Cottle Zero Net Energy Home Monitoring Performance Evaluation Report, 12 Months of Occupancy

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ABBREVIATIONS AND ACRONYMS

ACH_{50}	Air changes per hour @ 50 pascals
CEC	California Energy Commission
CRRC	Cool Roof Rating Council
DC	Direct current
DEG	Davis Energy Group
DHW	Domestic hot water
DOE	Department of Energy
EER	Energy efficiency ratio
EEM	Energy efficiency measure
EUI	Energy use intensity (kBtu/sqft)
HERS	Home Energy Rating System
HSPF	Heating seasonal performance factor
HRV	Heat recovery ventilator
HVAC	Heating, ventilation, and air conditioning
IAQ	Indoor air quality
kW	Kilowatt
kWh	Kilowatt-hour
NREL	National Renewable Energy Laboratory
PHPP	Passive House Planning Package
PV	Photovoltaic
QII	Quality Insulation Installation
SEER	Seasonal energy efficiency ratio
SHGC	Solar heat gain coefficient
TDV	Time dependent valuation
TED	The Energy Detective
ZNE	Zero net energy

FIGURES

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EXECUTIVE SUMMARY

PROJECT GOAL

The main objective of this project is to evaluate how well the Cottle ZNE Home achieved the design goals of reaching zero net energy performance over the course of 12 months and to compare original modeling estimates to actual monitored data when occupied.

PROJECT DESCRIPTION

The Cottle ZNE Home is a 3,170 ft^2, two-story spec home on an in-fill lot in San Jose, California (CA Climate Zone 4). The house was designed to Passive House standards and incorporates 5.5 kW of photovoltaic panels and solar water heating. According to CalCERTS, this is the first house in the California registry to have a Home Energy Rating System (HERS) index of less than zero (-1). Energy efficiency measures (EEMs) that contribute to the home's performance include triple-pane windows, a non-vented insulated crawlspace, advanced framing with exterior foam (R-23), R-50 ceiling insulation, tight construction (0.60 ACH50), a heat recovery ventilator (HRV), 18 SEER heat pump with ventilation cooling, ducts in conditioned space, and a condensing water heater.

PROJECT FINDINGS/RESULTS

The project achieved zero net energy over the 12 month monitoring period (April 1, 2013 – March 31, 2014) by various metrics, including the following:

- TDV Energy (gas + electricity less electric vehical charging): On an annual basis, the house produced 12 kBtu/ft^2 (28%) more TDV energy than it consumed.
- Site Electricity (electricity only less electric vehicle charging): On an annual basis, the house produced 1,492 kWh (16%) more electricity than it consumed.
- Source Energy (gas + electricity less electric vehicle charging): On an annual basis, the house produced 8,994 kBtu (11%) more source energy than it consumed.

Including electric vehicle charging, the house produced 95% of total TDV energy, 84% of total site electricity, and 81% of total source energy needs over the 12 month monitoring period.

The occupants are very satisfied with the house including the comfort it affords and the lower utility bills.

Actual total house TDV use tracked very well with modeling estimates, within 4%; however, differences by end-use were very large, particularly for space cooling. This may partially be explained by the differences between the weather files and actual weather and certain modeling limitations. However, it's expected this is largely a result of much lower thermostat set points in the Cottle house than those assumed for Title-24 modeling.

Actual total house electricity use tracked very well with BEopt modeling estimates, within 1%; however, differences by end-use were very large in certain cases. Actual plugs and miscellaneous loads were 14% higher, while actual lighting and appliance use were approximately 20% lower.

PROJECT RECOMMENDATIONS

Miscellaneous energy use is a significant contributor to total house energy, particularly in ZNE homes with low cooling and heating loads. In the future, incentive and early adopter programs need to target this end-use. Research to better understand this end-use and potential reduction strategies is necessary.

The Cottle house is a successful example of a high performance home meeting California's zero net energy goals. While incremental costs of some of the measures are higher than can be currently justified in residential housing across the state, pilot projects such as this are essential to future widespread adoption by demonstrating technology and identifying and disseminating lessons learned to the community, ultimately driving down costs.

INTRODUCTION

This report presents the results of detailed monitoring of the Cottle Zero Net Energy (ZNE) Home over 12 months from April 1st, 2013 through March 31st, 2014. The home has been occupied during the monitoring period by a family of five who moved in February 2013. Analysis includes evaluation of ZNE performance, annual and monthly energy use by end-use, and comparison of the monitored energy use to the original modeled estimates.

BACKGROUND

The Cottle ZNE Home is a 3,170 ft^2, two-story spec home on an in-fill lot in San Jose, California (CA Climate Zone 4). The house was designed to Passive House standards and incorporates 5.5 kW of photovoltaic panels and solar water heating. According to CalCERTS, this is the first house in the California registry to have a Home Energy Rating System (HERS) index of less than zero (-1). Energy efficiency measures (EEMs) that contribute to its performance include triple-pane windows, a non-vented insulated crawlspace, advanced framing with exterior foam (R-23), R-50 ceiling insulation, tight construction (0.60 ACH50), a heat recovery ventilator (HRV), 18 SEER heat pump with ventilation cooling, ducts in conditioned space, and a condensing water heater[1].

House construction was completed in February 2012, and the monitoring system was installed and commissioned by Davis Energy Group (DEG) in March of that year. In early March, the home was occupied by the builder and his family; they moved out at the end of June. The house remained unoccupied until it was sold in early 2013,

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[1] Additional information is available at http://www.siliconvalleyzeroenergyhome.com/.

and the new owners, a family of five, moved into the house. Results from the 2012 analysis can be found in the Cottle Residential Monitoring Final Performance Evaluation Report from December 2012[2]. The occupants purchased an electric vehicle, a Toyota RAV4-EV, towards the end of March 2013 and have been using the charging station regularly since then. Full year monitoring period for this study began after the purchase of the electric vehicle.

Figure 1 illustrates the occupants' heating and cooling seasons during the evaluation period of April 1 2013 – March 31 2014 as observed via the monitoring data. Between November 1 and November 17 the thermostat switched periodically between heating and cooling mode. The three shaded periods are times when the house appeared to be unoccupied or minimally occupied, based on total house energy use.

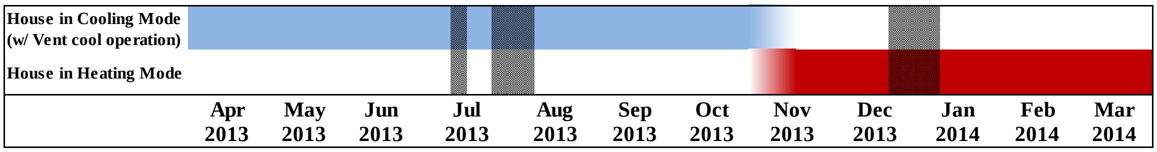

FIGURE 1: COOLING AND HEATING SEASONS

EMERGING TECHNOLOGY

Details of the house efficiency measures are listed in Table 1, along with a comparison to a baseline building built to minimum 2008 Title-24 standards and details of incremental costs by measure. Total incremental costs above the baseline comparison amount to $94,800 ($67,800 incremental cost for efficiency measures and $27,000 for the photovoltaic (PV) system). Incremental costs were offset by utility incentives and federal tax credits totaling $29,800 ($9,800 for efficiency and $20,000 for PV). Unless otherwise specified, costs are builder estimates from as-built costs and include labor.

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[2] Contact Peter Turnbull at pwt1@pge.com for additional information.

Table 1: Building Efficiency Specifications & Incremental Costs

BUILDING COMPONENT EFFICIENCY FEATURE	BASE CASE	ZNE DESIGN - "AS-BUILT"	INCREMENTAL COSTS ($)	NOTES
ENVELOPE				
Roofing (%Reflec./%Emittance)	Asphalt Shingle, standard	Asphalt Shingle, CRRC rated (8%/85%)	-	Prem comp shingle
Roof (attic)	Vented attic, R-30 blown	Vented attic, R-50 blown	$1,200	
Radiant Barrier	Yes	No	-	
Wall (Exterior; Cavity+Foam Sheathing)	2x4 16"o.c., R-13 batt	2x6 24"o.c., R-21 blown + 1" ext. foam, Advanced Frame	$5,000	No difference in frame costs
Wall (garage)	2x4 16"o.c., R-13 batt	2x6 24"o.c., R-21 blown, Advanced Frame		
Quality Insulation Installation Verified (HERS)	No	Yes	-	see below for costs
Foundation Type	Slab-on-grade, no insulation	Sealed conditioned crawlspace, R-21 perimeter wall	$19,000	Pier and grade beam $$$
Floor over Garage/Open	R-19	R-19	-	
Exposed Thermal Mass	N/A	N/A	-	
Envelope Leakage Verified (ACH50) (HERS)	No (5.0)	Yes (0.6)	$4,700	Doesn't include HERS verification
Windows (U-factor / SHGC)	0.40 / 0.40	Sorpethaler: U-value/SHGC = 0.19/0.50 Serious (fixed): U-value/SHGC = 0.17/0.27	$12,500	Base = prem wood or fiberglass dbl pane
HERS Measures	Tight ducts	Tight ducts, QII, Blower door, EER	$800	
HVAC SYSTEM				
System Type	4-ton single speed heat pump	2-ton dual speed heat pump	$1,300	
Cooling (SEER / EER)	13 / 10	17 / 13		
Verified EER (HERS)	No	Yes		Cost included above
Furnace (AFUE) / Heat Pump (HSPF)	7.7	9.5		
Duct Location	Attic	Conditioned space	-	Included in HP costs, no significant difference due to downsizing
DUCT LEAKAGE - TESTED < 6% LEAKAGE	YES	YES		

Building Component Efficiency Feature	Base Case	ZNE Design - "As-Built"	Incremental Costs ($)	Notes
(HERS)				
Duct Insulation (R-value)	R-6	R-6		
Verified Refrigerant Charge (HERS)	No	No		
Verified Adequate Airflow (HERS)	No	No		
Verified Fan Watt/cfm < 0.58W/cfm (HERS)	No	No		
Nightime Ventilation Cooling	None	NightBreeze	$2,500	
Mechanical Ventilation	Exhaust fan, continuous	HRV, Zehnder ComfoAir 350	$9,600	
Water Heating				
Water Heating System	Standard 50gal Gas, 0.62 EF	Condensing gas, AO Smith Vertex. 50gal 0.96 EF	$1,600	
Solar DHW: Solar Fraction	N/A	81%; Closed Loop, 3-4x8 collectors, 80 gallon storage	$7,000	
Distribution Type	Kitchen Pipes Insulated	Demand recirc w/ insulated pipes	$1,600	2 recirc pumps
Lighting				
LED% / CFL% / Incandescent	0% / 35% / 65%	100% LED + CFL	$1,000	
Controls	None	Vacancy sensors		
Other Energy Efficiency Features				
EnergyStar Appliances	None	Fridge, dishwasher, clothes washer	$0	
Cooking	Gas	Gas	-	
Clothes Dryer	Electric	Electric	-	
Fireplace, yes/no & fuel type	No	No	-	
Home Energy Management System	N/A	The Energy Detective (TED)	N/A	Cost not provided
% Better than 2008 Base Case	N/A	66.4%		
On-Site Generation				
Solar Photovoltaic System	None	5.5kW DC PV System	$27,000	
		Total Incremental Costs:	$94,800	
		Utility Incentives / Tax Credits:	($29,800)	
		Net Incremental Costs:	$65,000	

Following is detailed information on individual measures that were selected, with discussion of their tradeoffs as appropriate.

THERMAL ENVELOPE

Walls: The exterior wall construction is 2x6 framing, 24 inches on center, incorporating advanced framing techniques to minimize thermal bridging and reduce the amount of wood used for framing. When implemented correctly and early in the design phase this measure can result in material and cost savings along with energy savings and increased occupant comfort. One inch of rigid insulation sheathing was also installed on the exterior to reduce the thermal bridging effects due to framing. Cavity insulation was installed and inspected to meet Title 24 quality quality insulation installation (QII) criteria and achieve full credit for the installed insulation.

Conditioned Crawlspace: The house includes a conditioned crawlspace. Conditioned crawlspaces provide benefits over vented crawlspaces in regards to durability, health, safety, and comfort. The crawlspace was sealed using a 10 mil continuous vapor barrier over the soil and the foundation walls were insulated to R-21. A concrete slab was poured on the foundation floor to provide thermal mass and reduce cooling energy use during the summer.

Windows: High performance windows were installed throughout the house. Triple-glazed operable windows imported from Germany were installed in certain locations. These windows have an R-value of about R-5 but a relatively high SHGC (0.50) compared to most windows manufactured in the United States. Serious 525 series fixed windows (dual pane with a heat mirror film between the inside and outside pane) were installed on east and west orientations. They provide an equivalent R-value, but with a much lower SHGC.

Air Tightness: The house was built to the Passive House air tightness standard where tested leakage rate shall not to exceed 0.6 ACH50. A continuous air barrier was installed and all gaps and penetrations caulked and sealed to prevent air movement between conditioned and unconditioned space. Through careful attention to sealing of the building envelope and construction details, the measured air leakage was at 0.49 ACH50.

MECHANICAL SYSTEMS

Heating and Cooling: Both space heating and cooling are served by a high efficiency heat pump and air handler. NightBreeze ventilation cooling system and controls are incorporated to provide ventilation cooling during the summer[3]. The potential for reducing compressor-based cooling in this climate using ventilation cooling is high. Average daytime temperatures in the summer are 84 degrees with average nighttime lows usually dipping into the mid 50s. The air handler and all ductwork are located in conditioned spaces. Coordination early in design was critical in providing space for the equipment and ductwork within conditioned space. Duct size calculations were completed in accordance with ACCA Manual D Residential Duct Systems. Duct leakage was tested and verified by a HERS rater to be 5.6 percent of nominal system airflow.

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[3] http://www.davisenergy.com/r-and-i/products/

Fresh Air Ventilation: A Zehnder ComfoAir 350 heat recovery ventilator (HRV) was installed to provide mechanical ventilation[4]. The HRV exhausts air from the three bathrooms and the laundry and supplies tempered air to the bedrooms and living areas via a dedicated duct system. DEG worked with the builder to select an HRV with good performance characteristics to minimize fan energy use.

Water Heating: A closed loop solar water heating system was installed with three, four by eight foot flat panel collectors and a 120 gallon storage tank. This system preheats water which is then directed to a high efficiency (A.O. Smith Vertex) condensing gas storage water heater. A Metlund demand recirculation system was installed with two recirculation pumps that are activated by occupant operated buttons.

LIGHTING AND APPLIANCES

The 2008 California Title 24 standards for residential lighting require a certain percentage of high efficacy fluorescent fixtures in kitchens, but allow either fluorescent fixtures or incandescent fixtures with vacancy sensors (or dimmers in some rooms) in other locations. The builder, One Sky Homes, used a combination of LEDs, hard-wired fluorescent linear fixtures, and CFLs to exceed Title 24 requirements and installed high efficacy lighting in all hardwired lighting locations. The dishwasher, refrigerator, & clothes washer are all Energy Star listed models.

PHOTOVOLTAIC SYSTEM

The grid-connected 5.5 kW (DC) PV solar electric system consists of 28 southeast-facing BP Solar modules connected to EnPhase micro-inverters. The PV system is sized to provide almost all of the annual electrical energy use of the house, including the electric vehicle charging station. While the PV systems adds cost to the house, the builder targeted buyers interested in zero energy homes and thus an adequately sized PV system was the most important feature in the sale of this home.

ASSESSMENT OBJECTIVES

The main objective of this project is to evaluate how well the Cottle ZNE Home achieved the design goals of reaching zero net energy performance over the course of 12 months and to compare original modeling estimates to actual monitored data when occupied.

TECHNOLOGY EVALUATION

The project monitored and evaluated the whole house energy performance of the Cottle ZNE Home. Specifically, Davis Energy Group monitored the gas and electicity energy use for specific end uses: space cooling, space heating, lighting, appliances

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[4] http://zehnderamerica.com/our_products_categories/heat-recovery-ventilators-energy-recovery-ventilators/

and cooking, IAQ ventilation, and plug loads. The energy used for electric vehicle charging and the production of the PV system were also monitored.

This monitored energy use was used to determine whether the Cottle ZNE Home achieved ZNE performance while occupied over the course of a year. ZNE performance was evaluated using three ZNE metrics – zero net site energy, zero net TDV energy, and zero net source energy. Monitored energy use was also compared to predicted energy use from several modeling tools (EnergyPro, BEopt, PHPP) and approaches to determine where discrepancies between modeled and monitored data occurred.

TECHNICAL APPROACH/TEST METHODOLOGY

FIELD TESTING OF TECHNOLOGY

The general evaluation approach was to employ system commissioning, short term tests, long term monitoring, and detailed analysis of results to identify the performance attributes over a full 12 months. HVAC energy delivery was monitored using air side measurements, while DHW energy delivery was monitored using water side measurements. Equipment gas and electrical end uses were measured as well.

Monitoring data was carefully reviewed and analyzed in an effort to respond to the research goals of this project. Table 2 chronicles the problems encountered with the monitoring equipment, site visits, and any changes that may have affected the monitoring data.

Table 2: Cottle House Monitoring System History

DATE	DESCRIPTION
4/23/2013 - 8/22/2013	Short periods of lost data from analog sensors going down (Temp/RH)
5/29/2013 - 6/4/2013	Data logger lost program + data
7/5/2013	DEG site visit: replaced and upgraded analog transformer, checked chassis and analog ground, repaired insulation crimp in phone line
8/8/2013	Site visit to install isolator upstream of power supply
8/10/2013 – 8/16/2013	Short periods of lost data from analog sensors going down (Temp/RH)
8/20/2013	Ground removed from data logger (by homeowner via use of a 2-3 prong adapter plug) – loss of EGEN data point
8/23/2013	Site visit to replace data logger – resolve issue with analog sensor outages

TEST PLAN

The site was equipped with a data logger and modem for continuously collecting, storing, and transferring data via telephone lines or cellular communications. Sensors were scanned every 15 seconds, and data was summed or averaged (as appropriate) and stored in data logger memory every 15 minutes.

Table 3 lists all the measurement points that were monitored on a continuous basis.

SHORT TERM TESTS

Davis Energy Group and the HERS Rater collected additional data from the following short-term tests to support the calculations described in the test plan and facilitate answering DEG's research questions. The tests are outlined below:

- A blower door test using standard protocols to measure building leakage.
- A duct blast test to insure duct tightness and minimal leakage from the outside air damper and air handler cabinet.
- HVAC system airflow test to verify correct air handler tap settings. Supply plenum pressure data was taken at varying airflows to establish the relationship between airflow and plenum pressure readings.
- One-time measurement of HRV airflow to verify design ventilation rates.
- One-time measurement of greywater pump power and flow to quantify energy consumption and flow based on monitored pump status.

Table 3: Measurement points

Point No.	Abbrev.	Description	PRIORITY	Location	Sensor Type	Sensor Mfg./Model
1	TAO	Temp, air, outdoor	1	Mount on north side of house shaded from	RTD, 0-1V	RM Young 41372VF
2	RHO	Relative Humidity, air, outdoor			RTD, 0-1V	
3	TAI1	Temp, air, indoor, Floor 1	1	West wall of Great Room. Wall adjacent to	RTD, 4-20ma	Gen Eastern MRHT3-2-I
4	RHI1	RH, air, indoor, Floor 1			RH, 4-20ma	
5	TAI2	Temp, air, indoor, Floor 2	1	East wall of upstairs landing, adjacent to	RTD, 4-20ma	Gen Eastern MRHT3-2-I
6	RHI2	RH, air, indoor, Floor 2			RH, 4-20ma	
7	TAERVS	Temp, air, ERV Supply	sensor wired	ERV unit - Laundry Room dropped ceiling	RTD, 4-20ma	Vaisala HMD60Y
8	RHERVS	RH, air, ERV Supply			RH, 4-20ma	
9	TAS	Temp, air, AH Supply	sensor wired	Supply Plenum, FAU Closet	RTD, 4-20ma	GE MRHT 3-2-1
10	RHS	RH, air, AH Supply			RH, 4-20ma	
11	TAR	Temp, air, AH Return	sensor wired	Return Plenum, FAU Closet	RTD, 4-20ma	GE MRHT 3-2-1
12	RHR	RH, air, AH Return			RH, 4-20ma	
13	TATT	Temp, air, Attic	sensor wired	Attic near access	RTD, 4-20ma	LM34
14	TACRWL	Temp, air, Crawlspace	sensor wired	Crawlspace	RTD, 4-20ma	LM34
15	PSP	Pressure, Supply Plenum	1	Air Handler, FAU Closet	P.Transducer	
16	TSW2	Temp, Int. Surface, Serious Glass	2	Inside surf. of glass-2nd floor bath	Surface TT	Omega
17	TSW1	Temp, Int. Surface, Std window	2	Inside surf. of glass-dual pane laundry	Surface TT	Omega
18	MRT2	Temp, Globe, indoor, Bathroom	2	2nd Floor Bathroom-North Exposure	Type T TC	Omega
19	MRT1	Temp, Globe, indoor, Laundry	2	1st Floor Laundry-North Exposure	Type T TC	Omega
20	TAI3	Temp, air, indoor, Bathroom	2	2nd Floor Bathroom-North Exposure	Type T TC	Omega
21	TAI4	Temp, air, indoor, Laundry	2	1st Floor Laundry-North Exposure	Type T TC	Omega
22	TSCRWL	Temp, surface, Crawlspace slab	sensor wired	Crawlspace slab	Surface TT	Omega
23	EHSE1	Energy, Total House From Grid	1	Main Service Panel	Power Meter	Wattnode/WNB-3Y-208-P
24	EHSE2	Energy, Total House To Grid		Main Service Panel	""	""
25	EPV	Energy, PV System		Main Service Panel	""	""
26	EHP	Energy, Heat Pump	sensor wired	At Outdoor Unit	Power Meter	Wattnode/WNA-1-P-240P
27	EFAN	Energy, Air Handler Fan	sensor wired	Air Handler, FAU Closet	Power Meter	Wattnode/WNA-1-P-240P
28	EERV	Energy, ERV	sensor wired	ERV, Laundry Room dropped ceiling	Power Meter	Wattnode/WNA-1-P-240P
29	EPMPS	Energy, Solar Collector Loop Pump	sensor wired	Water Heater - Garage	Power Meter	Wattnode/WNA-1-P-240P
30	SGWP	Status, Greywater Pump	3	Greywater Pump Subpanel	Status	Hawkeye
31	NB	Disable Nightbreeze	1		Relay	Relay
32	ELTG	Energy, Lighting	sensor wired	Lighting Subpanel	Power Meter	Wattnode/WNA-1-P-240P
33	EPLG	Energy, Plug Loads	2	Plug outlet Subpanel	Power Meter	Wattnode/WNA-1-P-240P
34	EMAP	Energy, Major Appliances	2	Appliance Subpanel	Power Meter	Wattnode/WNA-1-P-240P
35	SDMP	Status, NightBreeze Damper Control	1	Air Handler, FAU Closet	Status	Hawkeye
36	SACT	Status NightBreeze Damper Position	1	Behind Return Grill	Contact Switch	Mech. Contact Switch
37	GWH	Gas, Water Heater	3	Water Heater - Garage	Gas Meter	Equimeter S-275P
38	EHTR	Energy, Electric Heaters	sensor wired	Bathroom Heater Subpanel	Power Meter	Wattnode/WNA-1-P-240P

INSTRUMENTATION PLAN

DATA LOGGER SPECIFICATIONS

A Data Electronics Model DT-800 data logger was used to collect and store monitoring data. Analog inputs were single-ended type (all referenced to ground). Digital inputs were used for power monitors and status signals; high speed counter inputs were used with water flow meters. The data loggers were provided with an RS232 communications interface and battery backup.

They also included integral cold junction circuitry for direct measurement of Type T thermocouples.

Manufacturer:	dataTaker, Inc.
Model:	DT-800
Analog Inputs:	Up to 36 single-ended and 24 double-ended
Digital Inputs:	16 total, 8 bidirectional, 1 kHz
Analog Accuracy:	0.02% of reading plus 0.02% of full scale.
Memory:	2 MB flash, 4 MB SRAM, 24 system variable registers

Sensor Types and Specifications

Standard specifications for the sensor types used are listed in Table 4. Sensor selection was based on functionality, accuracy, cost, reliability, and durability. Signal ranges for temperature sensors correspond approximately to listed spans.

Table 4: Sensor Specifications

Type	Application	Mfg/Model	Signal	Span	Accuracy
RTD	Outdoor temp and RH	RM Young 41372VF	0-10V	-50 – 150°F	±1F
				0 – 100%	+1%RH
RTD	Indoor temperature / RH	General Eastern MRHT 3-2-1	4-20 mA	50 - 90°F	±1.5F
				0 – 100%	+2%RH
RTD	Duct temperature / RH – HRV	Vaisala HMD60Y	4-20 mA	-4 - 176°F	±1.5F
				0 – 100%	±2%RH
RTD	Duct temperature / RH – Air Handler	General Eastern MRHT 3-2-1	4-20 mA	32 - 132°F	±1.5F
				0 – 100%	±2%RH
RTD	Indoor temperature – Attic, Crawlspace	LM34	10 mV /°F		±1F
Type T Thermocouple	Surface / Air temperatures	Omega		-99 to 500°F	0.4%
24VAC Relay	Fresh air Damper Status, zone damper status	Omron	dry contact	n/a	n/a
Small power monitor	Fan and condenser power	WattNode WNA-1-P-240-P	pulse	CTA/60 CTA/120 for PV	±0.5%
Large power monitor	Total house power, PV production	Watt Node WNB-3-D-240-PV	pulse	CTA/40	±0.5%
Pressure Transducer	Air Pressure	SETRA	4-20mA	0-0.5inWC	±1%FS
Gas Pulse Meter	Water Heater	IMAC	Pulse	10 pulses/cuft	

RESULTS

The following household data summaries are presented for the 12 month period between April 1, 2013 and March 31, 2014.

DATA ANALYSIS

OCCUPANT FEEDBACK

The occupants were surveyed to better understand general occupancy patterns and thermostat operation, identify any behavioral changes across the evaluation period, and evaluate their satisfaction with the house. During the monitoring period, the house was occupied by 2 adults and 3 children with at least one occupant in the house on the weekdays and most occupants home on the weekends, with the exception of vacation periods, which are noted.

Responses to home comfort questions are below in Table 5. The respondent was asked to respond with the following choices: Strongly Agree, Agree, Somewhat Agree, Neutral, Somewhat Disagree, Disagree, Strongly Disagree, Not Applicable.

Table 5: Occupant Survey Responses

QUESTION	RESPONSE
1. My home is comfortable in the winter.	Strongly Agree
2. My home is comfortable in the summer.	Agree
3. All rooms in my home are equally comfortable.	Agree
4. I am satisfied with the overall comfort of my home.	Strongly Agree
5. I am satisfied with the nighttime ventilation cooling system.	Somewhat Agree
6. My home has low utility bills for its size.	Strongly Agree
7. This house was a good value at the price I paid for it.	Agree
8. I am satisfied with my home overall.	Strongly Agree
9. I am satisfied with my solar array.	Agree
10. I am satisfied with the hot water delivery in my home.	Agree
11. I am satisfied with the indoor air quality in my home.	Agree
12. My heating and cooling system is quiet.	Agree
13. I am satisfied with my utility bills.	Strongly Agree

OVERALL HOUSEHOLD PERFORMANCE

The overall energy performance of the Cottle ZNE Home was evaluated using three ZNE metrics: site energy use, TDV energy use, and source energy use. Detailed analysis of the energy performance for each ZNE metric is in the sections below.

SITE ENERGY USE

Figure 2 and Figure 3 demonstrate monthly electricity and natural gas energy consumption, respectively, for each major end use. PV production is shown in Figure 2 as negative values below the x-axis. Monthly net electricity is displayed as a black line in the graph. Over 12 months, 84 percent of total site electricity (not including gas) needs were offset from the 5.5kW DC rated PV system. Removing electric vehicle charging electricity use brings this offset percentage up to 116 percent.

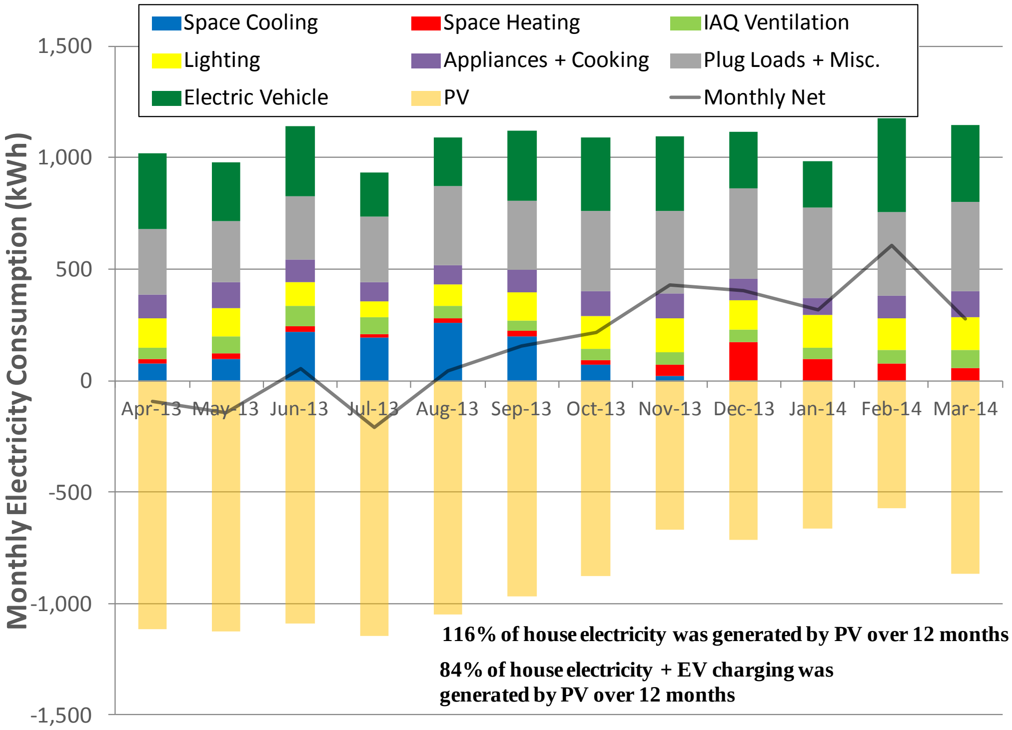

FIGURE 2: MONTHLY ELECTRICITY CONSUMPTION BY END USE AND PV ELECTRICITY GENERATION (MONTHLY NET ELECTRICITY SHOWN AS BLACK LINE)

Figure 4 shows the distribution of electricity and gas consumption by end-use over the 12 month period. Plugs loads[5] and electric vehicle charging[6] represent the two largest electrical end-uses at 32% and 27%, respectively, of total electricity consumption. Next is lighting at 12% followed by space cooling and major appliances each with 10%. Aside from the electric vehicle, the occupants reported no significant electric loads such as deep freezers, wine coolers, or shop equipment. There is neither a spa nor a pool on the property.

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[5] This category also includes miscellaneous items not separately sub metered, including but not limited to, garage energy use and pumping for the solar hot water and greywater systems.

[6] While EV charging is not on a dedicated circuit, it manifests a rather unique load profile. Energy consumption for vehicle charging can be estimated by identifying this profile relative to the other loads on the circuit that have a relatively consistent but different profile.

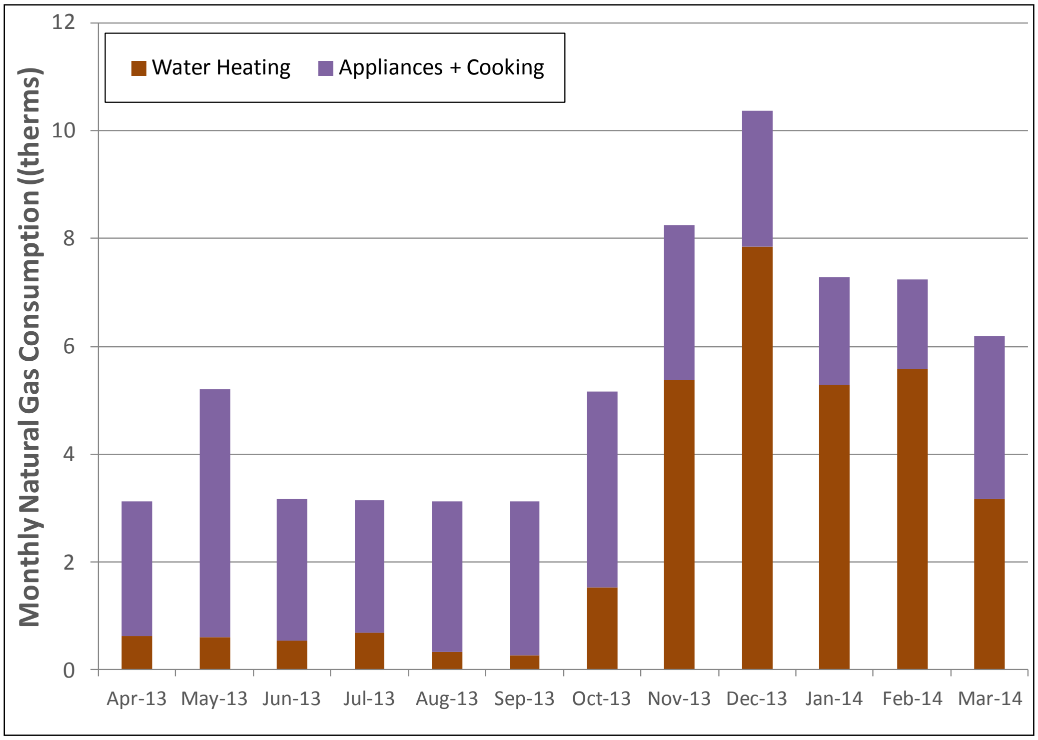

FIGURE 3: MONTHLY NATURAL GAS CONSUMPTION BY END USE

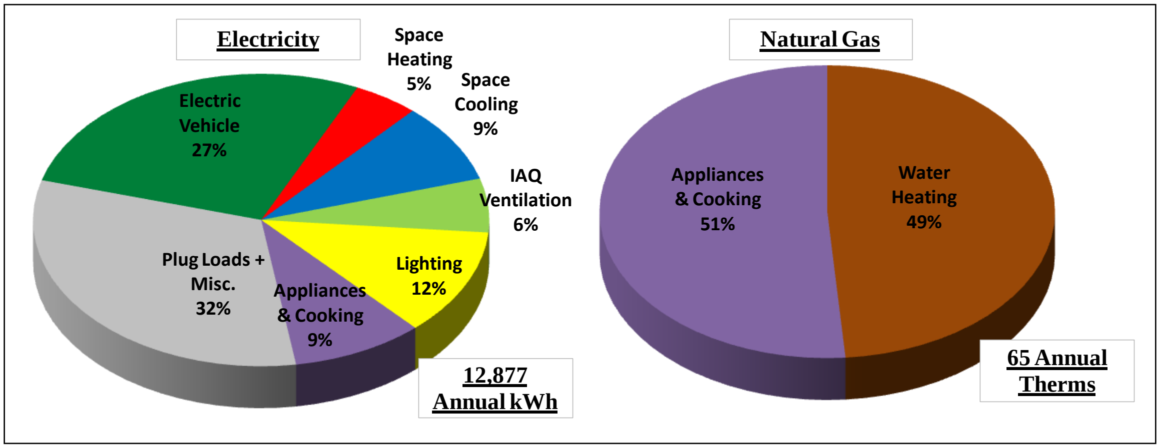

FIGURE 4: DISTRIBUTION OF ANNUAL ELECTRICITY AND NATURAL GAS CONSUMPTION BY END USE

Cooling system operation extended for about 7 months from April through October, 2013. The NightBreeze thermostat installed at the Cottle house accepts a comfort range as a cooling set point input, the lower value representing the lower limit for ventilation pre-cooling and the upper limit the temperature at which mechanical cooling will be engaged. Heating and cooling thermostat set points as reported by the occupant are listed in Figure 5 along with measured average interior temperatures. The reported upper limit cooling set point is higher than what was observed in the monitoring data, with average summer afternoon temperatures of

74°F. The pre-cooling function of the NightBreeze thermostat was also used during the hottest periods of the summer. This function supplements ventilation cooling pre-cooling with mechanical cooling and operates the air conditioner during the morning hours based on an adjustable schedule. Heating energy use during the cooling season, Figure 2, is a result of the electric resistance heaters in the bathrooms used by the occupants in the morning, not heat pump operation.

Mode	Thermostat Set point[1]	Avg Interior Temp
Cooling	Comfort range: 65°F - 78°F	Avg. 72.6°F
Heating	72°F w/ 70°F setback day & night	Avg. 71.5°F

[1] As reported by occupants

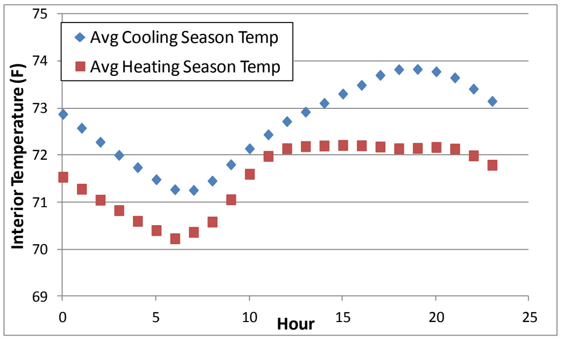

FIGURE 5: THERMOSTAT SET POINT COMPARISON & HOURLY INTERIOR TEMPERATURE PROFILE DURING HEATING AND COOLING SEASONS

The water heating system is a condensing gas storage heater with solar pre-heat and 96ft^2 of collector area. It can be seen in Figure 3 that the solar system satisfied the majority of the water heating load during the summer. Water heating gas use during the summer months was less than 1 therm per month and peaks in December with just under 8 therms per month. Cooking gas use is relatively consistent throughout the year with an average of 2.8 therms per month.

DAILY ENERGY USE

Figure 6 summarizes daily electricity consumption by end-use relative to minimum, maximum, and average daily outdoor temperatures. Average daily electricity consumption (less electric vehicle charging) ranges from about 13 kWh, during unoccupied periods, to almost 45 kWh, when occupied. The addition of electric vehicle charging further increases that range up to 80 kWh. Based on days on which electric vehicle charging occurs, the average daily consumption for vehicle charging is 12.0 kWh/day, with a range between 0.7 and 40.0 kWh/day.

The base load during the unoccupied period in July and August is approximately 13 kWh/day. It's noted that this increases during the December and January unoccupied period by roughly 50 percent. This is due, in part, to the heat pump system remaining on, in heating mode in December/January, while it appeared to have been turned off during the summer period. However, this increase in base load is primarily due to almost 60 percent higher plug load energy use, indicating how important managing stand-by loads can be.

Figure 7 summarizes PV production relative to total household consumption. For 36 percent of the days the house is a net generator to the grid, for the other 64 percent it is a net consumer.

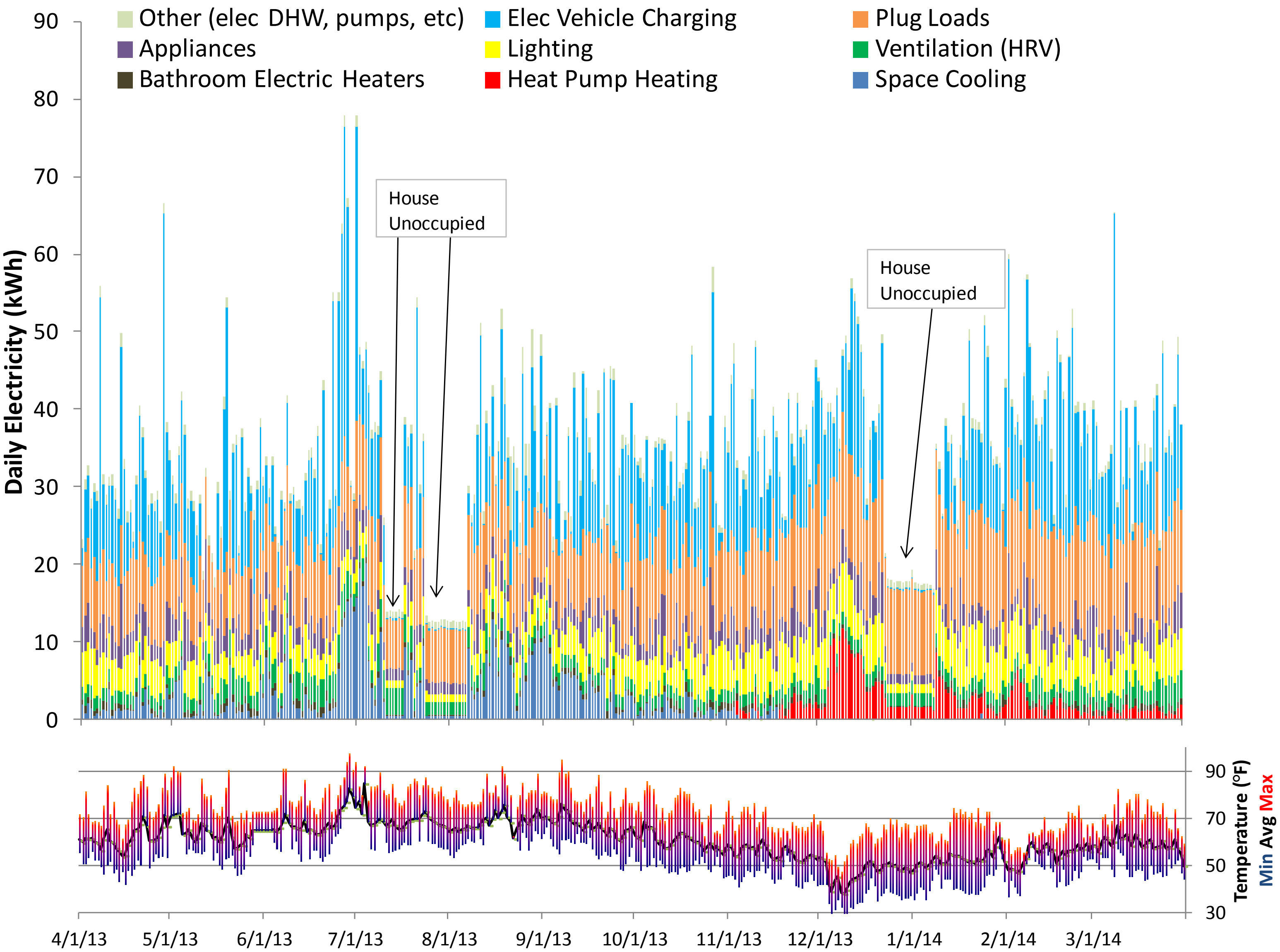

FIGURE 6: DAILY ELECTRICAL USAGE BY END-USE AND TEMPERATURE PROFILE

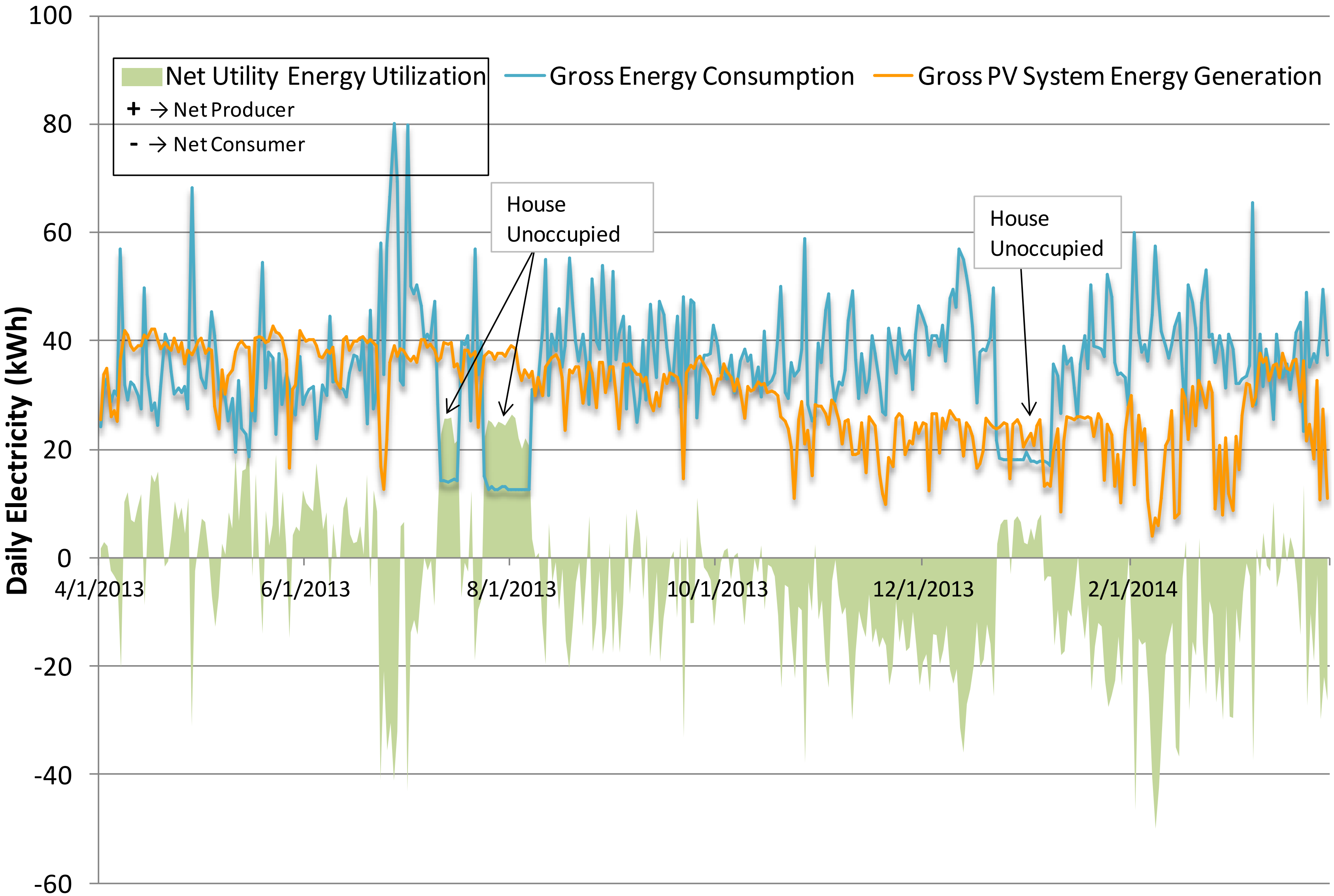

FIGURE 7: DAILY TOTAL HOUSE ENERGY USAGE AND PV GENERATION

TDV ENERGY USE

Estimated measured time-dependent valuation (TDV) energy use was calculated by using monitored electricity and gas consumption along with hourly TDV multipliers. The hourly TDV multipliers were based on the 2008 multipliers for Climate Zone 4. The natural gas TDV multipliers, which only vary month by month, were used directly. The electricity TDV multipliers are tied primarily to hourly temperatures in the climate zone weather, so it was necessary to align the TDV values to the actual 12 month weather data to correspond with the monitored energy use. Daily TDV profiles were grouped into two tiers and averaged based on maximum daily temperature in the climate zone weather file. These profiles were then applied to monitoring data based on actual weather. This process is described in more detail in the Appendix.

Figure 8 shows monthly TDV energy consumption for each major end use along with PV energy production, which is shown as negative values below the x-axis. Monthly net energy is displayed as a black line in the graph. Over 12 months, including electric vehicle charging this project was very close to achieving net zero TDV with 95% of total TDV consumption offset by PV generation. Removing electric vehicle charging, which represented more than a quarter of annual TDV energy use as shown in Figure 9, the project achieves net zero TDV with 128% of TDV energy use was offset by PV generation. Miscellaneous electric loads and electric vehicle charging combined represent over half of total TDV energy use. Regulated loads such as space heating, space cooling, IAQ ventilation, and water heating only contribute 21 percent of the total.

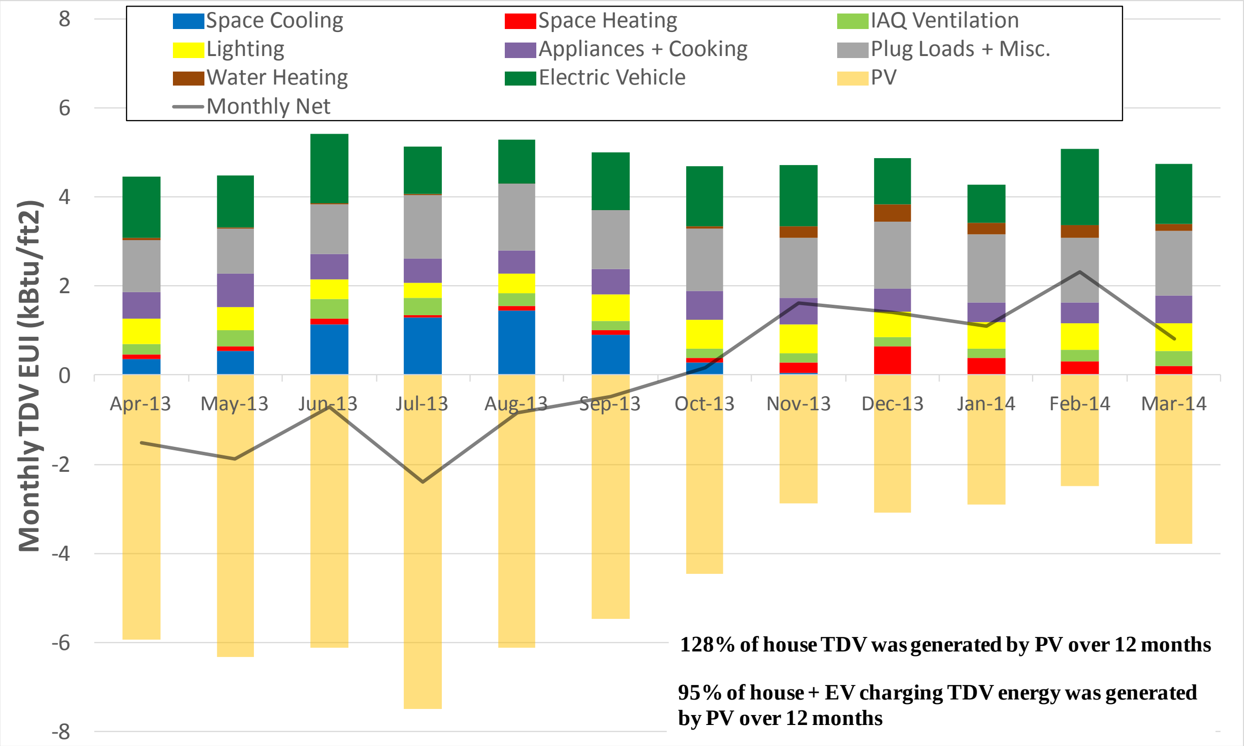

FIGURE 8: MONTHLY TDV ENERGY CONSUMPTION BY END USE

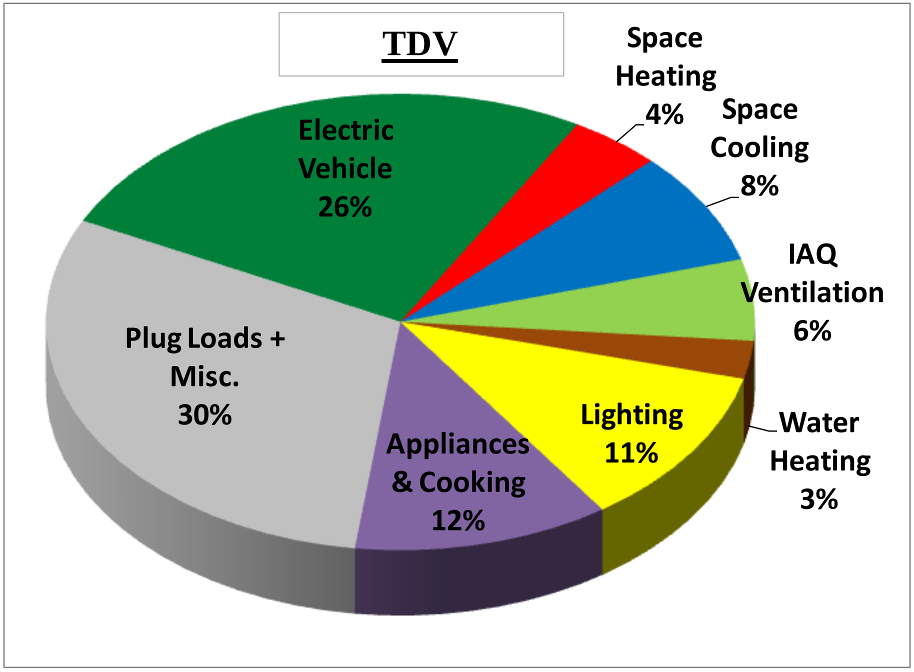

FIGURE 9: DISTRIBUTION OF ANNUAL TDV ENERGY CONSUMPTION BY END USE

SOURCE ENERGY USE

Source energy use was also calculated and evaluated to determine whether the Cottle ZNE Home achieved zero net source energy. The concept of the site-to-source multiplier represents how much energy is needed to generate and deliver one unit of energy to the end user. The concept of source energy provides a mechanism for direct comparison of the energy impacts between natural gas technologies and electric technologies. The electric site-to-source multiplier varies by utility based on its current mix of generation resources, as well as its overall transmission and distribution efficiency. According to PG&E the fuel mix for 2010 consisted of 35% natural gas, 21% nuclear, 13% large hydroelectric, 10% renewable, 4% geothermal, 1% coal, 1% other, and 15% unspecified. The "other" fuel is estimated to be 98.2% petroleum coke, 1.4% diesel, and 0.4% residual fuel. The "unspecified" fuel is purchased fuel from third parties and is predominantly natural gas[7]. The PG&E fuel mix values are comparable to the 2007 EPA eGrid statistics presented for carbon emissions with the exception of an increased presence of non-hydroelectric renewables. Site-to-source multipliers for each fuel type were used to generate an overall weighted site-to-source multiplier of 2.504 for electricity as shown in Table 6. This value is less than the national average electric site-to-source multiplier of 3.365.

The site-to-source multiplier for natural gas is the energy required to process, transport, and deliver the fuel to the end user. This value does not significantly vary with location or utility, with the national average being 1.092[8].

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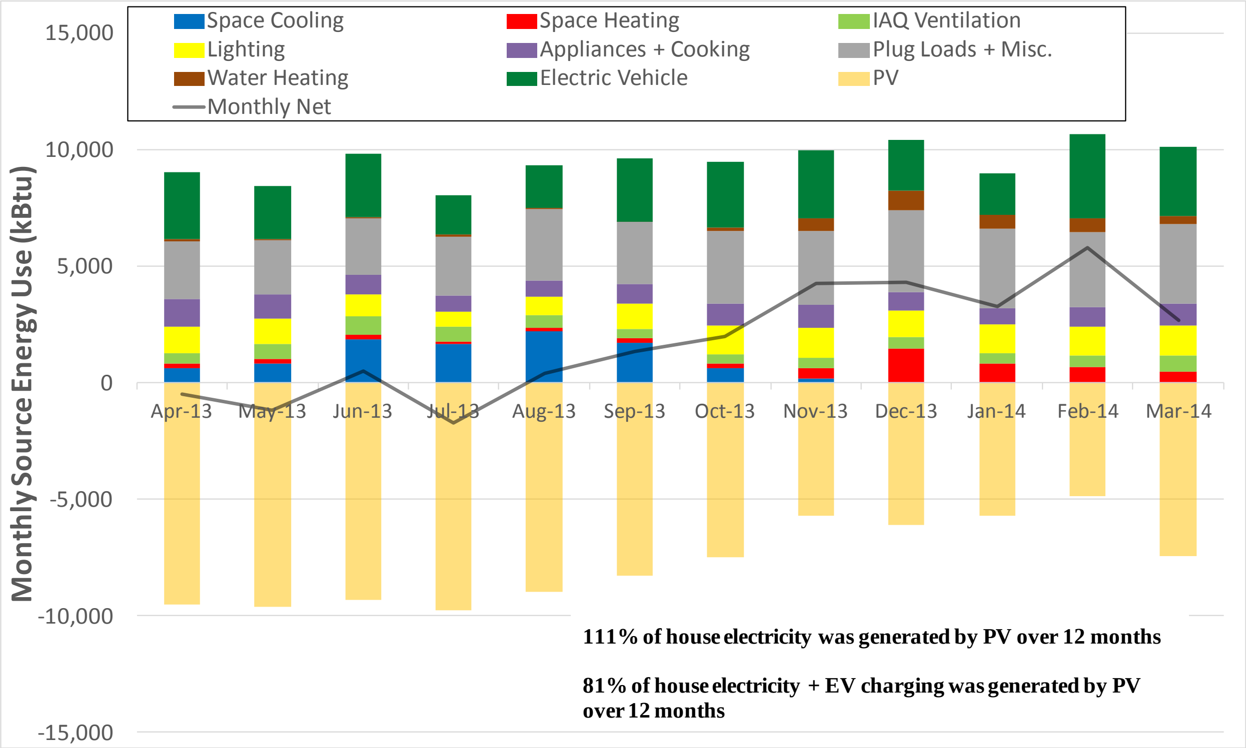
[7] Personal communication with John Whitlow, PG&E, 4/20/2011

[8] U.S. LCI Database. www.nrel.gov/lci. Golden, CO: National Renewable Energy Laboratory

Table 6: Calculation of PG&E Electricity Site-to-Source Multiplier

FUEL SOURCE	% OF TOTAL GENERATION	SITE-TO-SOURCE MULTIPLIER	WEIGHTED MULTIPLIER
Natural Gas	35%	2.631	0.921
Nuclear	21%	3.083	0.647
Large Hydroelectric	13%	1.000	0.130
Renewable- other	10%	1.000	0.100
Renewable- geothermal	4%	6.160	0.246
Unspecified	15%	2.631	0.395
Coal	1%	3.035	0.030
Other	1%	3.404	0.034
		Overall PG&E Site-to-Source	**2.504**

Monthly source energy is presented for each major end use in Figure 10. PV production is shown in Figure 10 as negative values below the x-axis. Monthly net energy is displayed as a black line in the graph. Over 12 months, 81 percent of total source energy needs were offset from the 5.5 kW DC rated PV system. Removing electric vehicle charging electricity use brings this offset percentage up to 111 percent. Natural gas use is only 6 percent of total source energy use.



111% of house electricity was generated by PV over 12 months

81% of house electricity + EV charging was generated by PV over 12 months

FIGURE 10: MONTHLY SOURCE ENERGY CONSUMPTION BY END USE

EVALUATIONS

MODEL COMPARISON

Figure 11 compares measured annual TDV energy use with that originally estimated using the 2008 Title-24 compliance software, Micropas v8.1. Energy use of non-regulated loads came from HERS II modeling in EnergyPro by the HERS Rater. Figure 12 shows a similar comparison but for site electricity and gas. Total building TDV energy (less electric vehicle charging) is within 3 percent and energy use of regulated loads only is within 14 percent. However, there are significant differences by end-use, with space cooling the most egregious. Following are some possible reasons for these differences:

- Due to modeling limitations, certain house characteristics were not accounted for in the energy model, including ventilation cooling, and heat recovery ventilation (HRV).
- Limited modeling capabilities for non-regulated loads
- The actual ventilation rate from the HRV is higher than the rate required by ASHRAE 62.2 and higher than the rate assumed in the Title-24 model.
- Actual occupancy and use patterns for appliances, lighting, plug loads and water heating may be very different than the assumptions in the energy model.
- Actual thermostat set points differ from settings assumed in energy model. Measured average cooling set points are 8°F lower than those assumed for Title-24 [9], which would result in higher actual cooling energy use compared to the model. Although heating thermostat set points are higher than 2008 Title-24 assumptions, actual heating energy use is much lower than estimates. Heat recovery via the HRV may be one reason for this discrepancy.
- Differences between actual weather and the weather file used for modeling. As shown in Figure 13, actual heating degree-days (HDD) were 17 percent lower than the CZ04 weather file, and actual cooling degree-days (CDD) were 65 percent higher than the weather file. Model results were not normalized to actual year weather.

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[9] According to the 2008 Building Energy Efficiency Standards Residential Alternative Calculation Method Approval Manual (publication# CEC-400-2008-002-CMF) thermostat setpoints used for Titel-24 compliance purposes are as follows: Heating: 68°F w/ night setback of 65°F 11pm-7am; Cooling: 78°F w/ setup ranging from 79°F to 83°F 7am to 5pm.

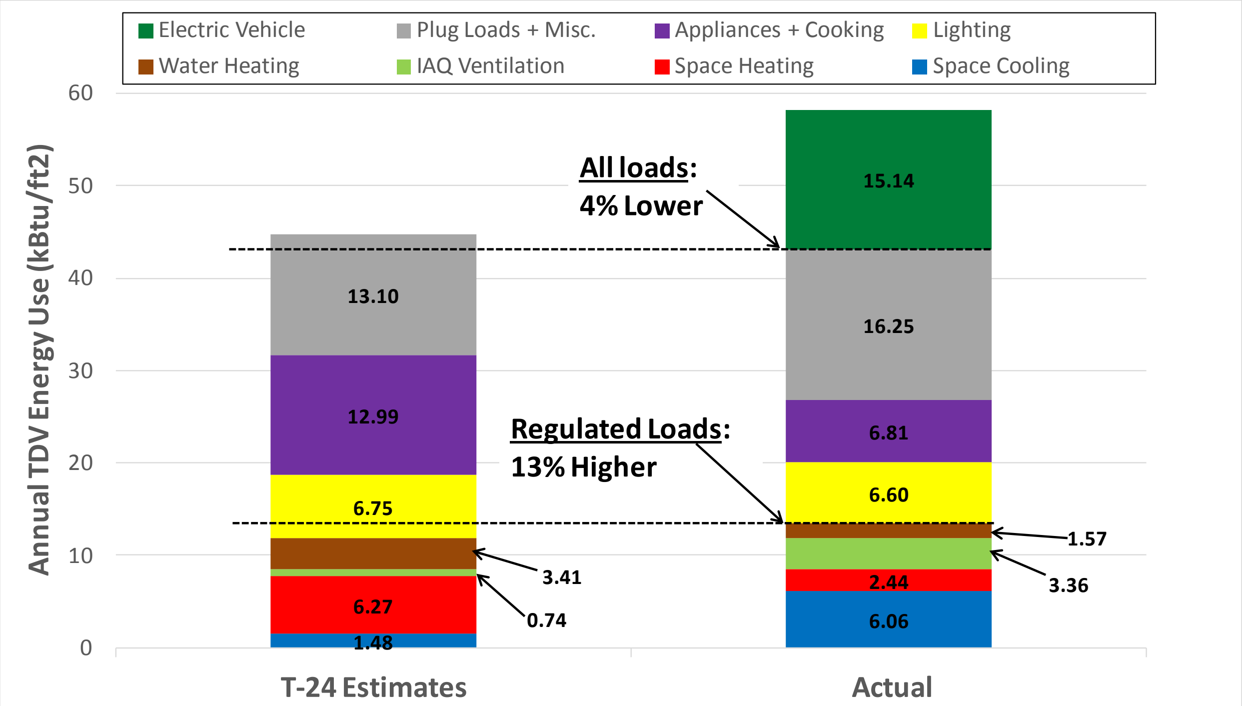

FIGURE 11: ANNUAL TDV ENERGY USE BY END USE COMPARED TO TITLE-24 SOFTWARE ESTIMATES

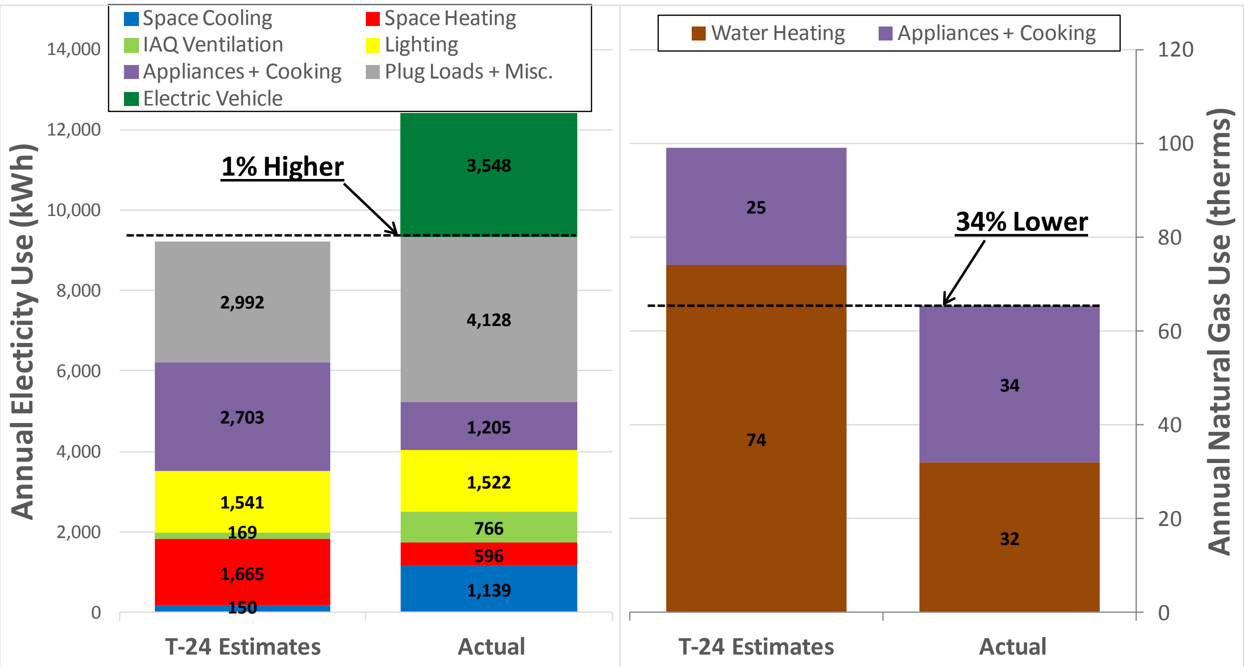

FIGURE 12: ANNUAL ELECTRICITY AND NATURAL GAS USE BY END USE COMPARED TO TITLE-24 SOFTWARE ESTIMATES

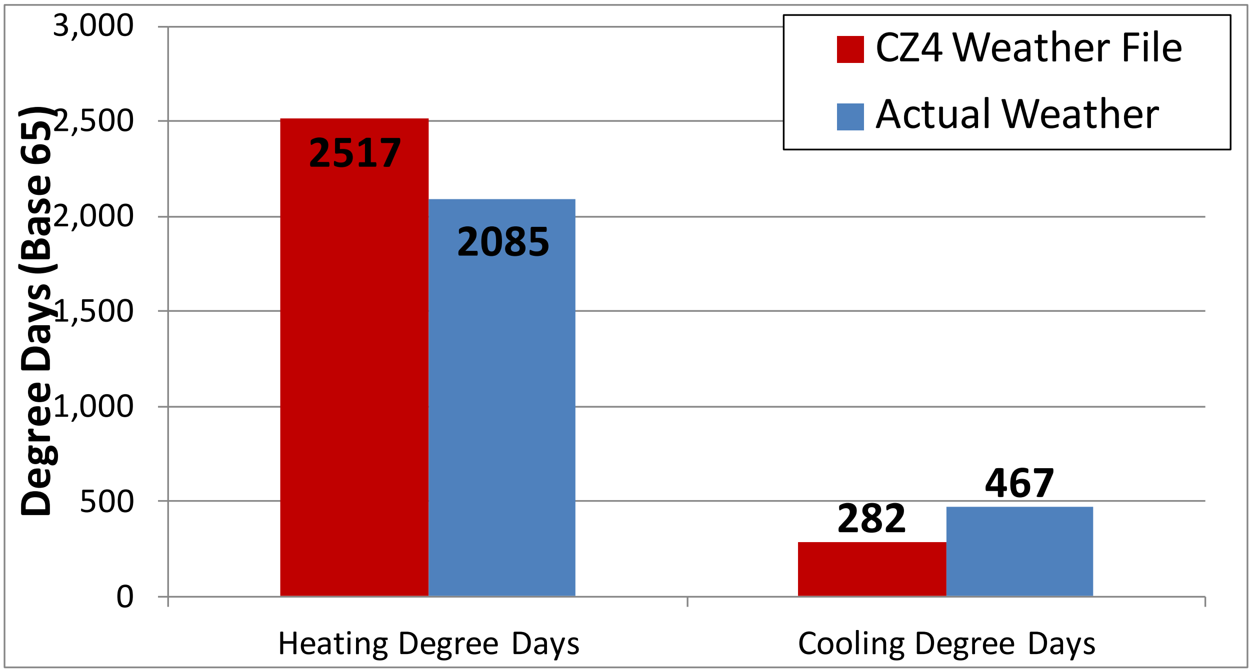

FIGURE 13: COMPARISON OF HEATING AND COOLING DEGREE DAYS FOR THE TITLE-24 CLIMATE ZONE 4 WEATHER FILE AND ACTUAL YEAR WEATHER

COMPARISON TO BEOPT AND PHPP

Monitored energy use was also compared to the Passive House program targets and model estimates made by the program software, the Passive House Planning Package (PHPP). Figure 14 demonstrates this comparison. Actual annual home primary energy use[10] (less electric vehicle charging) was 15 percent lower than the threshold and 17 percent higher than original estimates[11].

The key metric for compliance with the Passive House program is meeting the specific space heat demand, which is the annual heating load of the house. The high R-value envelope, windows designed for passive solar heat gain, and the HRV all are important in driving this value down. Aside from the efficient building envelope design, additional building internal gains, including those from people, appliances, lighting, and plug loads, further reduce the space heat demand. The contribution both from the heat pump and the bathroom electric heaters is included in the 0.71 kBtu/ft^2/yr. Heating from the bathroom heaters was only attributed during the winter months; during the cooling season they were considered internal gains that require supplemental cooling.

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[10] Primary energy use calculated with source multipliers as defined in the PHPP of 2.7 for electricity and 1.1 for natural gas. Floor area used in the calculations is the treated floor area as defined in the PHPP, which is 2,776ft^2.

[11] The PHPP includes rudimentary assumptions for non HVAC energy use and allows the user to update these accordingly for the project. The designer, One Sky Homes, used a combination of published appliance data, one-time measurements, and operating assumptions to arrive at estimates for whole building energy use.

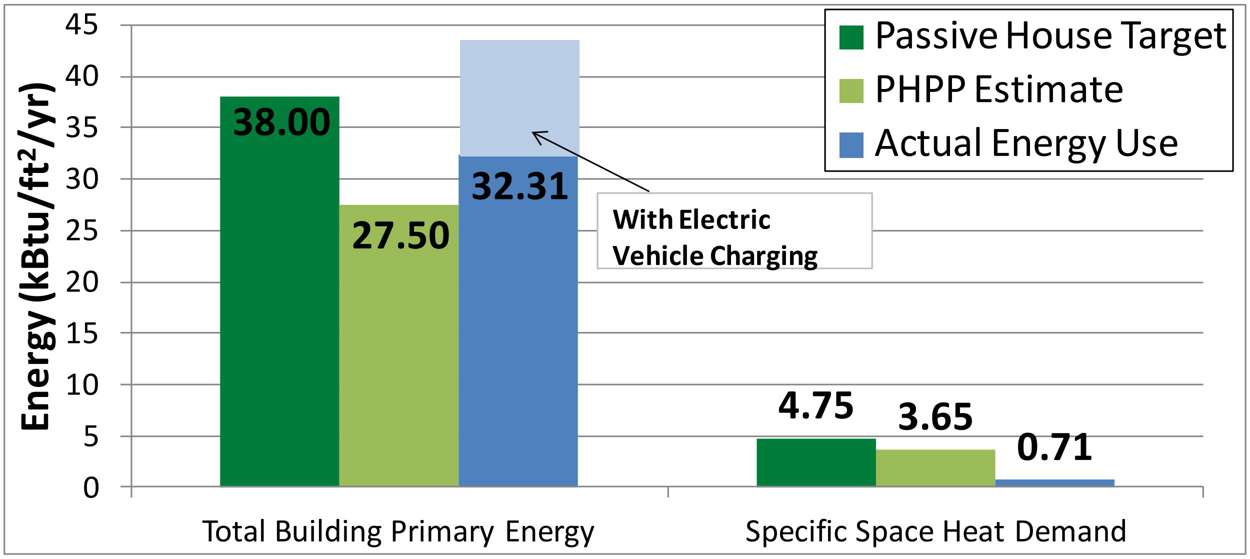

FIGURE 14: COMPARISON OF ACTUAL ENERGY TO PASSIVE HOUSE TARGETS

Comparisons were also made to NREL's BEopt v2.0.6 simulation software, which is used for the DOE Building America program. The results shown in Figure 15 are based on a calibrated model, which was evaluated using actual meteorological year data for the 12 month analysis period of April 2013 through March 2014. Calibration steps included adjusting heating and cooling thermostat set points to reflect occupant settings (see Figure 5) as well as HRV airflow and fan efficacy to monitored values. BEopt does not have the capability of modeling ventilation cooling; however, actual cooling energy use is within 10 percent of estimates. The model was evaluated without natural ventilation since the occupants indicated they do not open windows during the summer months.

Actual monitored heating energy is about 60 percent higher than estimates based on the calibrated BEopt model; however, 232 kWh of the monitored heating energy can be attributed to the bathroom space heaters, which are used year round. Total non-HVAC energy use (lighting, appliances, and plug loads) is within 3 percent of estimates.

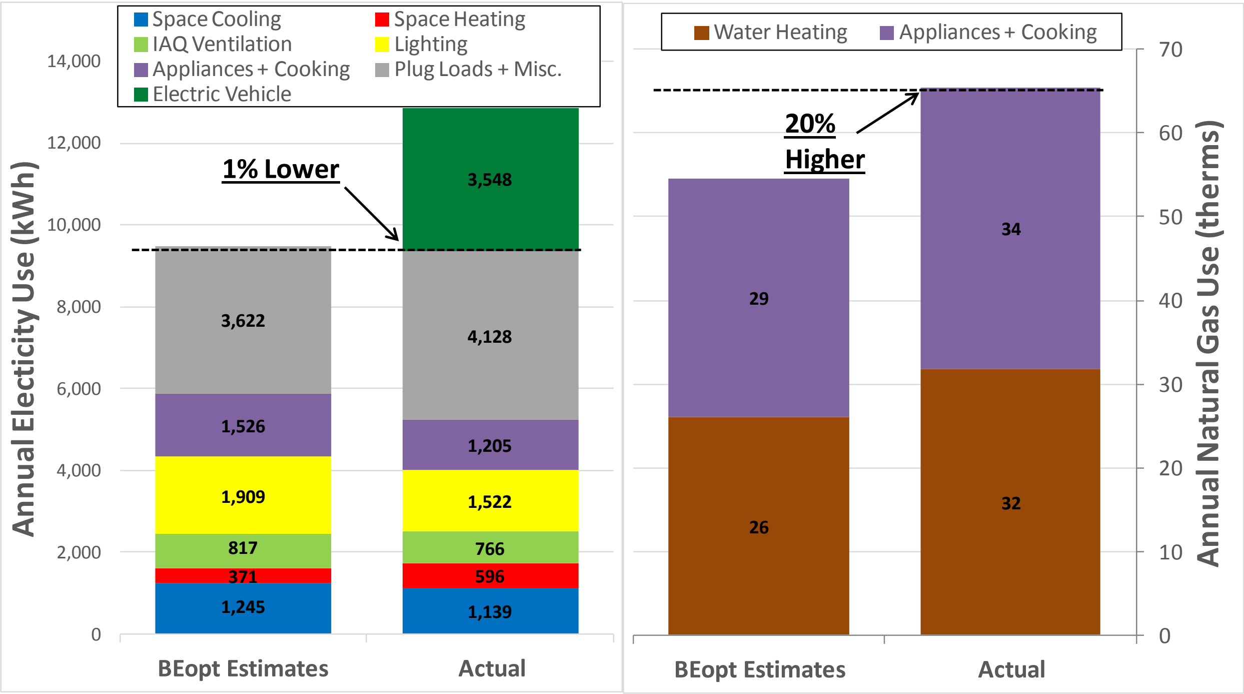

FIGURE 15: ANNUAL ELECTRICITY AND NATURAL GAS USE BY END USE COMPARED TO NREL'S BEOPT SOFTWARE ESTIMATES

FINANCIAL ANALYSIS

The Cottle house is located in a high-end San Jose neighborhood where homes can sell for over $2M and in 2013 it sold for a comparable price. In a high value market such as San Jose, the incremental costs of additional energy efficiency measures to achieve ZNE design and performance goals are not as significant, especially when countered by improved building "quality" as characterized by improved thermal comfort and sound attenuation. In other, lower-cost real estate markets, increased attention must be paid to EEM selection and cost effectiveness for ZNE projects. Zero net energy performance can still be achieved using less expensive building components. However, there is value to early adopter investment in advanced products to help push the U.S. market toward higher energy efficiency. For example, cost and availability of triple-pane windows have improved since the Cottle house was designed and built.

Finding the optimized balance of energy efficiency measures and PV can be challenging, especially in the current environment where PV costs are subsidized and have been steadily falling. The balance point shifts with climate and space conditioning loads, as the "savings per dollar invested" for efficiency is dependent upon the specific loads. Incremental cost for the PV system was $27,000, or just under $5 per watt. With all of the incentives and tax credits available for PV at the time, the net incremental cost dropped to $7,000, or $1.27/Watt. Similar incentive levels do not exist for most of the high cost efficiency measures such as triple-glazed windows and the HRV. Given the market in which the home was sold, the builder can afford to invest in high quality and high cost measures and get a return on his investment. It's important to note that this simple cost comparison does not take into account the longer lifetime of certain building components as compared to PV systems and their non-energy benefits such as comfort and durability.

CONCLUSIONS & RECOMMENDATIONS

Following are conclusions from analysis of the Cottle Zero Net Energy Home:

- The project achieved zero net energy over the 12 month monitoring period by various metrics, including the following:
  - TDV Energy (gas + electricity less electric vehical charging): On an annual basis, the house produced 12 kBtu/ft^2 (28%) more TDV energy than it consumed.
  - Site Electricity (electricity only less electric vehicle charging): On an annual basis, the house produced 1,492 kWh (16%) more electricity than it consumed.
  - Source Energy (gas + electricity less electric vehicle charging): On an annual basis, the house produced 8,994 kBtu (11%) more source energy than it consumed.
- Including electric vehicle charging, the house produced 95% of total TDV energy, 84% of total site electricity, and 81% of total source energy needs over the 12 month monitoring period.
- The occupants are very satisfied with the house including the comfort it affords and the low utility bills.
- Actual total house TDV use tracked very well with modeling estimates, within 4 percent; however, differences by end-use were very large, particularly for space cooling. This may partially be explained by the differences between the weather files and actual weather and certain modeling limitations. However, it's expected this is largely a result of much lower cooling thermostat set points used by the homeowners in the Cottle house than those assumed for Title-24 modeling.
- Actual total house electricity use tracked very well with BEopt modeling estimates, within 1 percent; however, differences by end-use were very large in certain cases. Actual plugs and miscellaneous loads were 14 percent higher, while actual lighting and appliance use were approximately 20 percent lower.
- Miscellaneous energy use is a significant contributor to total house energy, particularly in ZNE homes with low cooling and heating loads. In the future, incentive and early adopter programs need to target this end-use. Research to better understand this end-use and potential reduction strategies is necessary.
- The Cottle house is a successful example of a high performance home meeting California's zero net energy goals. While incremental costs of some of the measures are higher than can be justified in residential housing across the state, pilot projects such as this are essential to future widespread adoption by demonstrating technology and identifying and disseminating lessons learned to the community, ultimately driving down costs.

APPENDICES

APPROACH TO ESTIMATED TDV ENERGY USE WITH MONITORED DATA

METHODOLOGY

The aim of this study is to identify electricity time-dependent-valuation (TDV) profiles which can be directly applied to monitored energy data based on actual weather. Because the hourly electricity TDV multipliers are tied to parameters in the climate zone TMY weather file, it is necessary to identify this relationship and generate generalized profiles that can then be applied to measured energy use data. TDV values for natural gas only vary month by month, and therefore can be applied directly to actual data.

In general, the approach followed by Davis Energy Group (DEG) is outlined in Figure 16. PG&E and Energy & Environmental Economics (E3), who develop the TDV multipliers, were consulted on the general methodology. First, trends in the daily TDV profiles were identified, including effects of outdoor temperature conditions, type of day, and month or season. Based on the observed trends, the days were divided into weekdays and weekends, and weekdays were subsequently divided into two tiers (2008 TDV) or three tiers (2013 TDV). As a starting point this process was tested for CA Climate Zone 4 only. Hourly outdoor air temperature data was taken from the TMY3 Climate Zone 4 weather file for both the 2008 and 2013 TDV multipliers.

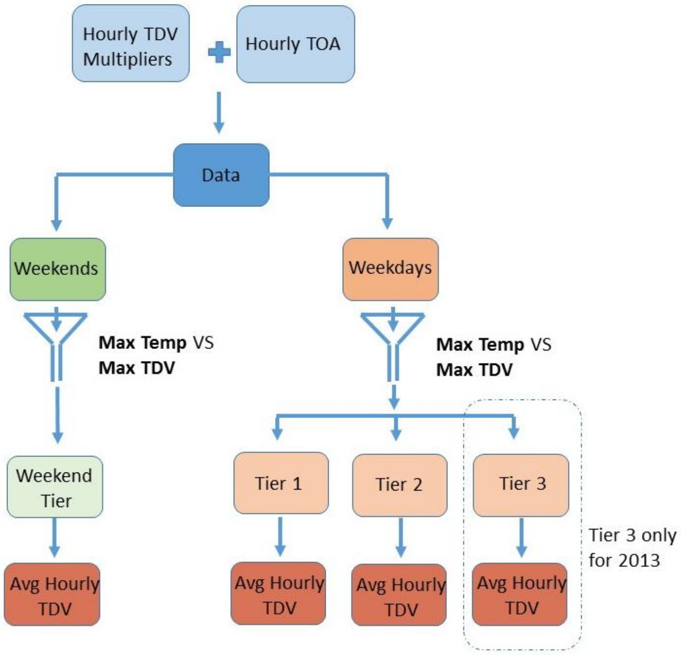

FIGURE 16: FLOW OF APPROACH

This analysis was limited to looking at the relationship between outdoor air temperature and the TDV multipliers. There are other factors that affect the TDV multipliers to a lesser extent that are included when the TDV values are developed that are not accounted for here because it was not possible to correlate to actual year conditions. In discussions with E3, this proposed methodology was thought to be a reasonable approximation for this analysis .

RESULTS

Figure 17 and Figure 18 demonstrate the relationship between daily maximum TDV multiplier and daily maximum outdoor air temperature for 365 days for the 2008 and the 2013 TDV, respectively. Weekends and weekdays are evaluated separately since weekend profiles don't present any dependence on temperature conditions (see orange squares in Figure 17 and red squares in Figure 18). It is evident that the weekday TDV values are influenced by outdoor air temperature. This relationship is more pronounced in the 2013 TDV since one of the key changes in 2013 TDVs compared to the 2008 methodology is improved correlation between the multipliers and the weather files[12].

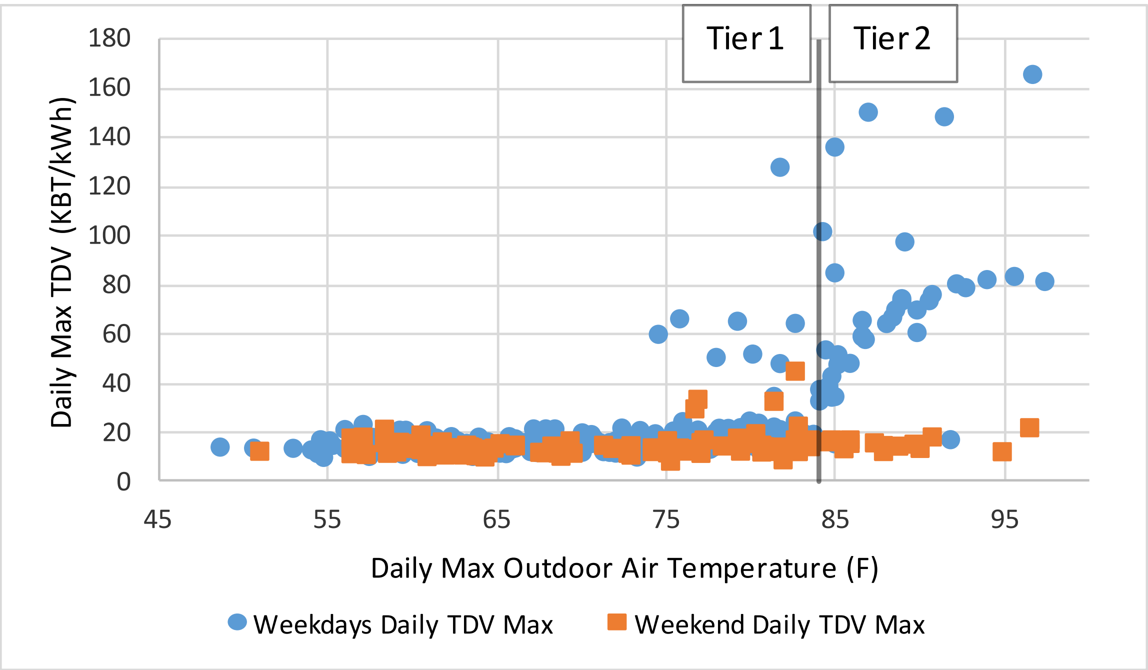

FIGURE 17: RELATION BETWEEN 2008 DAILY MAXIMUM TDV AND DAILY MAXIMUM OUTDOOR AIR TEMPERATURE

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[12] "Time Dependent Valuation of Energy for Developing Building Efficiency Standards." Energy + Environmental Economics. Submitted to the California Energy Commission. February 2011.

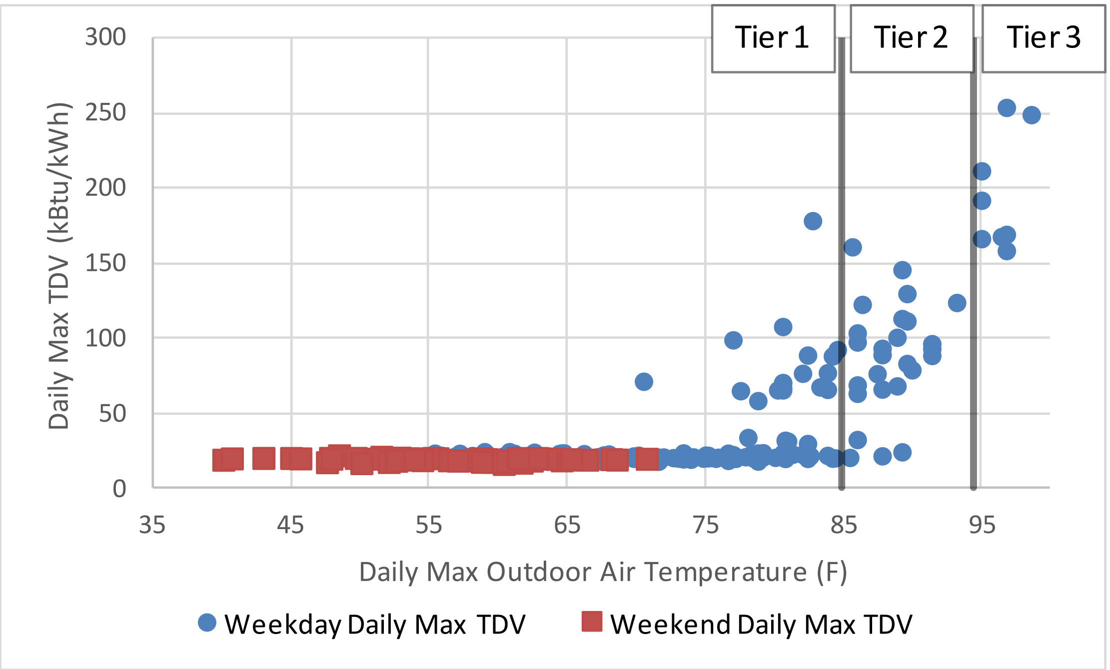

FIGURE 18: RELATION BETWEEN 2013 DAILY MAXIMUM TDV AND DAILY MAXIMUM OUTDOOR AIR TEMPERATURE

Based on

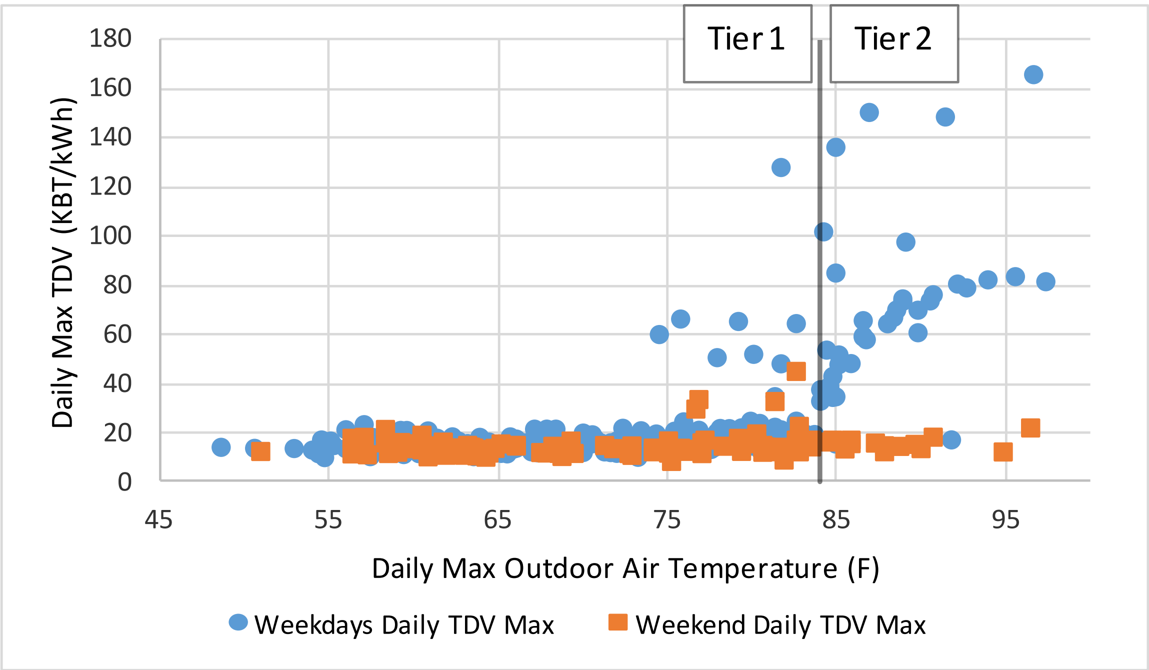

Figure 17 and Figure 18, weekdays were divided into two groups for 2008 TDV and three groups for 2013 TDV based on daily maximum outdoor air temperatures. The top roughly ten days were selected for the top tier in the 2013 TDV based on recommendations by E3.

The remaining data was grouped into two tiers. Initially the 2008 TDV was also divided into three groups; however, because the relationship between daily max TDV and outdoor air temperature is not as clear as with the 2013 TDV, the three tier approach did not provide good results during model validatation. An improved relationship was obtained by using two tiers for the 2008 TDV. The corresponding TDV values for each hour within each group were averaged and an average hourly profile for each group was developed. Figure 19 and Figure 20 present these profiles for 2008 and 2013 TDV, respectively.

The two weekday groups for 2008 TDV are as follows:

1. Tier 1, daily max outdoor air temp < 84°F, and
2. Tier 2, daily max outdoor air temp >= 84°F.

The three weekday groups for 2013 TDV are as follows:

1. Tier 1, daily max outdoor air temp < 85°F,
2. Tier 2, daily max outdoor air temp >=85°F & < 95°F, and
3. Tier 3, daily max outdoor air temp >=95°F.

All the weekend TDV profiles were averaged to develop a single average weekend profile.

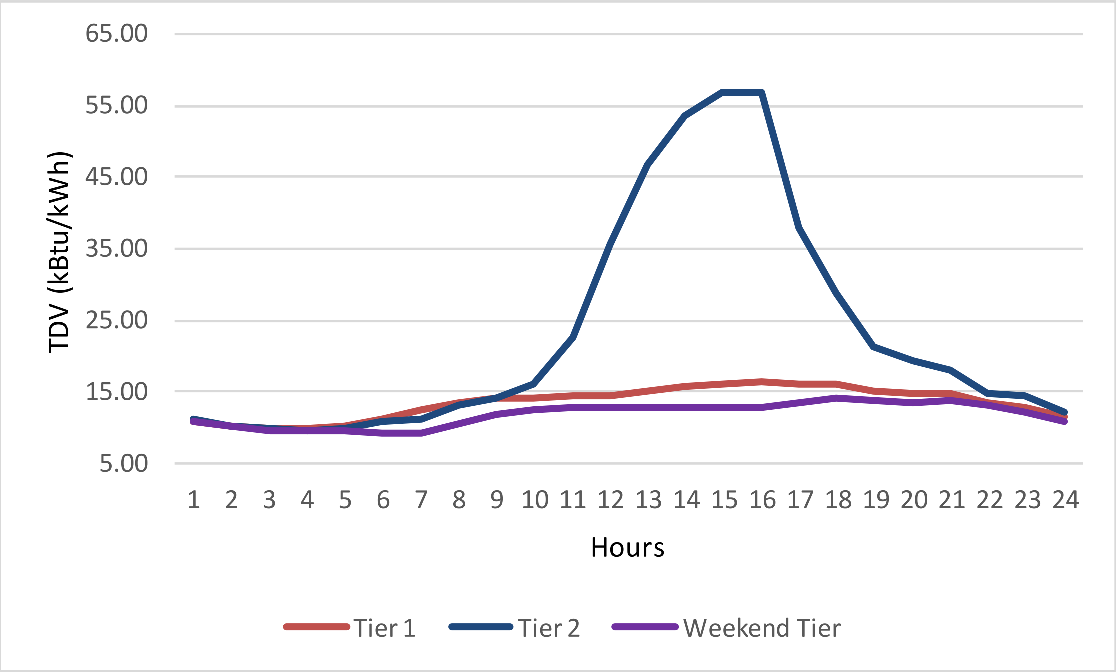

FIGURE 19: AVERAGE HOURLY TDV MULTIPLIER FOR 2008

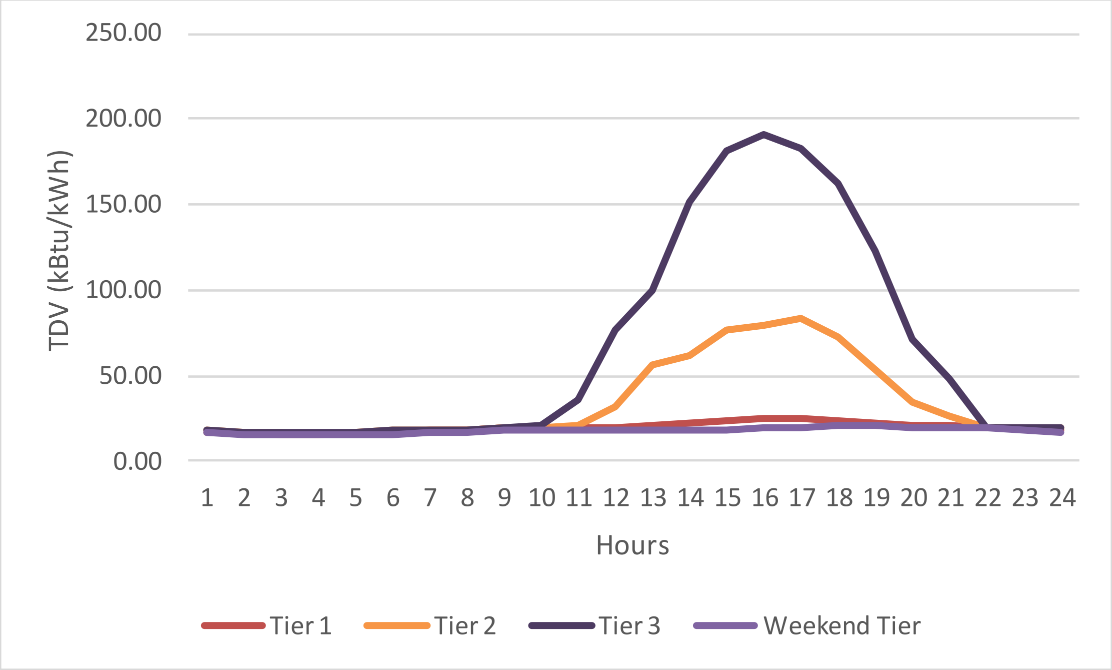

FIGURE 20: AVERAGE HOURLY TDV MULTIPLIER FOR 2013

VALIDATION

To validate this approach for the 2008 multipliers, annual TDV use for a typical 2,000 ft^2 two-story single family residential building in Climate Zone 4 was calculated using the actual 8760 hourly TDV multipliers and the revised profiles presented above. An hourly profile of total site electricity use was generated from the 2008 Title-24 compliance software, EnergyPro v5 and used for this exercise. On comparison, the annual TDV calculated using the revised profile was found to be just 3.5% lower than that calculated using the actual multipliers. Similarly an hourly profile of total site electricity was generated using EnergyPro v6 and the 2013 multipliers. On comparison the annual TDV calculated using the revised profiles was found to be 6 percent higher than that calculated using the actual multipliers.

APPLICATION TO ACTUAL WEATHER

Once the TDV hourly profiles and tier thresholds have been developed for the climate, this methodology can be applied to monitored data by grouping the actual data according to weekends and weekdays and further grouping the weekdays based on the tiers defined above for daily maximum outdoor air temperature. This analysis is specific to California climate zone 4, but this methodology can be applied to future projects and other climates using the process described above. Each California climate zone will have unique modified TDV profiles and tier thresholds. In addition, hourly outdoor temperature data for the monitoring period for each application is necessary, either from on-site data collection or the nearest weather station.

This process was tested using the 2008 TDV multipliers for the 12 month period from April 2013 through March 2014 for San Jose, CA. Figure 21 presents the difference in cooling degree days (CDD) and heating degree days (HDD) between the Climate Zone 4 weather file and the actual 12 month period. Actual HDDs are 17 percent less, and actual CDD are 65 percent higher than the weather file.

Table 7 compares the number of days that fall into each tier for both the weather file and the actual year data. There is no simple correlation between degree days and number of peak cooling days. For the monitoring period, there are 65% more cooling degree days, but fewer days in the Tier 2 bin.

Annual cooling TDV energy use was calculated using the adjusted TDV multipliers and the approach outlined above. Alternatively, annual cooling energy use was calculated by directly applying the hourly 2008 TDV multipliers without regard to daily temperature. The latter was calculated to be 8 percent higher than that calculated with the adjusted profiles. While 8 percent is not too large of a difference, it is expected that this difference will be higher for the 2013 TDV because the magnitudes between the peak day and off-peak days are much larger.

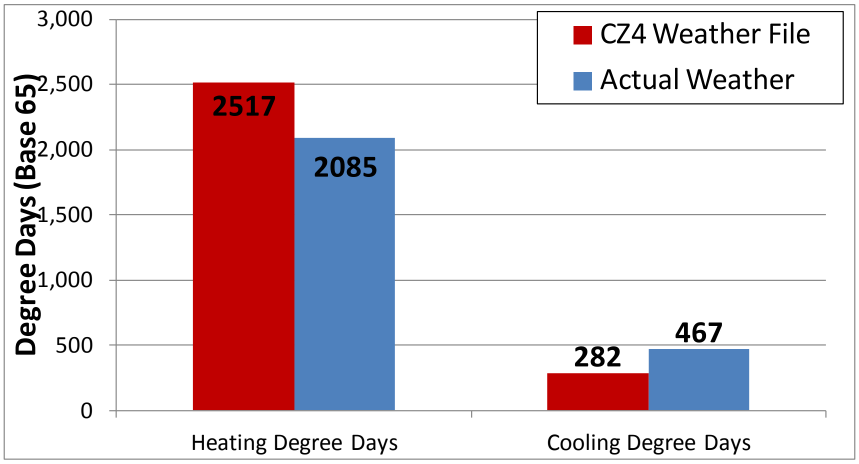

FIGURE 21: COMPARISON OF HEATING AND COOLING DEGREE DAYS FOR THE TITLE-24 CLIMATE ZONE 4 WEATHER FILE AND ACTUAL YEAR WEATHER

Table 7: Number of Days in Each Tier

	# DAYS FROM WEATHER FILE	**# DAYS FROM ACTUAL YEAR**
Tier 1	221	238
Tier 2	40	23
Weekend Tier	104	104