioner that combined to reduce the modeled energy consumption by 11% compared to their standard practice at that time. The 5.58 kW PV array has an expected generation sufficient to offset the modeled source energy consumption. During the year of monitoring, the solar energy produced by the PV array offset 53% of annual site energy consumption, commensurate with the 47% predicted by the energy modeling. Heating, ventilation, and air conditioning (HVAC) loads and water heating were the two largest end uses; together they accounted for 66% of the consumption.[1]

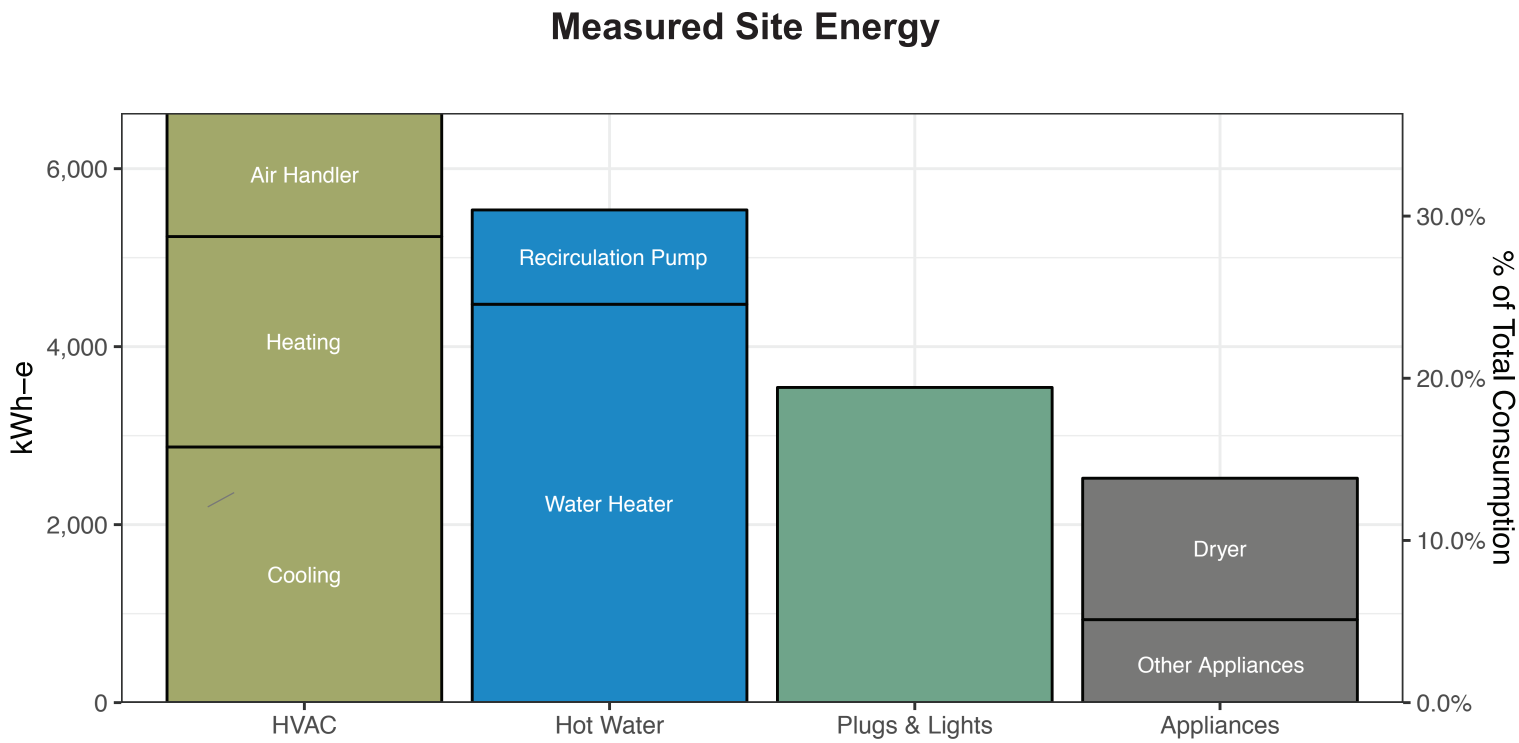
Measured Energy Performance

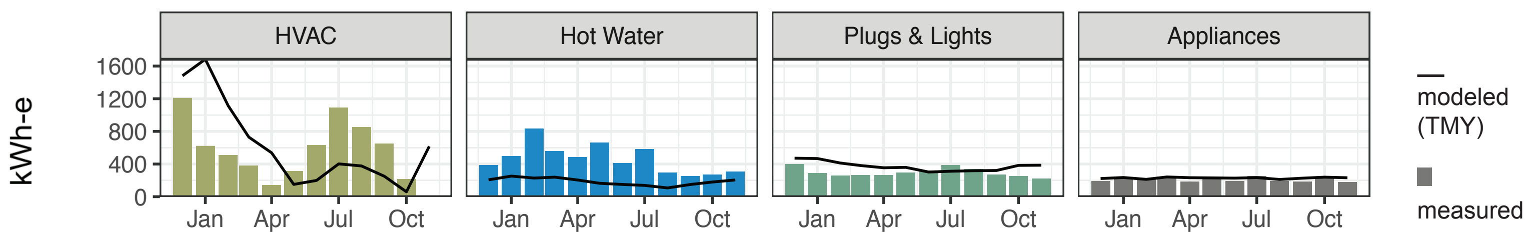
The energy consumption of specific end uses was monitored for a year to understand the house's performance while occupied.

To align with California building energy code, the ZNE goal for the Demonstration was based on Time Dependent Valuation (TDV). Because TDV is a modeling metric that cannot be accurately assessed for measured energy performance data,[2] ZNE performance was evaluated using the site energy performance predictions of the TDV model. The measured data showed that the PV production offset 53% of site energy consumption, slightly more than the 47% predicted by the model, so the performance was in line with the home's ZNE design.[3]

Site energy consumption was 16% more than modeled, but production was 30% more than modeled, so the net balance was consistent with the model. The majority of the increase in consumption was due to hot water, with a significant contribution from cooling as well.

[1] "End use" refers to the final work that the energy did. For example, electricity might be ultimately used to run appliances, and natural gas might be used to heat water.
[2] TDV multipliers are tied to specific weather, grid, and economic projections and assumptions that will not be met exactly over the course of a year, so it is not appropriate to apply them to measured data.
[3] See design case study for information about building specs and design decisions.





The figures above show the measured energy consumption broken down by end use for the entire year of monitoring and by month. On the facing page, the charts compare modeled and measured energy consumption and outdoor temperature.

HVAC

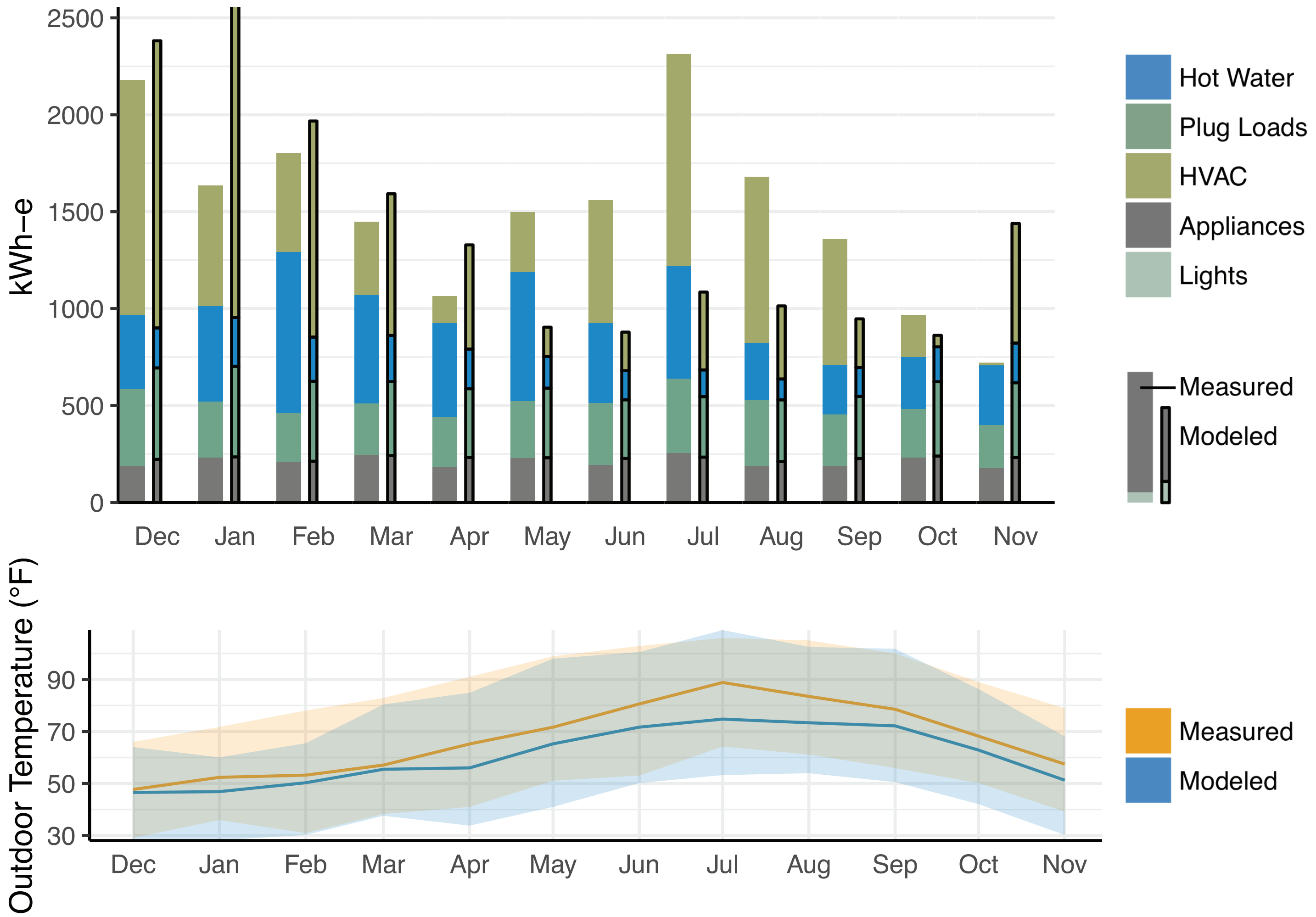
HVAC energy accounted for 36% of the total consumption. The energy model was run twice – once with the Typical Meteorological Year (TMY) weather file that is used for code compliance and once with the Actual Meteorological Year (AMY) weather file that corresponds to the real weather during the monitoring period.[4] In this case, the AMY data was substantially warmer than the TMY data, so the measured heating was much less than the TMY model and the cooling was much more: 58% less and 148% more respectively. However, when compared using the AMY model, both heating and cooling were more than modeled, although the difference was not as great: 11% and 72% respectively. Taken together, HVAC consumption was 12% less than the TMY model and 40% more than the AMY model.

Hot Water

Domestic hot water accounted for 30% of the total consumption, more than heating or cooling on their own. It was more than twice as much as predicted by the modeling.

[4] Elsewhere in the case study, modeled numbers refer to the TMY data.

Energy and Temperature Comparisons: Modeled vs Measured



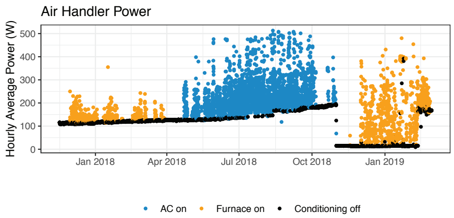
Plug Loads and Lights

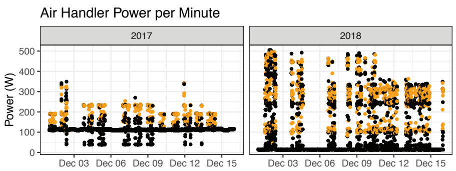
Plug loads and lights together accounted for 20% of measured energy use, and the total was less than 2% more than modeled.[5] It is unusual for the measured and modeled energy consumption of plug loads to be so consistent because plug loads are entirely driven by occupant behavior; the builder and designers have very little influence in this realm.

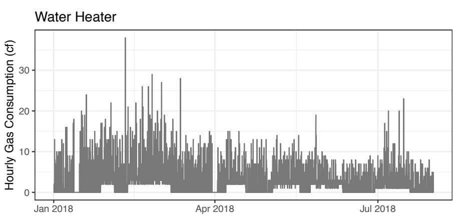
Appliances

Appliances were the smallest end use, accounting for only 14% of total consumption. They were also the only end use to consume less energy than predicted by the AMY model; the difference was approximately 8%.

[5] Plug loads and lights were wired on the same circuits and must be considered together.







Highlight: Continuous Operation

For the first 10 months of occupancy, the air handler fan was on almost continuously regardless of whether there was a call for heating or cooling. As shown in the top figure to the left, the minimum hourly average power also increased gradually during this time, likely because of particle buildup in the air filter. In October 2018 the HVAC contractor replaced a faulty relay board that was causing the nearly continuous operation, and the fan power dropped to zero for much of the time without demand for space conditioning. The middle figure to the left shows the difference between the two run modes for a week in December.[6] However after approximately 3 months the fan returned to continuous operation.

The extra energy consumed from this nearly continuous operation was substantial. During the monitoring period, the air handler fan consumed about 780 kWh during times without a call for heating or cooling. This is approximately half of the increase in measured HVAC consumption compared to the AMY model.

The water heater also had periods of weeks when it was continuously on. It is not known what caused this behavior, but it contributed to the energy used for heating water being about twice as much as the modeling predicted.

Lessons Learned

Over the course of the first year of occupancy, the house consumed approximately 16% more energy than modeled using the typical meteorological year weather. A substantial contributor to the overconsumption was the almost continuous operation of the air handler fan and the water heater during portions of the monitoring period. While many kinds of improper operation of equipment can be difficult to identify, continuous operation often stands out as a clear cause of overconsumption and can therefore be one of the first performance issues to address.

PROJECT TEAM

Builder Team:

De Young Properties

Monitoring Team:

Frontier Energy, Inc.

ZNE Team:

PG&E

BIRAenergy

Resource Refocus LLC

This case study was written by Resource Refocus LLC based on consultant reports and project analysis.

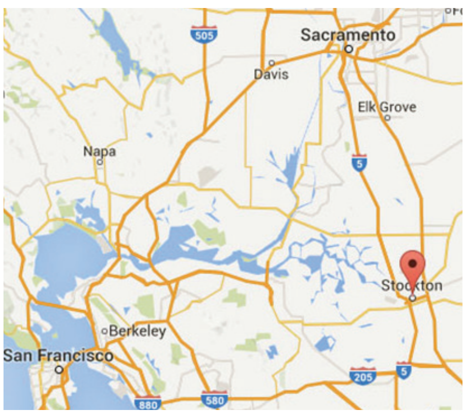
[6] The natural gas meter does not have a high resolution - it measures in increments of one cubic foot - so many of the minutes where the fan power exceeds the baseline are likely to be during periods of heating even though they are colored black in the graph.

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

APPENDIX C: SJC HABITAT CASE STUDIES

Zero Net Energy Demonstration Home Habitat for Humanity of San Joaquin County *Design Case Study*

Source: Chitwood Energy Management



PROJECT OVERVIEW

Floor Area: 1,229 sf

Bedrooms: 3

Location: Stockton, CA

CA Climate Zone: 12

Completion: February 2016

Modeled EUI: 21.8 kBtu/sf/yr

PV Array: 3.36 kW

Habitat for Humanity of San Joaquin County (SJC Habitat) completed a zero net energy (ZNE) demonstration house with support from Pacific Gas and Electric Company (PG&E) and its consultant team. The team utilized a volunteer building crew and completed the ZNE package at a $3,000 reduction in incremental cost from the base model. The efficient home design used an integrated collaborative approach to focus on the energy saving benefits of advanced framing and air sealing. SJC Habitat is continuing to innovate new solutions on their low energy design, incorporating the features from this demonstration home into its standard practice and going beyond them in future projects.

About PG&E ZNE Production Builder Demonstration

The State of California has a goal that all new residential buildings be zero net energy (ZNE) by 2020.[1] To support builders in designing and constructing ZNE homes, PG&E offered support through a ZNE Production Builder Demonstration. Participating builders received technical support from start to finish to upgrade one of their existing prototypes to ZNE while preserving their look and feel, and in a way that works for their team. The ultimate goal was to achieve a ZNE home that the builder could replicate to begin to build ZNE homes at scale. For each builder, the design consultants recommended energy efficiency measures for the builder's standard design based on performance modeling and substantial past experience with zero net energy and energy-efficient homes. They also visited the site during construction to ensure that the measures were being properly installed. As part of this offering, PG&E reimbursed up to $15,000 in incremental cost of the energy efficiency measures; experience shows that the incremental costs will drop in subsequent projects. Finally, the monitoring consultants tracked the end-use energy consumption of the completed home for a year after occupancy to determine whether the ZNE home is performing as designed and to diagnose any operational issues.

[1] CPUC (2017) "Energy Efficiency Strategic Plan" http://www.cpuc.ca.gov/General.aspx?id=4125

ZNE Goal and Project Approach

The ZNE goal for the project design was zero net TDV to align with California building energy code, which incorporates Time Dependent Valuation (TDV).[2] The team produced two distinct sets of modeled results for the home. The first was to use modeling to establish a zero net energy design according to the California Energy Commission's TDV metric, the energy metric used to regulate energy use by the building code in California. Once a code-based ZNE design was established, the team then translated the TDV model into a site energy model to represent actual projected energy use.

At SJC Habitat the design team, engineering team, construction management, and all the trades (foundation, framing, roofing, mechanical, electrical, plumbing, etc.) are all the same person. This means that the design process is automatically integrated and collaborative. A simple example of how this collaboration worked on the exterior walls of this home: 1) the framer pre-drilled wiring holes at the bottom of each wall stud while the studs were still in stacks, 2) the electrician ran the wiring through the pre-drilled holes and stapled the wire to the bottom plate and wall studs, and 3) the framer then added insulation to the cavity, an insulation process made simpler and easier (and ultimately more effective thermally) with the absence of wiring "in the way."

SJC Habitat Zero Net Energy Package

SJC Habitat had been iterating energy efficient and ZNE designs for a few years, so there were relatively few changes made to the design during the formal Demonstration project. This case study documents the changes made, and the performance outcomes, from House 1 to House 10 in the subdivision. The major improvements included:

- Wall cavity insulation increased from R-11 to R-21
- R-5 exterior wall insulation added, raising the total wall R-value to R-26
- Air sealing focus increased, with envelope leakage rate reduced to 1.5 ACH_{50}
- Gas furnace and air conditioner replaced by a ¾-ton mini-split heat pump, a large decrease from typical practice
- Ducts moved to conditioned space (dropped hallway ceiling)
- All LED fixtures installed

The ZNE measures reduced the net cost of the home by nearly $3,000, which was made possible by a holistic, highly integrated approach. Framing factor reduced from 0.35 to 0.13 representing a 63% reduction. Framing with careful attention to the placement of each stud reduced required labor and avoided a cost increase from going to 2x4 to 2x6. Compact lay-outs of ducts and water pipes reduced the material required. The increased insulation and ducts in conditioned space allowed the HVAC to be downsized from 3 to ¾ tons.

[2] TDV values energy differently based on its source and on when and where it is consumed or produced. Because "peak" electricity during hot summer afternoons is the most costly energy for the grid operators to produce, procure and deliver, it is weighted the most heavily by TDV.

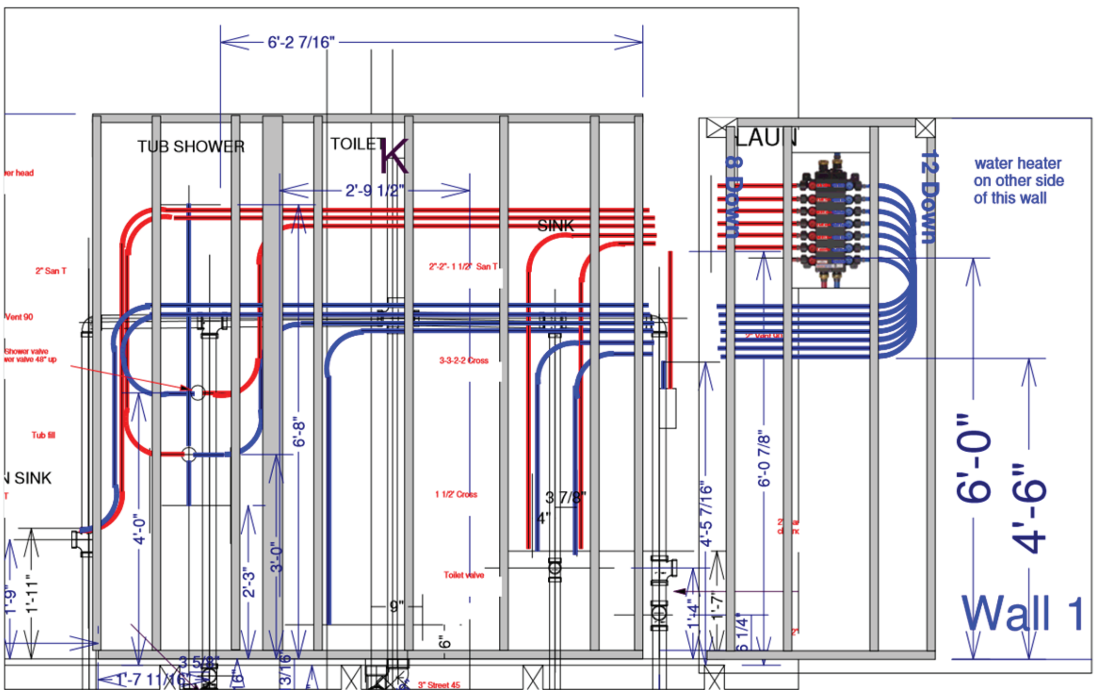
Detailed Specifications and Costs

		Baseline	ZNE	Cost Diff.
Envelope				
Exterior Walls	cavity R value, insulation type	R-11 fiberglass	**R-21 denim**	$ -100
	framing type, spacing	2x4 16" oc, 0.35 framing factor	**2x6, 24" oc, 0.13 framing factor**	$ -300
	continuous insulation	none	**R-5 XPS**	$ 600
Glazing	U / SHGC	0.5 U / 0.25 SHGC	**0.27 U / 0.24 SHGC**	$ -1,505
	WWR	13.2% WWR	**6.4% WWR**	
	shading	**1' eaves**		
	skylights	**no skylights**		
Roof	insulation type, R value	**R-42 cellulose**		
	insulation location	**attic floor**		
	vented/unvented attic	**vented attic**		
	radiant barrier	**radiant barrier**		
	roof material	**composite shingles**		
Foundation	type	slab	**low ventilation crawlspace (0.5 ACH)**	
	insulation		**R-21 denim**	
	framing type, spacing		**4x6, 32" oc**	
Air Leakage	ACH50	4.75 ACH50	**1.5 ACH50**	$ 1,200
HVAC System				
Ventilation	type		**2 ERVs**	donated
Heating & Cooling	heating system type	3-ton split gas furnace	**3/4-ton ducted mini split**	$ -2,000
	heating efficiency	80%	**12.5 HSPF**	
	heating capacity	60,000 Btuh	**12,000 Btuh**	
	cooling system type	conventional a/c		
	cooling efficiency	13 SEER	**24.5 SEER**	
	cooling capacity	3-ton split system	**3/4-ton ducted mini split**	
	equipment location	attic	**cond. space (hall soffit)**	$ -150
	thermostat	code-compliant setback	**wired web-enabled**	
Ducts	location	attic	**dropped ceiling - conditioned space**	
	insulation	**R-8**		
	duct length	250'	**50'**	$ -600
Water Heating				
Water Heater	water heater type, efficiency	**tankless gas, 0.82 EF**		
	equipment location	garage	**interior wall**	
DHW Distribution	insulation, pipe material	**PEX in cond. space**		
	recirculation system	**no recirculation**		
	low flow fixtures	**low flow fixtures**		
	change in pipe length	WH to last fixture 60'	**WH to last fixture 12', avg fixture run 8'**	$ -470
Electric Loads				
Lighting	type	50% CFL, 50% incandescent	**100% LED**	$ 390
Appliances	fridge	fridge	**ENERGY STAR fridge**	donated
	cooking	**electric cooking**		
	dishwasher, washer, dryer	**not provided, assumed inefficient electric**		
Other	indicator lights, switches, etc.		**indicators for garage and porch lights; power disconnect for heat pump and water heater; EV circuit**	$ 73
Total				
				$ -2,862

Note: a blank cell indicates no change, bold indicates final package

Highlight: Integrated, Iterative Design Process

The SJC Habitat Demonstration was unique in the level of investment and awareness the construction manager and the company had of Zero Net Energy practices. The construction manager proactively participated in numerous PG&E-sponsored efficiency and ZNE training classes over the previous few years. At this location, SJC Habitat constructs one new home at time. SJC Habitat has been iteratively incorporating efficiency improvements into each new home in a progressive series of new home models. After each build, the team conducts a cost-benefit analysis and adjusts for the next build accordingly. This “Model 10” ZNE home builds off previous iterations, incorporating the successful features of the previous homes and targeting specific system improvements to achieve the team’s ZNE goals.



Plumbing schematic

Source: Habitat for Humanity of San Joaquin County

Typically, integrated design includes a number of team leaders with varying levels of knowledge, commitment to energy goals, and competency in implementing high-performance building strategies. But in this case, George Koertzen, the SJC Habitat construction manager, fulfilled many roles on site, thereby streamlining integration between various trades. As an example of the integrated approach, the Habitat team carefully located water-using appliances and fixtures to minimize hot water delivery times and water waste. The reduced length of piping runs minimized material costs and energy losses associated with longer runs.

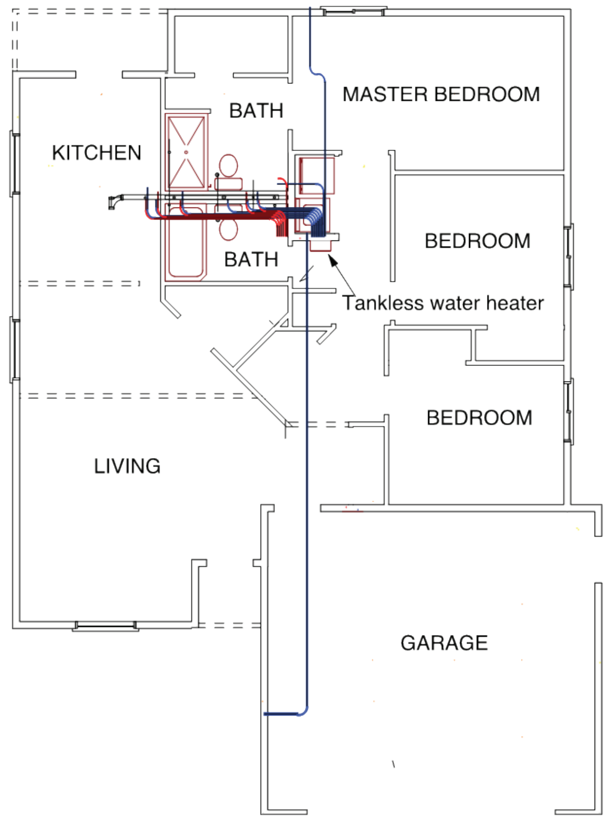
A core part of this Habitat chapter’s approach is to teach the student trainees and volunteers constructing the homes to enact the energy efficient design features and advanced framing best practices. As part of this, detailed templates and large-scale laminated schematics are provided for most tasks to provide consistency house-to-house, crew-to-crew, and to speed construction.

Highlight: Advanced Framing and Compact Design

The ZNE approach adopted by SJC Habitat was two-pronged - first, reevaluate every detail, and then identify and capture cross-trade synergies. SJC Habitat implemented very detailed advanced framing techniques, going far beyond the basic change of increasing stud spacing from 16” to 24”. For example, they slightly modified the dimensions of the walls and windows and the window placement to fit exactly into the 24” module, installed 2 stud corners, and used single top plates. As you can see in the image below, windows were carefully placed to minimize requirements for additional studs, thereby saving material and labor costs and increasing the thermal performance of the wall. All of these techniques resulted in a framing factor of 0.13, 67% less than the original value of 0.35.

This approach is reflected in the enclosure in numerous advanced framing measures, both tried-and-true (albeit rarely implemented) strategies, as well as innovations unique to this project. Examples include locating wires only along the studs and bottom and top plates to minimize insulation obstructions (with notches in the bottom of the studs to facilitate this); ordering windows to fit within the 24-inch stud framing intervals; and to assure that no extra framing lumber is used, showing every allowable stud on the plans.

Grouping all the points of hot water use in the center of the house allowed the longest pipe run to be only 12’, saving water, energy, and material as well as reducing wait times for hot water. A compact design of the duct system achieved similar results.



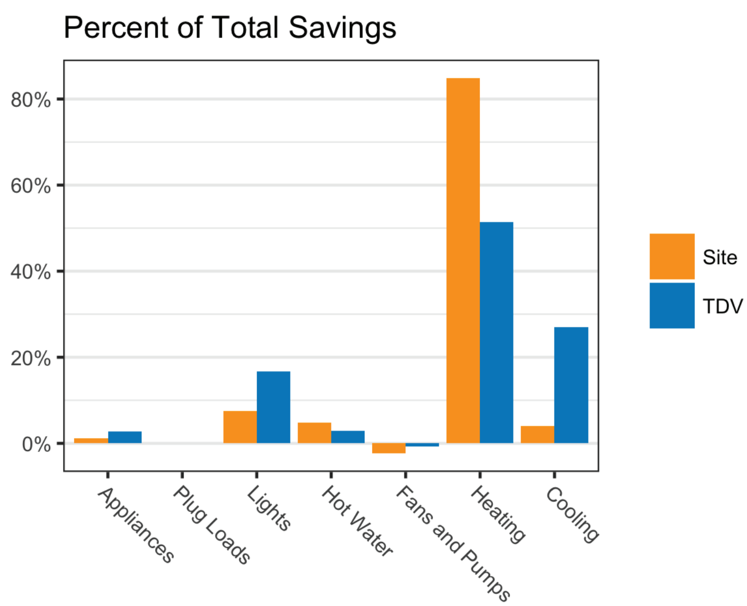
Source: Habitat for Humanity of San Joaquin County

Example of window placement in advanced framed wall

Source: Chitwood Energy Management

Modeled Energy Performance

SJC Habitat's iterative process allowed them to continue to improve a single design over several builds. The implemented energy efficiency measures on this iteration reduced modeled site energy consumption by 41% compared to the original design, and by 6% compared to the previous iteration. 85% of the modeled savings came from heating, where the savings were achieved by dramatically improving the building envelope and replacing the gas furnace with an efficient heat pump. Because of this fuel switching, the impact of the package on modeled TDV savings was not as great – 28% compared to the original and 1% compared to the previous iteration. About half of the modeled TDV savings were from heating, but the contribution of cooling was more significant – 27% for TDV vs. 4% for site energy – because those efficiency improvements impact consumption during peak hours.



Modeled monthly energy consumption shows a U-shape for site energy, demonstrating just how much the cooling loads were lowered. For TDV energy, the pattern is W-shaped because the TDV multipliers for electricity are the highest in July through September. This affects all of the end uses, not just the cooling.

For both site and TDV energy, PV production follows an inverted U-shape, with production peaking in the summer months. Although site PV production does not exceed consumption during any month, the home is still modeled as TDV zero because electricity is weighted more highly during afternoon peak production hours.

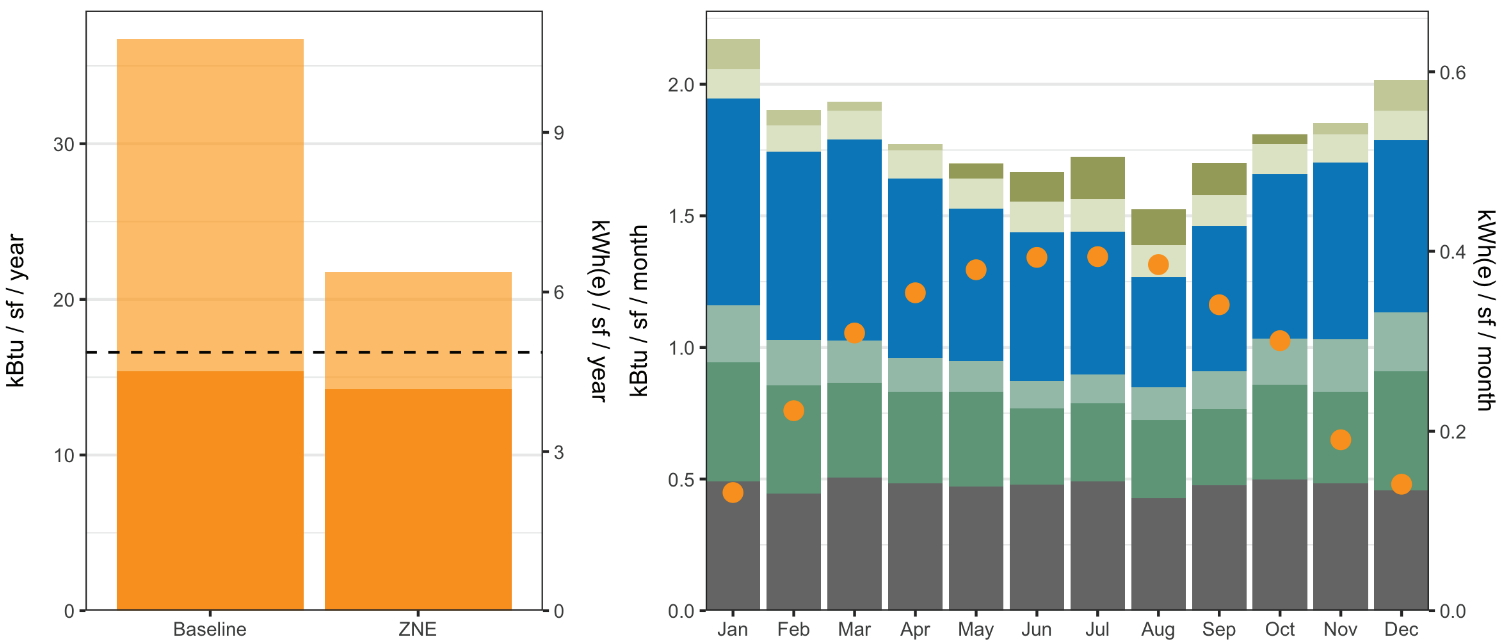
In order to place the site energy modeling results in a larger context, they were compared to the performance of an exemplar, as reported in *The Technical Feasibility of Zero Net Energy Buildings in California*.[3] The SJC Habitat ZNE package's modeled EUI, 21.8 kBtu/sf/yr, was about 30% higher than the EUI of the exemplar in the same climate zone. However the EUI metric privileges large buildings because major loads such as water heating and appliances scale by the number bedrooms instead of floor area. The exemplar building is 2,100 sf, 40% bigger than the SJC Habitat house, and they both have 3 bedrooms. Comparing to the performance of the exemplar using the number of bedrooms plus one as a proxy for number of occupants, the ZNE package is modeled as using 23% less energy per person than the exemplar.

[3] http://www.calmac.org/publications/California_ZNE_Technical_Feasibility_Report_CALMAC_PGE0326.01.pdf

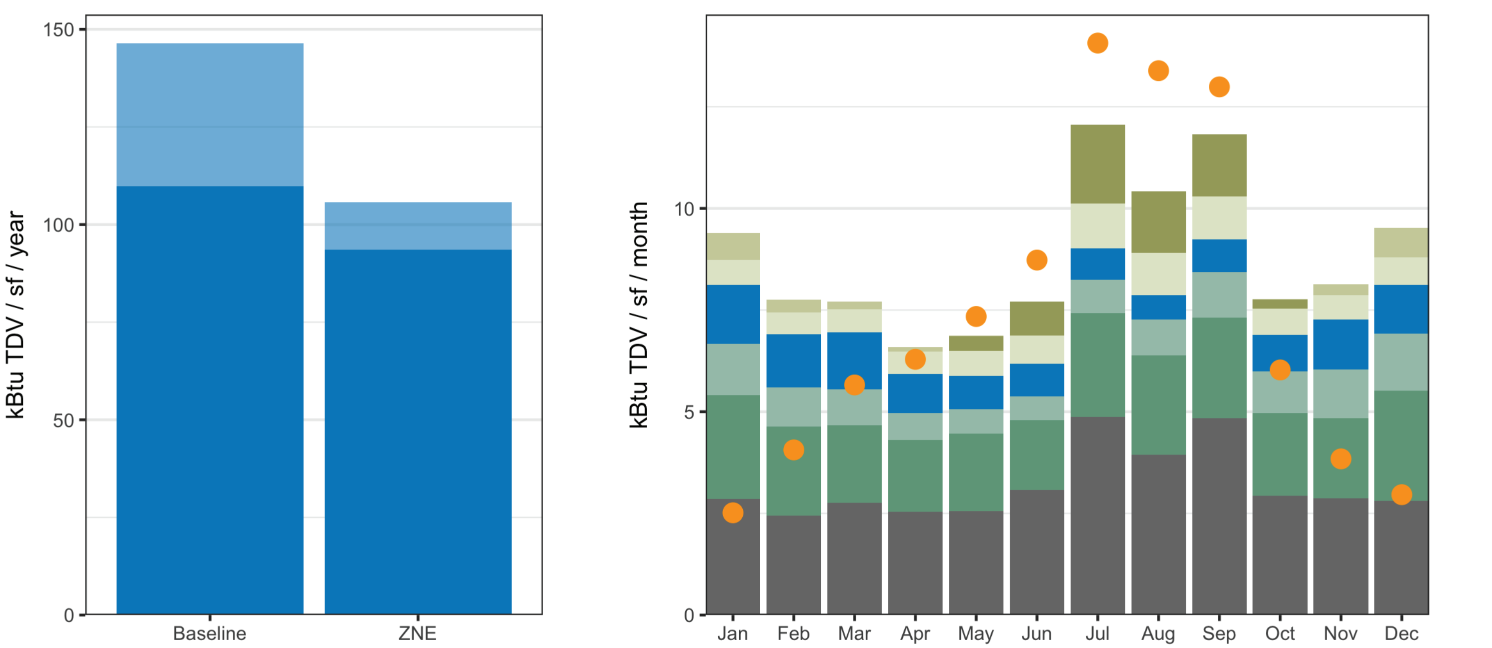
"This project demonstrates that ZNE can be highly affordable even on a limited budget; projects with more generous budgets should have no difficulty achieving ZNE provided they approach that goal with the same attention to detail shown by SJC Habitat."

-Ann Edminster, Principal, Design AVEnues

Modeled Site Energy



Modeled TDV Energy



Source: Chitwood Energy Management

"We at Habitat for Humanity of San Joaquin County are dedicated to building beautiful, safe, and affordable homes for well qualified, lower-income families to buy."

-Mike Huber, Executive Director, Habitat for Humanity of San Joaquin County

PROJECT TEAM

Builder Team:

Habitat for Humanity of San Joaquin County

ZNE Team:

PG&E

Design AVEnues LLC

Chitwood Energy Management, Inc.

Steve Easley & Associates, Inc.

Resource Refocus LLC

Frontier Energy, Inc.

This case study was written by Resource Refocus LLC based on consultant reports and project analysis.

Lessons Learned

Advanced Framing

This advanced framing approach reduced lumber use by more than 50%, saving cost on lumber and decreasing thermal bridging accordingly. Final air leakage measured at 1.5 ACH_{50}, less than one-third of the average for a new California home. As a result, the home uses smaller, more efficient mechanical equipment: system capacities have been reduced by 85% for heating and 75% for cooling.

Financial Findings

The ZNE measures reduced the net cost of the home by nearly $3,000, which was made possible by a holistic, highly integrated approach. Advanced framing with careful attention to the placement of each stud reduced required labor and avoided a cost increase from going to 2x4 to 2x6. Compact layouts of ducts and water pipes reduced the material required. The increased insulation and ducts in conditioned space allowed the HVAC to be downsized from 3 to ¾ tons.

This project proves that affordable ZNE is highly achievable. A common fear expressed within the mainstream construction industry is that meeting the 2020 ZNE goal will require adding costly features, thereby driving home prices too high.

But the SJC Habitat illustrates another path: a highly-integrated approach to efficiency that yields savings due to reduced quantities of framing lumber, drywall, ducting, and pipings, along with lower capacity HVAC equipment. These savings offset the modest cost increases for select higher efficiency items, such as the water heater. The number one Habitat for Humanity goal of affordability was never compromised; in fact, it was exceeded.

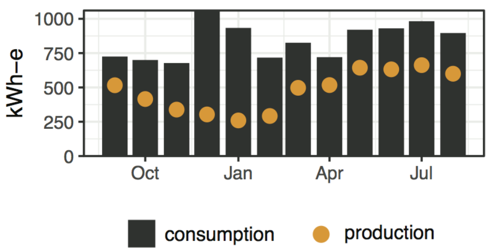
Completion and Next Steps

The completed SJC Habitat ZNE home was presented to the homeowners at a ceremony in February 2016. SJC Habitat is committed to building super efficient homes and is continuing to implement and iterate on the energy savings measures employed in this Demonstration home.

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

Habitat for Humanity of San Joaquin County *Monitoring Case Study*

Measured Site Energy: Monthly Consumption and Production



Energy Overview	Mod.	Meas.
EUI kBtu/sf/yr	21.8	28.1
PV Production kBtu/sf/yr	12.1	15.9
Offset % Site Energy	55%	55%

PROJECT OVERVIEW

Floor Area: 1,229 sf

Bedrooms: 3

Location: Stockton, CA

CA Climate Zone: 12

Completion: February 2016

Monitoring Dates: September 2016 - August 2017 (after PV active)

PV Array: 3.36 kW

Under the auspices of Pacific Gas and Electric Company's (PG&E) Zero Net Energy (ZNE) Production Builder Demonstration, Habitat for Humanity of San Joaquin County (SJC Habitat) built a ZNE home with an extraordinary envelope with very low air infiltration and framing factor and a 3⁄4-ton ducted mini-split heat pump in a hall soffit. The only gas appliance in the home is a tankless water heater. The specific focus of this effort was on reducing modeled loads. After completion of the home, the builder installed a 3.36 kW PV array, which was not sized to fully offset modeled TDV or site energy consumption. The solar energy produced by the PV array offset 55% of annual site energy consumption, consistent with its modeled performance. Heating, ventilation, and air conditioning (HVAC) loads were reduced enough that water heating and plug loads were the two largest end uses[1] and together accounted for 55% of the consumption.

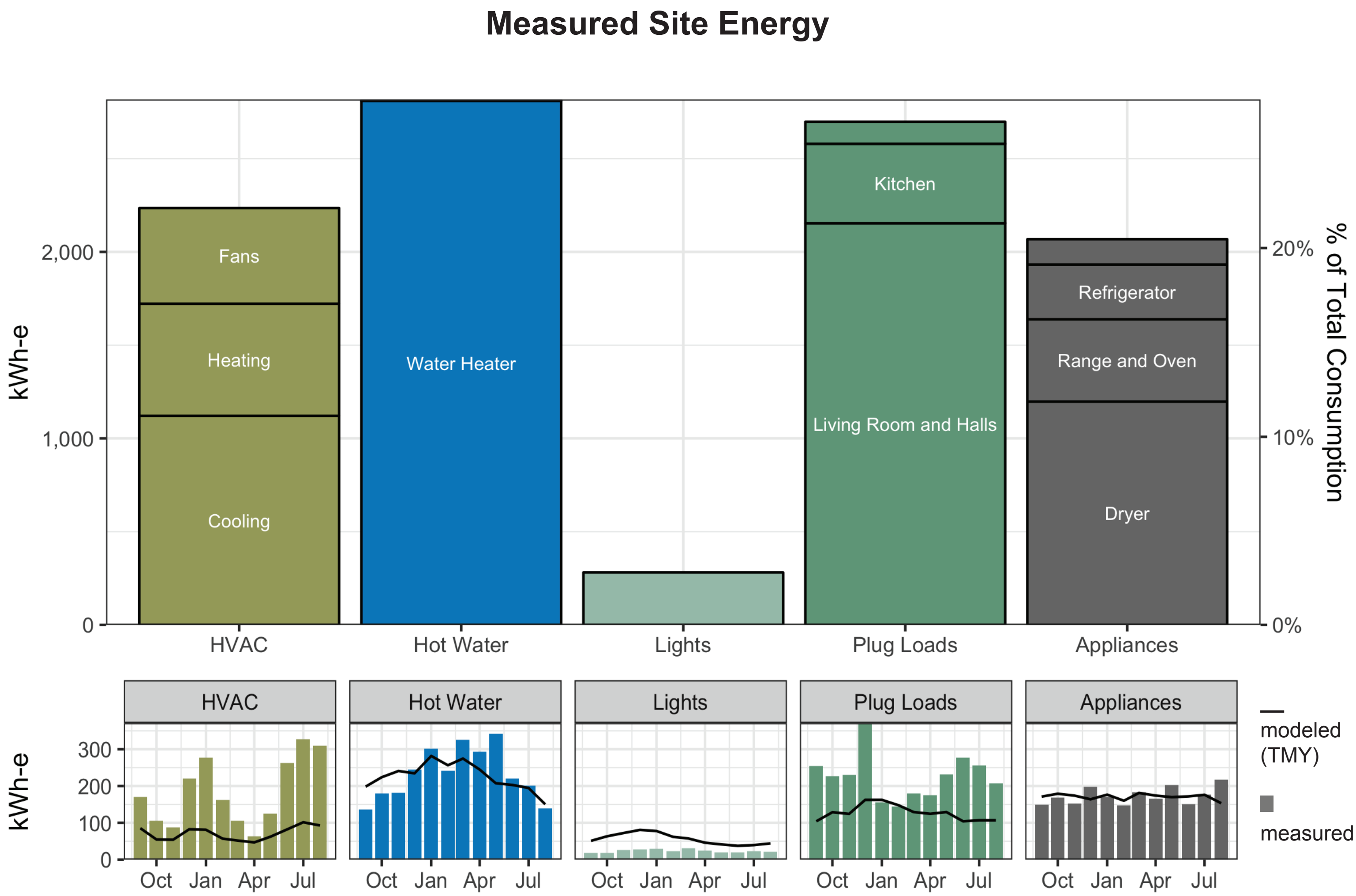
Measured Energy Performance

The energy consumption of specific end uses was monitored for a year to understand the house's performance while occupied.

To align with California building energy code, the ZNE goal for this project was based on Time Dependent Valuation (TDV). Because TDV is a modeling metric that cannot be accurately assessed for measured energy performance,[2] ZNE performance was evaluated using the site energy performance predictions of the TDV model. The measured data showed that the PV production offset 55% of site energy consumption, as predicted by the model, so the performance was in line with the home's ZNE target.[3]

Site energy consumption and production were both about 30% more than modeled. Half of the increase in consumption was due to plug loads, and the other half was primarily due to heating and cooling.

[1] "End use" refers to the final work that the energy did. For example, electricity might be ultimately used to run appliances, and natural gas might be used to heat water.
[2] TDV multipliers are tied to specific weather, grid, and economic projections and assumptions that will not be met exactly over the course of a year, so it is not appropriate to apply them to measured data.
[3] See design case study for information about building specs and design decisions.



The figures above show the measured energy consumption broken down by end use for the entire year of monitoring and by month. On the facing page, the charts compare modeled and measured energy consumption and outdoor temperature.

HVAC

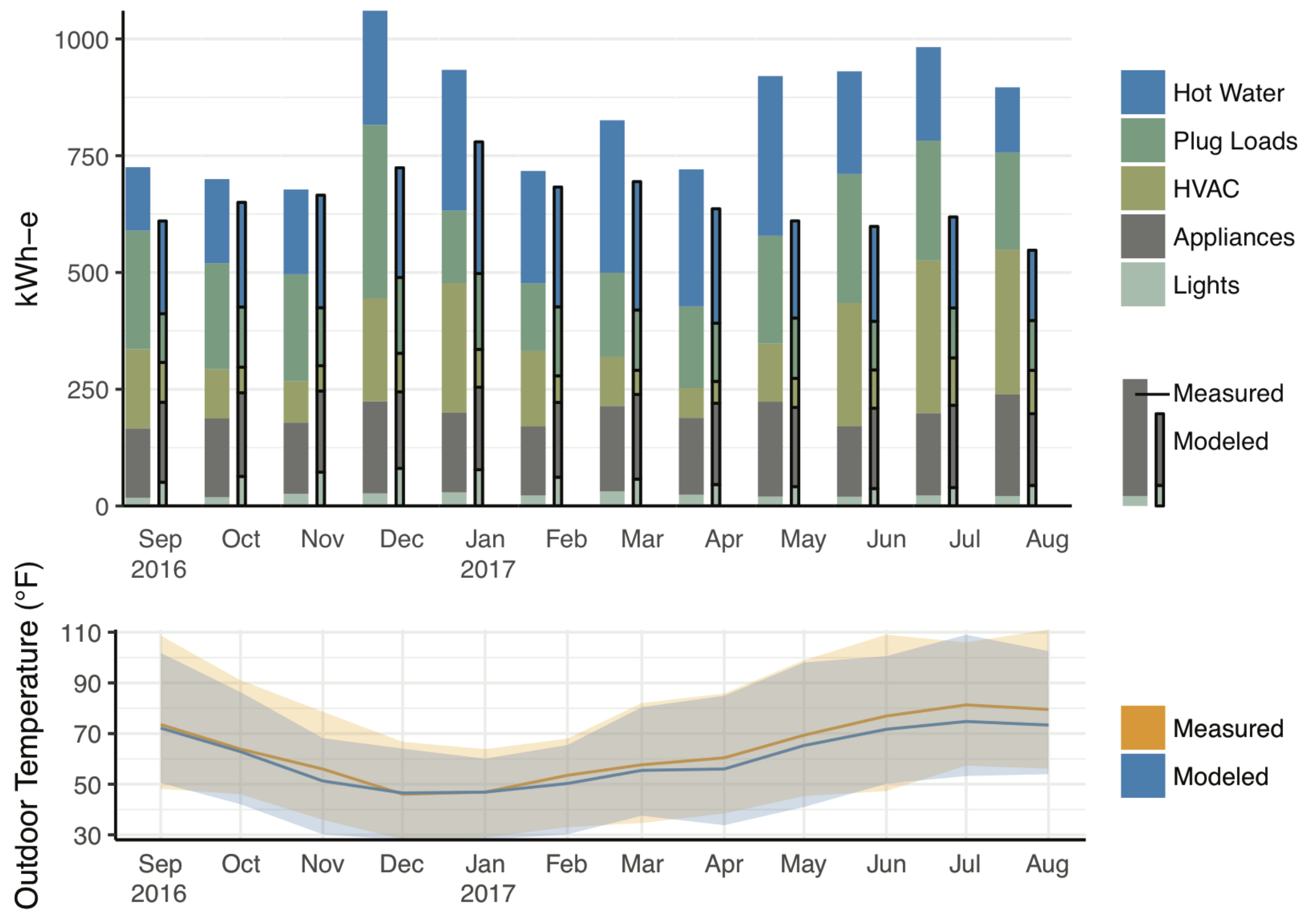
Heating and cooling consumption was higher than predicted. To check values, the energy model was run twice – once with the Typical Meteorological Year (TMY) weather file that is used for code compliance and once with the Actual Meteorological Year (AMY) weather file that corresponds to the real weather during the monitoring period.[4] Heating and cooling were more than 4 times as much as what was predicted using TMY weather. Using AMY weather, heating was 6 times as much as and cooling 1.7 times as much as predicted. Despite these large increases over the models, they made up only 17% of total measured consumption. The two energy recovery ventilators (ERVs) that provide outdoor air accounted for 5%, bringing HVAC up to 22% of total consumption.

Hot Water

Domestic hot water was the single biggest end use, accounting for 28% of the total measured consumption. It is also the only end use that includes gas. The measured consumption was only 3% higher than the model. This consumption could be further reduced by installing a condensing water heater to raise the energy factor from 0.82 to 0.97 EF.

[4] Elsewhere in the case study, modeled numbers refer to the TMY data.

Energy and Temperature Comparisons: Modeled vs Measured



Lights

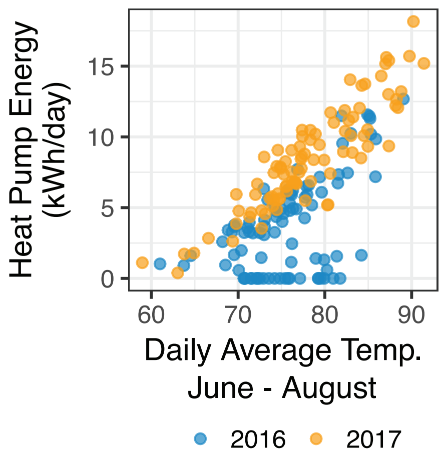
The energy consumption for hard-wired lighting was 60% less than modeled; this does not include plug-in lamps. Lighting was the only end use that consumed less than was modeled.

Plug Loads

Plug loads accounted for 27% of the total consumption, second only to hot water. The living room and halls circuit by itself accounted for 21% of the total consumption, which is more than appliance consumption or heating and cooling. During November and December there was an aquarium in the living room, which caused a spike in consumption, but this had little overall influence on the annual total. In all, plug load consumption was 76% more than modeled.

Appliances

Appliances accounted for 20% of the measured energy consumption. The occupant-selected electric dryer by itself was responsible for 58% of the appliance consumption and 12% of the total home consumption. This is marginally more than the measured cooling energy.



Heat pumps are generally slower to reach setpoints and adjust to abrupt setpoint changes, which can be an adjustment for occupants in terms of optimal behaviors and system performance expectations.

Highlight: Heat Pump

Space heating and cooling are served by a ¾ ton ducted mini-split heat pump located in a hall soffit in the center of the house. Heat pump performance data was collected from the time of occupancy in May 2016 through August 2017, including two cooling seasons and a heating season. During the 2016 cooling season, the heat pump ran 67% of the time and the indoor temperature stayed within 3° of the 72°F setpoint. However during the 2017 cooling season, the thermostat was used as an on-off switch and the system could not maintain the 70°F setpoint even with the heat pump running 88% of the time the system was on. In addition to not meeting the setpoint, this type of operation used much more energy. June 2016 and 2017 had very similar temperature profiles, yet approximately twice as much energy was used for cooling energy in June 2017 as June 2016. July 2016 and August 2017 had similar data.

The heat pump was able to maintain the 69°F heating setpoint throughout the whole heating season, even when the thermostat was used as an on-off switch.

Lessons Learned

The excellent envelope of this house allowed a significantly downsized ¾ ton mini-split heat pump, compared to SJC Habitat's previous standard practice of 2.5 tons. While this small heat pump was able to maintain the setpoint most of the time, when the thermostat was used as an on-off switch it could not reach setpoint during the cooling season. While turning off the heat pump saves energy during vacations, turning it on and off multiple times a day reduced comfort and increased energy consumption.

Especially in ZNE homes, where HVAC has been carefully designed to be energy efficient, the choices occupants make in terms of plug loads, appliances, and unregulated lighting can add up to a large portion of the total energy consumption, in this case 50% of the total. The dryer alone consumed more energy than cooling this house did, even in a climate with temperatures regularly reaching over 100°F. Although homeowners are typically responsible for buying their own appliances, builders can have a big impact on energy consumption by supplying efficient appliances.

PROJECT TEAM

Builder Team:

Habitat for Humanity of San Joaquin County

Monitoring Team:

Frontier Energy, Inc.

ZNE Team:

PG&E

Design AVEnues LLC

Chitwood Energy Management, Inc.

Steve Easley & Associates, Inc.

Resource Refocus LLC

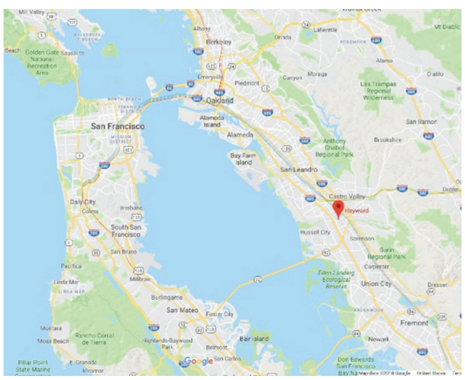
This case study was written by Resource Refocus LLC based on consultant reports and project analysis.

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

APPENDIX D: MERITAGE CASE STUDIES

Zero Net Energy Demonstration Home
Meritage Homes
Design Case Study

Source: Frontier Energy, Inc.



PROJECT OVERVIEW

Floor Area: 2,061 sf

Bedrooms: 5

Location: Hayward, CA

CA Climate Zone: 3

Completion: May 2017

Modeled EUI: 27.0 kBtu/sf/yr

PV Array: 4.05 kW

Meritage Homes completed a zero net energy (ZNE) demonstration house with support from Pacific Gas and Electric Company (PG&E) and its consultant team. The project team reduced the modeled site energy consumption by 3% compared to Meritage's standard practice, mainly through increasing exterior insulation, increasing furnace and air conditioner efficiency, and replacing CFLs with LEDs. A common efficiency measure for ZNE homes is to move ducts out of unconditioned space. However Meritage's baseline already included this measure as their ducts are in a semi-conditioned attic.

PG&E ZNE Production Builder Demonstration

The State of California has a goal that all new residential buildings be zero net energy (ZNE) by 2020.[1] To support builders in designing and constructing ZNE homes, PG&E offered support through a ZNE Production Builder Demonstration. Participating builders received technical support from start to finish to upgrade one of their existing prototypes to ZNE while preserving their look and feel, and in a way that works for their team. The ultimate goal was to achieve a ZNE home that the builder could replicate to begin t build ZNE homes at scale. For each builder, the design consultants recommended energy efficiency measures for the builder's standard design based on performance modeling and substantial past experience with zero net energy and energy-efficient homes. They also visited the site during construction to ensure that the measures were being properly installed. As part of this offering, PG&E reimbursed up to $15,000 in incremental cost of the energy efficiency measures; experience shows that the incremental costs will drop in subsequent projects. Finally, the monitoring consultants tracked the end-use energy consumption of the completed home for a year after occupancy to determine whether the ZNE home is performing as designed and to diagnose any operational issues.

[1] CPUC (2017) "Energy Efficiency Strategic Plan" http://www.cpuc.ca.gov/General.aspx?id=4125

ZNE Goal and Project Approach

The ZNE goal for the project design was zero net TDV to align with California building energy code, which incorporates Time Dependent Valuation (TDV).[2] The team produced two distinct sets of modeled results for the home. The first model was used to establish a zero net energy design according to the California Energy Commission's TDV metric, the energy metric used to regulate energy use by the building code in California. Once a code-based ZNE design was established, the team then translated the TDV model into a site energy model to represent actual projected energy use.

The Meritage team focused on finding a ZNE approach that worked within their existing supply chain. They wanted to try an approach that would be easy to apply to a whole community with minimum disturbance.

Meritage Zero Net Energy Package

Meritage implemented five energy efficiency measures beyond their standard practice to reduce the modeled site energy consumption of the house by 3%:

- Increasing exterior continuous insulation from R-4 to R-6
- Decreasing infiltration from 3.5 ACH_{50} to 3.0 ACH_{50}
- Increasing the efficiency of the furnace from 92% to 96% AFUE
- Increasing the efficiency of the air conditioner from 14 to 17 SEER
- Replacing CFLs with LEDs

Many of the projects participating in the Builder Demo tried a method for bringing ducts into conditioned or semi-conditioned space. However Meritage's standard practice is to use R-30 spray foam under the roof deck, so it was left unchanged in the ZNE package.

The home was modeled to meet its ZNE design goal with a 4.05 kW PV array.

[2] TDV values energy differently based on its source and on when and where it is consumed or produced. Because "peak" electricity during hot summer afternoons is the most costly energy for the grid operators to produce, procure and deliver, it is weighted the most heavily by TDV.

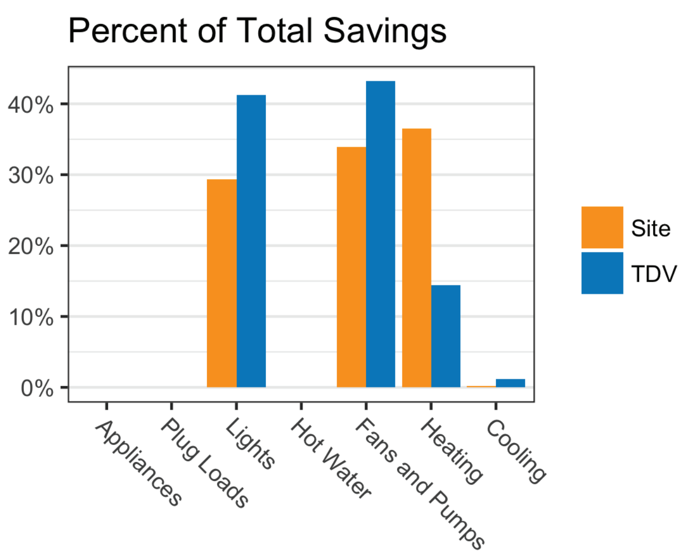
Detailed Specifications

		Baseline	ZNE
Envelope			
Exterior Walls	cavity R value, insulation type	**R-13 open cell foam**	
	framing type, spacing	**2x4 16" oc**	
	continuous insulation	R-4 EPS	**R-6.2 EPS**
Glazing	U / SHGC	**0.30 U / 0.22 SHGC**	
	WWR	**16% WWR**	
	shading		
	skylights	**no skylights**	
Roof	insulation type, R value	**R-30 foam**	
	insulation location	**under roof deck**	
	vented/unvented attic	**unvented attic**	
	radiant barrier	**no radiant barrier**	
Foundation	type	**slab**	
	insulation	**none**	
Air Leakage	ACH50	3.5 ACH50	**3 ACH50**
HVAC System			
Ventilation	type	**supply**	
Heating & Cooling	heating system type	**gas furnace**	
	heating efficiency	92% AFUE	**96% AFUE**
	cooling system type	split system a/c	**split system a/c, 2 speed**
	cooling efficiency	14 SEER	**17 SEER, 12.8 EER**
	cooling capacity	**3 tons**	
	equipment location	**semi-conditioned attic**	
	thermostat		
Ducts	location	**semi-conditioned attic**	
	change in duct length		**none**
Water Heating			
Water Heater	water heater type, efficiency	**tankless gas condensing, 0.95 EF**	
	equipment location	**garage**	
DHW Distribution	insulation, pipe material	R-4 PEX, kitchen line only	**R-2 PEX**
	recirculation	none	**piping but not pump provided**
	low flow fixtures		
Electric Loads			
Lighting	type	100% CFL	**100% LED**
Appliances	fridge	fridge	**ENERGY STAR fridge**
	cooking	**gas cooking**	
	dishwasher, washer	**ENERGY STAR**	
	dryer	**gas dryer**	
Other			

Note: a blank cell indicates no change, bold indicates final package

Modeled Energy Performance

The implemented energy efficiency measures reduced modeled site energy consumption by 3% and modeled TDV energy consumption by 5% compared to Meritage's standard practice. In terms of site energy, the savings were approximately evenly split between lighting, HVAC fans & pumps, and heating. In terms of TDV, however, heating only accounted for 14% of savings while HVAC fans & pumps and lighting were each over 40%. This is because of how TDV weighs electricity more heavily than gas.



Modeled monthly energy consumption is mostly U-shaped for site energy but W-shaped for TDV energy. Once again, this difference is because of how much more heavily TDV weighs electricity compared to gas. The seasonal dependence of TDV can also be seen in the higher appliance consumption in July through September compared to the rest of the year.

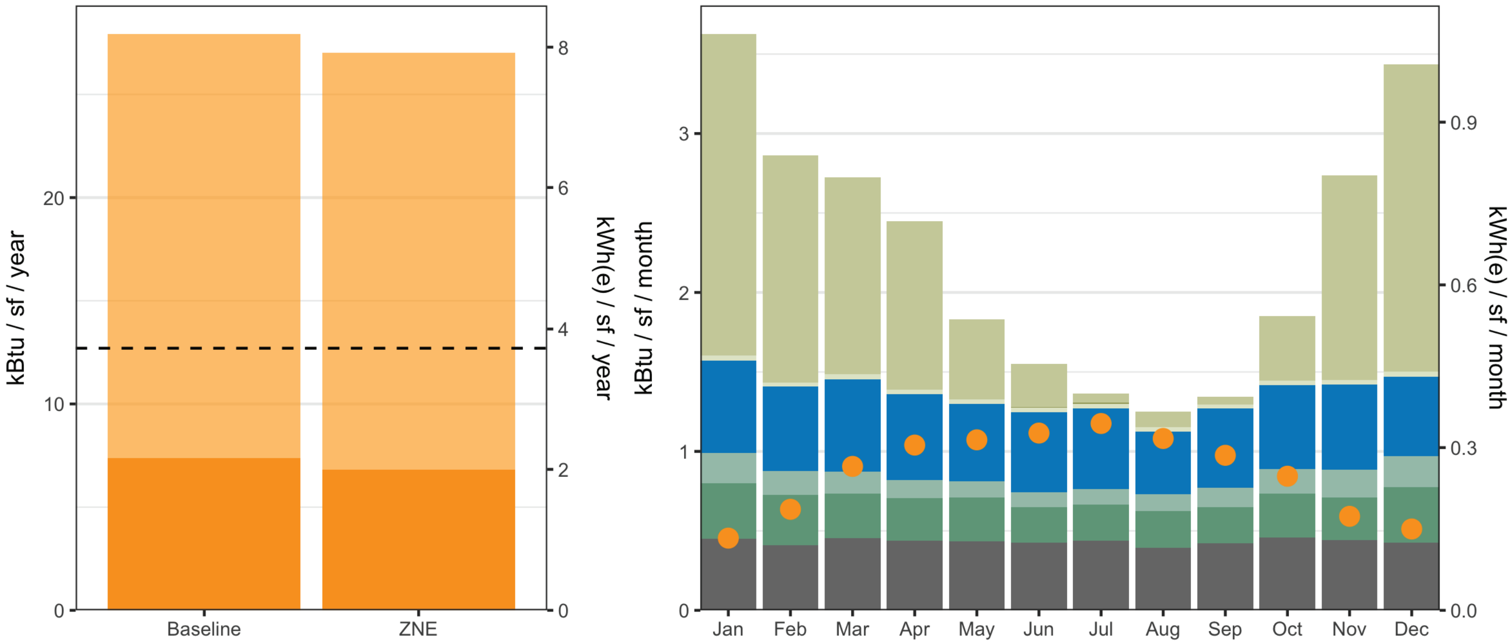
For both site and TDV energy, PV production follows an inverted U-shape, with production peaking in the summer months.

In order to place the site energy modeling results in a larger context, they were compared to the performance of an exemplar, as reported in *The Technical Feasibility of Zero Net Energy Buildings in California*.[3] The Meritage ZNE package's modeled EUI, 27.0 kBtu/sf/yr, was more than twice the 12.7 kBtu/sf/yr EUI of the exemplar in the same climate zone. This difference is primarily due to the gas furnace.

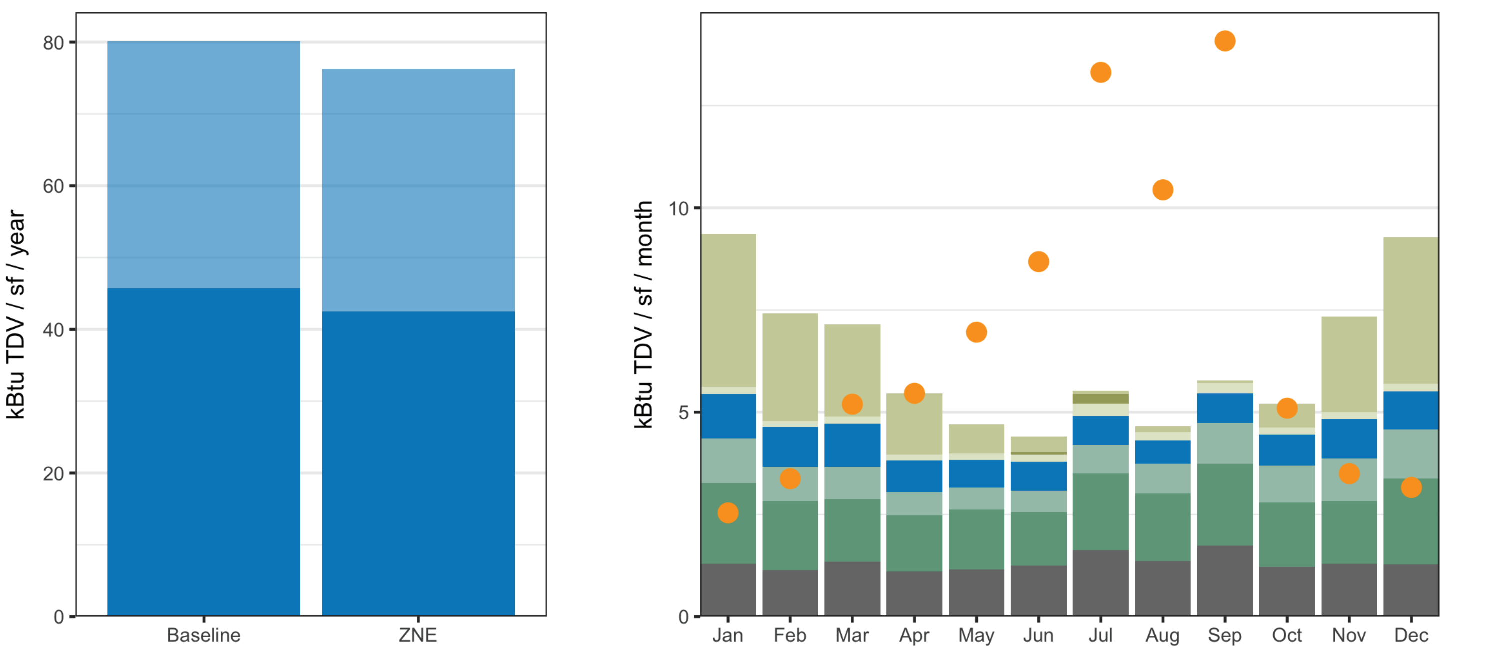
When modeling, some loads, such as heating and cooling, vary depending on floor area, but others, such as water heating, appliances, and plug loads, vary mostly based on the number of occupants. Because the Meritage home has virtually the same floor area but more bedrooms than the exemplar, it is modeled to consume only 40% more per occupant, as approximated by the number of bedrooms plus one, than the exemplar.

[3] http://www.calmac.org/publications/California_ZNE_Technical_Feasibility_Report_CALMAC_PGE0326.01.pdf

Modeled Site Energy



Modeled TDV Energy



Measures Considered But Not Implemented

Meritage considered including an air source heat pump to meet the space conditioning needs of the ZNE home. In the end they went with a combined furnace and air conditioner system, which is their standard. They cited several reasons for not installing the heat pump – higher first cost; distributors not stocking them; worse consumer acceptance particularly because of low gas prices; desire to choose a ZNE package that would be easier for them to replicate. For the Demonstration house PG&E's incremental cost buy down would cover the extra cost for the heat pump, but that support would not be present if they were to build a whole community of ZNE homes. Although the furnace and air conditioner that they ultimately installed were higher efficiency than their standard models, the switch back to the gas furnace significantly increased the modeled EUI.

Meritage also considered measures to increase the R-value of their walls. They use open cell spray foam as their standard practice, but closed cell is almost twice as insulating for the same thickness. Ultimately they stayed with open cell because of cost and because closed cell can be a fire risk in unvented attics. Instead of increasing the R-value per inch of insulation, another option that they considered was increasing the total inches of insulation by switching from 2x4 to 2x6 walls. However this would involve additional costs, notably from continuing to use 16" oc stud spacing with more costly 2x6 and the delayed timeline from redrawing building plans.

Completion and Next Steps

This Meritage ZNE home was completed in February 2017 and occupied in May 2017. Meritage is continuing to build high efficiency homes and is offering homeowners the option of adding enough solar PV to their home to achieve ZNE.[4] Concurrently with this Builder Demo home Meritage was collaborating with Southern California Edison and the Electric Power Research Institute (EPRI) to build a community of 20 ZNE homes in Fontana.[5]

[4] https://urbanland.uli.org/sustainability/residential-office-developers-preparing-realities-net-zero/
[5] http://eprijournal.com/zero-net-energy-for-the-masses/

PROJECT TEAM

Builder Team:

Meritage Homes

ZNE Team:

PG&E

BIRAenergy

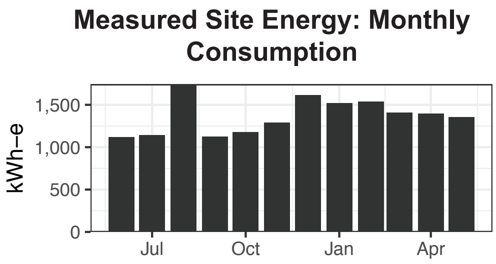
Frontier Energy, Inc.

Resource Refocus LLC

This case study was written by Resource Refocus LLC based on consultant reports and project analysis.

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

Meritage Homes
Monitoring Case Study



Energy Overview	Mod.	Meas.
EUI kBtu/sf/yr	27.3	26.1
PV Production kBtu/sf/yr	10.5	N/A
Offset % Site Energy	38%	40%

PROJECT OVERVIEW

Floor Area: 2,047 sf

Bedrooms: 5

Location: Hayward, CA

CA Climate Zone: 3

Completion: February 2017

Monitoring Dates:
June 2017 - May 2018 (after occupancy)

PV Array: 4.05 kW

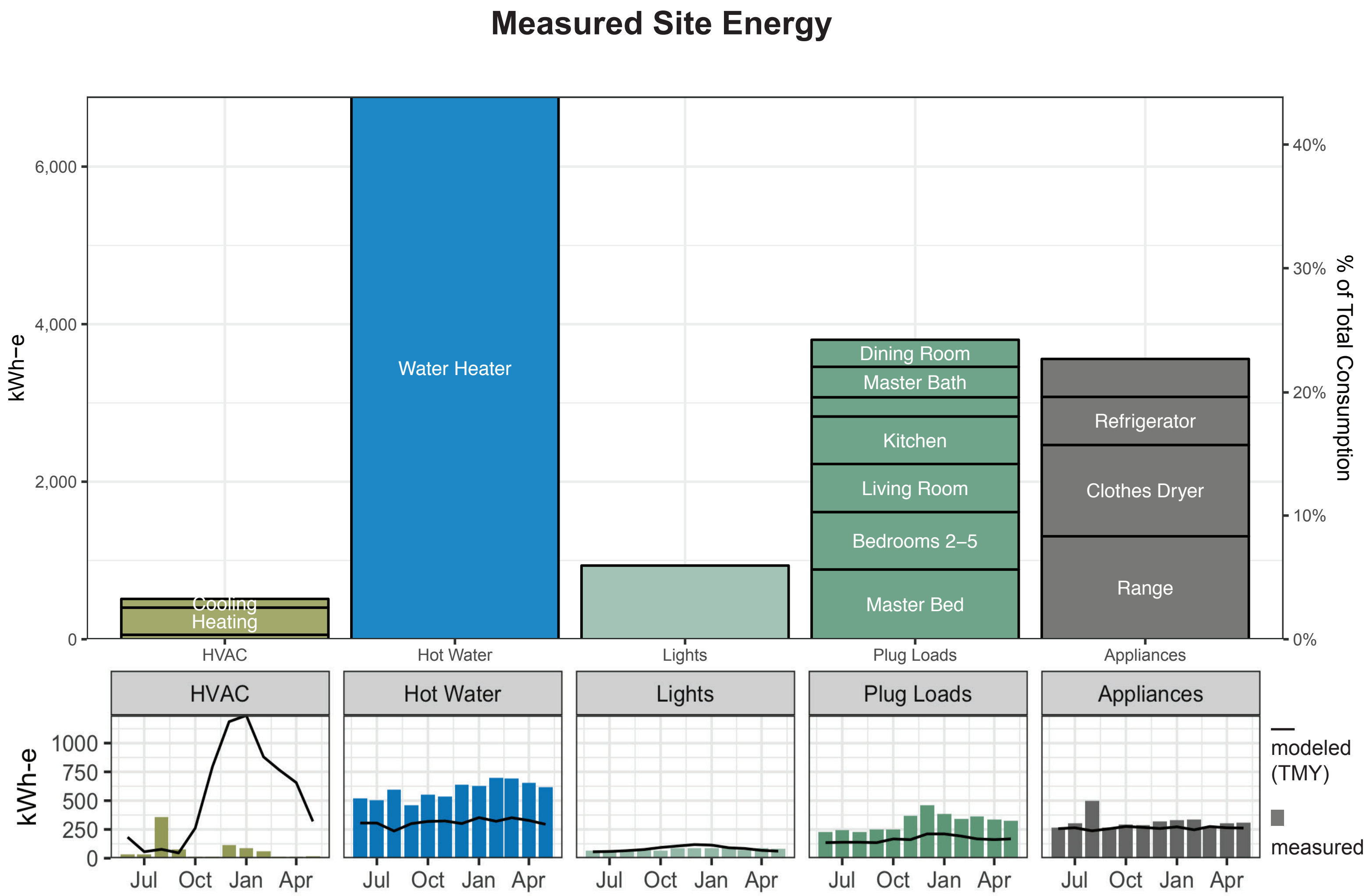
Meritage Homes built a ZNE house under the auspices of Pacific Gas and Electric Company's (PG&E) Zero Net Energy (ZNE) Production Builder Demonstration. The house features high efficiency appliances, increased exterior wall insulation, improved envelope air sealing, and a PV system. Domestic hot water and plug loads were the two largest end uses[1] and together accounted for 68% of total consumption. Unexpected occupant behavior patterns resulted in many monitored end uses deviating significantly from the model. Still, total site energy use was 4% less than modeled with typical meteorological year (TMY) weather data and 11% higher than modeled with actual meteorological year (AMY) weather data.

Measured Energy Performance

The energy consumption of specific end uses was monitored for a year to understand the house's performance while occupied. To align with California building energy code, the ZNE goal for this project was based on Time Dependent Valuation (TDV). Because TDV is a modeling metric that cannot be accurately assessed for measured energy performance data,[2] ZNE performance was evaluated using the site energy performance predictions of the TDV model. Despite active encouragement from the entire project team, the occupants chose not to activate the PV system. As a result, there was no PV production to offset household energy use during this monitoring period. Model data based on the AMY data from the local weather station was used to estimate what PV production would have been, had the PV system been activated. During the design phase, PV production was modeled as offsetting 38% of site energy consumption. PV production estimated with AMY data offset 40% of measured site energy consumption, so the performance was not in line with the home's ZNE design.[3]

Site energy consumption was 4% less than modeled. Although energy for water heating and plug loads was almost twice what was predicted, the furnace was used so seldomly that whole house consumption was less than predicted.

[1] "End use" refers to the final work that the energy did. For example, electricity might be ultimately used to run appliances, and natural gas might be used to heat water.
[2] TDV multipliers are tied to specific weather, grid, and economic projections and assumptions that will not be met exactly over the course of a year, so it is not appropriate to apply them to measured data.
[3] See design case study for information about building specs and design decisions.



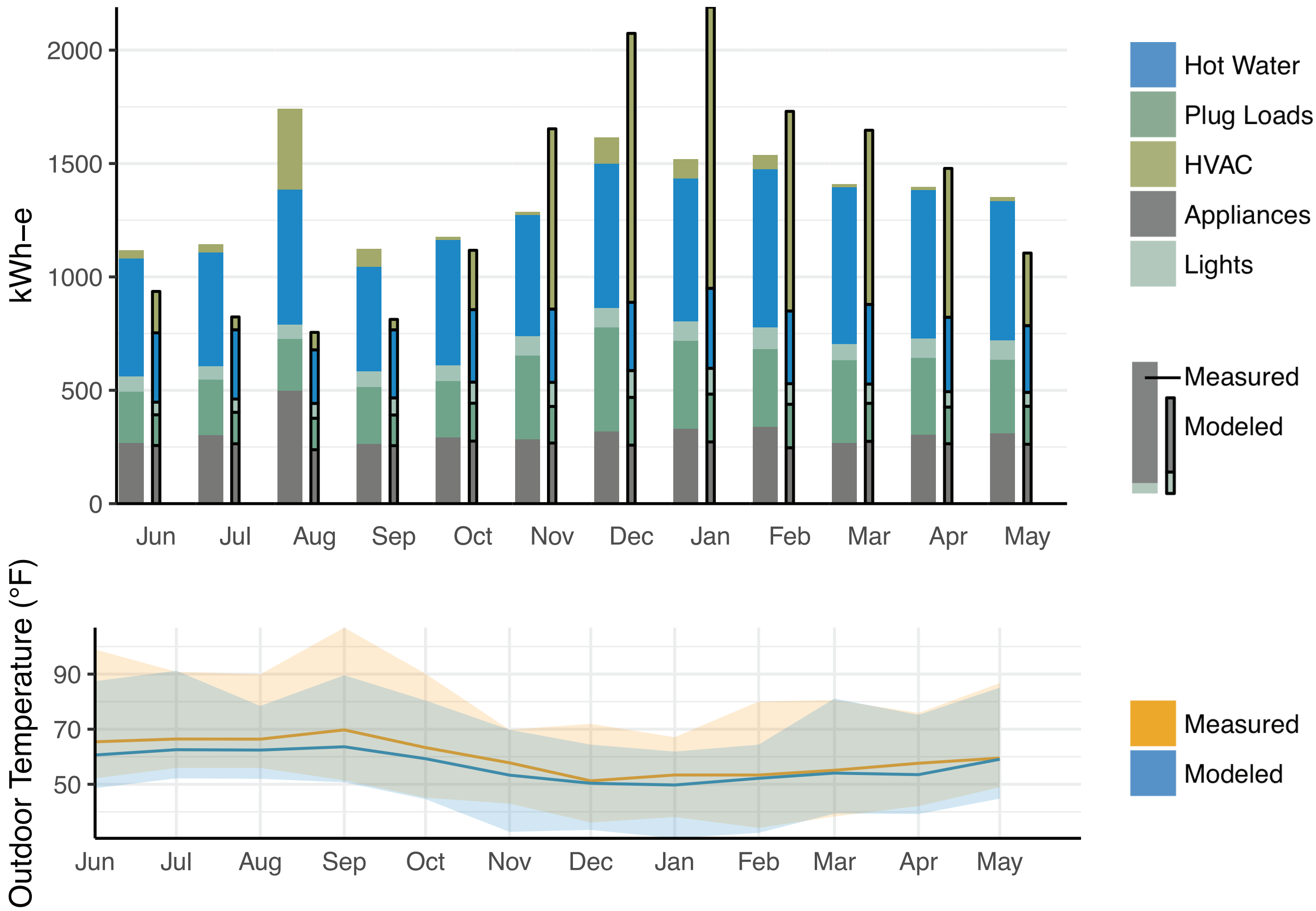
The figures above show the measured energy consumption broken down by end use for the entire year of monitoring and by month. On the facing page, the charts compare modeled and measured energy consumption and outdoor temperature.

HVAC
Heating was 90% less than predicted using either TMY or AMY models. This is mainly due to low heating set points and the occupants frequently putting the thermostat in "Off" mode. Recorded temperatures in the living zone were frequently below 65°F in the winter. However, because the actual summer temperatures were higher than is typical, cooling energy consumption was almost 4 times more than predicted with the TMY model but still 39% less than with the AMY model. In all, HVAC accounted for 3% of total consumption.

Hot Water
Domestic hot water, sourced from a high efficiency gas condensing tankless water heater, was the largest energy end use, accounting for 44% of the total measured consumption. The measured consumption was 84% higher than modeled. This increased load is due to warm/hot laundry loads totaling at least 140 more than modeled and occupant choice to never use the dishwasher. A 2006 study by the California Energy Commission showed that 37% more hot water is used when washing dishes by hand.[4]

[4] California Energy Commission, 2006. "Energy Commission Offers Kitchen Tips for an Energy-wise Thanksgiving."

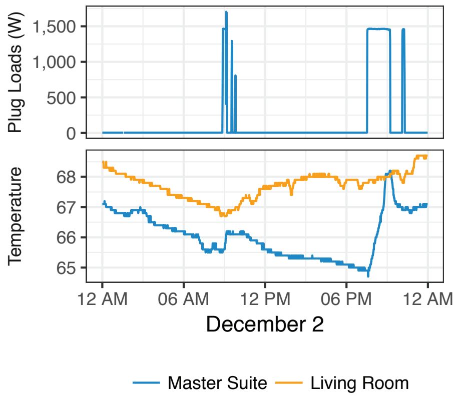
Energy and Temperature Comparisons: Modeled vs Measured



Lights
The energy consumption for hard-wired lighting was 6% of total consumption, as modeled. This does not include plug-in lamps.

Plug Loads
Plug loads accounted for 24% of the total consumption, tied with appliances as the second largest end use. The master bedroom and closet accounted for nearly one quarter of plug load consumption and 5.6% of the total household energy use. Because of entertainment centers, the living room is often the location with the highest plug load consumption. However, in this house the living room circuit was only slightly more than the master bath circuit: 15% vs 10% of plug load consumption. In all, plug load consumption was 91% more than modeled.

Appliances
Appliances accounted for 23% of the measured energy consumption, tied with plug loads as the second largest end use. The gas cooking range and clothes dryer each accounted for about a third of the appliance consumption and 8% of whole house consumption. The refrigerator was also a significant energy consumer. Appliance total use was 13.5% more than modeled.



Highlight: Space Heater

The occupants used the furnace very rarely, but sometimes they used an electric resistance space heater in the master suite. The graph on the left shows the temperature in the master bedroom increasing quickly at about 7:30 pm, when a 1,500 W load came on in the master bathroom. The furnace was off the whole day and there was no corresponding rise in living room temperature, so this is most likely a space heater (1,500 W is a typical wattage).

Furnaces and electric resistance or space heaters have similar efficiencies on a site energy basis, meaning that about 95-100% of the energy coming in is turned into useful heat. However, electric resistance heaters are usually discouraged for a variety of reasons: only about 30% of the energy in the original fuel comes to the house as electricity, natural gas is generally cheaper for occupants than electricity, heat pumps are several times more efficient, and until recently electricity in California was more carbon intensive than gas. Still, space heaters can be an appropriate choice for heating small spaces or individual rooms.

Energy consumption by the space heater was estimated as the difference between plug load energy in the master bathroom during the winter and during the baseline period of June through October. Based on this calculation, the energy used for heating, including both the furnace and the space heater, was 85-90% less than modeled. This is because of the low whole-house heating set point and the fact that the space heater only heated a small area.

Lessons Learned

One of the largest variables in the performance of ZNE buildings is occupant behavior. In this case the occupants chose to use space heaters instead of the furnace but because they were heating only a small space they saved energy overall. At the same time using the water-efficient dishwasher and activating the PV system would have improved the home performance.

PROJECT TEAM

Builder Team:

Meritage Homes

Monitoring Team:

Frontier Energy, Inc.

ZNE Team:

PG&E

BIRAenergy

Resource Refocus LLC

This case study was written by Resource Refocus LLC based on consultant reports and project analysis.

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APPENDIX E: PULTE CASE STUDIES

Zero Net Energy Demonstration Home

PulteGroup
Design Case Study

Source: Can Anbarlilar, PG&E

PulteGroup (Pulte) completed a zero net energy (ZNE) demonstration house with support from Pacific Gas and Electric Company (PG&E) and its consultant team. Beginning with an existing Pulte home design, the project team was able to reduce the modeled site energy consumption by 52% compared to their standard practice through strategies such as moving the ducts into semi-conditioned space and replacing the furnace with a heat pump. The incremental cost for the ZNE package, including appliance upgrades, was more than offset by the final sale price. Going forward, Pulte plans to include a number of features piloted as part of the demonstration in a new all-electric multifamily development in the San Francisco Bay Area.

PROJECT OVERVIEW

Floor Area: 2,344 sf

Bedrooms: 4

Location: Brentwood, CA

CA Climate Zone: 12

Completion: May 2016

Modeled EUI: 17.2 kBtu/sf/yr

PV Array: 4.62 kW

PG&E ZNE Production Builder Demonstration

The State of California has a goal that all new residential buildings be zero net energy (ZNE) by 2020.[1] To support builders in designing and constructing ZNE homes, PG&E offered support through a ZNE Production Builder Demonstration. Participating builders received technical support from start to finish to upgrade one of their existing prototypes to ZNE while preserving their look and feel, and in a way that works for their team. The ultimate goal was to achieve a ZNE home that the builder could replicate to begin to build ZNE homes at scale. For each builder, the design consultants recommended energy efficiency measures for the builder's standard design based on performance modeling and substantial past experience with zero net energy and energy-efficient homes. They also visited the site during construction to ensure that the measures were being properly installed. As part of this offering, PG&E reimbursed up to $15,000 in incremental cost of the energy efficiency measures; experience shows that the incremental costs will drop in subsequent projects. Finally, the monitoring consultants tracked the end-use energy consumption of the completed home for a year after occupancy to determine whether the ZNE home is performing as designed and to diagnose any operational issues.

[1] CPUC (2017) "Energy Efficiency Strategic Plan" http://www.cpuc.ca.gov/General.aspx?id=4125

ZNE Goal and Project Approach

The ZNE goal for the project design was zero net TDV to align with California building energy code, which incorporates Time Dependent Valuation (TDV).[2] Site energy was modeled to understand the energy efficiency of the home.

The Pulte team also had an internal goal of minimizing the number of trades affected during construction and the behavior change required of the occupants to achieve ZNE performance. This approach increases the potential to use the features and techniques in a large production environment. The national and regional purchasing directors were the main people on the Pulte side interfacing with the PG&E team.

PulteGroup Zero Net Energy Package

Broadly, Pulte made five major moves to improve energy efficiency and to reduce the modeled site energy consumption of the house by 52%:

- Raising the attic insulation to directly under the roof deck to bring the ducts into semi-conditioned space
- Replacing a furnace and air conditioner with a heat pump
- Installing a condensing tankless water heater
- Using LEDs instead of CFLs
- Providing an induction cooktop and ENERGY STAR® appliances

A gabled roof was chosen for the ZNE home to accommodate the required photovoltaic (PV) array; other homes in the Pulte community have a variety of roof shapes, including hipped and gabled styles. A pop-up was also added on the front (south-facing) roof to optimize the angle of the PV panels and obscure them from view in the home's front yard. After significantly reducing the modeled energy consumption, the home was modeled to meet the zero net TDV design goal with a 4.62 kW PV array.

[2] TDV values energy differently based on its source and on when and where it is consumed or produced. Because "peak" electricity during hot summer afternoons is the most costly energy for the grid operators to produce, procure and deliver, it is weighted the most heavily by TDV.

"California is clearly leading the charge on Zero Net Energy, and we believe this is an opportunity to harness the lessons learned with our building partners so we can offer consumers the ultimate combination of affordability, quality and energy efficiency in the future. We are already developing plans for future Net Zero prototypes." ***-Ryan Marshall, President, PulteGroup***

Detailed Specifications

		Baseline	ZNE
Envelope			
Exterior Walls	cavity R value, insulation type	**R-15 Fiberglass**	
	framing type, spacing	**2x4 16" oc**	
	continuous insulation	**R-4 XPS**	
Glazing	U / SHGC	**.32 U/ .25 SHGC**	
	WWR	**15% WWR**	
	shading		
	skylights	**no skylights**	
Roof	insulation type, R value	R-30	**R-38**
	insulation location	attic floor	**under roof deck**
	vented/unvented attic	vented attic	**unvented attic**
	radiant barrier	radiant barrier	**no radiant barrier**
	roof material	**tile**	
Foundation	type	**slab**	
Air Leakage	ACH50	**4.9 ACH50**	
HVAC System			
Ventilation	type	**exhaust**	
	air flow		
Heating & Cooling	heating system type	gas furnace	**heat pump**
	heating efficiency	0.8 AFUE	**9.2 HSPF**
	heating capacity	110,000 Btuh	
	cooling system type	air conditioner	**heat pump**
	cooling efficiency	16 SEER, 13 EER	**18 SEER**
	cooling capacity	4 ton	**3 ton**
	equipment location	unconditioned attic	**semi-conditioned attic**
	thermostat	code-compliant setback	**smart thermostat**
Ducts	location	unconditioned attic	**semi-conditioned attic**
	insulation	**R-8**	
	leakage	7.5%	
	change in duct length		**none**
Water Heating			
Water Heater	water heater type, efficiency	gas tank, 0.62 EF	**condensing gas tankless, 0.95 EF**
	tank size	50 gal	
	equipment location	**garage**	
DHW Distribution	insulation, pipe material	unsinsulated copper	**R-2 PEX**
	recirculation system	no recirculation	**recirculation**
	low flow fixtures		
	change in pipe length		
Electric Loads			
Lighting	type	100% CFL	**mostly LED, some CFL**
	controls		**color controls in kitchen**
Appliances	fridge	not provided	**ENERGY STAR fridge**
	cooking	gas cooking	**induction stove**
	dishwasher	**provided**	
	washer	not provided	**ENERGY STAR washer**
	dryer	not provided	**gas dryer**

Note: a blank cell indicates no change, bold indicates final package

Highlight: Ducts in Semi-Conditioned Space

To move the ducts into semi-conditioned space, the project team shifted the insulation from the attic floor to directly under the roof deck using Owens Corning's boxed netting solution. The netting was stapled to the trusses, creating long cavities that were blown full of loose fill fiberglass insulation. Because putting the insulation up against the roof deck brought the attic within the thermal envelope, the attic was not vented.

Owens Corning used the Pulte ZNE home as a demonstration project, providing training for the contractors and sending representatives from the technical marketing team on site to assist with the installation. This support reduced builder concerns about using a new method.

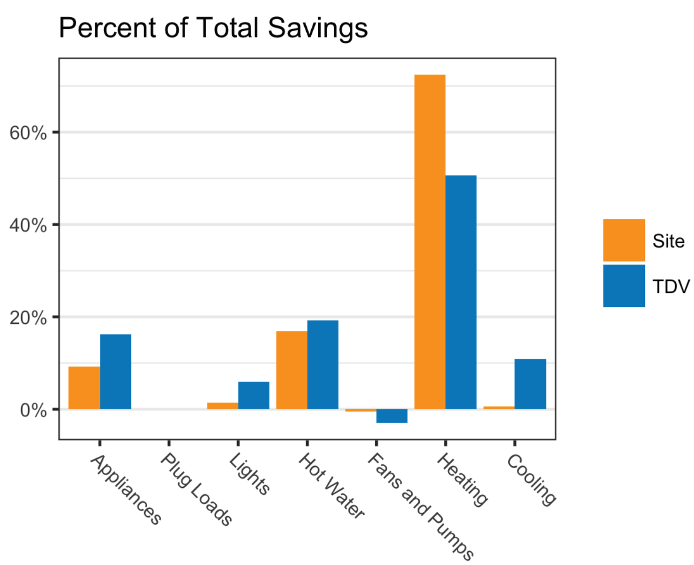
Source: Can Anbarlilar, PG&E

Measures Considered But Not Implemented

A number of measures initially recommended by the design consultants were not ultimately incorporated into the final design. Based on modeled energy savings, including high solar heat gain coefficient (SHGC) windows and high thermal mass was not cost effective in this case. There were construction concerns about including a cool roof and skylights, maintenance and water-use concerns about using evaporative cooling in a drought-prone area, and maintenance and water tank storage space concerns about including solar water heating.

Modeled Energy Performance

The energy savings impact of the implemented energy efficiency measures was evaluated using both site energy and TDV metrics to weigh their impact on the overall modeled energy performance. Because TDV is weighted seasonally and hourly, the modeled energy savings are different in each metric. The final package reduced the modeled site energy consumption by 52% and the modeled TDV energy to 22%, compared to standard practice for the same home model.[3]



As seen to the left, efficiency improvements in heating had the most significant impact on modeled site energy and TDV savings. Cooling is generally needed during peak TDV periods, so the reduction in modeled energy consumption for cooling was a substantial component of TDV savings (11%) but did not have a significant impact on site energy savings.

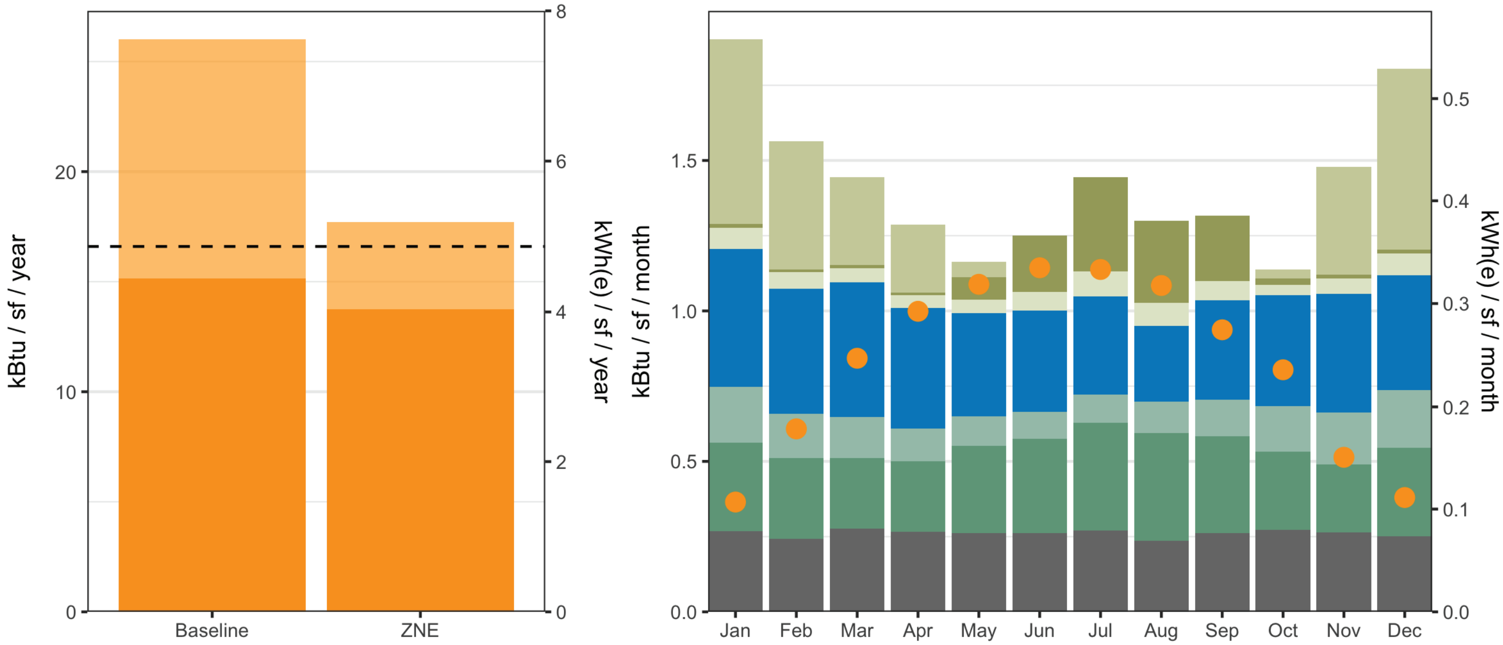
As seen on the next page, the modeled monthly energy consumption shows a W-shape for both site and TDV energy, primarily because of seasonal heating and cooling loads. TDV multipliers for electricity are the highest in July through September and affect all end uses, not just the cooling.

For both site energy and TDV energy, PV production follows an inverted U-shape, with production peaking in the summer months. Although site PV production does not exceed consumption during any month, the home is still modeled as net zero TDV because electricity is weighted more highly during the afternoon peak production hours using the TDV metric.

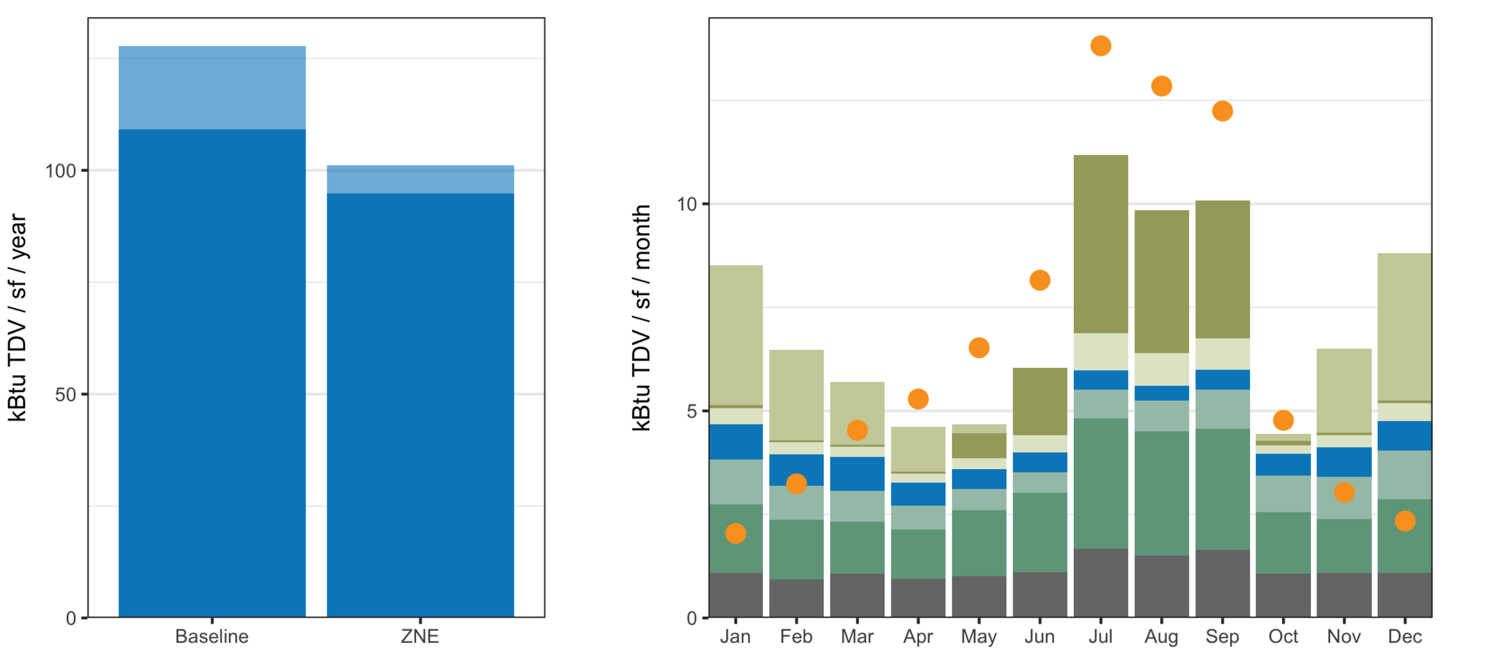
In order to place the site energy modeling results in a larger context, the Pulte ZNE home modeling results were compared to the performance of a ZNE exemplar home, based on project results from *The Technical Feasibility of Zero Net Energy Buildings in California*.[4] The Pulte ZNE package's modeled energy use intensity (EUI), 16.8 kBtu/sf/yr, was virtually the same EUI as the exemplar in the same climate zone. Comparing energy performance using only EUI can penalize smaller homes, since some loads, such as heating and cooling, vary depending on floor area, but others, such as water heating, appliances, and plug loads, vary mostly based on the number of occupants. Comparing to the performance of the ZNE exemplar home using the number of bedrooms plus one as a proxy for number of occupants, the Pulte ZNE package is modeled as using 9% less energy per person than the 3 bedroom, 2,100 sf ZNE exemplar home.

[3] Energy modeling was done with BEopt 2.3 using the 2013 CEC weather file for California climate zone 12.
[4] http://www.calmac.org/publications/California_ZNE_Technical_Feasibility_Report_CALMAC_PGE0326.01.pdf

Modeled Site Energy



Modeled TDV Energy



Lessons Learned

Boxed Netting Installation

Installing the cathedralized attic with boxed netting for the first time took about four times as long as Pulte's standard blown in insulation on the attic floor; the Pulte team plans to cut this in half, but it is still longer than the standard process. This attic solution is also a critical path task, resulting in a shorter window in which it has to be installed without pushing back the whole project schedule. The safety requirements are also different for this ZNE demonstration home; extra boards were laid for fall protection and for workers to walk on. In a production environment this might not be adequate.

Initial measurements show that the system is performing well and keeping the attic within 1-2°F and 5-8% relative humidity of the house. This performance is despite being only a semi-conditioned space; there are no supply or return grills in the attic.

Heat Pump

Heat pumps do not raise the temperature of air as quickly as furnaces; this required behavior adjustments from both the contractors and occupants. After installation of the multistage heat pump, the way the controls were ultimately configured, without specific consideration of heat pump operation, resulted in the inefficient electric resistance backup heat strips coming on frequently. Changing the setting to use 100% indoor air during the coldest times of day generally resolved the issue.[5] Also, the air coming out of supply vents is not as hot with a heat pump as with a furnace for a given indoor air temperature. To get supply air at the expected temperature, the occupants increased the setpoints, which also resulted in initial high use of the heat strips. The indoor temperature in homes with a heat pump does not recover as quickly from setbacks as the temperature in a house that is heated by a furnace. Even though the smart controls of the house could detect when the occupants were coming home (based on location of their cell phones), the house was not always warm enough on arrival because the setpoint setbacks were so large. Training the occupants to choose a smaller range of setbacks resulted in a comfortable home.

Financial Findings

The incremental cost associated with the ZNE package for the Pulte ZNE home totaled less than 3% of the sale price. The induction cooktop and ENERGY STAR appliances accounted for more than 40% of the incremental cost. Pulte does not typically provide a refrigerator or laundry machines, and the cooktop was chosen primarily as an upgrade rather than as an efficiency measure. The attic insulation and the heat pump each accounted for about 17% of the incremental cost. The home was sold using a bid process, resulting in a final price that more than covered the incremental cost of the efficiency upgrades.

[5] In colder climates energy recovery ventilators (ERVs) or heat recovery ventilators (HRVs) can be installed to prewarm the outdoor air before it enters the heat pump to avoid long periods of 100% indoor air.

Source: Resource Refocus LLC

Source: Resource Refocus LLC

"The learning has been immense, and the project has been a pleasure."

-Brian Jamison,

National Purchasing Director, PulteGroup

PROJECT TEAM

Builder Team:

PulteGroup

ZNE Team:

PG&E

BIRAenergy

Resource Refocus LLC

Frontier Energy, Inc.

This case study was written by Resource Refocus LLC based on consultant reports and project analysis.

Completion and Next Steps

The Pulte ZNE home was completed in May 2016, with a subsequent ribbon cutting attended by officials from the State of California, Pulte, PG&E, and other partners. The process of completing the ZNE home with PG&E is already influencing how Pulte is proceeding with new homes in California.

Residential heat pumps are not common in California; the Lennox representative was surprised when Pulte wanted to install one. If Pulte, one of the biggest builders in the country, continues to install them in this community and beyond, it will require Lennox to shift its distribution system. Hopefully this will make heat pumps more accessible and affordable for everyone.

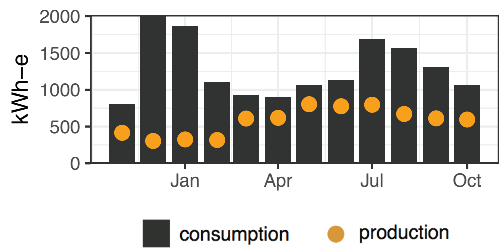
Although training the homeowners of ZNE homes can be effective for a small number of homes, it is impractical at production volumes and does not carry over when ownership eventually changes. Therefore Pulte is working with thermostat manufacturers to address some of the issues that were revealed in this ZNE demonstration home with updated control strategies. They would like the "away" mode of the thermostats to be turned off during set up in high performance homes with heat pumps so that the setbacks do not cause occupant discomfort by taking longer than expected to get the indoor temperature back up to the set point.

Finally, Pulte has purchased land where they plan to build a high performance, all electric multifamily development using some of the features piloted in this demonstration, including a semi-conditioned attic with boxed netting, heat pumps, and 100% LEDs.

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

PulteGroup
Monitoring Case Study

Measured Site Energy: Monthly Consumption and Production



Energy Overview	Mod.	Meas.
EUI kBtu/sf/yr	17.2	22.5
PV Production kBtu/sf/yr	9.9	10.0
Offset % Site Energy	58%	44%

PROJECT OVERVIEW

Floor Area: 2,344 sf

Bedrooms: 4

Location: Brentwood, CA

CA Climate Zone: 12

Completion: June 2016

Monitoring Dates: November 2016 - October 2017 (after occupancy)

PV Array: 4.62 kW

Under the auspices of Pacific Gas and Electric Company's (PG&E) Zero Net Energy (ZNE) Production Builder Demonstration, PulteGroup (Pulte) built a ZNE home with R-38 fiberglass insulation under the roof deck creating a semi-conditioned attic for the air source heat pump and ducts. Both the condensing tankless water heater and the clothes dryer are gas, but the cooking is induction. The builder installed a 4.62 kW PV array, which was sized to fully offset modeled TDV but not site energy consumption. The solar energy produced by the PV array offset 44% of annual site energy consumption, less than the 58% predicted by the energy modeling. Heating, ventilation, and air conditioning (HVAC) loads were the single biggest end use[1], accounting for 29% of total consumption, followed by plug loads at 24%.

Measured Energy Performance

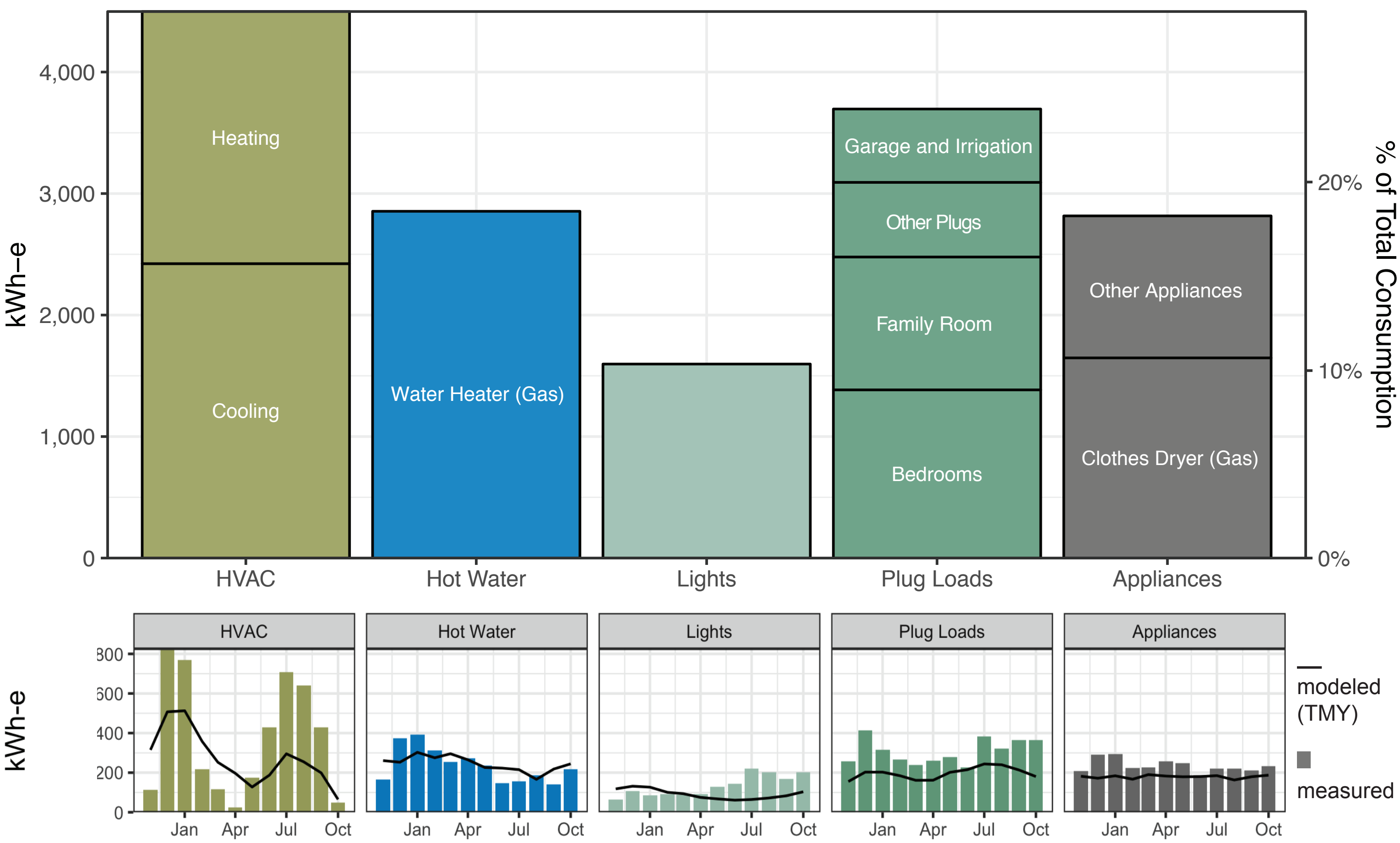
The energy consumption of specific end uses was monitored for a year to understand the house's performance while occupied.

To align with California building energy code, the ZNE goal for this project was based on Time Dependent Valuation (TDV). Because TDV is a modeling metric that cannot be accurately assessed for measured energy performance data,[2] ZNE performance was evaluated using the site energy performance predictions of the zero net TDV model. The measured data showed that the PV production offset only 44% of site energy consumption, substantially less than the 58% predicted by the model, so the performance was not in line with the home's ZNE design.[3]

Site energy production was within one percent of what was modeled, but consumption was about 30% more. About 70% of this increase was due to cooling and plug loads, although appliances and lighting consumption were also more than modeled.

[1] "End use" refers to the final work that the energy did. For example, electricity might be ultimately used to run appliances, and natural gas might be used to heat water.
[2] TDV multipliers are tied to specific weather, grid, and economic projections and assumptions that will not be met exactly over the course of a year, so it is not appropriate to apply them to measured data.
[3] See design case study for information about building specs and design decisions.

Measured Site Energy



The figures above show the measured energy consumption broken down by end use for the entire year of monitoring and by month. On the facing page, the charts compare modeled and measured energy consumption and outdoor temperature.

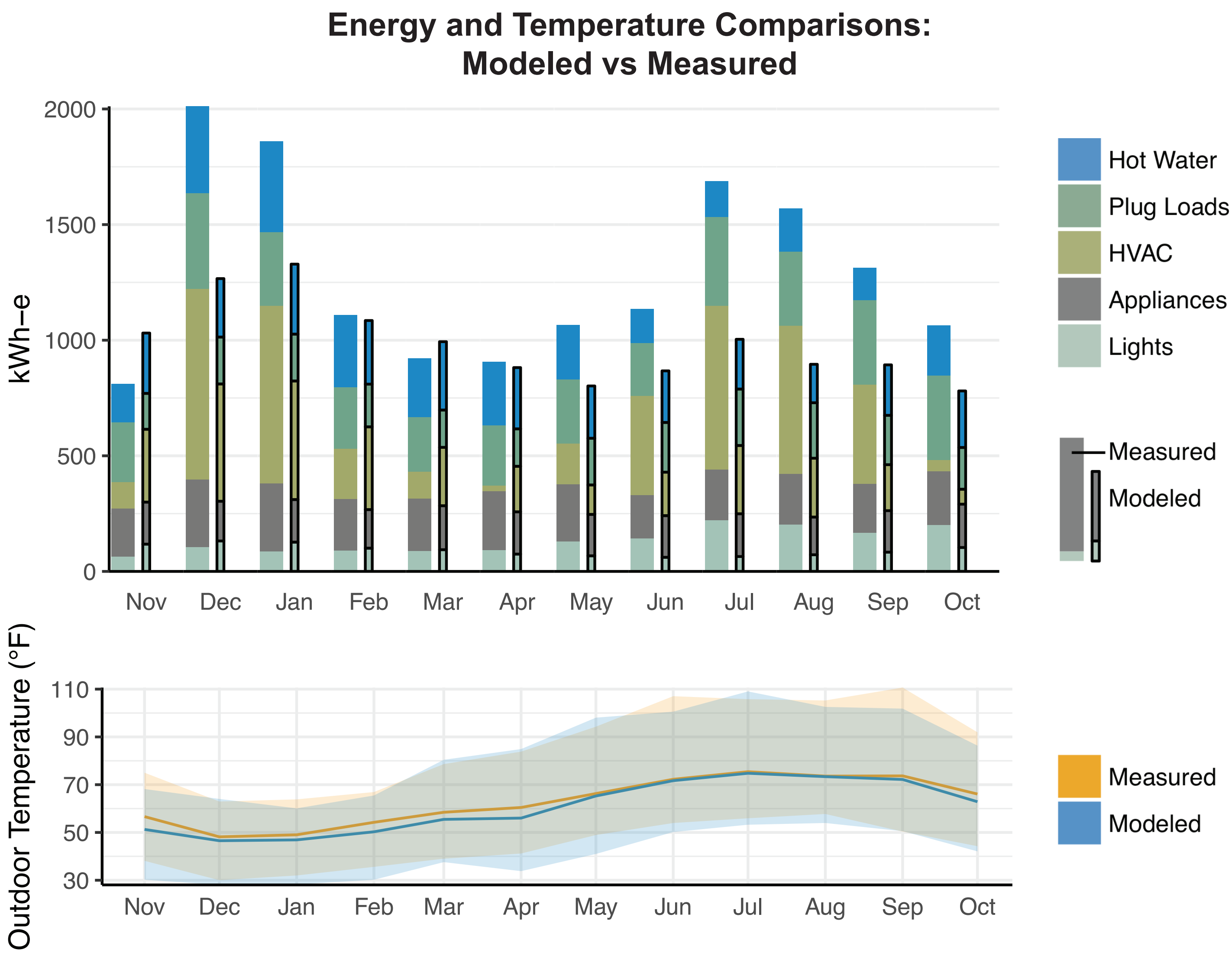
HVAC

HVAC was the single largest end use, accounting for 29% of the annual energy consumption. This space conditioning consumption was also much more than was predicted. To check the values, the energy model was run twice – once with the Typical Meteorological Year (TMY) weather file that is used for code compliance and once with the Actual Meteorological Year (AMY) weather file that corresponds to the real weather during the monitoring period.[4] The AMY weather was milder than the TMY weather, so while space heating was 2.3% less than TMY predictions it was 42% more than AMY predictions. Cooling, on the other hand, was more than twice as much than predicted using both weather files, but the difference was slightly more for TMY than AMY (152% and 126% respectively).

Hot Water

Domestic hot water accounted for 18% of the total measured consumption. The measured consumption was slightly less than the model: 3% lower. It is one of the two end uses that include gas.

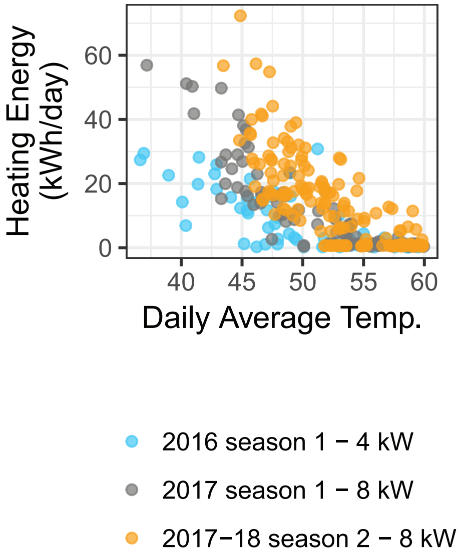
[4] Elsewhere in the case study, modeled numbers refer to the TMY data.



Lights
The energy consumption for hard-wired lighting accounted for 10% of overall consumption, 45% more than modeled even without including plug-in lamps.

Plug Loads
Plug loads accounted for 24% of the total consumption, second only to HVAC. 30% of that was from the family room, likely because of an entertainment center. Interestingly, the garage circuit which also includes irrigation was also a significant contributor, at 16%. In all, plug load consumption was 45% more than modeled

Appliances
Appliances accounted for 18% of the measured energy consumption. The gas dryer by itself was responsible for 58% of the appliance consumption and 10% of the total home consumption. This is the same percentage as the lights.



On the cooling side, the increase in energy consumption compared to the model was much larger, but the cause is not clear. The indoor set-point of 76°F is similar to the energy model, and the system is sized so that it is running long enough to be efficient. Possible causes include distribution losses for the two-zone system or in the ducts or lower seasonal efficiencies than manufacturer ratings.

Highlight: Heat Pump

Space conditioning is provided by a 3-ton air source heat pump located in the semi-conditioned attic and an outdoor air handler with auxiliary heat strips. The system consumed substantially more energy than expected given the weather conditions.

Heat strips are present to meet the heating demand more quickly and at colder temperatures than the compressor can by itself. They are included by default despite being less than a third as efficient as the compressor itself and unnecessary in most California climates. The occupant complained that the heating system was not working, likely because heat pumps are slow to recover from setbacks and because air coming from the vent is not as hot as with a furnace. In response more heat strips were added to the air handler in December 2016, increasing the total from 4 to 8 kW. At the same time, the controls were changed so that the heat strips would only be used at lower temperatures than they had been but still at much higher temperatures than is typical. The net effect of these changes was an increase in consumption to heat the house at the same outdoor temperatures. Because they ran so often, drawing such high power, the heat strips were responsible for 49% of heating energy.

Lessons Learned

Heat pumps can be a very efficient way to condition a home, but they require both occupant education and careful programming of the controls. Performance testing beyond what is required for HERS rating can also be necessary to ensure that the distribution system is efficient.

Especially in ZNE homes, where HVAC has been carefully designed to be energy efficient, the unregulated end uses of plug loads, appliances, and lighting make up a large portion of the total energy consumption; 54% in this case. This is despite the heating and cooling consuming 46% more than the TMY and 77% more than the AMY models. As Title 24 becomes more stringent, builders need to pay more attention to loads, such as appliances, that have typically not been under their control.

PROJECT TEAM

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