APPENDICES

Appendix A: Development Profiles of the Four Project Locations

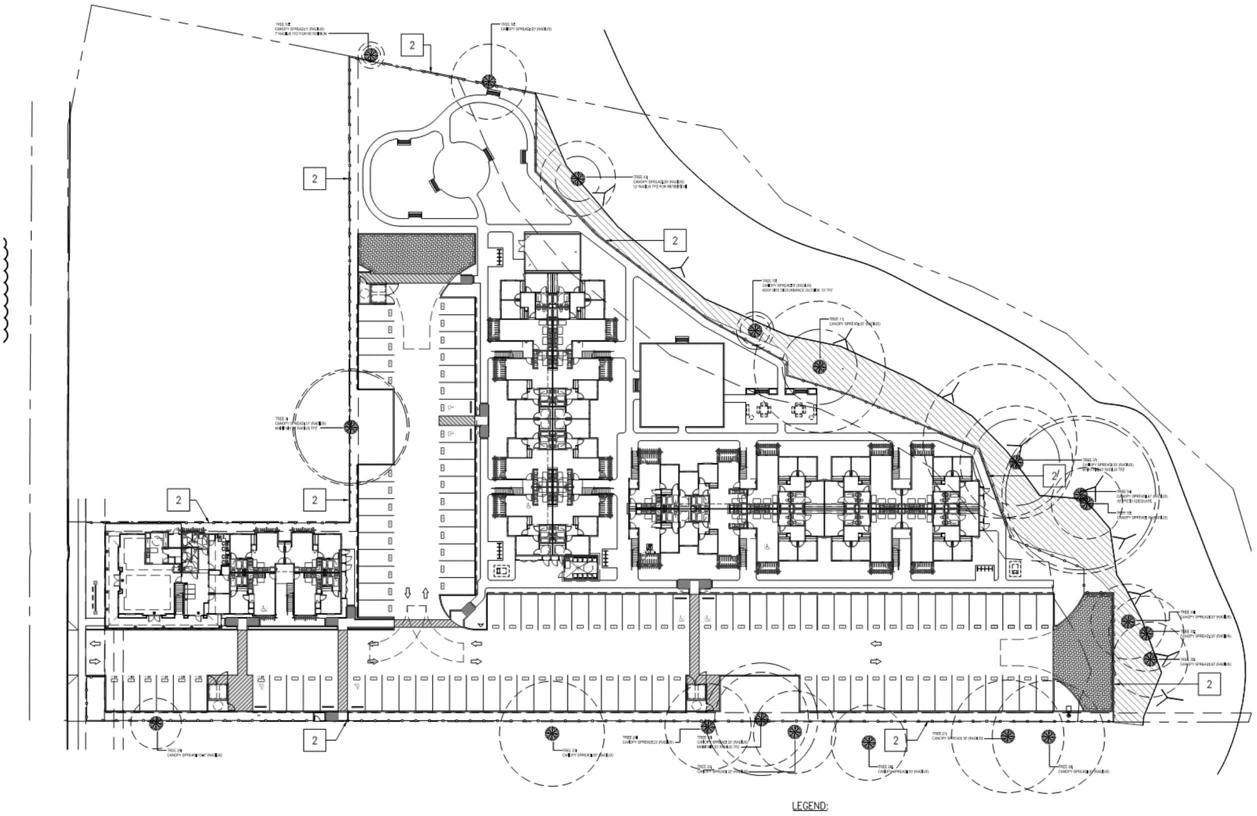
Calistoga Profile

Developer: Community for Better Housing	Demographic: 30%–50% AMI farmworker housing
Contractor: BLH Construction Energy Consultant: Redwood Energy	Total Units: 48 Bedroom Types: 1 bedroom (6 units), 2 bedroom (16 units), 3 bedroom (16 units)
Climate zone: 2 Construction completion: 2015	Square Footage: 41,433 ft^2

	COMMON END USES	NUMBER OF UNITS	NUMBER OF STORIES
BUILDING ONE	**Community room, computer room, offices, common bathroom, and kitchen**	**12**	**2**
BUILDING TWO	**Central Aermec system, laundry room**	**16**	**2**
BUILDING THREE	**None**	**20**	**2**

Calistoga Photos

Calistoga Site Plan



Cloverdale Profile

Developer: Community for Better Housing

Contractor: BLH Construction
Energy Consultant: Redwood Energy

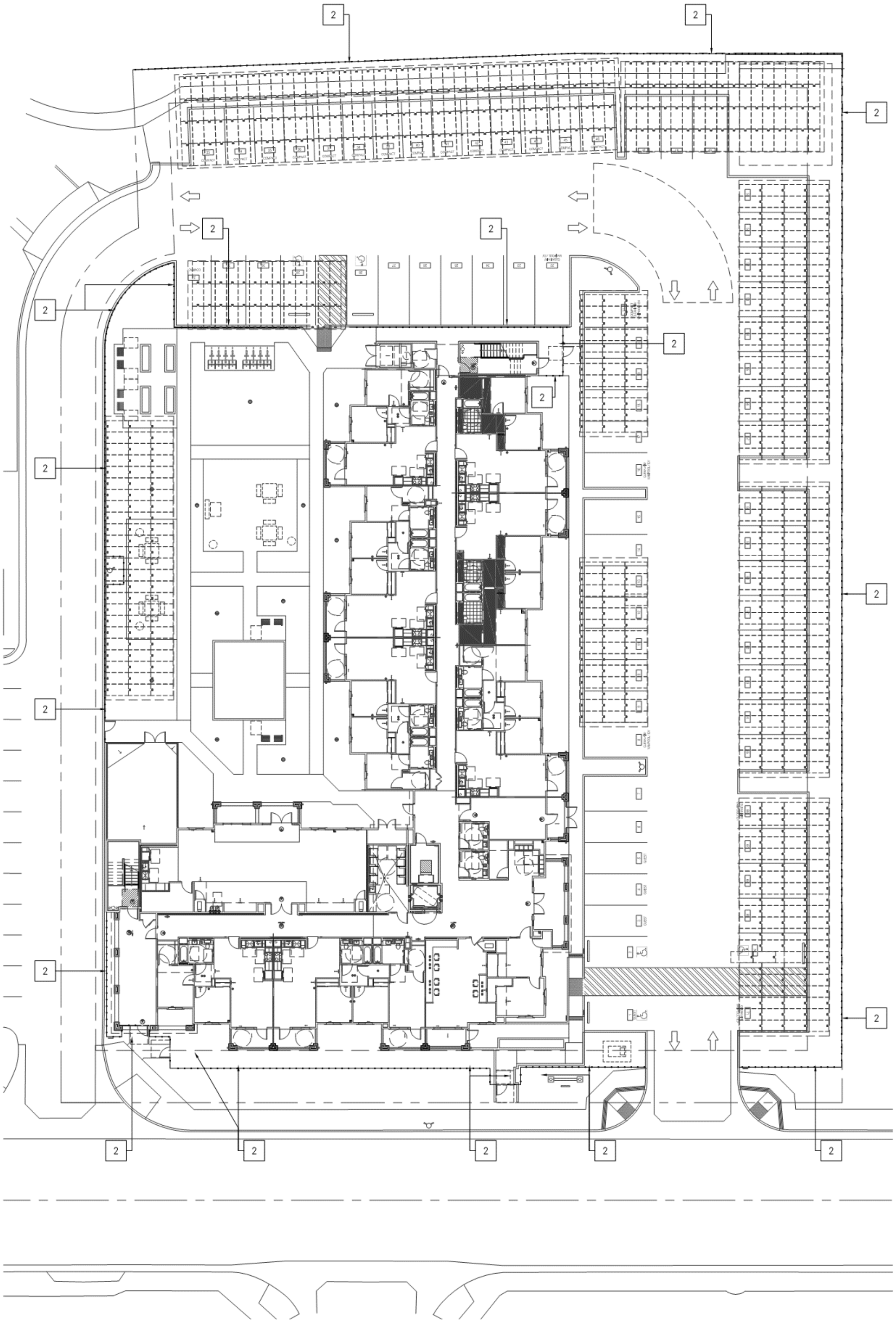
Climate zone: 2
Construction completion: 2016

Demographic: 30%–50% AMI farmworker housing
Total Units: 32
Bedroom Types: 2 bedroom (16 units), 3 bedroom (16 units)
Square Footage: 43,967 ft^2

	COMMON END USES	NUMBER OF UNITS	NUMBER OF STORIES
BUILDING ONE	**Community room, computer room, offices, common bathroom, elevator, and kitchen**	**30**	**3**

Cloverdale Photos

Cloverdale Site Plan



Calistoga/Cloverdale Energy Efficiency Measures

Project Name	**Calistoga**	**Cloverdale**
CEC Climate Zone	2	2

Wall Insulation	R-21	R-19 + R-5 exterior
Roof Insulation	R-49	R-38
Roof Special Features	Radiant barrier, cool roof	N/A
Roof Reflectance	0.75	0.18
Roof Emittance	0.89	0.89
Window U-factor	0.30	0.30
Window SHGC	0.28	0.22

DHW Type	Central, Combined hydronic heat pump, Aermec	Central, Combined hydronic heat pump, Aermec
DHW Energy Factor (EF)	2.0	2.0

HVAC Type	Air to water heat pump	Air to water heat pump
HVAC HSPF	2.86 COP	2.86 COP
HVAC SEER	13 SEER, 9.63 EER	13 SEER, 9.63 EER
Duct Location	Located in conditioned space	Located in conditioned space
Duct Insulation	R-8	R-8

HERS Verification	Quality Insulation Installation (QII)	Quality Insulation Installation (QII)
	Verified radiant barrier	IAQ mechanical ventilation
	Verified opaque surfaces and glazing values	Minimum cooling system airflow

	Verified heating efficiency (COP)	Refrigerant charge
	Verified SEER	Fan efficacy watts/CFM
	Verified water heater efficiency	Duct sealing
	Ducts, plenums and HVAC unit located within conditioned space	Ducts, plenums and HVAC unit located within conditioned space
	HVAC duct leakage to the outside equal to or less than 25 cfm	HVAC duct leakage to the outside equal to or less than 25 cfm
	DHW pipe insulation, all lines	DHW pipe insulation, all lines
		Recirculation with temperature modulation and monitoring

Over more than 30 years BLH Construction has built more than one hundred apartment complexes for the Corporation for Better Housing (CBH), most of them with the Mechanical, Electrical and Plumbing (MEP) designs performed by Breen Engineering. This stable, experienced team has developed standard approaches to the energy systems of their 80 gas hybrid, and since 2014, 20 all-electric apartment complexes. CBH and BLH Construction share a common owner, making understanding of MEP system costs a shared goal. BLH Construction purchases all MEP components directly, not with contractor mark-up, and employs a mix of subcontractors and employees to install the MEP systems. Consequently BLH’s President, Brian Holland, was. able to give exact materials costs, but unable to provide consistently broken-out labor costs for the MEP systems.

Nonetheless, the material costs of central gas boilers and chillers is 18% greater than electric central heat pump systems (Table A-1). The central MEP systems, in turn, are 28% more expensive (Gas) and 17% more expensive (Electric) than individual MEP system for each apartment. However, lacking Labor costs, we cannot conclude that individual systems are actually less expensive than central systems, only that Gas central systems are more 18% expensive than Electric central systems.

Table A-1: CBH Cost Comparison for Central Gas, Central Electric and Individual Electric for 32 Unit Building

Materials Costs from BLH Construction for their Standard Central Gas Systems (n=100+), Central Heat Pump Systems (n=2), and Individual Heat Pumps Systems (n=18)

System Type	Component Description	Price
Gas Infrastructure Engineering	Gas Lateral Engineering fees (per apartment)	$470
Gas Infrastructure	Gas Lateral Materials **and Labor** (per apartment)	$938
Central Gas Domestic Hot Water	Central DHW gas boiler, recirculation pump and piping materials (per apartment)	$1,719
Central Gas HVAC	Central Gas Hydronic Heating Boiler and Chiller materials (per apartment)	$6,205
Individual Gas HVAC	Hydronic fan coil and ductwork materials (per apartment)	$5,725
Central Gas Total Cost Per Apartment		**$15,057**
Electric Infrastructure and Engineering	Transformer--No Sizing Difference Reported	$ -
Electric Heat Pump Central HVAC + DHW	Aermec Central DHW + HVAC air source heat pump materials (per apartment)	$7,070
	Hydronic fan coil and ducts for air-source central Aermec System materials (per apartment)	$5,725
Central Heat Pump Total Cost Per Apartment		**$12,795**
Electric Infrastructure and Engineering	Transformer--No Sizing Difference Reported	$ -
Electric Heat Pump Individual Apt HVAC	High performance heat pumps and ductwork materials (per apartment)	$9,195
Electric Heat Pump Individual Apt Domestic Hot Water	Individual 80 gal DHW materials (per apartment)	$1,704
Individual Heat Pump Total Cost Per Apartment		**$10,899**

Atascadero Profile

Developer: Community for Better Housing

Contractor: BLH Construction

Energy Consultant: Redwood Energy

Construction time period: 2016–2018

Climate zone: 4

Demographic: 30%–50% AMI farmworker housing

Total Units: 60

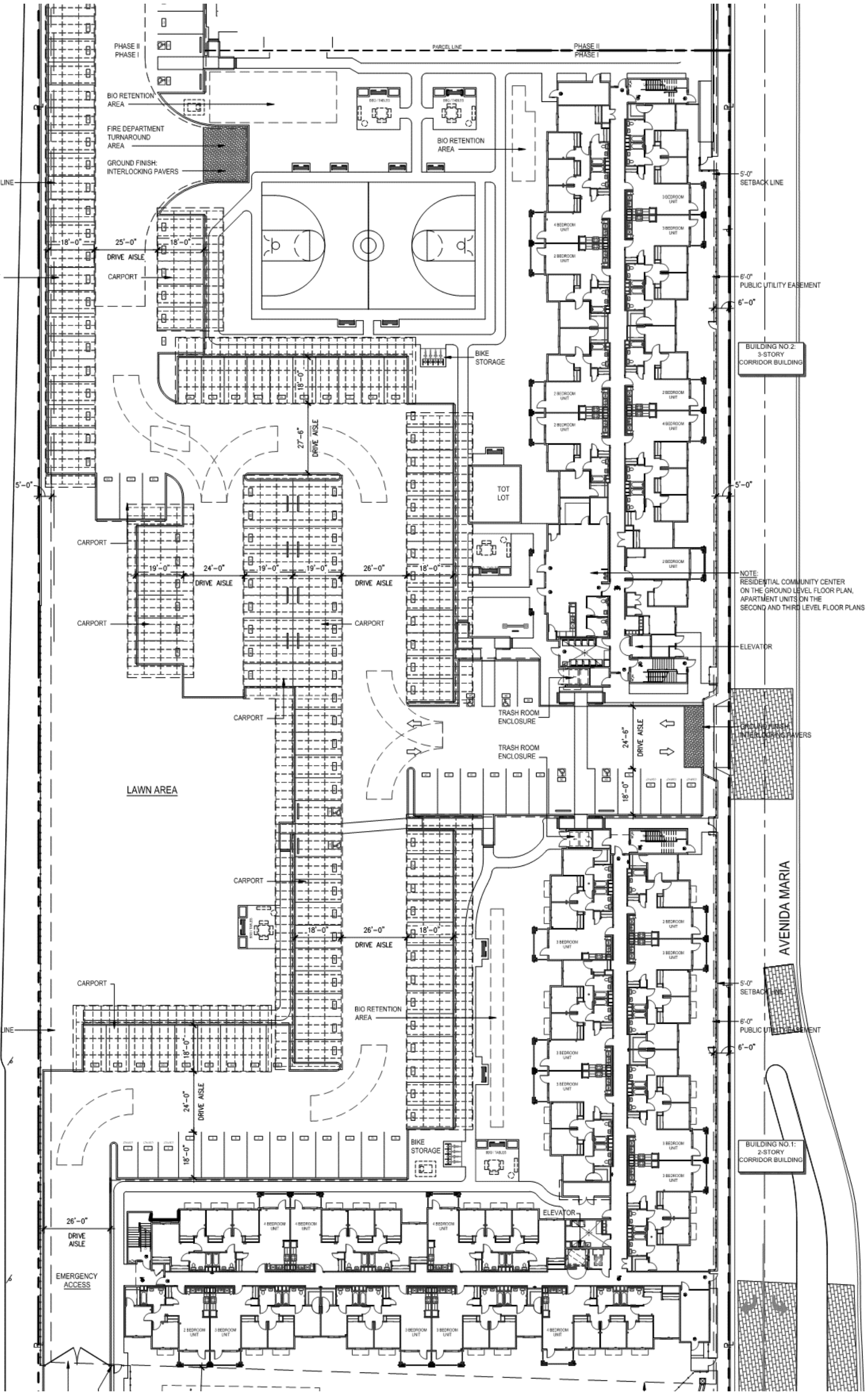
Bedroom Types: 2 bedroom (22 units), 3 bedroom (24 units), 4 bedroom (14 units)

Square Footage: 60,842 ft^2

	COMMON END USES	NUMBER OF UNITS	NUMBER OF STORIES
BUILDING ONE	**Community room, computer room, offices, common bathroom, elevator, and kitchen**	**30**	**3**
BUILDING TWO	**Laundry room, elevator**	**30**	**2**

Atascadero Site Photos

Atascadero Site Plan



Atascadero Energy Efficiency Measures

Project Name	**Atascadero**
CEC Climate Zone	4

Wall Insulation	R-21 + R-5 exterior
Roof Insulation	R-49
Roof Special Features	N/A
Roof Reflectance	0.10
Roof Emittance	0.85
Window U-factor	0.30
Window SHGC	0.28

DHW Type	Individual, NEEA-Rated tanks, 50 and 80 gallons
DHW Energy Factor (EF)	3.4

HVAC Type	Split heat pump
HVAC HSPF	10
HVAC SEER	19
Duct Location	Located in conditioned space
Duct Insulation	R-8

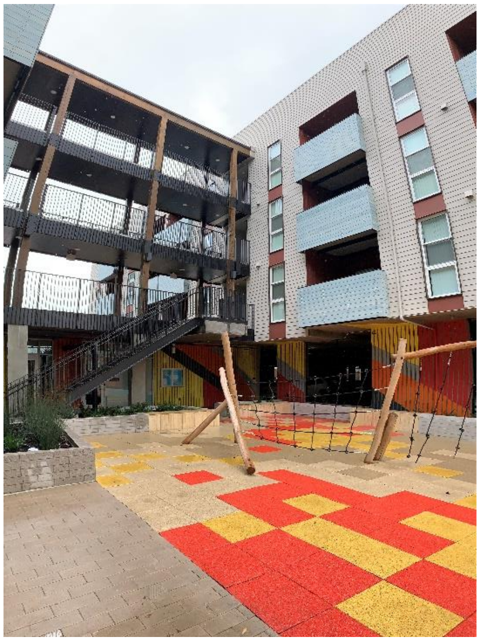
HERS Verification	Quality Insulation Installation (QII)
	IAQ mechanical ventilation
	Minimum cooling system airflow
	Verified EER
	Verified SEER
	Refrigerant charge
	Fan efficacy watts/cfm
	Duct sealing
	DHW pipe insulation, all lines

Sunnyvale Profile

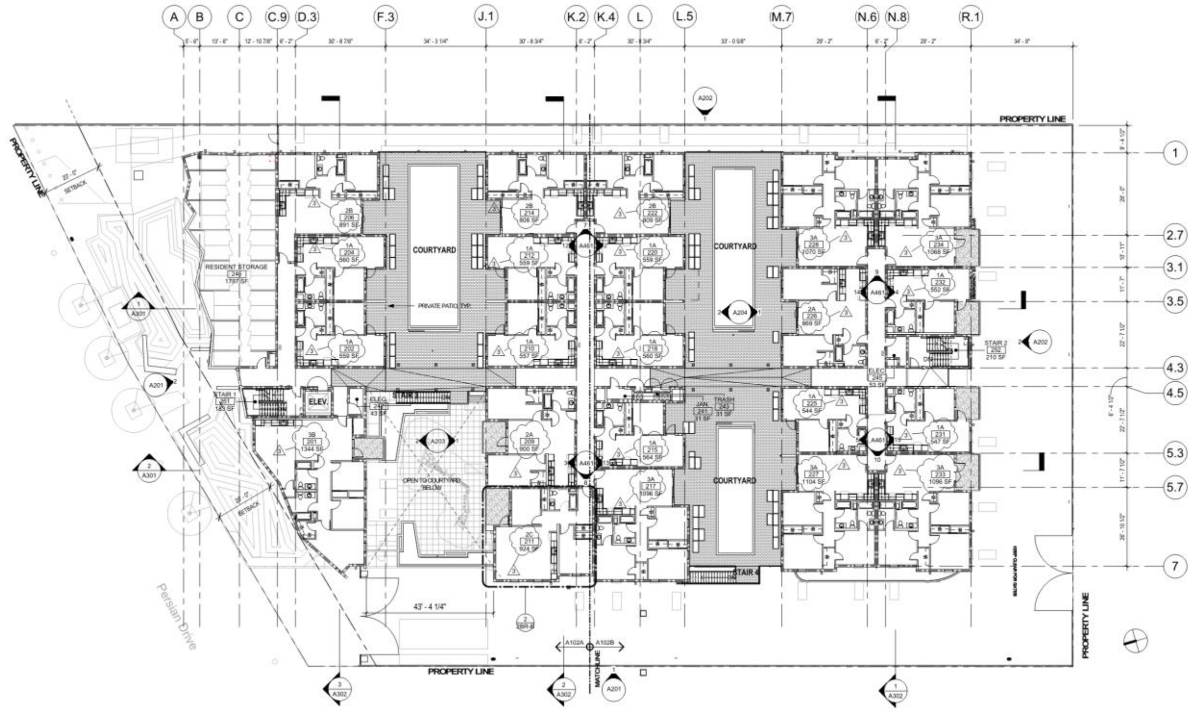
Developer: Midpen Housing Architect: David Baker Associates Energy Consultant: Association for Energy Affordability	Demographic: Low income Total Units: 66 Bedroom Types: 1 bedroom (30 units), 2 bedroom (19 units), and 3 bedroom (17 units)
MEP Engineer: Emerald City Engineers (ECE) Climate zone: 4 Construction completion: 2018	Square Footage: 100,826 ft^2

	COMMON END USES	NUMBER OF UNITS	NUMBER OF STORIES	NUMBER OF BEDROOMS	NUMBER OF OCCUPANTS
WINGS ONE AND TWO	**Community room, computer room, offices, common bathroom, kitchen, laundry, CHPWH**	**42**	**4**	**69**	**101**
WING THREE	**None, CHPWH**	**24**	**4**	**51**	**81**

Sunnyvale Photos



Sunnyvale Site Plan



Sunnyvale Energy Efficiency Measures

Project Name	**Sunnyvale**
CEC Climate Zone	4

Wall Insulation	R-19
Roof Insulation	R-38
Roof Special Features	Cool Roof
Roof Reflectance	0.72
Roof Emittance	0.89
Window U-factor	0.29
Window SHGC	0.31

DHW Type	Central, ganged-Sanden air source heat pump
DHW Energy Factor (EF)	3.23 (4.99 COP)

HVAC Type	Ductless Mini-split heat pump
HVAC HSPF	8.2 HSPF
HVAC SEER	14 SEER/11 EER
Duct Location	N/A
Duct Insulation	N/A

HERS Verification	No HERS Verification - N/A

Recirculation Approaches

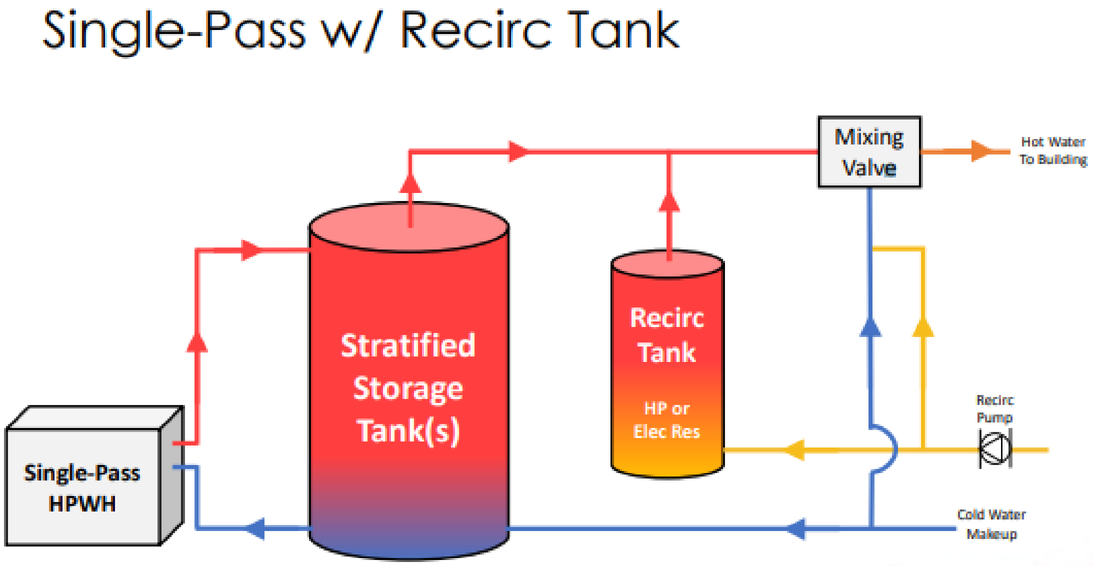
Heat pump water heaters, particularly those that use CO_2 as a refrigerant, operate most efficiently when making very cold water very hot, in one pass. To ensure these optimal conditions, the heat pump is piped to draw cold water from the bottom of the tank, heat it all the way up to set point (140°+) in a single pass, and deliver the hot water to the top of the tank. This configuration charges the tanks from top to bottom and results in a highly-stratified tank, with the coldest water at the bottom, and the hottest water at the top. Stratification not only maximize heat pump efficiency, but also results in a higher effective storage volume, with the vast majority of the fully charged tank at or near the heat pump's very high outlet temperature.

Introducing a recirculation system, however, can complicate matters. In a standard boiler system the recirculated water is blended in with the cold water makeup before it enters the primary storage tank. If this approach were taken with a heat pump system, this recirculation water would mix up and de-stratify the tank, reducing heat pump efficiency and effective storage.

There are two primary approaches to handling recirculated water in a heat pump system to avoid de-stratifying the main tanks, both of which involve bringing the warm recirculated water back to its own dedicated heater, separate from the primary tank.

The first approach to handling recirculation return in a central heat pump water heating plant uses what we will call a recirculation heater (Figure A-1). In this configuration the recirculation water is brought back to the bottom of its own dedicated heater, which can be either a resistance water heater or a HPWH. This recirculation heater is piped in parallel with the primary storage tank(s) on the way to the hot side of the mixing valve.

Figure A-1: Recirculation Heater Diagram



The second approach is to bring the recirculated water back to what is referred to as a swing tank, which can also be either an electric resistance heater or a heat pump water heater. In this configuration the outlet from the primary storage tank is piped to the bottom of the swing tank. Anytime there is hot water demand from the building, the very hot water from the primary storage tank runs through the swing tank and then out to the hot side of the mixing valve. In this way, the swing tank is effectively charged with very hot water during draw period, and this very hot water is then slowly diluted by the warm recirculation return water when there is no demand. As this happens, the tank will "swing" in temperature between the primary storage tank temperature (usually 140°-150°) and the mixing valve setpoint of 120°-125°, at which point the heat source in the swing tank will turn on to ensure delivered water does not fall below 120°F. With regular-enough demand periods, the heat source in the swing tank may never (or rarely) turn on, meaning the recirculation heat load is being effectively met by the very-efficient single-pass heat pump piped to the primary tank.

At Benner Plaza the Recirculation Heater strategy was used.

Below is a description of the design iterations of the domestic hot water system for Edwina Benner Plaza in Sunnyvale. Table A-2 lays out the performance specifications for the four design iterations, from condensing gas boilers to heat pumps.

Table A-2: Sunnyvale Evaluations of Central Plant Sizing

#	1	2	3	4
Iteration	One Central Plant: 4 x Gas Water Heaters	3 Separate Plants: (A) 10 x 2HP+83gal B) 5 x 2HP+83gal C) 5 x 2HP+83gal	3 Separate Plants: (A) 2 x 4HP+400gal (B) 1 x 4HP+400gal (C) 1 x 4HP+400gal	3 Separate Plants: (A) 2 x 4HP+500gal (B) 1 x 4HP+500gal (C) 1 x 4HP+500gal
Fuel	Natural Gas	Electricity	Electricity	Electricity
Base System	AO Smith BTH-199	2 Sanden SANCO2 Heat Pumps + 83 gal Sanden tank	4 Sanden SANCO2 Heat Pumps + 400 gal Lochinvar tank	4 Sanden SANCO2 Heat Pumps + 500 gal Lochinvar tank
First Hour Storage Ratio	19	43	75	79
Total First Hour Rating (gal)	1,572	2,924	1,594	1,894
Total Recovery Rate (BTU/hr)	796,000	616,000	246,400	246,400
Total Storage (gal)	400	1,660	1,600	2,000
System Count	4	20	4	4
System First Hour (gal)	393	146	398	473
System Recovery (BTH/hr)	199,000	30,800	61,600	61,600
System Storage (gal)	100	83	400	500

In addition to pushing for higher-performance water heating and ventilation, the research team also modeled the effect of a few different envelope and lighting options early in the design process. The iterations and savings are shown in Table A-3.

Table A-3: Sunnyvale Savings by Design Modeling Runs under 2013 Energy Code (Individual, not Additive) – kTDV/sf

Model Version	Heating	Cooling	Lighting	Fans	Total	Title 24 Compl. Margin[1] (%)
T24 Standard Building (2013)	13.9	15.6	39.6	37.4	129.4	**0.0**
A. Base Design	14.6	16.3	39.6	31.7	113.4	**12.4**
B. 2" Continuous Rigid Rock Wool Wall Insulation at Upper Floors (R 4.2/in)	13.2	15.5	39.6	31.6	111.1	**14.1**
C. 100% LED Lighting	14.7	16.3	38.4	31.7	112.3	**13.2**
D. Insulate concrete/CMU walls (2" Continuous Rock Wool Equivalent)	12.6	16.4	39.6	31.6	111.4	**13.9**
E. Insulate garage ceiling	13.8	16.0	39.6	31.7	112.3	**13.2**

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[1] Compliance margins were based on calculations using compliance software for the California Energy Code.

Appendix B: Monitoring Plans and Equipment Lists

Table B-1 describes the metering equipment specified to monitor and collect data on energy consumption and water usage associated with the central heat pump heating, cooling, and water heating plant and apartment level electrical end use. For all four projects, Nexi devices were deployed to monitor circuit level energy consumption and provide feedback to occupants on energy consumption compared to the overall daily budget. The lighting displays were programmed to have fraction of budget correlate to color in order to communicate level of daily consumption to occupants.

Table B-1: Nexi Monitoring Equipment Budget Distributions for Lighting Displays

. Budget versus Nexi Display Colors at Calistoga and Cloverdale in kWh/day

Color Level	1 Bedroom	2 Bedroom	3 Bedroom	% of Budget
Green	0.0	0.0	0.0	<40
Yellow	2.9	3.5	4.2	40–70
Orange	5.1	6.2	7.3	70–95
Red	6.9	8.4	9.9	95–110
Fuchsia	8.0	9.7	11.4	>110

Budget versus Nexi Display Colors at Atascadero in kWh/day

Color Level	2 Bedroom	3 Bedroom	4 Bedroom	% of Budget
Green	0.0	0.0	0.0	<40
Yellow	4.4	5.2	6.0	40–70
Orange	7.7	9.1	10.4	70–95
Red	10.4	12.3	14.2	95–110
Fuchsia	12.0	14.3	16.4	>110

Budget Versus Nexi Display Colors at Sunnyvale in kWh/day

Color Level	1 Bedroom	2 Bedroom	3 Bedroom	% of Budget
Green	0.0	0.0	0.0	<40
Yellow	3.6	4.4	5.2	40–70
Orange	6.3	7.7	9.1	70–95
Red	8.5	10.4	12.3	95–110
Fuchsia	9.9	12.0	14.3	>110

Table B-2 below describes equipment used at both Cloverdale and Calistoga.

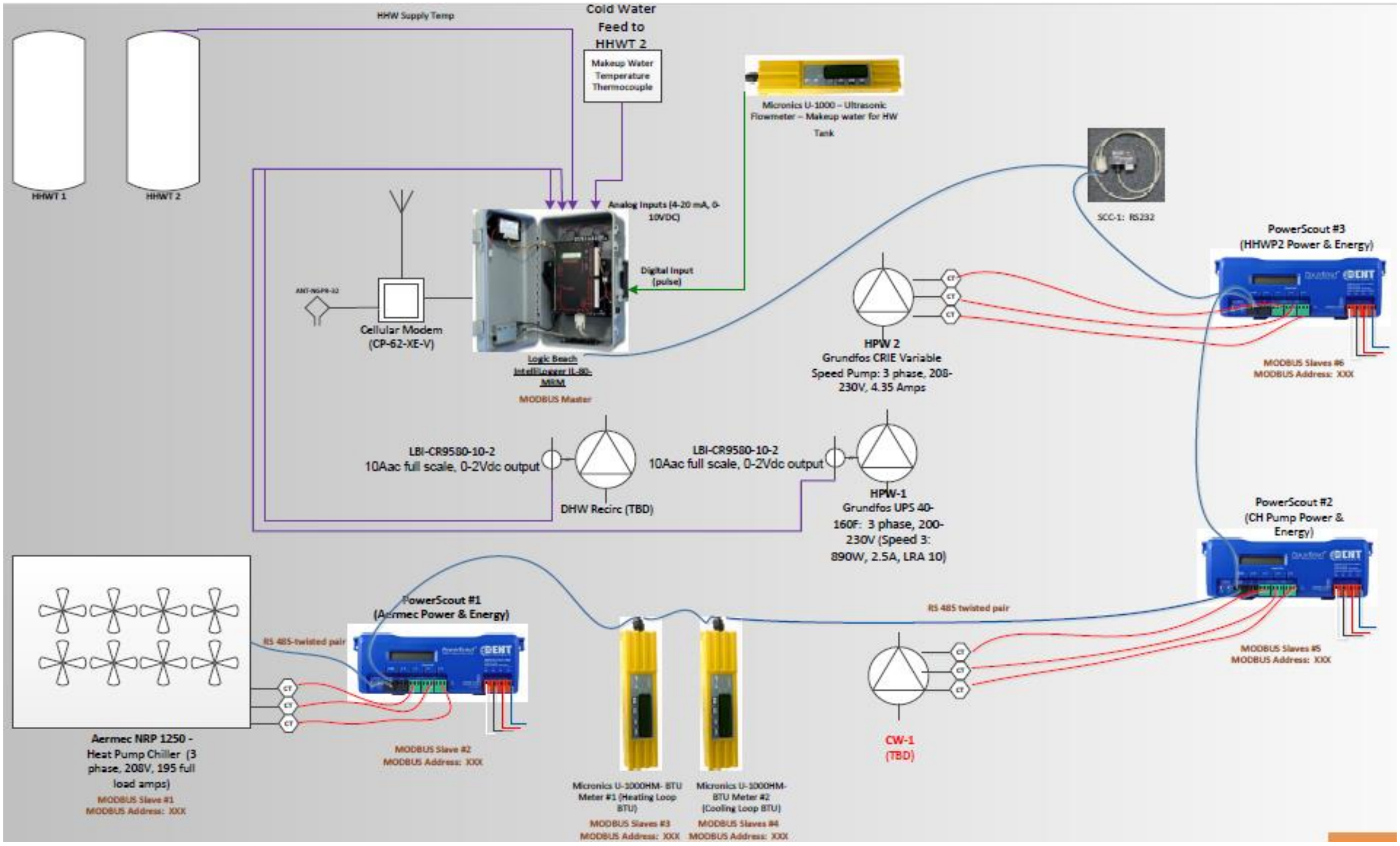
Table B-2: Cloverdale and Calistoga Equipment List of the Aermec Combined Central System to Evaluate Performance

Service Being Metered	Metering Device	Measurements	Communications
Electrical Power/Energy of Aermec (kW, kWh)	Dent PowerScout 3037 Power Meter #1 (with 200 Amp CTs)	kW, kWh, kW System Max, kW System Min, kW System Avg., Amps	Modbus
Hot Water Energy (Btu)	Micronics U1000HM – Heat Meter #1	Supply & return water temp, gpm, Btu	Modbus
Chilled Water Energy (Btu)	Micronics U1000HM – Heat Meter #1	Supply water temp, return water temp, GPM, Btu	Modbus
Flow (GPM)	Micronics U1000 – Flow Meter	Makeup water flow (GPM)	4-20mA to IL-80 Digital Input-A
Makeup Water Supply Temp (°F)	K-Type Thermocouple	Makeup water temp	IL-80 Thermocouple input Ch-A
DHW Supply Temp (°F)	K-Type Thermocouple	DHW supply water temp	IL-80 Thermocouple input Ch-B
Pumping Energy (HWP-2 VFD secondary pump)	Dent PowerScout 3037 Power Meter #2 (with 15 Amp CTs)	kW, kWh, kW System Max, kW System Min, kW Sys. Avg., Amps	Modbus
Pumping Energy (CHWP-2 VFD secondary pump)	Dent PowerScout 3037 Power Meter #3 (with 15 Amp CTs)	kW, kWh, kW System Max, kW System Min, kW Sys. Avg., Amps	Modbus
Pumping Energy (DHW Recirc)	LBI-CR9580-10-2 AC Current Sensor	Amps	Analog Input Channel D
Pump Energy (Aermec to Hx)	LBI-CR9580-10-2 AC Current Sensor	Amps	Analog Input Channel E
Aermec Internal Functions	Logic Beach IL-80 or AerWeb300	Heat recovery, internal pumps, compressor runtimes	Modbus or Direct from the AerWeb Portal (integral to the Aermec)
Apartment and Laundry energy consumption	Nexi	kW and amps. Whole apt. energy consumption and selected circuits	none
Indoor Temperature	HOBO data loggers	Air temp (sampled units)	

VFD = variable frequency drive; Hx =Heat exchange

The graphic (Figure B-1) below is a schematic showing the layout of the monitoring equipment for the Aermec system.

Figure B-1: Calistoga and Coverdale Monitoring Schematic



At Atascadero, the team monitored a sample of the domestic hot water systems and individual electrical usage at all apartments. Table B-3 below describes equipment used.

Table B-3: Atascadero Monitoring Equipment List

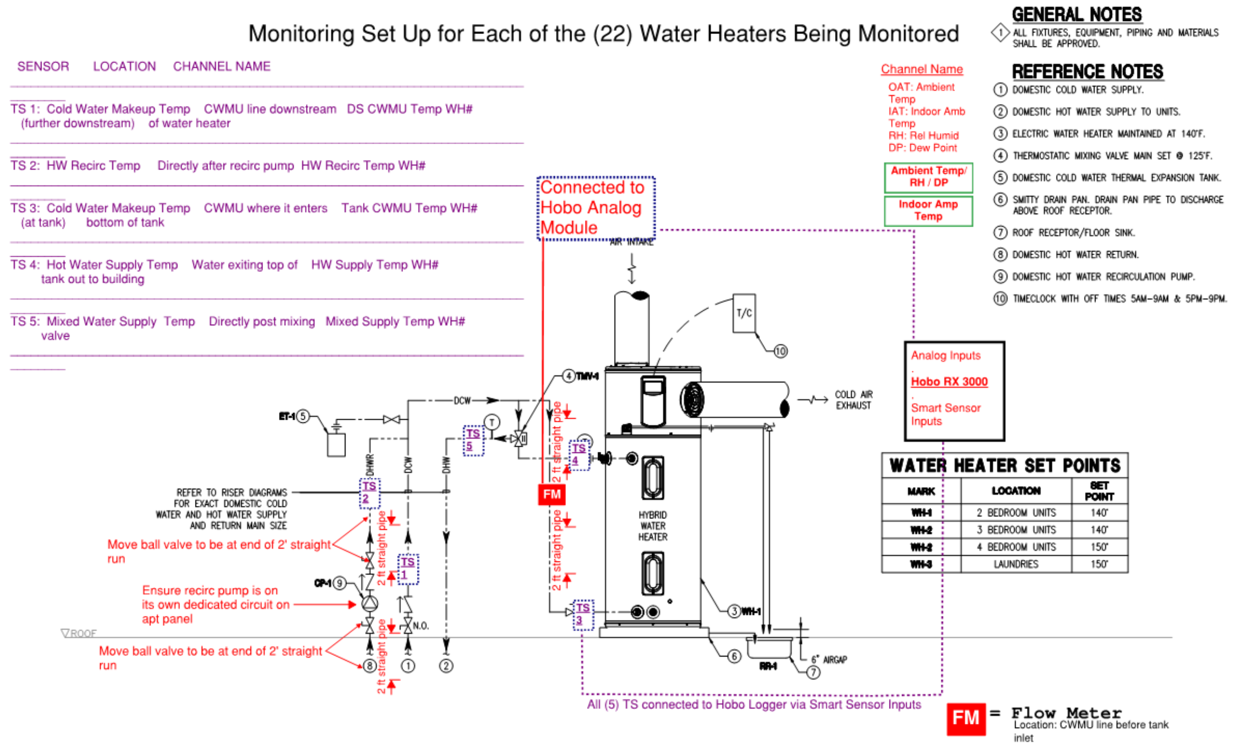
Service Being Metered	Metering Device	Measurements
Flow (GPM)	Magnetic Induction In-Line Flow Meter	In-line flow meter on incoming water
Cold Water Makeup Temperature (°F)	K-Type Thermocouple	Makeup water temp at incoming tank
Cold Water Makeup Temperature (°F), at shed	K-Type Thermocouple	Makeup water temp, piping at border of shed and outdoors
Hot Water Recirculation Temperature (°F)	K-Type Thermocouple	DHW recirculation water temp
Hot Water Supply Temperature (°F)	K-Type Thermocouple	DHW water supply prior to mixing valve
Mixed Water Supply Temperature (°F)	K-Type Thermocouple	DHW mixed water supply to building, post-mixing valve
Ambient Temperature (°F)	K-Type Thermocouple	Ambient temperature in water heater shed
Ambient Temperature (°F)	Weatherproof K-Type Thermocouple	Ambient temperature outside of water heater shed
Relative Humidity (rH)	Weatherproof K-Type Thermocouple	Relative humidity outside of water heater shed
Dew Point (°F)	Weatherproof K-Type Thermocouple	Dew point outside of water heater shed
Whole Building and Circuit Level Electrical End Use	Nexi	kW and amps at circuit level for all units
Rheem Data		Upper and lower tank temps, HPWH mode, compressor and resistance runtime, set point temp
Central Laundry (washer and dryers in both laundry rooms)	Nexi	kW and amps
Indoor Temperature Set Point	Site Observations	°F

The monitoring plan for the unitary heat pump water heaters was extensive, and therefore the monitoring was limited to 22 of the 60 apartments. Figure B-2 summarizes monitored units, and the graphic shows the monitoring setup.

Figure B-2: Atascadero Monitoring Plan

Apartment parameters with monitored heat pump water heaters

Bedroom Type	Number of Units	Average Square Footage	HPWH Size (gallons)	Average Occupancy (at move-in)
2	8	793	50	3.00
3	7	1,048	80	4.43
4	7	1,284	80	5.43



Monitoring Set Up for Each of the (22) Water Heaters Being Monitored

SENSOR	LOCATION	CHANNEL NAME
TS 1: Cold Water Makeup Temp (further downstream)	CWMU line downstream of water heater	DS CWMU Temp WH#
TS 2: HW Recirc Temp	Directly after recirc pump	HW Recirc Temp WH#
TS 3: Cold Water Makeup Temp (at tank)	CWMU where it enters bottom of tank	Tank CWMU Temp WH#
TS 4: Hot Water Supply Temp	Water exiting top of tank out to building	HW Supply Temp WH#
TS 5: Mixed Water Supply Temp	Directly post mixing valve	Mixed Supply Temp WH#

Channel Name

OAT: Ambient Temp

IAT: Indoor Amb Temp

RH: Rel Humid

DP: Dew Point

GENERAL NOTES

1. ALL FIXTURES, EQUIPMENT, PIPING AND MATERIALS SHALL BE APPROVED.

REFERENCE NOTES

① DOMESTIC COLD WATER SUPPLY.
② DOMESTIC HOT WATER SUPPLY TO UNITS.
③ ELECTRIC WATER HEATER MAINTAINED AT 140'F.
④ THERMOSTATIC MIXING VALVE MAIN SET @ 125'F.
⑤ DOMESTIC COLD WATER THERMAL EXPANSION TANK.
⑥ SMITTY DRAIN PAN. DRAIN PAN PIPE TO DISCHARGE ABOVE ROOF RECEPTOR.
⑦ ROOF RECEPTOR/FLOOR SINK.
⑧ DOMESTIC HOT WATER RETURN.
⑨ DOMESTIC HOT WATER RECIRCULATION PUMP.
⑩ TIMECLOCK WITH OFF TIMES 5AM–9AM & 5PM–9PM.

WATER HEATER SET POINTS

MARK	LOCATION	SET POINT
WH-1	2 BEDROOM UNITS	140'
WH-2	3 BEDROOM UNITS	140'
WH-2	4 BEDROOM UNITS	150'
WH-3	LAUNDRIES	150'

Connected to Hobo Analog Module

Analog Inputs . Hobo RX 3000 . Smart Sensor Inputs

Move ball valve to be at end of 2' straight run

Ensure recirc pump is on its own dedicated circuit on apt panel

Move ball valve to be at end of 2' straight run

REFER TO RISER DIAGRAMS FOR EXACT DOMESTIC COLD WATER AND HOT WATER SUPPLY AND RETURN MAIN SIZE

All (5) TS connected to Hobo Logger via Smart Sensor Inputs

FM = Flow Meter
Location: CWMU line before tank inlet

At the Sunnyvale project, the team monitored the central system and individual electrical usage. Table B-4 below describes the equipment used.

Table B-4: Sunnyvale Monitoring Equipment List

Service Being Metered	Metering Device	Measurements
Electrical Current of Sandens 1-16	CR Magnetics CR9580-20	Amps (kWh)
Electrical Current of Recirculation Pumps	CR Magnetics CR9580-20	Amps (kWh)
Electrical Current of Recirculation Water Heaters	CR Magnetics CR9580-50	Amps (kWh)
Cold Water Makeup Flow	Onicon F-4600-250-110-160	GPM (GPH, total gallons)
Hot Water Supply to Main Tanks Flow	Onicon F-4600-250-110-160	GPM (GPH, total gallons)
Heat Pump Bank 1-4 Flow	IFM SM8604	GPM (GPH, total gallons)
Recirculation Return Flow	IFM SM9604	GPM (GPH, total gallons)
Recirculation Return to Recirculation Water Heater Flow	IFM SM9604	GPM (GPH, total gallons)
Ambient Air Temperature	Onset S-TMB-M006	˚F
Garage Air Temperature	Onset S-TMB-M006	˚F
Mechanical Room Air Temperature	Onset S-TMB-M006	˚F
Cold Water Makeup Temperature	Veris TIHAoCo	˚F
Recirculation Return Temperature	Veris TIHAoCo	˚F
Recirculation Tank Delivered Temperature	Veris TIHAoCo	˚F
Main Tank (Post Recirc, Pre-Mix Valve) Temperature	Veris TIHAoCo	˚F
Mixed HW to Building (Post Mix-Valve) Temperature	Veris TIHAoCo	˚F
Tank – Supply to Heat Pump Bank 1-4 Temperature	Veris TIHAoCo	˚F
Tank – Return from Heat Pump Bank 1-4 Temperature	Veris TIHAoCo	˚F
HW Supply from Tank 1-4 Temperature	Veris TIHAoCo	˚F

Tank Level 1 Tank 1 Temperature	Onset S-TMB-M006	˚F
Tank Level 2 Tank 1-4 Temperature	Onset S-TMB-M006	˚F
Tank Level 3 Tank 1-4 Temperature	Onset S-TMB-M006	˚F
Tank Level 5 Tank 1-2,4 Temperature	Onset S-TMB-M006	˚F
Tank Level 6 Tank 1-4 Temperature	Onset S-TMB-M006	˚F
Whole Building and Circuit Level Electrical End Use	Nexi	kW and amps at circuit level for all units
Rheem Data	Recirculation System	Upper and lower tank temperature, HPWH mode, compressor and resistance runtime, set point temperature
Central Laundry	Nexi	kW and amps
Indoor temperature set point	Temp Sticks	˚F

Figures B-3 and B-4 illustrate the placement of the monitoring equipment to be installed for each wing**.**

Figure B-3: Sunnyvale Monitoring Plan Wings 1 and 2

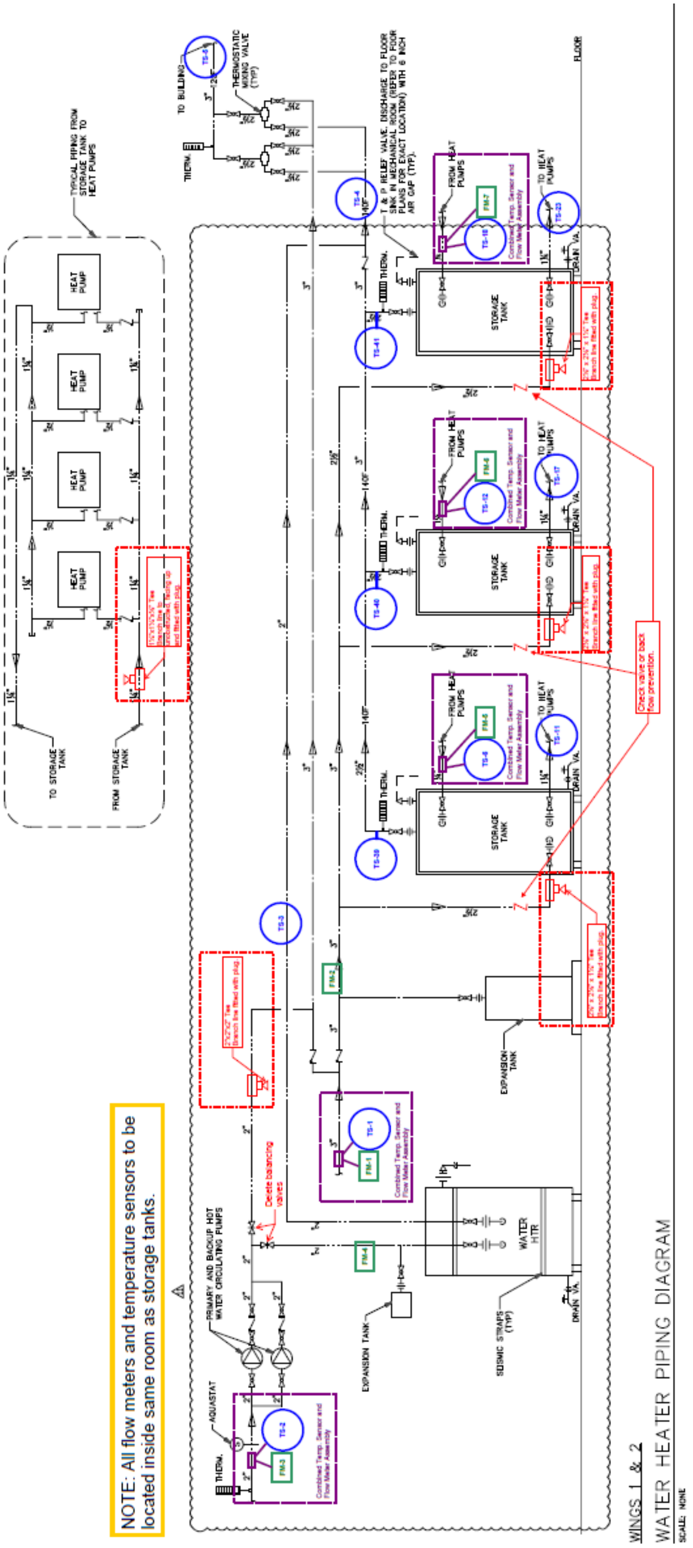
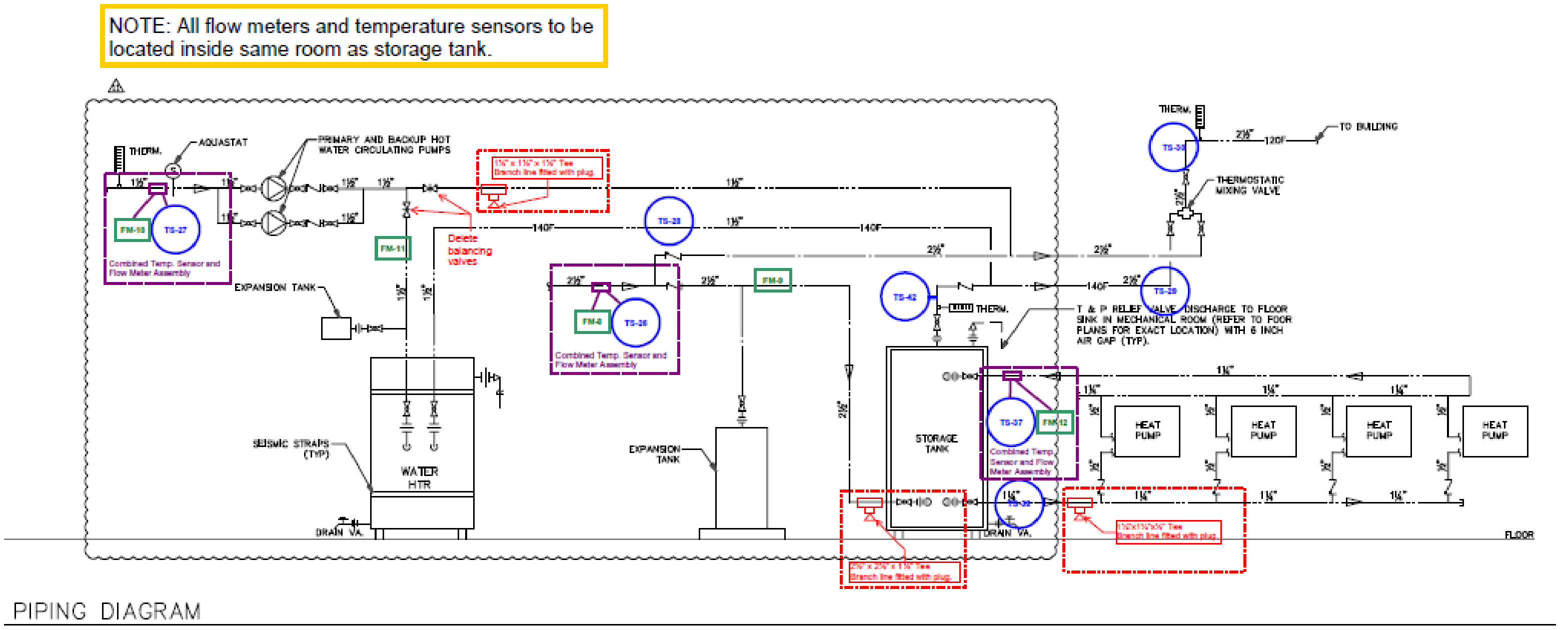


Figure B-4: Sunnyvale Monitoring Plan Wing 3


NOTE: All flow meters and temperature sensors to be located inside same room as storage tank.

Appendix C: Methodology

Efficiency Methodology

In our CEC multifamily ZNE research project, we calculated efficiency of heat pump water heating systems using COP. The methodology for each system type is described below.

COP

$$COP = \frac{q}{w} = \frac{Produced\ Hot\ Water\ (Q)}{Electrical\ Input\ to\ HPWH\ (W)}$$

$$COP = \frac{f * (T_{out} - T_{in}) * c_{p,water} * \rho_{water}}{P_{electrical}}$$

f = flow of hot water demand (gallons/min)

T_{out} = Temperature of delivered hot water, measured at the outlet of the tank (°F)

T_{in} = Incoming water temperature (°F)

$c_{p,water}$ = specific heat of water (kWh/lb_m °F)

ρ_{water} = density of water (lb/gal)

$P_{electrical}$ = electrical power (kW)

For each system type, there is a slight variation on how we calculated COP. In all cases incoming and outgoing water temperatures (T_{in} and T_{out}) were only used when there was hot water demand (flow both out of and into the tank) and therefore appliance was operating. The methodology for each of the three systems (Combined Central, Modular Central, and Individual) is described below.

Time Averaging

Flow meters was read at milliseconds, electrical consumption was read at one second intervals, and temperature was sampled at one minute intervals. These were averaged on a minute basis for COP on a minute basis. COPs were calculated over specific time frames to provide daily, monthly, seasonal, or annual COPs, to demonstrate performance over that specific time frame.

Central Combined System (Aermec)

COP was calculated for heating only performance (including both space heating and domestic hot water heating), cooling only performance, and simultaneous performance at one minute intervals. These data were then aggregated to demonstrate performance over different time periods, such as daily or seasonal, using averages over that time period. The COP was calculated by dividing the sum of the total heating output and total cooling output by the total electrical input to the Aermec. Each minute for which this calculation was performed was tagged as heating only (flow occurring on the HW primary loop, but no flow occurring on the CHW primary loop), cooling only (no flow occurring on the HW primary loop, but flow occurring on the CHW primary loop), or simultaneous heating and cooling (flow occurring on both the HW and CHW primary loops). Total output and total input were appropriately scaled based on the operation and validated this methodology's functionality.

Heating Only:

$$COP\ heating = \frac{(\text{HW Supply}_{Aermec} - \text{HW Return}_{Aermec}) * f_{Aermec,\ HW\ Primary\ Loop}}{\text{Electrical Input}_{Aermec}}$$

Hot water produced was defined as the difference between the hot water supplied from the Aermec and the return water to the Aermec. Electrical input to the Aermec was assumed to be heating energy input if the primary hot water circulating pump was operating during that minute.

Cooling Only:

$$COP\ cooling = \frac{(\text{CHW Return}_{Aermec} - \text{CHW Supply}_{Aermec}) * f_{Aermec,\ CHW\ Primary\ Loop}}{\text{Electrical Input}_{Aermec}}$$

Chilled water produced was defined as the difference between the chilled water returned to the Aermec and the supplied chilled water from the Aermec. Electrical input to the Aermec was assumed to be cooling energy input if the primary chilled water circulating pump was operating during that minute.

Simultaneous:

$$COP\ simultaneous = \frac{((\text{Supply}_{Aermec} - \text{Return}_{Aermec})_{heating} * f_{Aermec,\ HW\ Primary\ Loop}) + ((\text{Return}_{Aermec} - \text{Supply}_{Aermec})_{cooling} * f_{Aermec,\ CHW\ Primary\ Loop})}{\text{Electrical Input}_{Aermec}}$$

Chilled water produced was defined as the difference between the chilled water returned to the Aermec and the supplied chilled water from the Aermec. Electrical input to the Aermec was assumed to be simultaneous heating and cooling energy input if the both the primary hot water and chilled water circulating pumps were operating during that minute.

Individual Rheem HPWH with Recirculation Loop

COP was calculated at one-minute intervals. This data were then aggregated to demonstrate performance in different time periods such as daily or seasonal. The input temperature and flow were measured on the cold-water makeup line prior to recirculation loop return. The temperature and flow out were at the supply to the building prior to the thermostatic mixing valve. The electrical input energy included both compressor and resistance usage.

$$COP = \frac{\left(\text{Hot Water Out}_{Top\ of\ Tank}\ -\ \text{Supply}_{CWMU}\right) * f_{cwmu}}{\text{Electrical Input}_{HPWH}}$$

Central Modular Sanden

With a modular Sanden system, COP was calculated for both the bank of heat pumps and the plant. In this case, there were four heat pumps and one 500 gallon storage tank per bank, and those three banks were piped together to form the plant.

Bank COP used inputs isolated to the individual banks of heat pumps. Hot water produced was defined as the difference between the supply from the bank of four heat pumps to the storage tank and the incoming water supplied to the bank of four heat pumps from the storage tank. The calculation also takes into account measured flow measured during the several minutes before and at five minutes after the calculated COP to calculate only during a flow event. It also only takes into account when there is electrical input and the compressor is running.

$$COP_{Bank} = \frac{f_{Supply\ to\ bank} * (Hot\ Water\ Out_{bank} - Hot\ Water\ In_{bank})}{Electrical\ Input_{Bank}}$$

Plant COP was calculated and characterized in two ways: Plant COP and Plant Efficiency. Both performance metrics utilized the methodology of summation of parts to inform the whole.

Plant COP was calculated by dividing the total kWh output by the total kWh input of heat pump components. The Plant COP is essentially an aggregate of the individual bank COPs and the recirculation heat pump water heater COP.

$$COP_{Plant} = \frac{Total\ Output_{Plant}}{Total\ Input_{Plant}}$$

$$Total\ Output_{Plant} = \frac{\left(\text{HP Bank 1}\,\frac{\text{Output}}{\text{60min}}\right) + \left(\text{HP Bank 2}\,\frac{\text{Output}}{\text{60min}}\right) + \left(\text{HP Bank}\,\frac{\text{3 Output}}{\text{60min}}\right) + \left(\text{Recirc HPWH}\,\frac{\text{Output}}{\text{60min}}\right)}{\text{3,412kWh/BTU}}$$

$$\begin{aligned} Total\ Input_{Plant,\ \ heat\ pump\ components} \\ = \ HP\ Bank\ 1\ Input/60\text{min}\ ) + (HP\ Bank\ 2\ Input/60\text{min}\ ) + (HP\ Bank\ 3\ Input/60\text{min}\ ) \\ + (Recirc\ HPWH\ Input/60\text{min}\ ) \end{aligned}$$

Plant Efficiency is an aggregate of the individual bank COPs and the recirculation heat pump water heater COP, but it also incorporates recirculation pumping energy to observe total power input to the plant instead of total power input of heat pump components of the plant in Plant COP.

$$Plant\ Efficiency_{Plant} = \frac{Total\ Output_{Plant}}{Total\ Input_{Plant} + Input_{Recirculation\ Pump}}$$

Average Daily DHW Consumption

To determine average daily DHW consumption, the CWMU gallons were summed over the course of each day. Those daily consumption values were averaged over each month of the year to identify the average daily consumption per occupant for each month to better understand any seasonal temporal variations in hot water usage. These average daily DHW consumption per month per occupant values were then averaged over the year to determine the average daily DHW usage per occupant.

Zero Net Energy Evaluation

Zero net energy is defined as 0 kWh of net consumption (building energy consumption – solar PV production) over a 12-month period.[2] To determine whether ZNE was achieved, utility data were used with solar monitoring data to evaluate building energy consumption and solar PV production over the course of a year. This was done on a calendar year basis, but also on a mid-year cycle. The monitored data were used in concert with utility data to validate the monitoring data. To compare the ZNE outcomes of the two properties, the utility data were normalized for weather, using heating degree days and cooling degree days. Depending on the data granularity (daily common area energy consumption and monthly tenant energy consumption were available), the daily or monthly energy consumption was divided by the same time period's heating or cooling degree days.

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[2] The CEC defines *zero net energy* as 4,500 kWh of net consumption or less over the course of a 12-month period.

End Use Disaggregation for DHW, Heating, and Cooling for Aermec

First, calculations were performed to disaggregate the energy consumption of the plant to understand total heating (space heating and domestic water heating) and total cooling output. Energy consumption for heating and cooling were calculated based on flow and temperature differences between the supply and return water on the primary heating and chilled water loops. The resulting ratio of heating and cooling energy was then applied to total Aermec electrical input energy derived from our power monitoring.

The end use energy was disaggregated by calculating the energy output of each end use using monitored data on a minute basis, identifying the proportional energy output on a daily basis, and applying those proportional energy output percentages per end use to the total daily energy input of the Aermec, thereby arriving at energy input per end use each day. These daily input values were then averaged to understand the typical percent input per end use on a seasonal and annual basis.

The following calculation methodology was used to disaggregate the energy consumption by end use. Total heating energy output and total cooling energy output used the same calculation: using the primary loop, the primary flow was multiplied by the temperature difference between the water entering the Aermec and the water leaving the Aermec and then multiplied by 500, the BTU conversion constant to take into account the fluid’s weight, in this case water. This equation was respectively used on both the heating and cooling primary loops.

Primary Flow x (Primary Delta T) x 500

Nexi Budget Calculation Methodology

To establish the appropriate daily allowances for color-coded feedback regarding energy use, the team:

1. Established which loads would be tenant-paid and therefore appropriate for tenant feedback, using modeled loads from EnergyPro for HVAC and DHW loads, and with the CUAC for all other whole house loads.
2. Established (primarily through data collected previously) that the DHW and HVAC loads are seasonal, but plug loads, lighting, and appliances are relatively constant.
3. Established the daily baseline quantities for Tier I energy pricing by reviewing the Pacific Gas and Electric (PG&E) Baseline Territory map and examining the E-1 Rate Baseline quantities for gas heat versus electric heat.

4. Determined that each day would have the same quantity of energy "allowance" in the Nexi, matching projected daily consumption for each day of the year, with no variation.

Nexi Data Cleaning

Raw Nexi data were retrieved at regular intervals, and occasionally loads were swapped, which involved physically moving the CT in the breaker panel. On-site notes were collected on whether the CTs looked damaged or whether the display unit appeared to be malfunctioning. These would point to a potential data quality issue that could be easily identified ahead of time. Erroneous data due to CT or data processing unit failures were eliminated from the dataset. Additionally, large loads (i.e., microwave) were briefly turned on during site visits to ensure properly functioning equipment by causing the display unit to register a change.

Post-retrieval, data were cleaned and calibrated using a variety of methods:

- **Unity Calibration:** Nexi performed calibrations on a subset of their devices for each size CT (20 A, 30 A, 50 A). This provided a single calibration upon which to calculate actual power from the Nexi readings (11-bit signature). This resulted in a two-part regression function for both the linear (high current) and nonlinear (low current) regions of the CT curves. ANOVA was also performed to assess the impact of error, as all CTs vary in their manufacture slightly. This ultimately resulted in approximately 4 W resolution for these sensors.
- **Filters:** Both low and high-pass filters were implemented. Nexi devices were designed to float high in the case of an error, so these values could be picked out easily by a high-pass filter. Low-pass noise filters were also implemented. For some dedicated appliances, a specific low-pass filter was implemented where it was known that the devices drew no power when off.
- **Interpolation:** Interpolation was mostly avoided, but infrequent 1-second gaps were present when the Nexi attempted to re-synch its clock with "real" time. Gaps of one second were interpolated.

Cleaned data were aggregated at various time intervals (1-minute, 15-minute, etc.). A final qualitative analysis was performed, in case any anomalies were missed in the quantitative approach to data cleaning mentioned previously. Erroneous data were relatively easy to identify and followed a recognizable pattern.

Nexi Averaging

At Atascadero, not all circuits were monitored in each apartment, as shown in the electrical end use sampling table. When a percentage of units were monitored, average energy use for that end use as applied for the entire project was based on the average of the monitored data set.

Nexi lighting display evaluation

Nexi lighting displays were installed in all apartments. Lighting displays were calibrated to the expected (modeled) usage for each apartment based on metered appliances and bedroom count. In two apartment complexes (Calistoga and Cloverdale) lighting displays were installed in a staggered manner to attempt to study the effect (if any) these devices have on energy usage. This created a test and a control group for this analysis.

Table C-1: Installation Schedule for Monitoring and Lighting Displays

Site	Bed-rooms	Number of Units	Initial Install Date	1st Nexi Install Date	Nexi Qty on 1st Install	2nd Nexi Install Date	Nexi Qty on 2nd Install	Final Data Pull Date
Cloverdale	2	16	6/27/17	12/15/17	8	5/4/18	8	2/13/20
	3	16			8		8	
Calistoga	1	6	6/27/17	12/15/17	3	5/4/18	3	
	2	16			8		8	
	3	16			8		8	

Upon the initial install, no Nexi displays were installed, though monitoring equipment was installed on all units. Six months later (12/15/2017), Nexi displays were installed in half the units in both Calistoga and Cloverdale. At approximately a year after the initial install (5/4/2018), the remaining half were given Nexi display units. This allowed for a control period of 6-12 months for each apartment, as well as a control and treatment group during that first year. This allowed for comparisons both across time and between different apartments of similar sizes. The units were compared to the control group.

Two primary methods were implemented to assess the impact of Nexi displays:

- **Weather normalized savings attribution:** The first method involves first normalizing whole house energy consumption to temperature data. Weather was collected on site in minute increments. EEMmeter (an open-source weather normalization tool) was used to normalize data to temperature. Finally, pre- and post-Nexi installation data were analyzed to determine if a statistically significant difference between the time periods exists. These methods were performed on an hourly and daily basis.
- **Weather-independent savings attribution:** Since both sites have central HVAC and DHW, the tenants only pay for operation of a fan coil unit. This was monitored directly and can be subtracted from whole house data. Pre- and post-Nexi installation data also were compared for these (ostensibly) non weather dependent loads.

Survey Processing

After the surveys were digitized, a first-pass qualitative assessment was performed. The purpose of this was to identify any glaring anomalies and become familiar with question responses in a qualitative manner. Data were cleaned by eliminating non-responses and converting categorical responses to nominal values. For instance, the response "7 times per week" would be converted to "7." For certain responses, an estimate was used (for instance, "3 to 4 times per week" was changed to "3.5"). This would allow for regressive analysis to be performed without creating dummy variables, since these categories are proxies for nominal values. Data were also indexed by occupancy, number of bedrooms, and conditioned floor area.

After cleaning, basic exploratory data analysis was undertaken for each question in order to make general statements and to guide deeper analysis. The survey response data were then merged with quantitative data (Nexi end use data and in-unit temperature/humidity data) as well as other metadata collected on-site (e.g., floor number, unit orientation). Cross-tabulation of responses was performed, and correlation plots were developed using all the merged data to speed identification of potentially important correlations. For those variables that could not be coerced into nominal values, dummy variables were created so these responses could be used in regression analysis and development of correlation plots.

Appendix D: Calistoga and Cloverdale Data

ZNE Performance

For Calistoga, at the time of the system's most optimal operations, in terms of energy consumption, the whole property was approximately 18 percent away from achieving zero net energy usage over the course of the year. At this point, the central plant would have needed to achieve a 36 percent reduction in operational energy usage for the property to achieve ZNE. However in December 2018, in an effort to avoid compressor failures that occurred from short cycling, the newly contracted service technician made operational changes that effectively enabled the system to run continuously. Because of this operational change, the Aermec's energy consumption in 2019 increased 45 percent as compared to 2018. The figures below show optimal potential to achieve ZNE with a 36 percent reduction (Figure D-1); 2018 performance (Figure D-2) and 2019 performance (Figure D-3).

Figure D-1: 2018 Calistoga Site Energy Usage vs. Site Usage with 36 percent Reduction of Aermec Energy Usage to Achieve ZNE

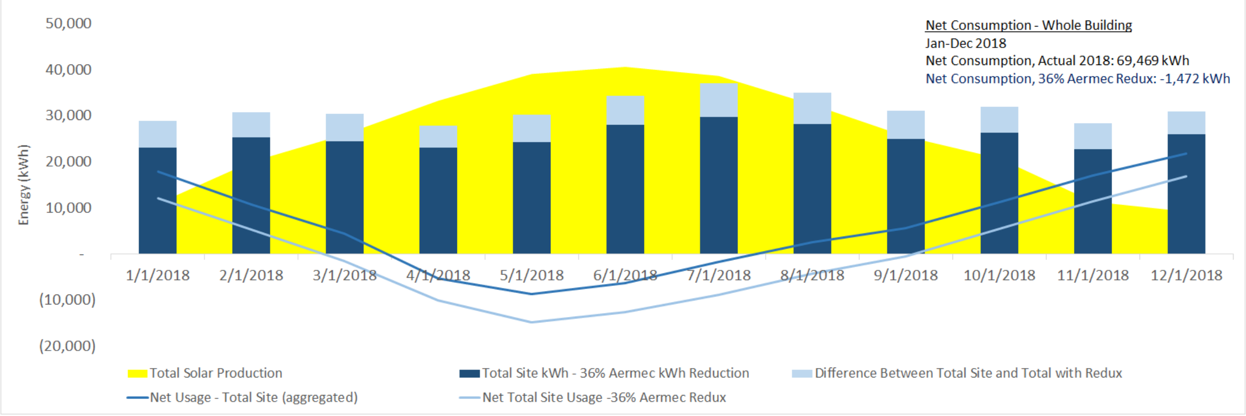


Figure D-2: Calistoga Whole Site Energy Consumption and Solar PV Production 2018

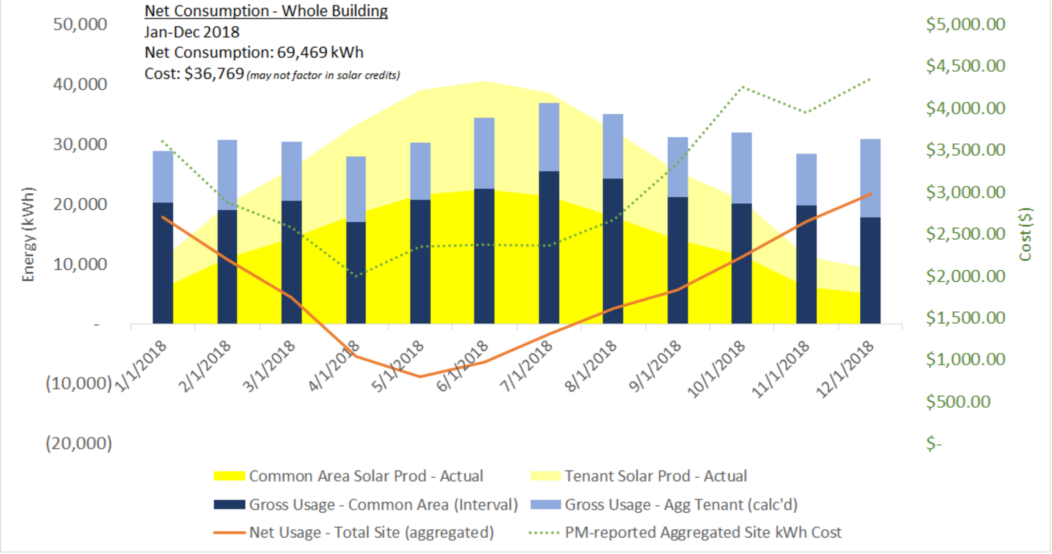
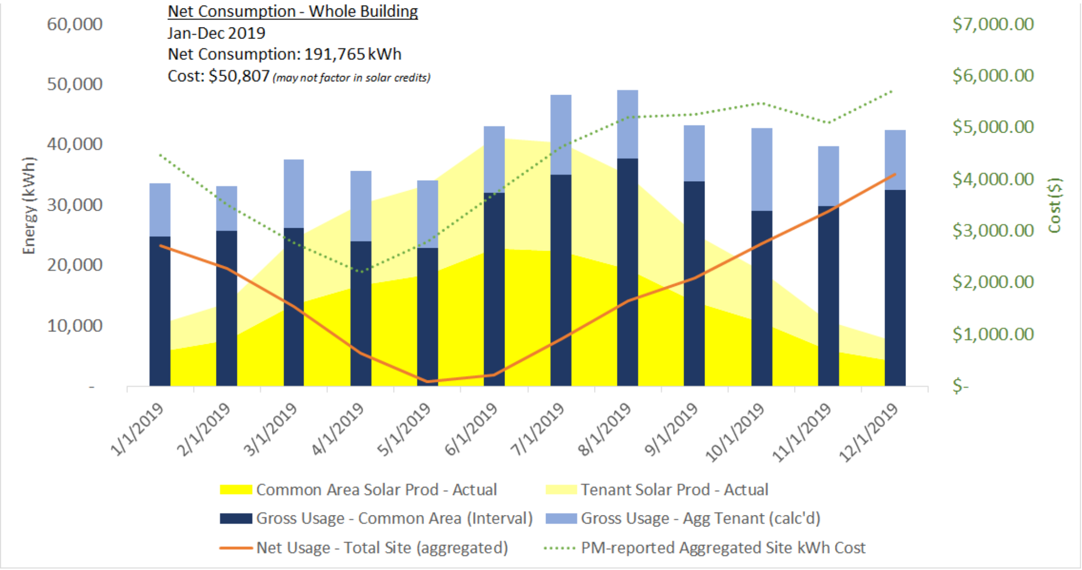


Figure D-3: Calistoga Whole Site Energy Consumption and Solar PV Production – 2019



ENERGY CONSUMPTION

Average daily consumption ranges from 4.3 to 15.1 kWh (Cloverdale) and 3.3 to 15.6 kWh (Calistoga). Consumption correlates better to occupancy rather than bedroom type (Figures D-4 and D-5). Daily usage is relatively distributed across apartments, with no clear outliers (Figure D-6).

Figure D-4: Cloverdale and Calistoga Consumption by Occupancy

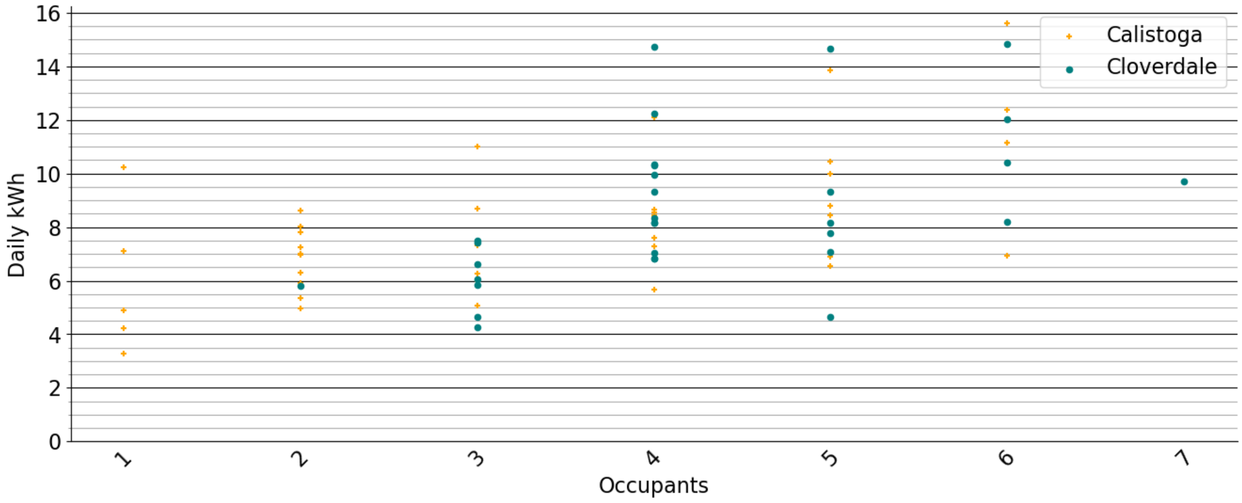


Figure D-5: Cloverdale and Calistoga Consumption by Bedroom Type

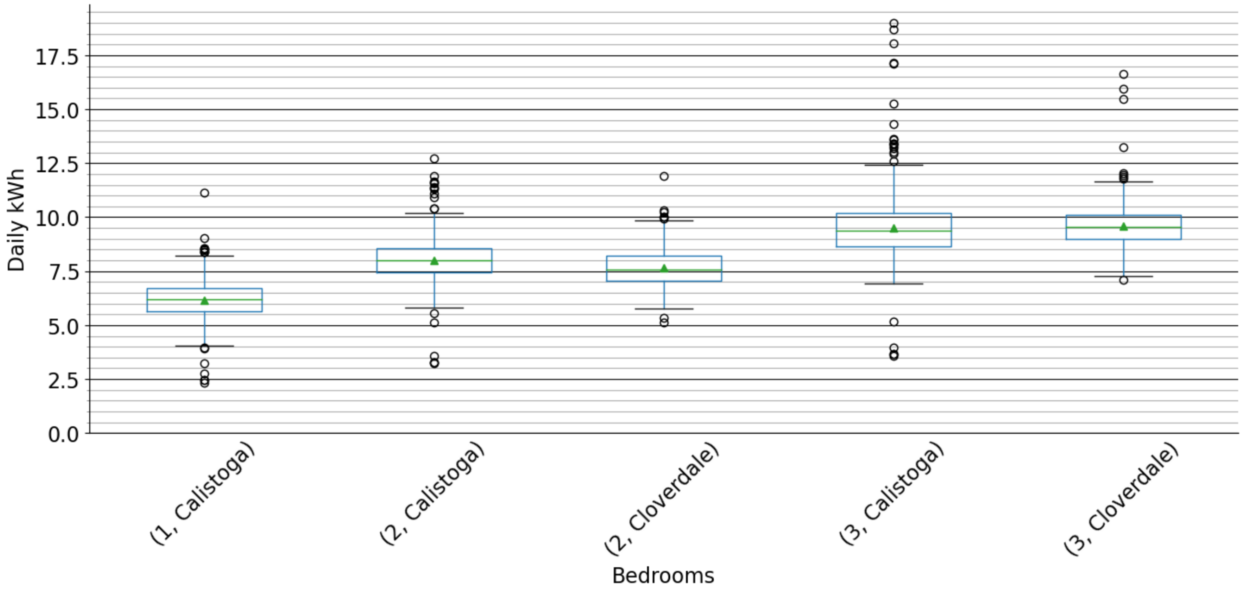
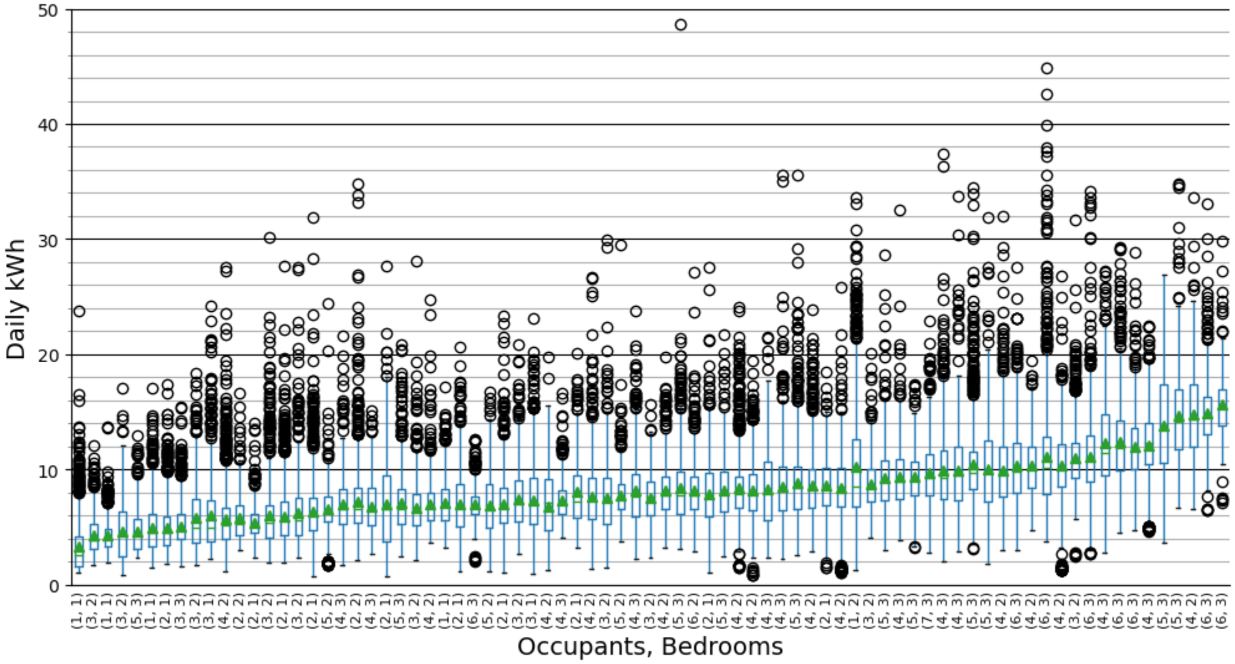
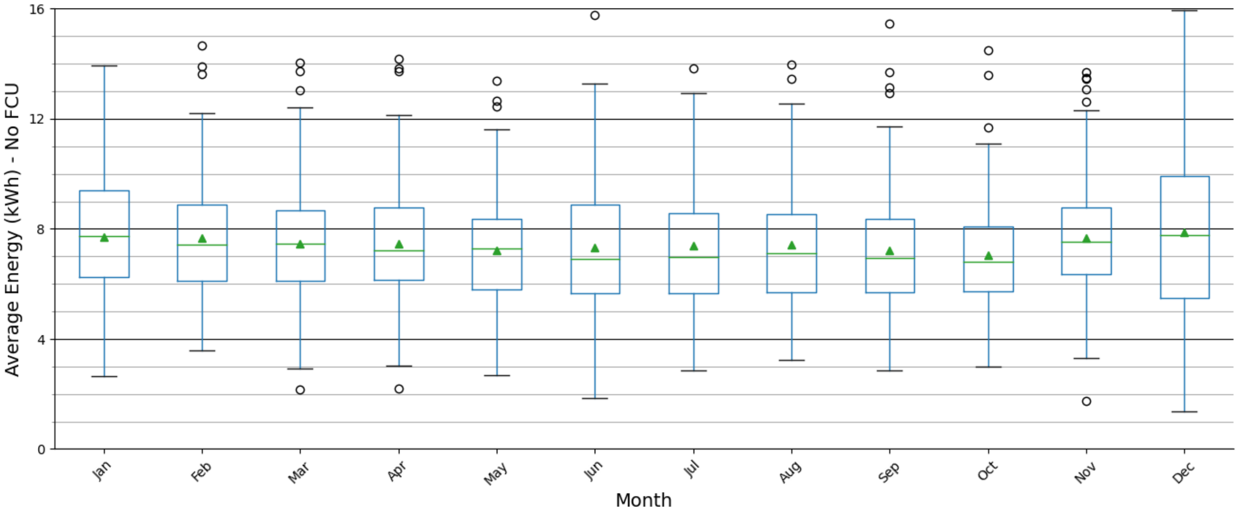


Figure D-6: Average Daily Usage that Is Normally Distributed Across Apartments for both Calistoga and Cloverdale



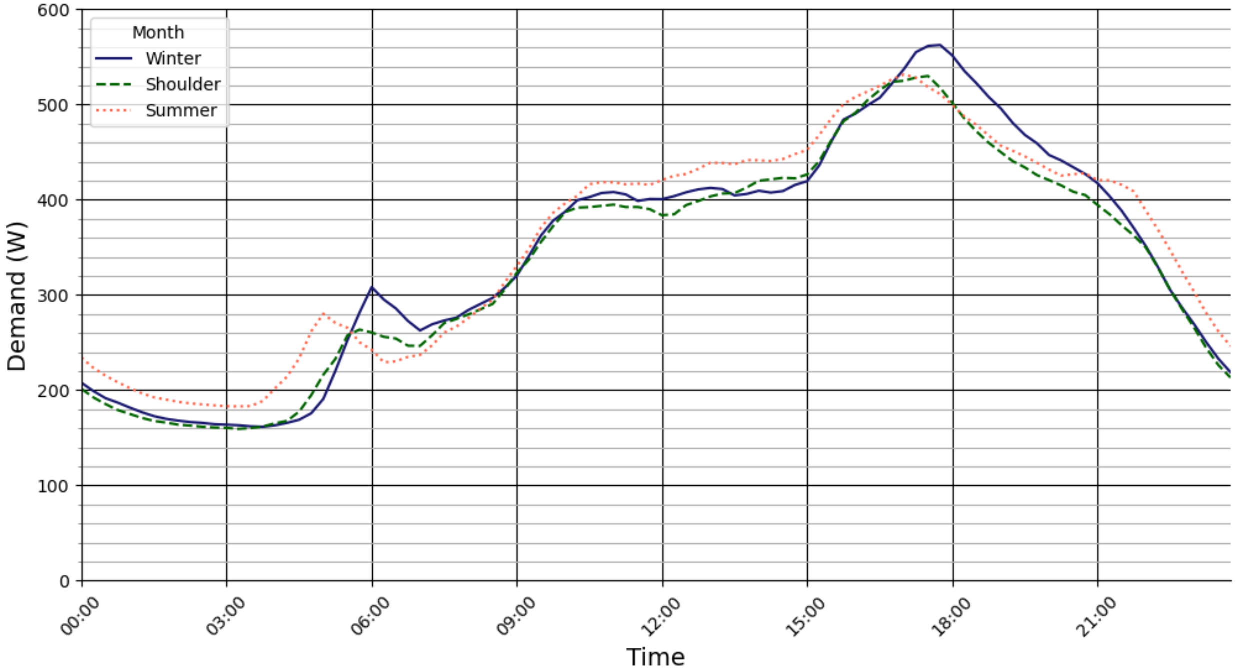
Daily usage is relatively normally distributed across apartments with no clear outliers. Within apartments, however, daily variation is much more variable, and nearly all the apartments' usage is positively skewed with clear outlying days. This is typical of residential usage, but with generally less variance due to the lessened impact of seasonality as shown in monthly data in Figure D-7.

Figure D-7: Similar to Cloverdale, Calistoga Average Daily Excluding Fan Coil Show Little Seasonal Impact



An average, yearly demand pattern at Cloverdale and Calistoga is shown in Figure D-8. Sitewide, demand peaks at about 5:45 pm. Evening peaks are reasonably consistent (80 percent of tenants' peak occur between the hours of 4 and 7 pm). Significant daytime load is present in certain apartments. Anecdotal evidence as well as survey data support these findings; many apartments are occupied by at least one person for much of the day, as indicated in survey results.

Figure D-8. Cloverdale and Calistoga Show Some Seasonal Variance in Demand



In analyzing system performance, it is useful to consider the amount of time the Aermec is operating to provide more context for the impact of the performance level. Table D-1 conveys the average percentage of time over the course of a season that the Aermecs at both Calistoga and Cloverdale are on and operating, and are off. Generally, we saw a low percentage of operational time, aside from cooling in the summer months, as shown in the table.

Table D-1: Percentage of Time in Each Operation by Plant

Location	Oper-ation	Winter		Spring		Summer		Fall	
		Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
Calistoga	On	40.3%	35.4%	74.7%	45.4%	63.3%	80.6%	53.5%	53.6%
	Off	59.7%	64.6%	25.3%	54.6%	36.7%	19.4%	46.5%	46.4%
Calistoga '18	On	9.9%	6.7%	26.1%	19.6%	28.4%	66.8%	8.0%	8.2%
	Off	90.1%	93.3%	73.9%	80.4%	71.6%	33.2%	92.0%	91.8%
Calistoga '19+	On	55.5%	49.8%	99.0%	58.2%	98.1%	94.3%	99.0%	98.9%
	Off	44.5%	50.2%	1.0%	41.8%	1.9%	5.7%	1.0%	1.1%
Cloverdale	On	11.9%	3.4%	9.1%	7.4%	8.8%	40.1%	10.5%	19.5%
	Off	88.1%	96.6%	90.9%	92.6%	91.2%	59.9%	89.5%	80.5%

At both sites, but particularly at Cloverdale, summer cooling demand makes up the majority of annual usage, though cooling runtimes vary significantly by apartment. This is evident in limited run time in winter months. Figure D-9 shows runtimes by month illustrating longer runtimes in summer months when there is cooling demand. At both sites, but particularly at Cloverdale, summer cooling demand made up the majority of annual usage, and runtimes varied significantly by apartment, as shown in Figure D-10.

Figure D-9: Average Daily Run Times for Cloverdale and Calistoga by Month

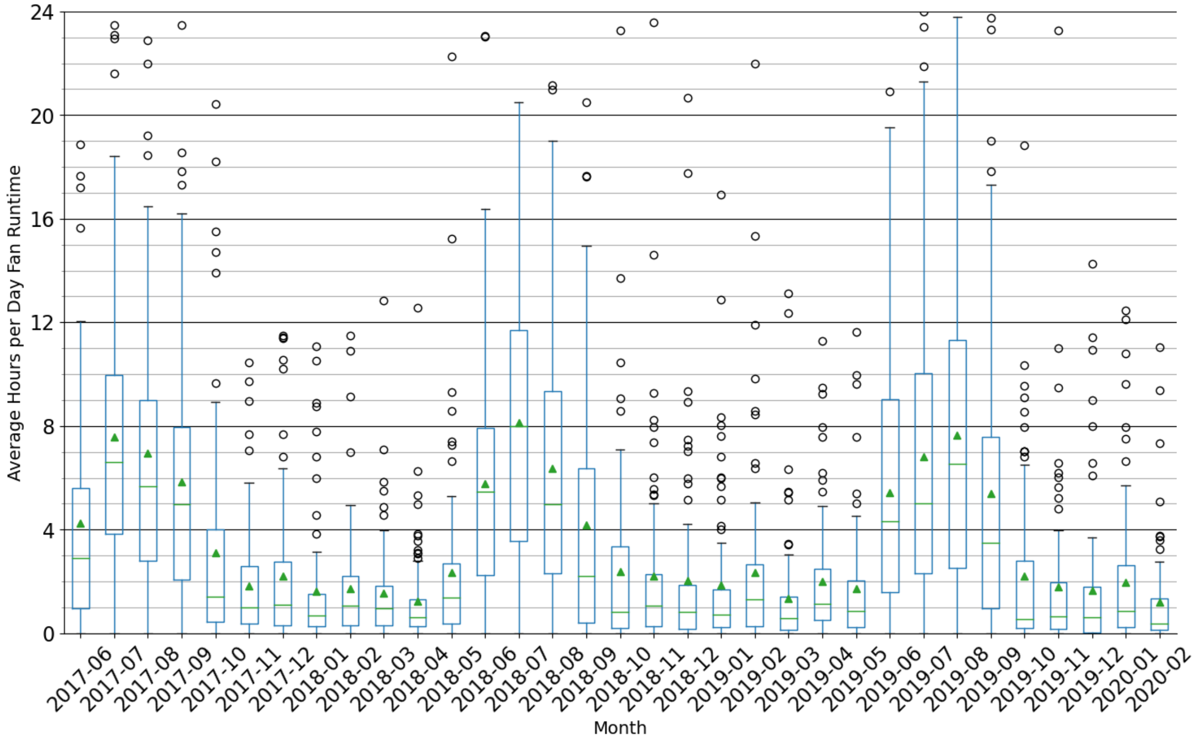
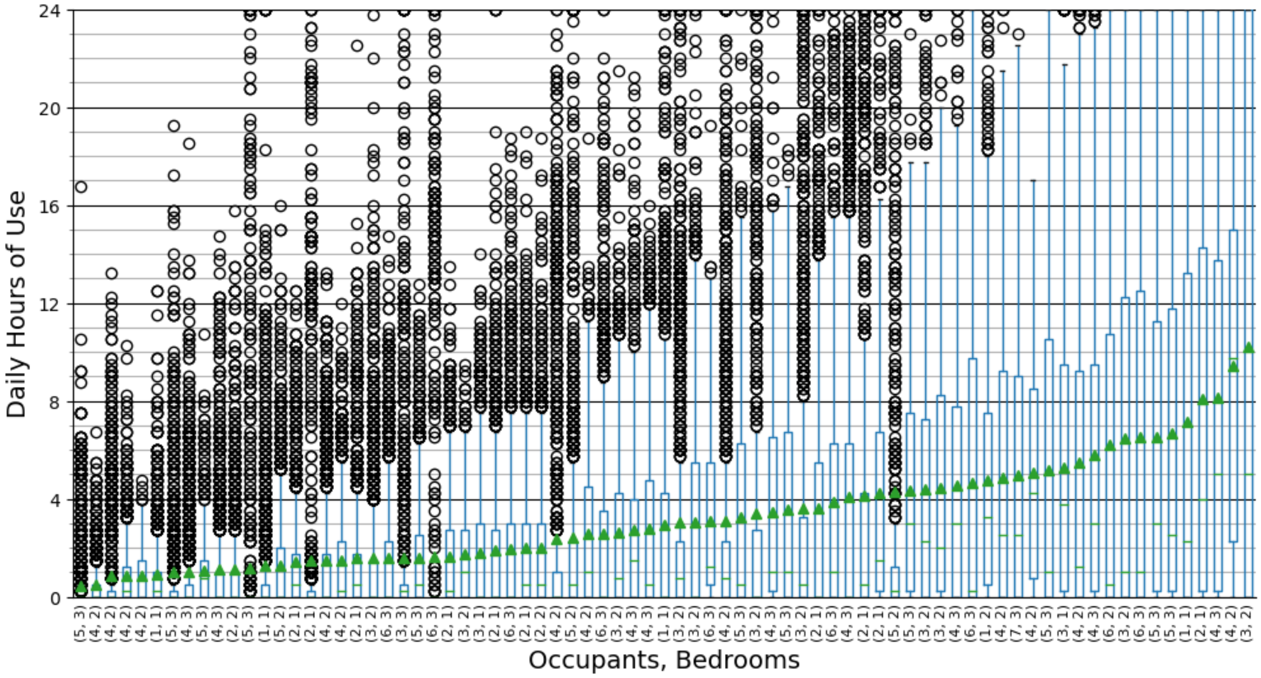
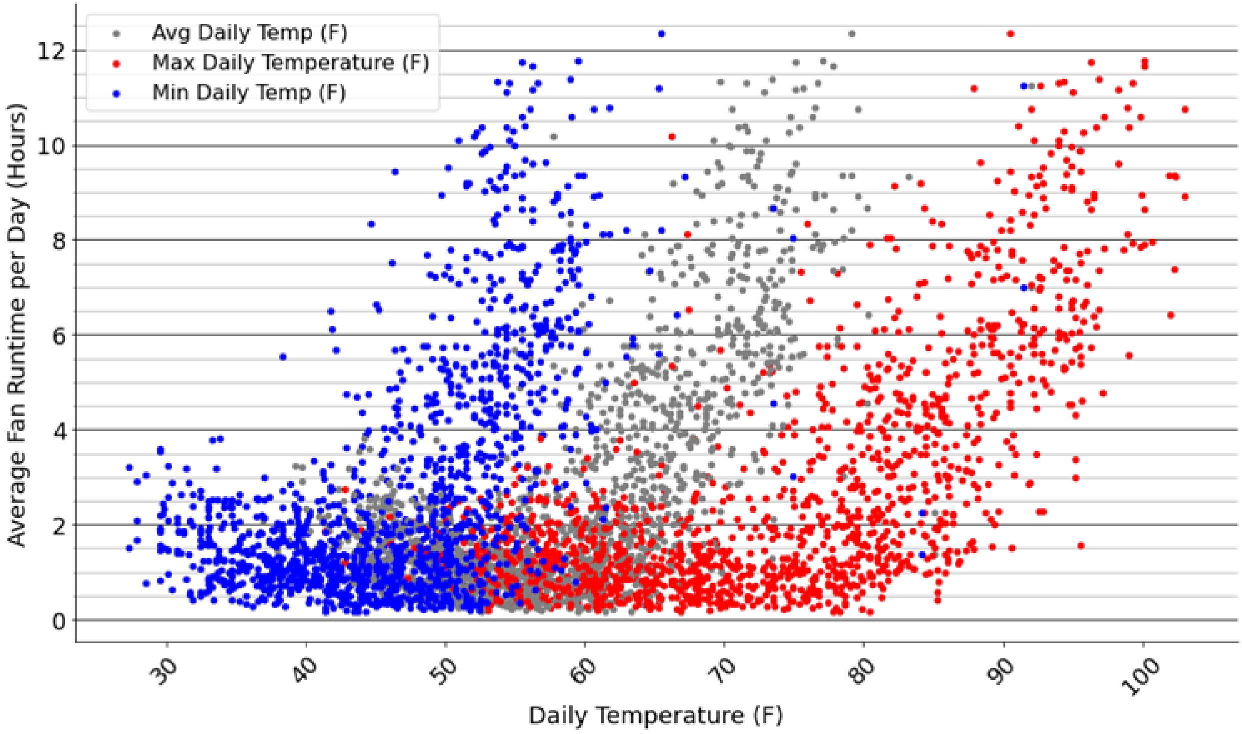


Figure D-10: Average Daily Run Times for Cloverdale and Calistoga by Apartment



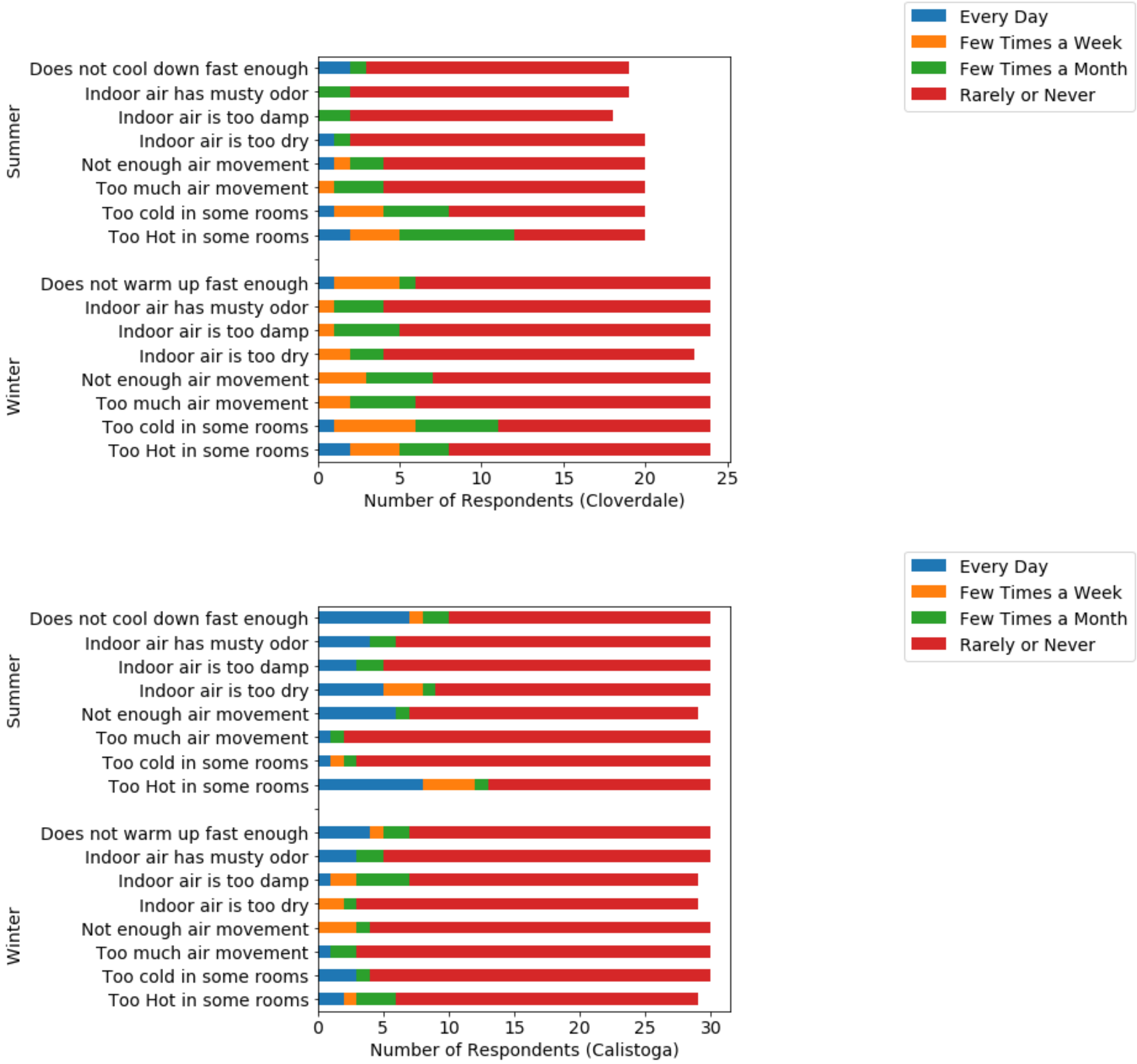
There is little sensitivity to cool temperatures, and for many apartments a heating balance point could not be calculated, as shown in Figure D-11. Winter heating temperatures were consistently noted to be warmer than summer cooling temperatures, which was somewhat counterintuitive, and the range is great (even excluding outliers) for both seasons. Cooling balance points, the outdoor temperature at which the building needs cooling, were calculated to range from 45°F–60°F at Cloverdale (average 53°F) and 48°F–70°F (average 57°F) at Calistoga. Heating balance points were calculated to range from 42°F–57°F at Cloverdale (average 46°F) and 48°F–60°F (average 52°F) at Calistoga. In general, R^2 values were acceptable, but (as expected) the relationship between outdoor temperature and runtimes were not incredibly straightforward.

Figure D-11: Fan Coil Runtime for Both Sites Shows Little Sensitivity to Cooler Outdoor Ambient Temperatures



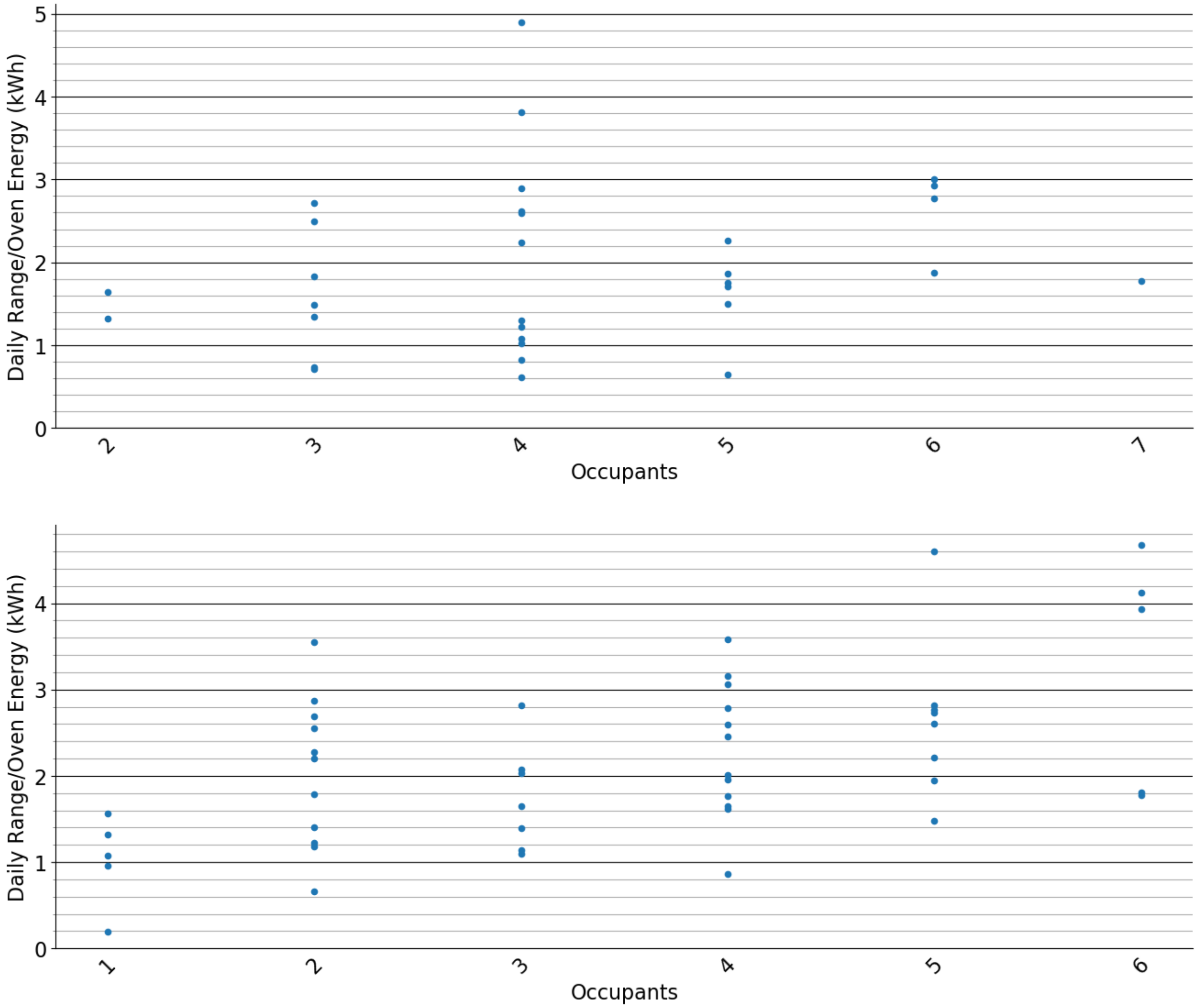
The survey results on HVAC performance (Figure D-12) revealed that many tenants use passive methods to cool and ventilate their homes, so the more active use of thermostats as on and off is likely. This aligns with lack of coincidence with fan coil runtimes and outdoor ambient temperature.

Figure D-12: Tenant Responses Show Some Issues with Adequacy in Heating and Cooling with Greater Number at Calistoga (below) than Cloverdale (above)



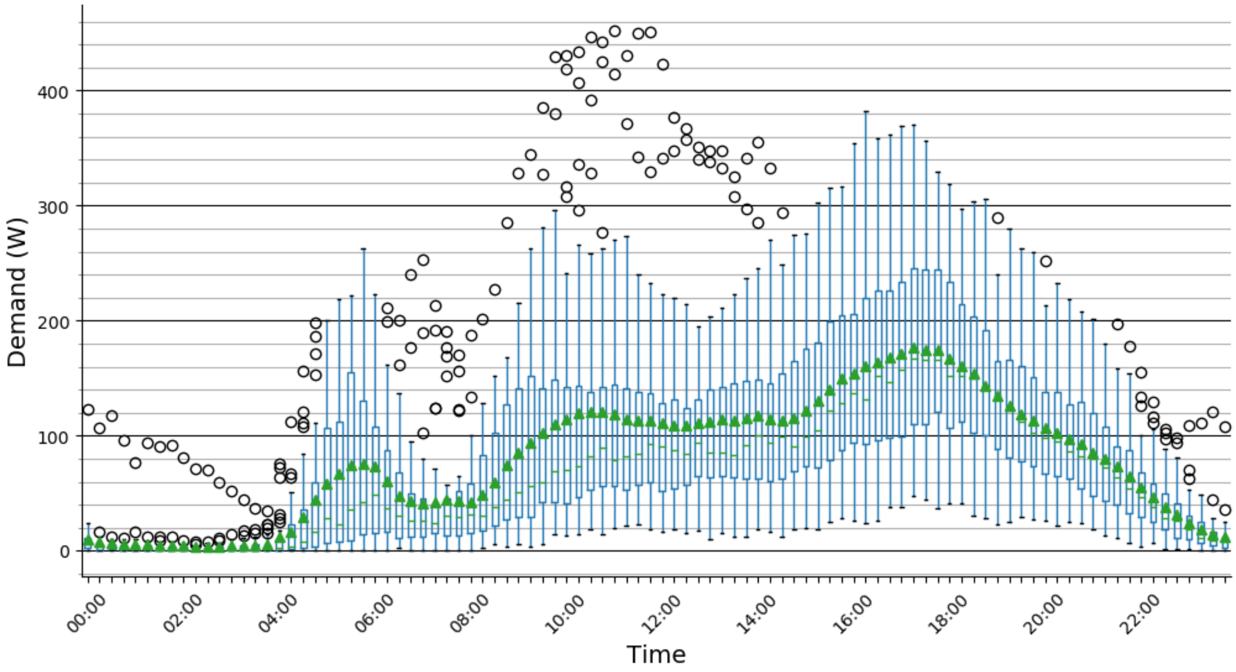
There is a somewhat strong relationship between average occupancy and average daily cooking energy. Cloverdale shows more individual variance and a looser relationship between occupancy and daily average energy than Calistoga and other sites (Figure D-13).

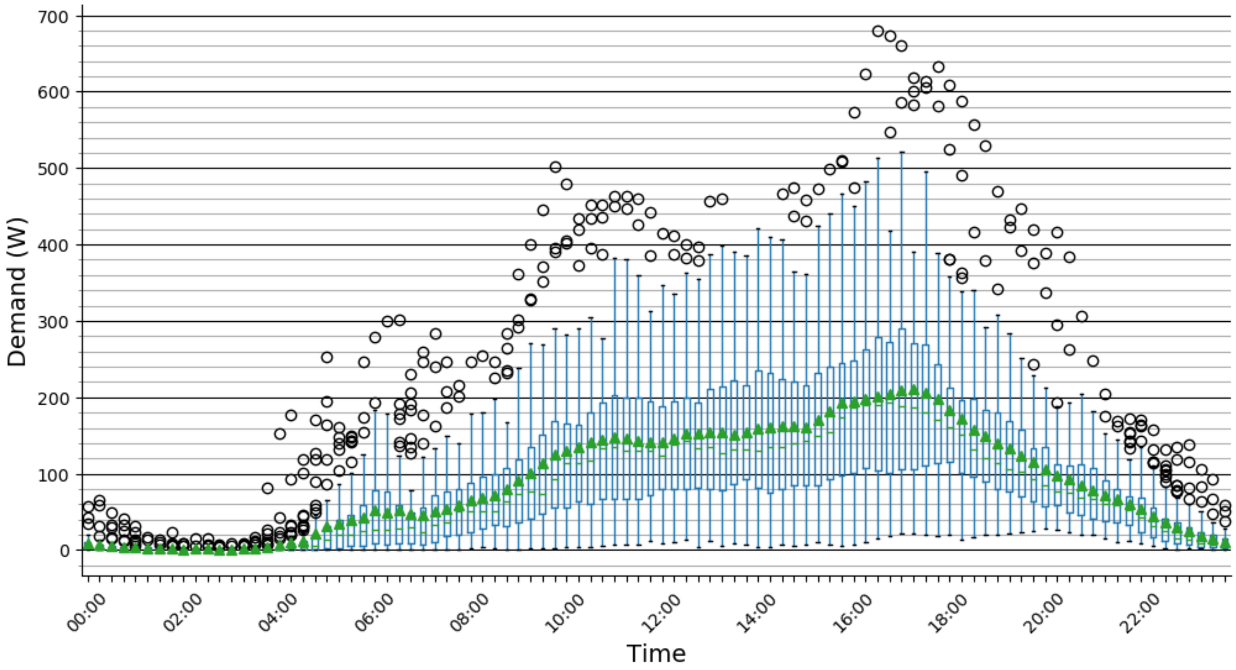
Figure D-13: Daily Averages Show Correlation to Total Occupants in an Apartment. (Cloverdale Above and Calistoga Below)



Daily cooking demand is highly variable except between 12 to 4 am, where it is virtually nonexistent. Most apartments follow a similar pattern that is present in Figure D-14, involving a late evening peak and often an early morning peak. On average, peak cooking across apartments occurred at approximately 5 pm (evening) and at 5:30 am (morning).

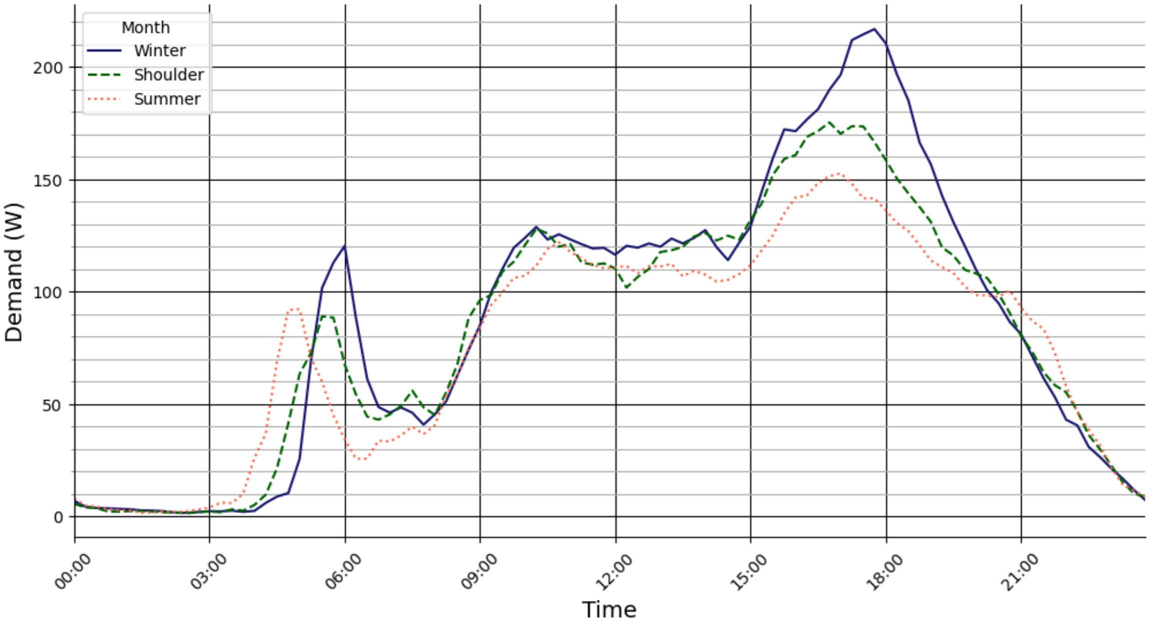
Figure D-14: Daily Cooking Patterns Are Relatively Consistent (Cloverdale above and Calistoga below) with the Exception of a Morning Peak at Cloverdale

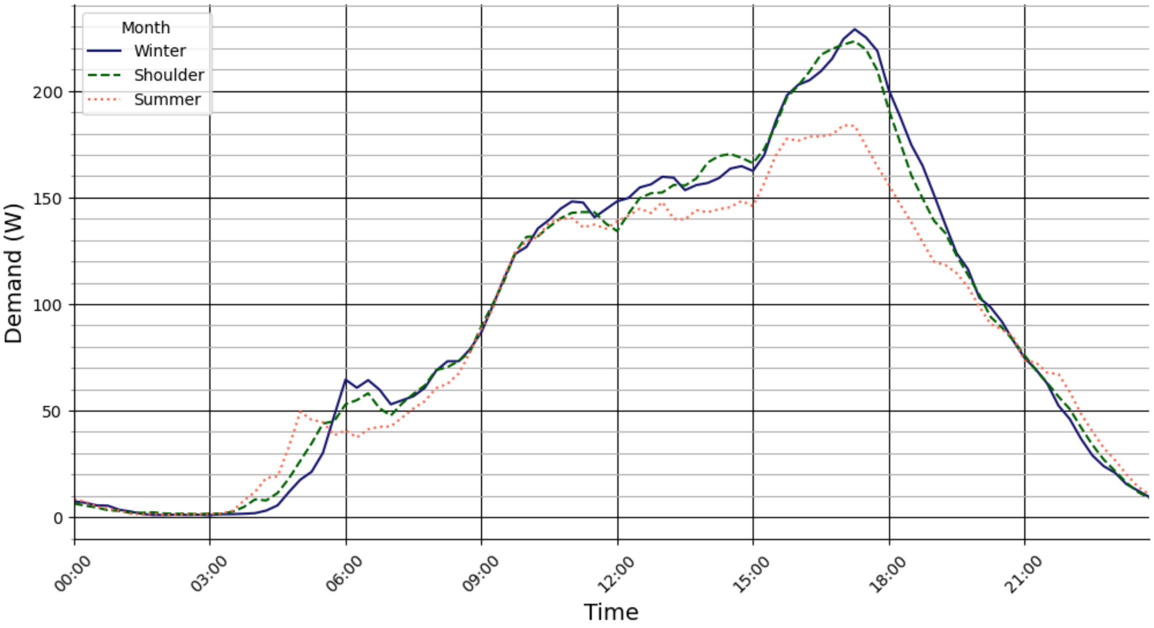




Seasonally, daily cooking energy (averaged across all apartments) increased 25 percent at Cloverdale from winter to summer, mainly in the evening hours from 4 to 7 pm (See Figure D-15), roughly by 0.5 kWh (June, 1.68 kWh; January; 2.10 kWh). This is a greater variation than in other similar complexes studied, including Calistoga, where daily average cooking energy ranged from 2.0 to 2.3 kWh month to month with less straightforward seasonal trends.

Figure D-15: Hourly Demand (Cloverdale above and Calistoga below) with an Increase in Winter Cooking Time Roughly by 0.5 kWh (June, 1.68 kWh; January; 2.10 kWh)

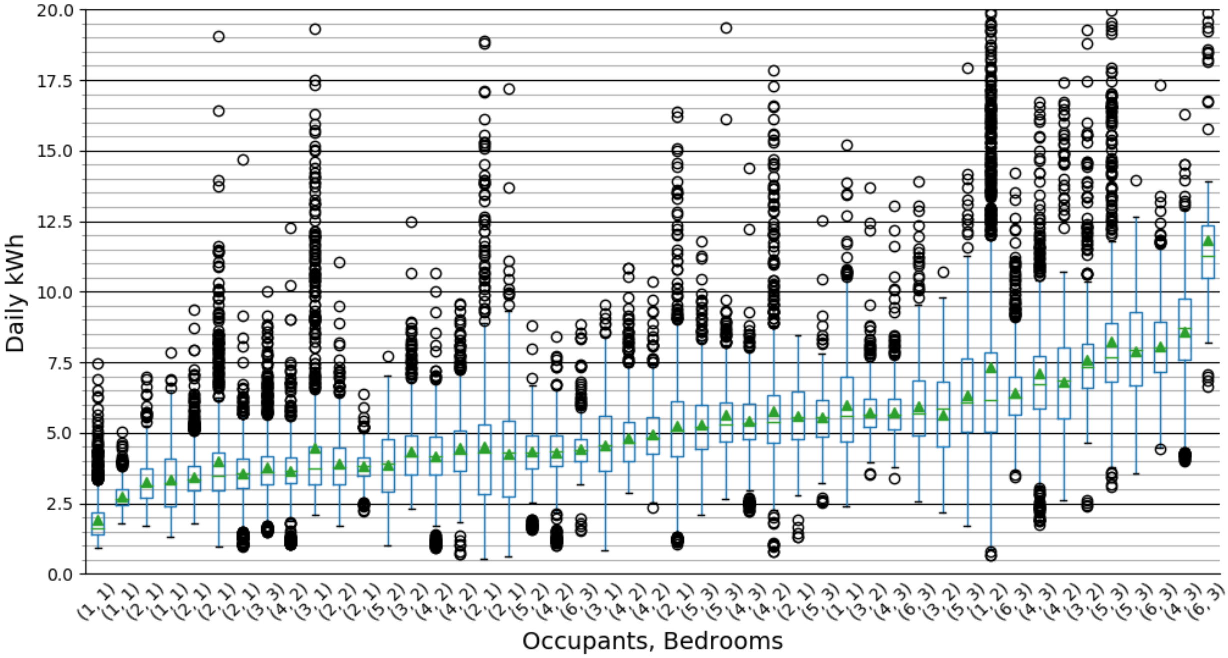




One side note to actual usage: Residents were not satisfied with the stoves, and had complaints over lengthy heat-up times or nonfunctional burners. This may be attributed to appliance performance under the lower voltage of 208 V rather than 240 V, where lower amperage and lower voltage resulted in longer cook times (e.g., eight minutes to boil water rather than six minutes).

The average daily consumption for MELs ranged from 1.9 to 11.8 kWh/day and Figure D-16 shows distribution across apartments.

Figure D-16: Average Daily MELs for Cloverdale (above) and Calistoga (below)



Total daily site washer and dryer energy was measured to be 52.3 kWh (0.32 kWh/person) at Calistoga and 35.7 kWh (0.27 kWh/person) at Cloverdale as shown in Figure D-17. Daily demand does not show significantly unique patterns across different seasons. Average demand peaks at approximately 4.3kW (4kW dryer, 0.3kW washer) at around 10AM and 4.2kW (3.8kW dryer, 400W washer) at 7PM at Calistoga (Figure D-18)

Figure D-17: Total Daily Laundry Use by Complex and Appliance

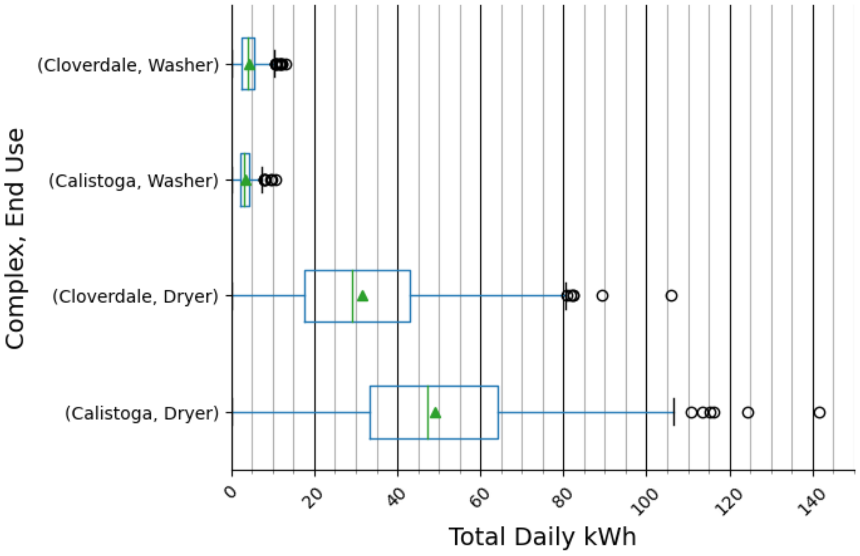
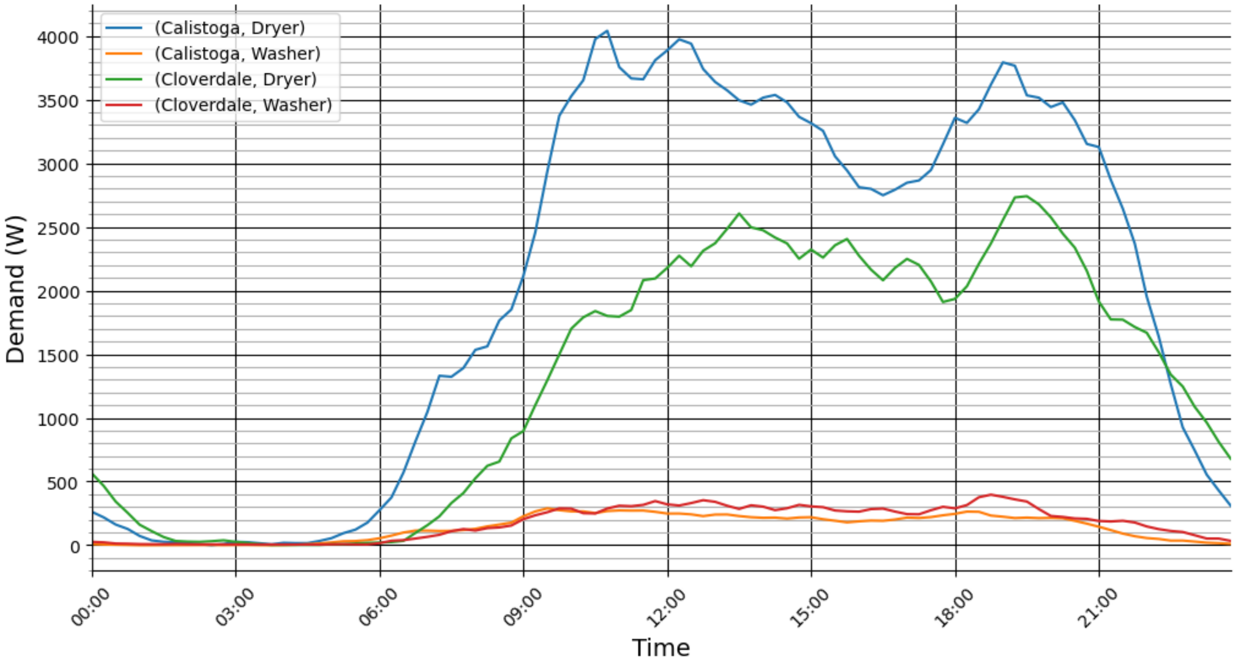


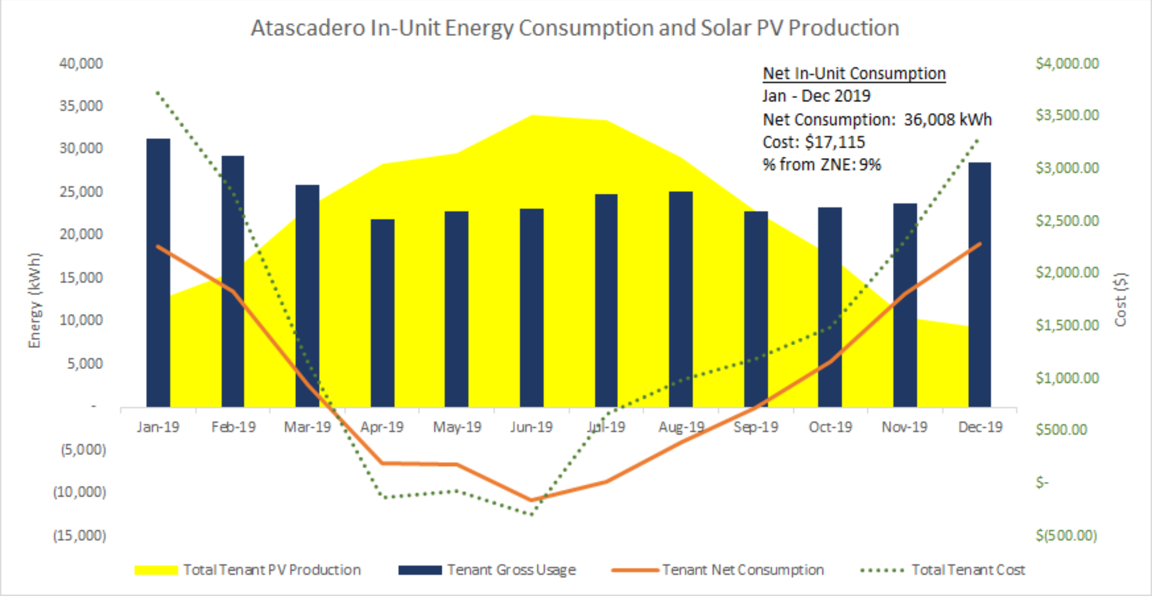
Figure D-18: Hourly Laundry Demand by Complex and Appliance



Appendix E: Atascadero Data

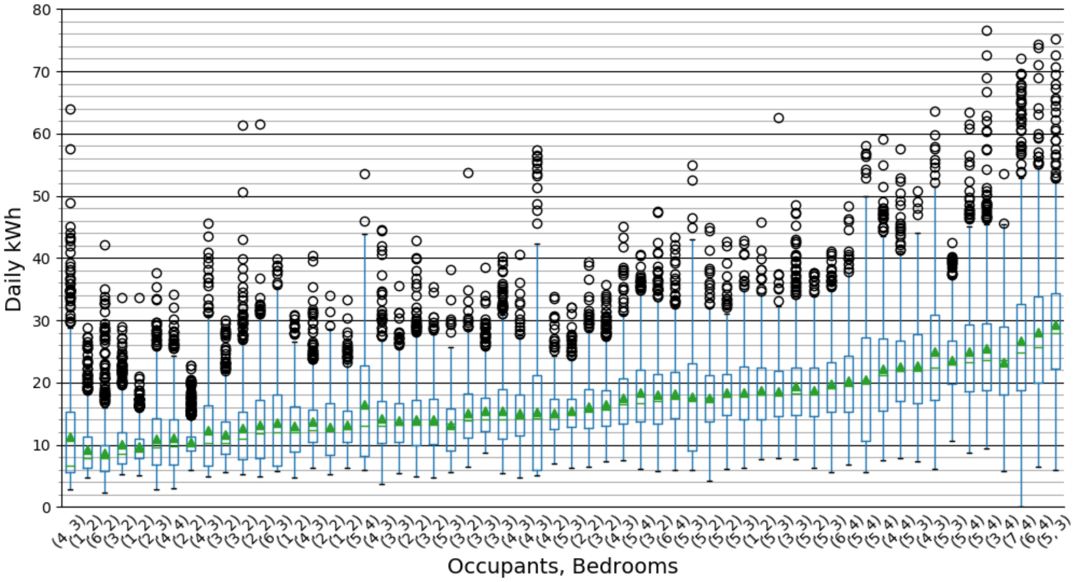
The net in-unit load energy consumption was far closer to achieving ZNE in the 2019 calendar year than were the loads attached to the common area meters. As Figure E-1 shows, the net in-unit energy consumption was 9 percent from achieving ZNE. This is significant because the major system end uses were defined as in-unit loads.

Figure E-1: Atascadero In-Unit Energy Consumption and Solar PV Production



Average daily consumption ranged from 8.1 to 28.9 kWh over the course of a two-year monitoring period (an average of 16.7 kWh). Usage is normally distributed across apartments as shown in Figure E-2.

Figure E-2: Average Daily Usage Is Relatively Normally Distributed Across Apartments With No Clear Outliers



Consumption is clearly sensitive to occupancy (Figure E-3) as seen in Cloverdale and Calistoga with individual behavior also being a primary driver in energy consumption. Differences in consumption between bedroom sizes are also present (Figure E-4), but occupancy is a much better predictor of consumption.

Figure E-3: Atascadero Daily kWh Based on Occupancy Show Correlation with Occupancy

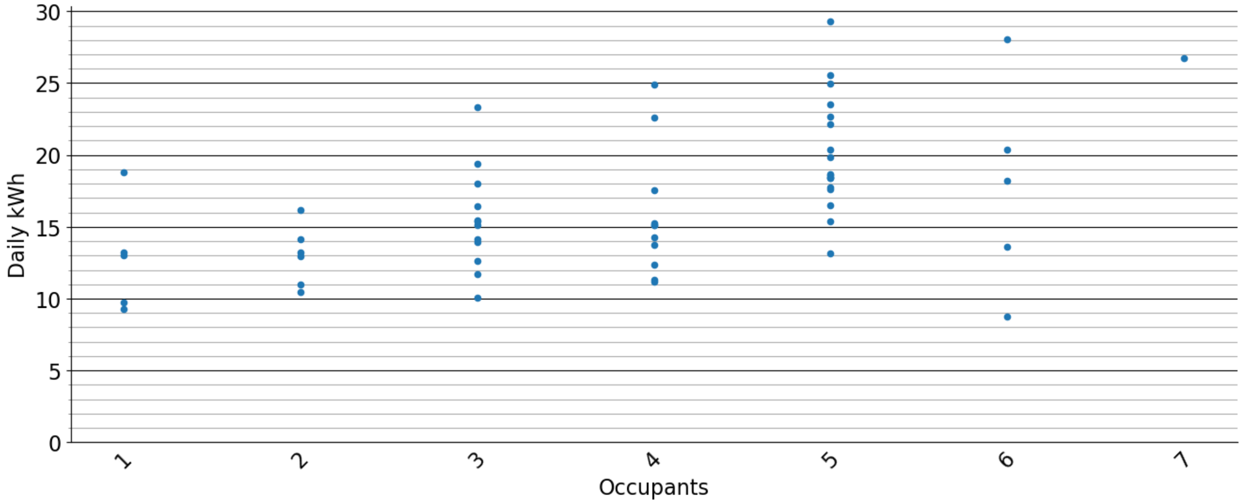
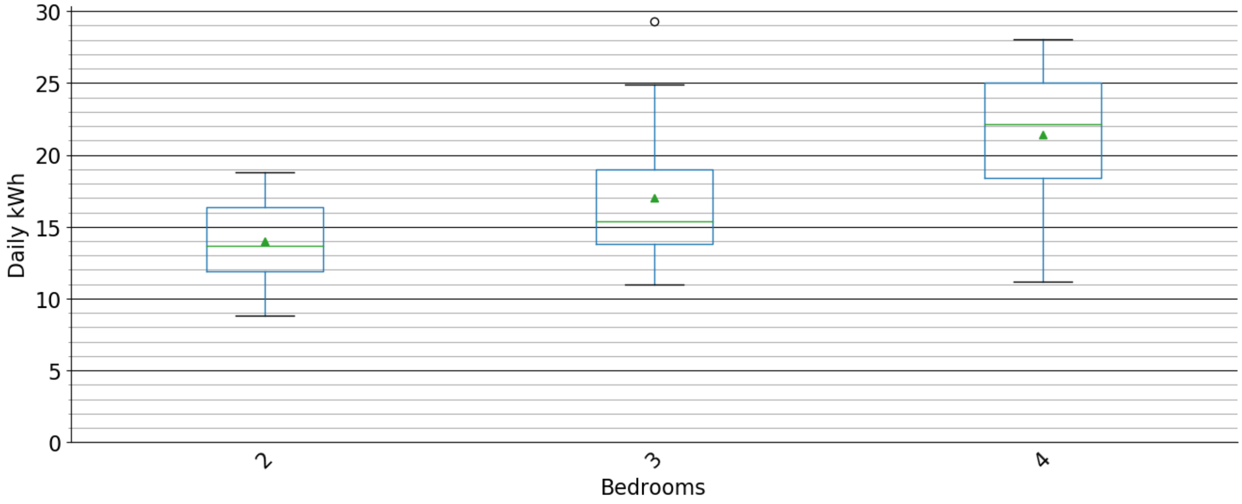
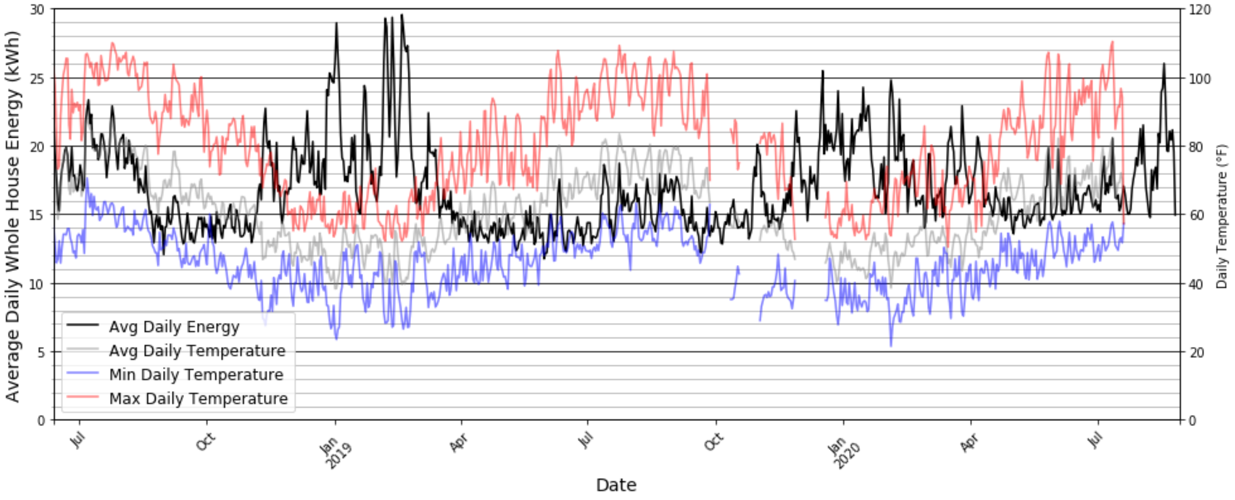


Figure E-4: Daily kWh Based on Occupancy and Number of Bedrooms, Show Greater Correlation with Consumption and Occupancy



Seasonality is a primary driver of whole house usage. Trends follow weather patterns; a relatively mild winter of 2019/20 resulted in much lower energy consumption overall than a colder, wetter 2018/2020. Similarly, a somewhat mild 2019 resulted in fewer abrupt spikes than was present in July 2020, as shown in Figure E-5.

Figure E-5: Seasonal Usage is Primary Driver of Consumption as it Relates to DHW and Space Conditioning



See Table E-1 for average monthly consumption of each end use by bedroom count.

Table E-1: Average Consumption for Each End Use by Bedroom Type

		Month											
Bedrooms	Load	1	2	3	4	5	6	7	8	9	10	11	12
2	Bathroom Recp	0.03	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.03	0.03
	CP	0.08	0.09	0.07	0.05	0.04	0.04	0.03	0.05	0.05	0.06	0.06	0.07
	CU	4.62	4.97	3.93	2.99	2.99	3.97	5.55	5.68	3.95	2.62	3.63	4.74
	DHW	4.79	5.49	4.13	3.13	2.72	2.35	2.06	1.97	2.35	3.51	4.01	4.54
	Dishwasher	0.03	0.05	0.05	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.06
	FC	0.53	0.52	0.55	0.54	0.58	0.6	0.68	0.75	0.66	0.61	0.6	0.51
	Hood	0.14	0.14	0.11	0.1	0.13	0.13	0.12	0.12	0.16	0.22	0.18	0.16
	Kitchen GFCI	0.24	0.26	0.22	0.19	0.17	0.19	0.21	0.21	0.19	0.23	0.24	0.23
	MELs and Lighting	5.21	5.34	5.37	5.06	4.69	5.11	5.5	5.16	5.22	5.12	5.39	5.28
	Range	1.35	1.24	1.23	1.2	1.14	1.2	1.22	1.23	1.24	1.44	1.41	1.22
	Refrigerator	0.79	0.76	0.85	0.9	0.89	0.95	0.97	1.01	0.98	0.94	0.82	0.81
3	Bathroom Recp	0.08	0.09	0.06	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.07
	CP	0.14	0.14	0.08	0.05	0.04	0.03	0.03	0.06	0.08	0.1	0.1	0.14
	CU	4.9	5.16	3.93	3.31	3.37	4.71	6.33	6.94	4.38	3.05	3.51	4.56
	DHW	5.43	5.99	4.99	3.74	3.21	2.86	2.56	2.4	2.5	3.29	4.2	5.72
	Dishwasher	0.01	0.01	0.03	0.02	0.01	0.02	0.01	0.01	0	0	0	0
	FC	0.63	0.6	0.53	0.5	0.6	0.67	0.68	0.74	0.66	0.56	0.56	0.63
	Hood	0.15	0.13	0.09	0.08	0.07	0.07	0.1	0.13	0.17	0.22	0.17	0.16
	Kitchen GFCI	0.27	0.26	0.29	0.32	0.31	0.35	0.34	0.32	0.26	0.3	0.28	0.3
	MELs and Lighting	4.57	4.28	4.11	4.08	3.83	3.97	4.24	3.96	3.56	3.57	4.21	5.48
	Range	2.35	2.15	2.43	2.46	2.43	2.11	2.16	2.28	2	2.3	2.48	2.46
	Refrigerator	0.79	0.75	0.75	0.84	0.86	0.97	1.02	1.06	1.08	1.05	0.87	0.78
4	Bathroom Recp	0.21	0.14	0.09	0.11	0.02	0.11	0.15	0.19	0.19	0.23	0.35	0.58
	CP	0.08	0.08	0.06	0.07	0.06	0.04	0.03	0.05	0.04	0.06	0.06	0.07

	CU	5.21	6.72	4.42	3.48	3.71	4.96	6.82	7.03	4.58	3.3	3.7	5.41
	DHW	9.74	9.68	7.99	6.82	6.36	5.35	4.66	4.37	4.23	6.29	7.35	8.18
	Dishwasher	0.01	0	0	0.09	0	0.01	0	0	0	0	0.01	0.01
	FC	0.47	0.43	0.38	0.38	0.46	0.62	0.7	0.68	0.5	0.41	0.43	0.42
	Hood	0.18	0.13	0.14	0.12	0.1	0.07	0.09	0.09	0.15	0.15	0.09	0.13
	Kitchen GFCI	0.27	0.27	0.22	0.21	0.19	0.22	0.24	0.23	0.27	0.3	0.28	0.3
	MELs and Lighting	4.28	3.85	3.82	3.91	4.05	4.35	4.63	4.5	4.4	4.36	4.2	5.1
	Range	2.22	2.5	2.24	2.44	2.23	2.12	2.44	2.26	1.98	1.93	2.26	2.19
	Refrigerator	0.94	0.96	0.93	1.13	1.19	1.32	1.29	1.24	1.25	1.05	0.98	0.92

Figures E-6, E-7, and E-8 show total daily demand for all apartments during summer, winter, and shoulder seasons, respectively. Winter shows greatest daily variance, most likley attributable to HPWH, and the summer variance was in the late afternoon, driven by cooling and HPWH recovery from earlier consumption. Shoulder seasons are more flat, compartatively.

Figure E-6: Summer Total Daily Demand Averages

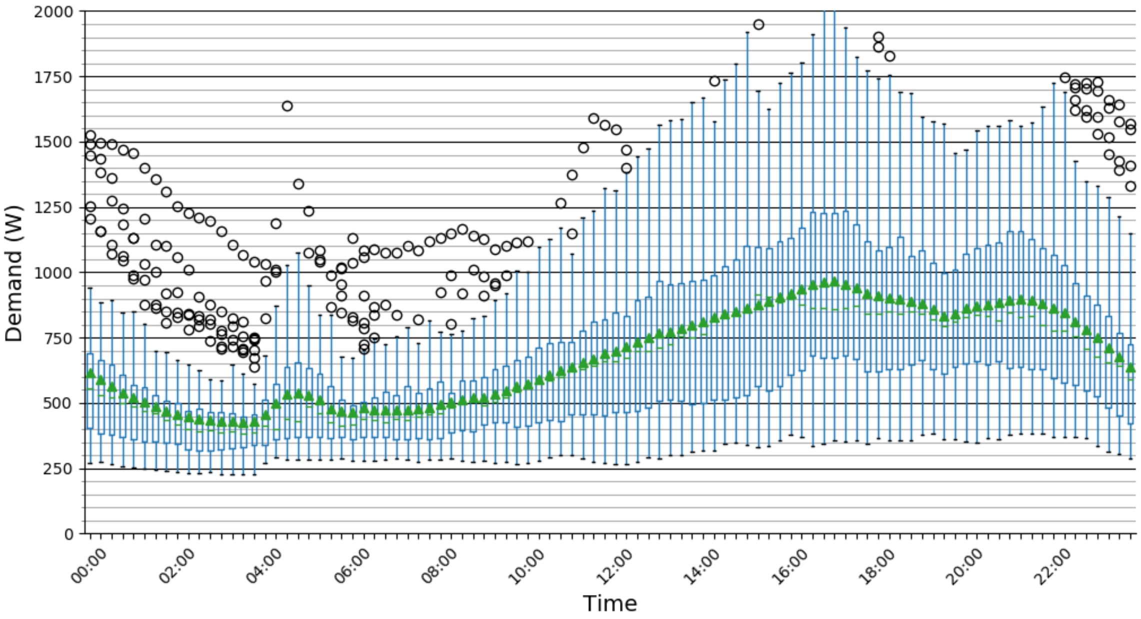


Figure E-7: Winter Total Daily Demand Averages

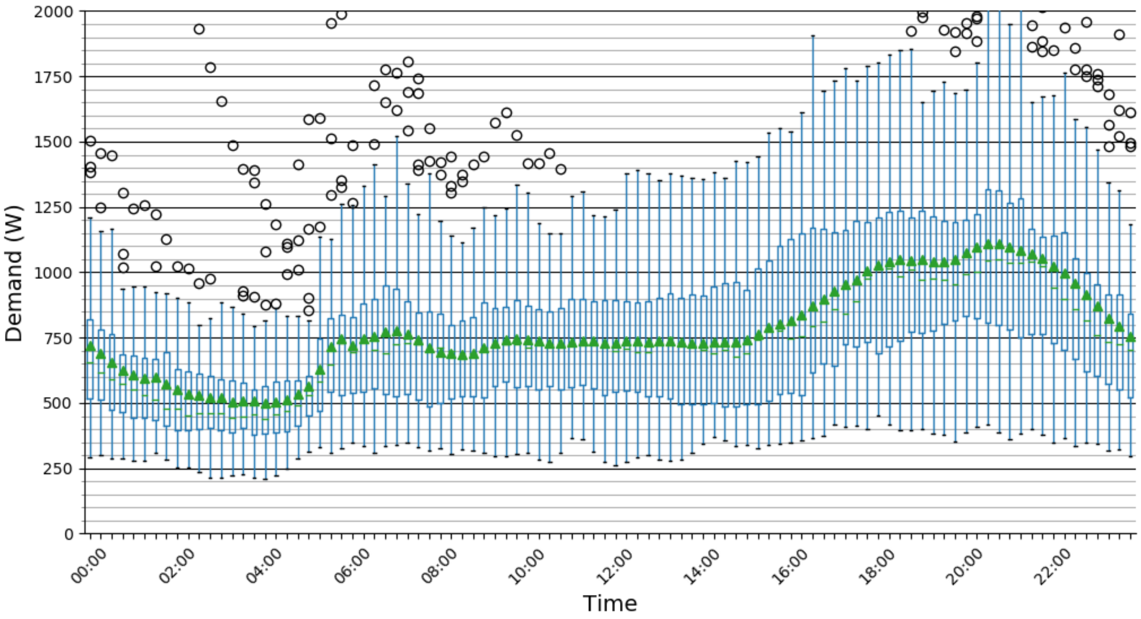
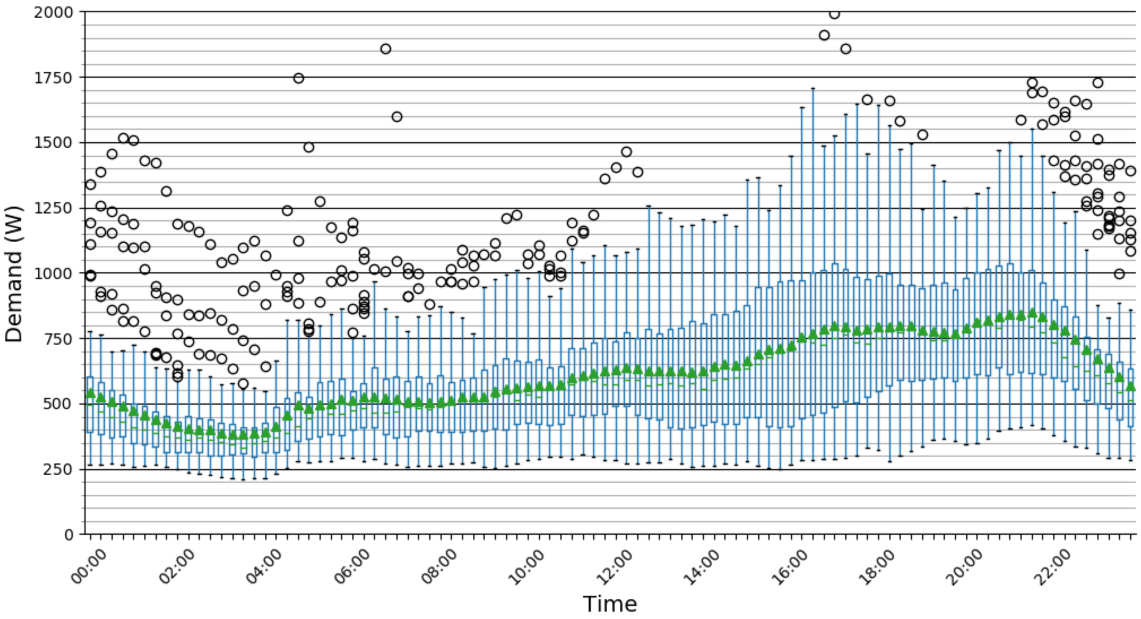
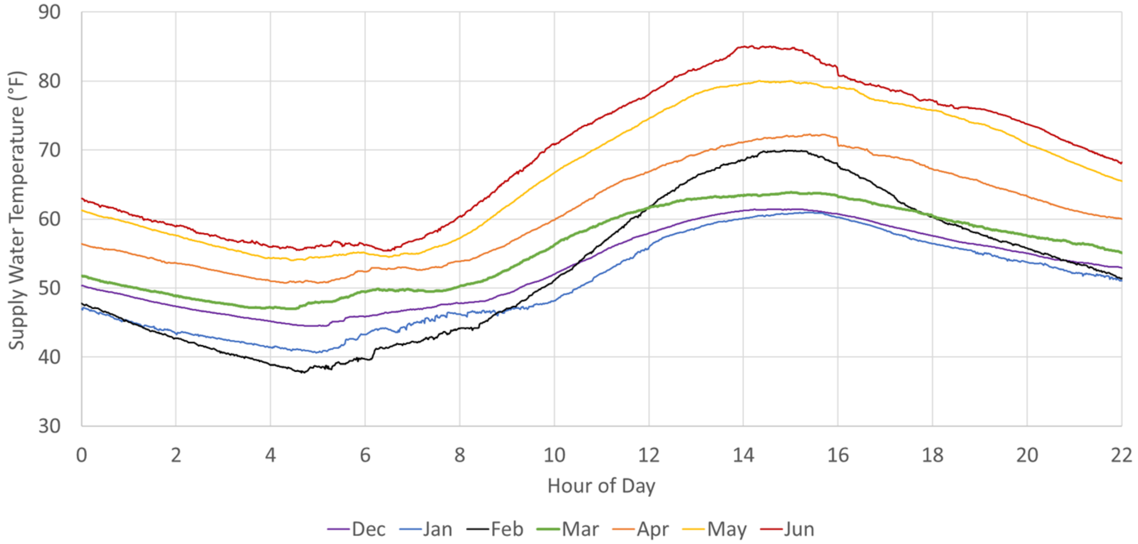


Figure E-8: Shoulder Total Daily Demand Averages



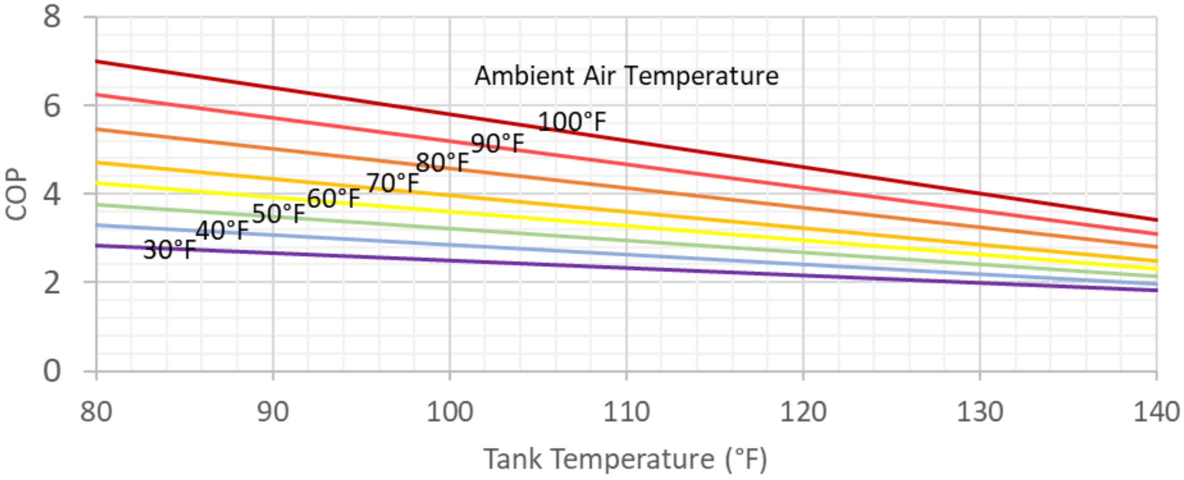
Incoming water temperatures are known to fluctuate seasonally, but due to outdoor exposure, incoming water temperatures were found to fluctuate more than expected according to the model. Figure E-9 shows average monthly incoming water temperatures for half the year in 2020. Note that February was uncharacteristically sunny, dry, and warm.

Figure E-9: Variation in Supply Water Temperature by Hour by Month



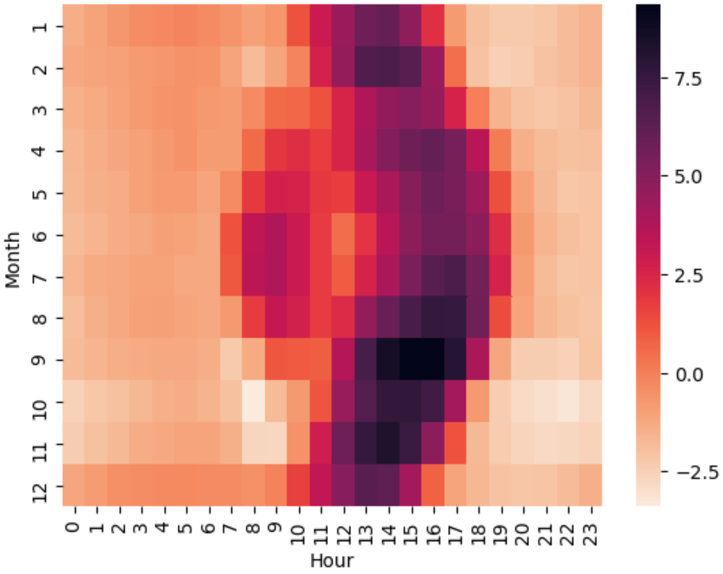
Ambient air temperatures have a number of effects on overall heat pump performance (Figure E-10).

Figure E-10: General Impact on COP and Tank Temperature Related to Ambient Air Temperature



Temperatures *inside* the HPWH shed (where the HPWH air was sourced from) roughly matched outdoor temperatures but appear to be subject to significant solar gain (Figure E-11) and colder than ambient nighttime temperatures (0°F to 3°F colder than the outdoor air). Anecdotally, during winter site visits, the shed felt much colder than the outdoor ambient temperature; this could be a result of the placement of the temperature sensor in the shed. This suggests that HPWH exhaust air is cooling the air inside the shed to some degree, negatively affecting performance. Overall, however, the impact of solar gain on the shed outweighs the cooling effect of exhaust air; average hourly temperatures are 4°F–8°F warmer than outdoor air in the afternoon, with the hottest shed temperatures being experienced during the beginning of peak hot water demand hours.

Figure E-11: Temperatures Inside Heat Pump Water Heater Shed Show Impact of Ambient Temperature



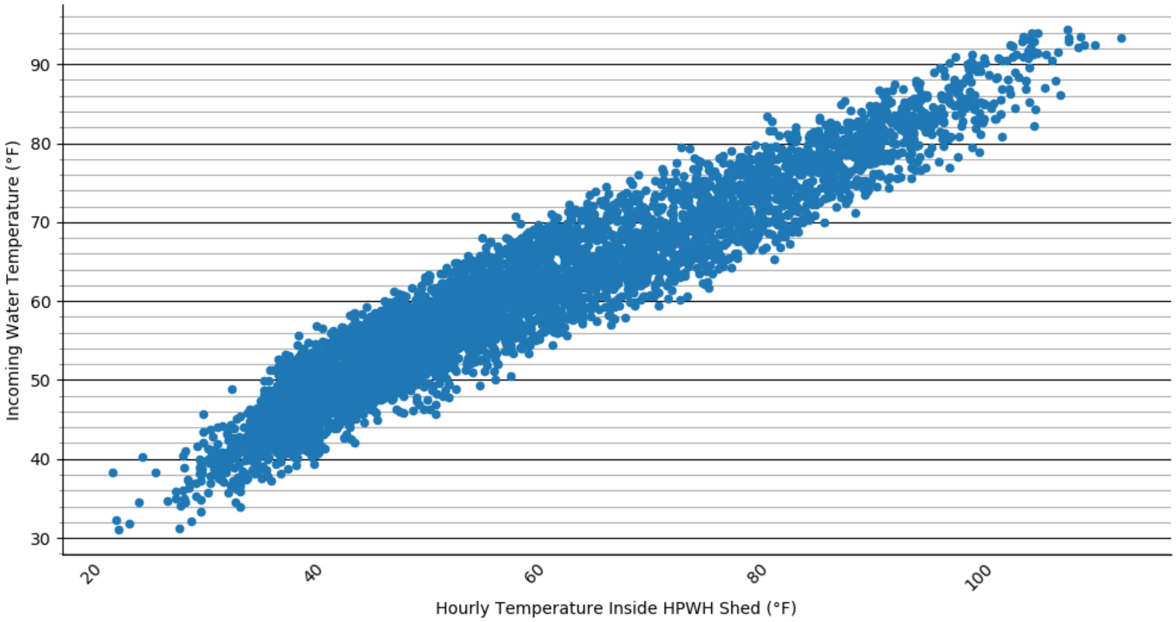
For 2018 and 2019, milder than modeled conditions generally resulted in better summer performance and worse winter with some exceptions, as shown in Table E-2.

Table E-2: Difference Between Actual and Modeled Temperature

	Difference Between Actual and Modeled Temperature (°F)		
Month	Average Daily (°F)	Maximum Daily(°F)	Minimum Daily(°F)
Jun-18	3.8	10.5	-0.9
Jul-18	12.1	18.1	5.9
Aug-18	5.4	13.5	0.3
Sep-18	1.3	10.4	-4.2
Oct-18	-0.1	5.3	-3.4
Nov-18	0.9	6.6	-3.1
Dec-18	-1.9	-0.1	-1.2
Jan-19	1.2	3.1	0.6
Feb-19	-5.5	-4.7	-5.7
Mar-19	-1.7	2.0	-2.7
Apr-19	3.2	8.6	0.7
May-19	-1.8	1.6	-2.3
Jun-19	3.9	11.6	-0.5
Jul-19	6.7	14.6	-0.6
Aug-19	5.8	14.2	1.1
Sep-19	4.4	11.7	-0.5
Oct-19	-3.1	5.4	-10.3
Nov-19	1.0	8.5	-4.2
Dec-19	-2.2	0.5	-2.7
Jan-20	-1.1	0.8	-1.8
Feb-20	-1.7	6.0	-7.0
Mar-20	-2.9	0.9	-3.0
Apr-20	1.6	4.6	-0.1
May-20	4.8	10.8	-1.2
Jun-20	4.2	11.0	-1.4
Jul-20	4.7	10.8	-2.3

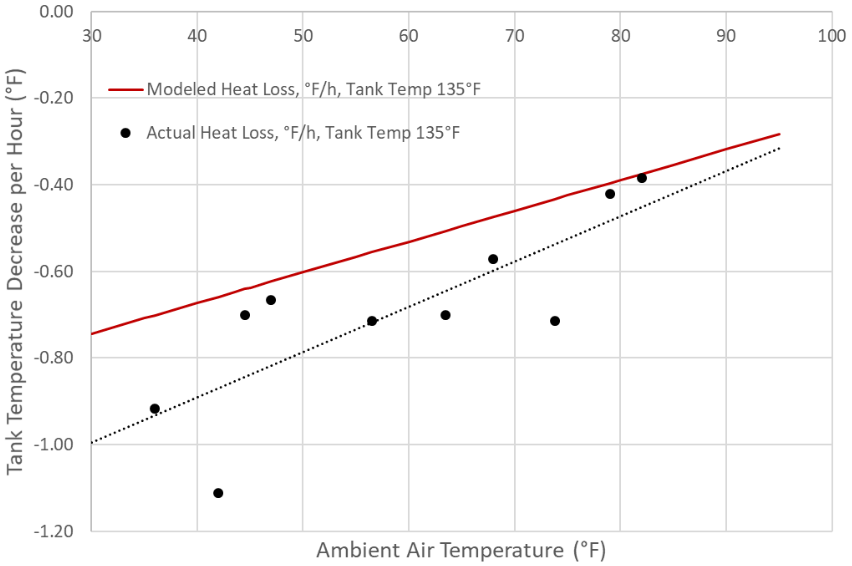
Incoming water temperatures are directly correlative to shed temperatures due to the location of piping in the shed, as shown in Figure E-12.

Figure E-12. Temperatures Inside the Heat Pump Water Heater Shed Correlate to Incoming Water Temperature



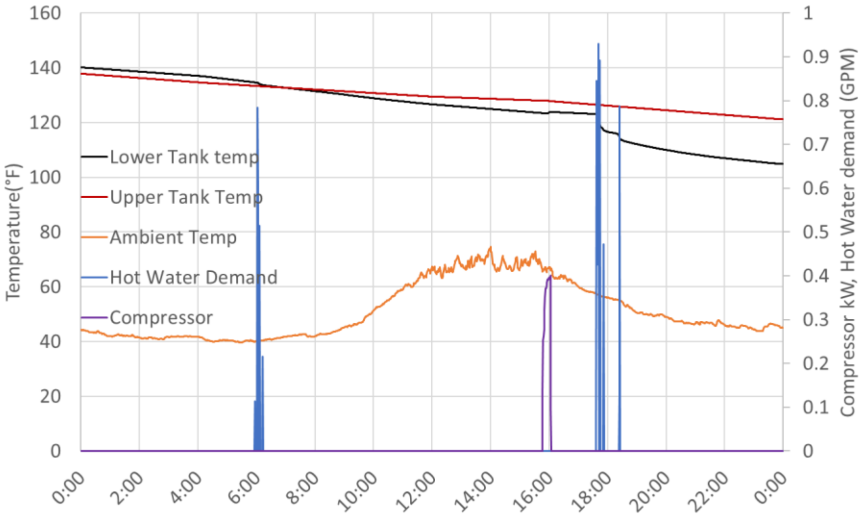
The insulation on these HPWHs is rated at R-20. CBECC-Res models assume R-16 tanks (or, 0.063 Btu/ft^2·h·°F; for a 50-gallon tank, 2.66Btu/°F lost each hour). Calculated rates of heat loss for periods where there was no demand (at night or vacant units) and average tank temperatures were 135°F showed higher rates of heat loss, especially at lower ambient temperature, when compared to modeled assumptions of R-16 (see **Error! Reference source not found.**). Figure E-14 below shows an apartment-specific example of heat loss.

Figure E-13. Tank Heat Loss Was Greater Than Modeled Heat Loss



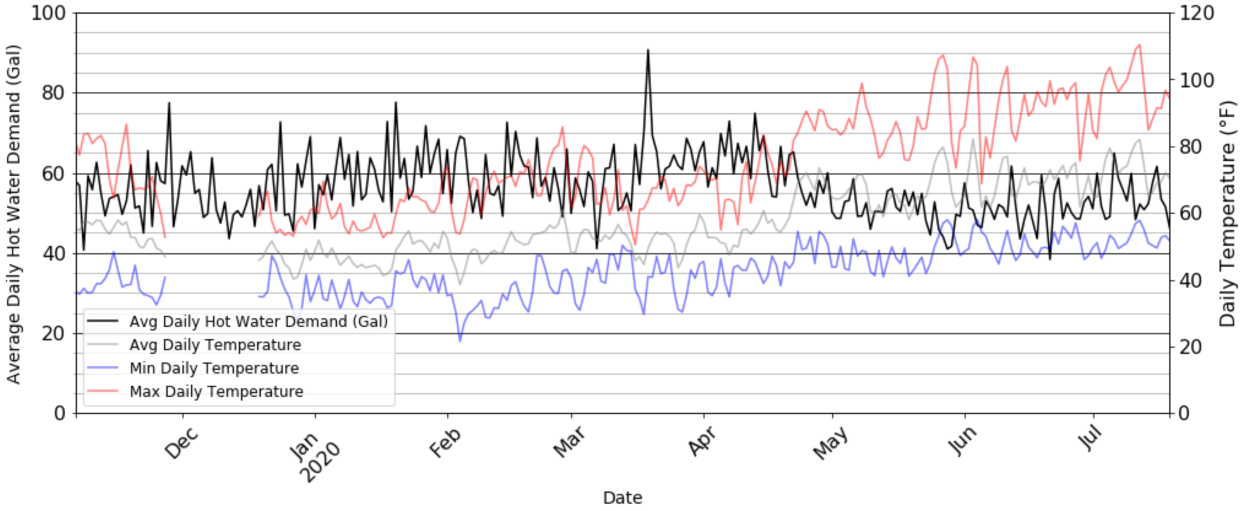
There was almost no hot water demand throughout the day, and the compressor only turned on once (no resistance energy) (Figure E-14). Overnight, the tank temperature dropped more than 1°F/hr before the first draw at 6 am. At that ambient temperature, the tank was modeled to lose only 0.67°F/hr.

Figure E-14: An Example of Greater Heat Loss Overnight Than the Modeled Heat Loss



Demand shapes varied less seasonally than they did simply due to tenant behavior, but there was a decrease in total consumption from winter to summer, coincident with warming temperatures, as shown in Figure E-15.

Figure E-15: Seasonal Variation in Domestic Hot Water Demand Shows Greater Demand in Winter.



A relatively mild winter of 2019/20 resulted in much lower energy consumption overall than a colder, wetter 2018/2020. Similarly, a somewhat mild 2019 resulted in fewer abrupt spikes than were present in July 2020. Figure E-16 for winter shows higher electric resistance loads than in summer (Figure E-17).

Figure E-16: Electric Resistance and Compressor Loads in Winter Showing Higher Resistance Load

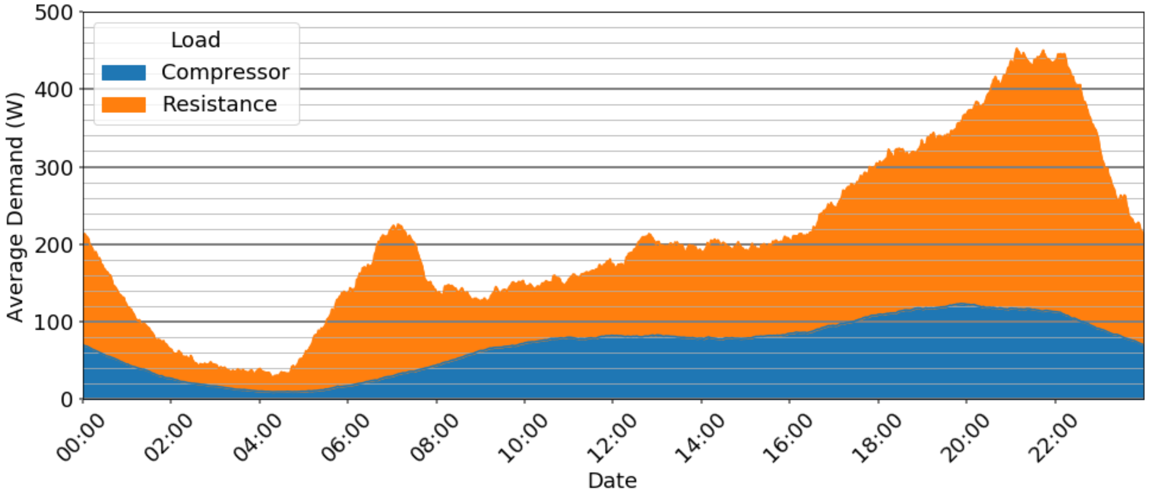


Figure E-17: Electric Resistance and Compressor Loads in Summer Showing Lower Resistance Load

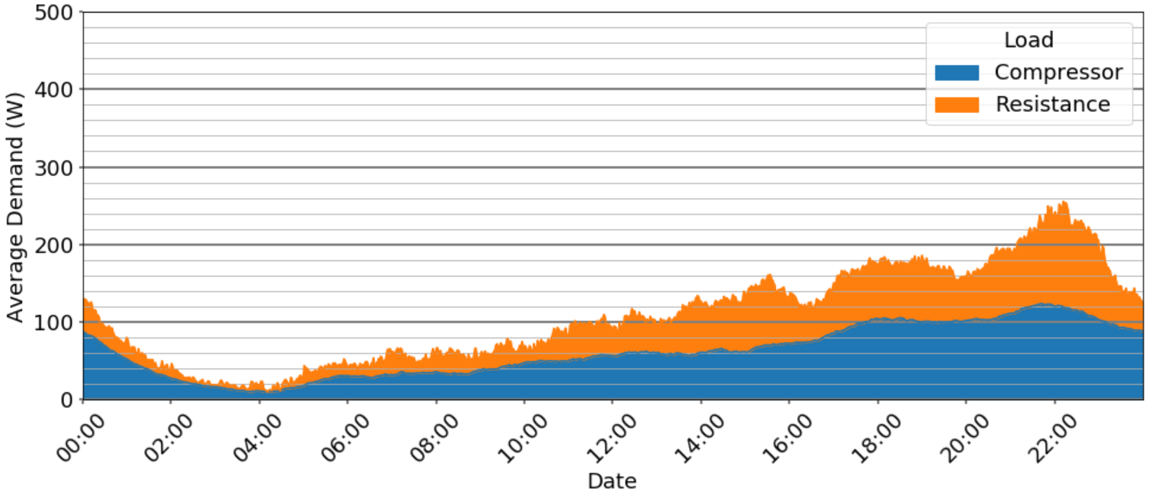


Table E-3 compares the sizing recommendations from ASHRAE and the plumbing code to field data from Atascadero.

Table E-3: Comparison of ASHRAE Calculation Assumptions to Field Data for a Two-Bedroom

2 bedroom	ASHRAE	Atascadero
Occupancy	3	3
Peak hot water hours	5 am–8 am 5 pm–8 pm	5 am–11 am 4 pm–9 pm
Delivery set point	125°F	125°F
Incoming water worst case	50°F	40°F
Max WH temp	140°F	125°F
Demand	31 gallons	11 gallons and 19 gallons

The domestic hot water draw profiles of the 22 dwelling units enrolled in the study at Atascadero were input into a model to determine the frequency that a heat pump water heater (HPWH) would be unable to deliver satisfactory hot water. The model simulated HPWH operation by comparing the hot water draw to the recovery of the HPWH at each minute of the study period. The model utilized the HPWH's performance curve to determine the recovery at different ambient temperatures recorded at the site. When the draw for hot water was greater than the recovery, water was then drawn from the hot water storage tank. Utilizing the first hour rating calculation and the RHEEM ProTerra HPWH specification sheet, it was assumed that 80 percent of the rated storage (gallons) of a fully charged tank was considered useful hot water. When the available stored hot water level fell below 20 percent of the rated storage volume, it was deemed that there was insufficient hot water and the HPWH was unable to deliver satisfactory hot water to the tenants.

Each of the 22 dwelling unit hot water draw profiles were evaluated in the model based on the HPWH that was installed for the study (50 Gal RHEEM ProTerra 2 and 3 bedrooms, 80 Gal RHEEM ProTerra 4 bedrooms) and evaluated using "code-sized" HPWHs based on Table 501.1 (2) in the 2019 California Plumbing Code. Table E-4 below summarizes the average results for each bedroom type, comparing the HPWH that was installed at the site and a "code-sized" HPWH.

Table E-4: Occurrence HPWH Cannot Provide Hot Water Code vs. Actual at 125°F Set Point

	RHEEM ProTerra (50 Gallon 2 & 3 Bedroom, 80 Gallon 4 Bedroom) Hybrid Mode	**RHEEM ProTerra (50 Gallon 2 & 3 Bedroom, 80 Gallon 4 Bedroom) Heat Pump Only Mode**	**Code-sized (40 Gallon 2 Bedroom, 50 Gallon 3 and 4 Bedroom) Hybrid Mode**	**Code-sized (40 Gallon 2 Bedroom, 50 Gallon 3 and 4 Bedroom) Heat Pump Only Mode**
2 Bedroom Average Occurrence HPWH Cannot Provide Hot Water	0.00%	1.53%	0.19%	4.17%
3 Bedroom Average Occurrence HPWH Cannot Provide Hot Water	0.00%	2.38%	0.07%	2.71%
4 Bedroom Average Occurrence HPWH Cannot Provide Hot Water	0.00%	6.04%	0.75%	12.81%

Thermal Storage Images

For two months prior to the beginning of the experiment, tank temperatures and hot water draw patterns were monitored to establish a baseline, yet during this period the recirculation pump controls were not functioning properly and were corrupting the baseline comparison.

The intent and results of the experiments are shown in figures E-18 through E-25 and tables E-5–E-12 below. In addition to the individual summary, average demand plots of compressor and resistance energy across all units with set point and mode are included for each experiment, to show the comparative effect of each experiment, despite variation in demand across apartments. A box plot of the total average daily DHW for the time period for each apartment is also displayed to the right, to show the number of high usage outliers that may be affecting the average demand plot.

Figure E-18: Experiment 1e with Set Point to Shed Load at Grid Peak

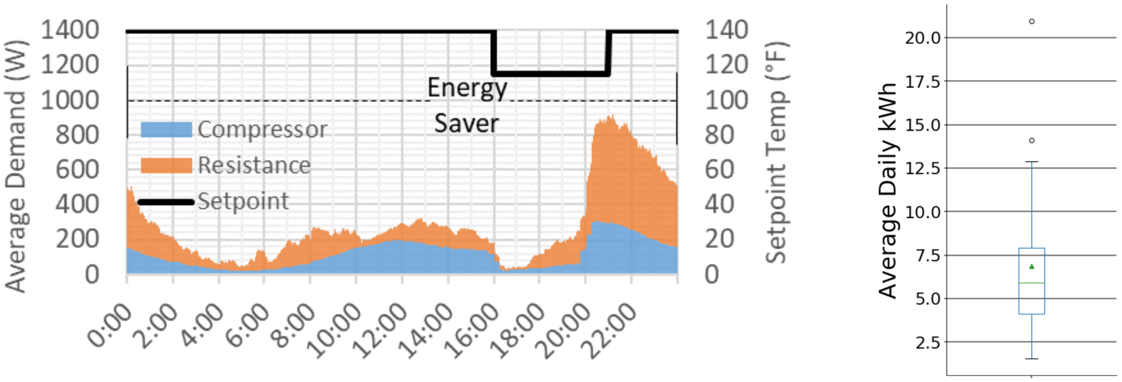


Table E-5: Experiment 1e: (Test #5: 12/2/19–1/10/20 [39 days])

Stage	Start Time	End Time	Set Point (°F)	Mode
Shed	4:00 pm	8:00 pm	115	Energy Saver
Baseline	8:00 pm	4:00 pm	140	Energy Saver

Intent: To reduce demand during the peak period (4 to 8 pm) through a reduced peak set point temperature.

Results: Energy usage during periods was reduced by up to half of that of the other experiments. Recovering from tank temperatures of 115°F to 140°F during periods of high demand resulted in extensive electric resistance runtime and was particularly pronounced for apartments with 8–10 pm hot water demand peaks. Reducing the temperature this much often virtually eliminated compressor usage during peak periods altogether, effectively increasing demand beyond what it would have been under a more static schedule. Peak demand around 8 pm was significantly higher than other schemes. There is one significant outlier shown in the box plot affecting overall results, while the remaining 21 units are well clustered.

Figure E-19: Experiment 1h with a Consistent Set Point of 140°F

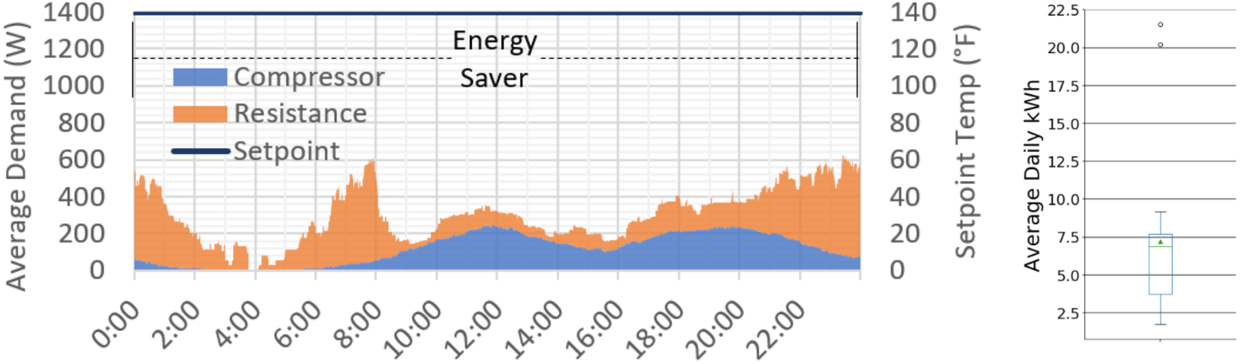


Table E-6: Experiment 1h (Test #8): 2/7–2/14/20 (7 days)

Stage	Start Time	End Time	Set Point (°F)	Mode
All times	N/A	N/A	140	Energy Saver

Intent: To establish a baseline of operation for Energy Saver mode at a high temperature. Provide water stored at higher temperature to drive down resistance incurred by large coincident demands.

Results: Large morning peaks were present, in part due to incoming water temperatures below 37°F, under which the compressor will not operate. Additionally, morning demand was often abrupt, which can cause lower tank temperatures to plunge rapidly and incur backup resistance operation as the HPWH responds to (and possibly underestimates) remaining hot water storage capacity. Electric resistance, while significant during peak and post peak, is present throughout the day and may be attributed to Rheem control logic for Energy Saver mode rather than actual hot water storage levels. Compared to experiment 1i, below, this approach resulted in significant extended electrical demand attributed to use of electric resistance to meet the 140°F set point.

Figure E-20: Experiment 1i with Consistent Set Point of 125°F

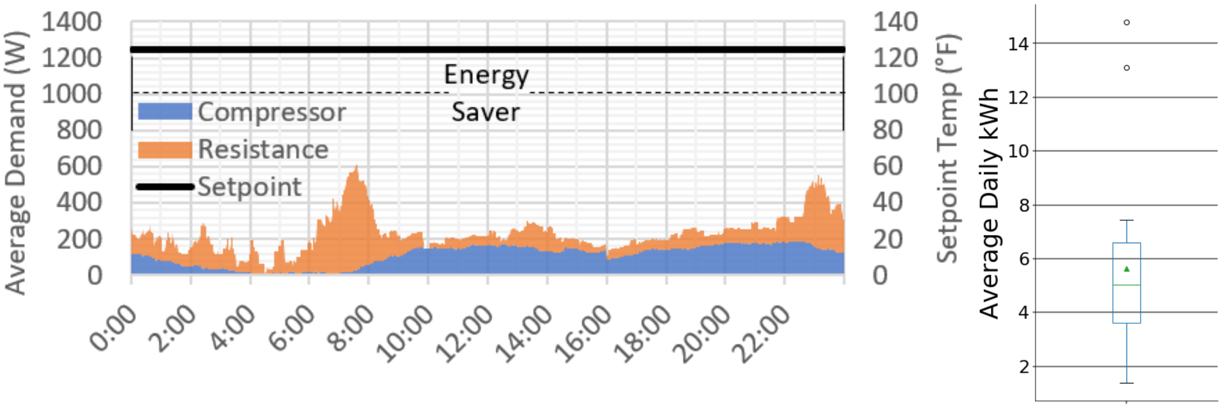


Table E-7: Experiment 1i (Test #9): 2/14–21/20 (7 days)

Stage	Start Time	End Time	Set Point (°F)	Mode
All times	N/A	N/A	125	Energy Saver

Intent: To establish a baseline of operation for typical factory settings.

Results: Twenty-three percent less energy usage on average (mostly reduced resistance) than experiment 1h (set point 140°F) and smaller peaks on average, but still very large morning peaks, similar to 1h. Resistance events were smaller in magnitude than experiment 1h but more frequent because the tank with the lower set point was drawn down more frequently. Unnecessary resistance was still very much present. Costs were lower in this experiment compared to 1e, due to lower resistance peaks from 8–9 pm. Greenhouse gases (GHGs) were also close to the lowest of all the experiments.

Figure E-21: Experiment 1j with a Consistent Set Point of 140°F at Heat Pump Only Mode

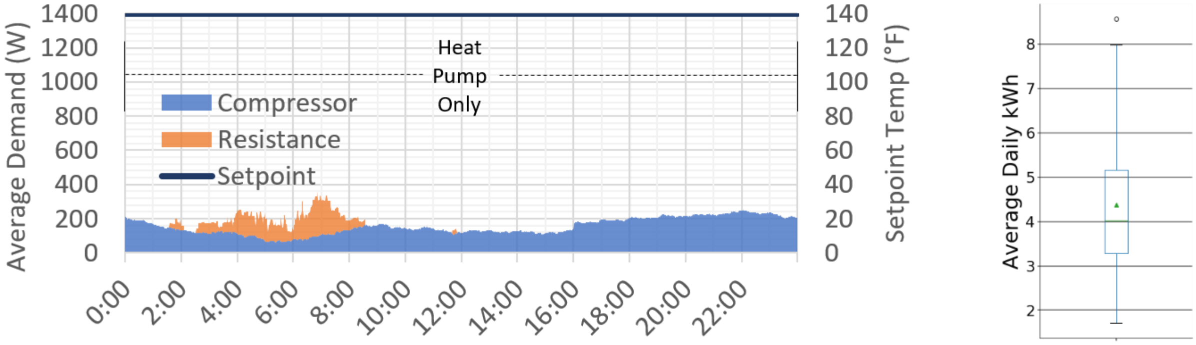


Table E-8: Experiment 1j (Test #10): 2/21–2/28/20 (7 days)

Stage	Start Time	End Time	Set Point (°F)	Mode
All times	N/A	N/A	140	Heat Pump Only

Intent: Understand performance in Heat Pump Only mode, attempt to eliminate unnecessary resistance operations seen in other experiments, and test whether high-temperature Heat Pump Only mode would be sufficient to meet delivery temperatures.

Results: Resistance energy was nonexistent, except for periods in the morning where incoming water temperatures were below 40°F. Except for a few extremely high-water-usage outliers, delivery temperatures were favorable, and peak demand (including during peak hours), costs, GHG emissions, and overall energy usage were the lowest of any experiment. This experiment represents a 7 percent reduction in costs and 6 percent reduction in GHGs compared to experiment 1i with 125°F and Energy Saver and 27 percent reduction in GHG savings and 29 percent reduction over experiment 1e. High set point temperatures and low COPs caused long compressor runtime, approximately 40 percent of the entire duration of the experiment.

Figure E-21: Experiment 1k with Varying Set Point Temperatures and Modes

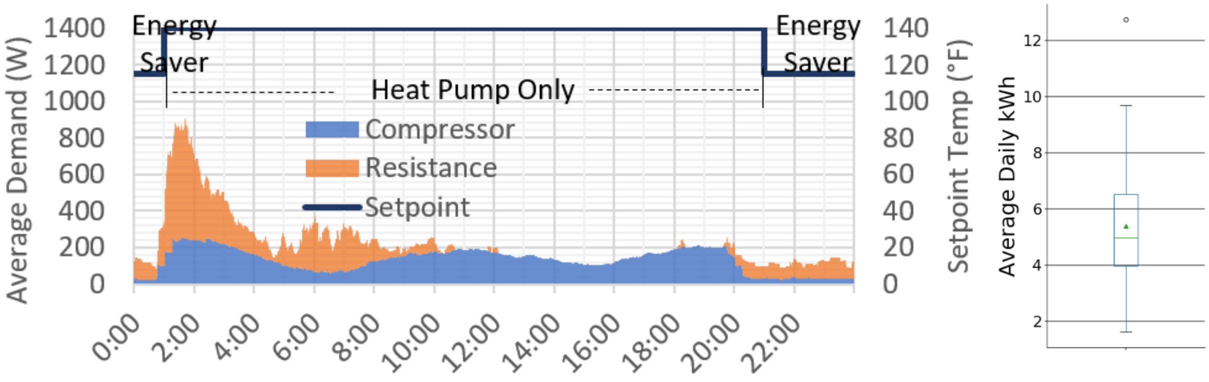


Table E-9: Experiment 1k (Test#11):2/28–3/9/20 (10 days)

Stage	Start Time	End Time	Set Point (°F)	Mode
Load Up	1:00 am	8:00 pm	140	Heat Pump
Baseline	8:00 pm	1:00 am	120	Energy Saver

Intent: Attempt to reduce the magnitude of these post-peak demands and resistance as seen in previous experiments when demand subsides. Allow full recharge overnight.

Results: This experiment showed significant resistance at shift back to 140°F and Heat Pump Only mode at 1 am. This was determined to be due to changing the mode and temperature simultaneously. During subsequent experiments, the mode change was made prior to the temperature change to this response.

Figure E-23: Experiment 1o with Varying Set Point Temperatures and Modes

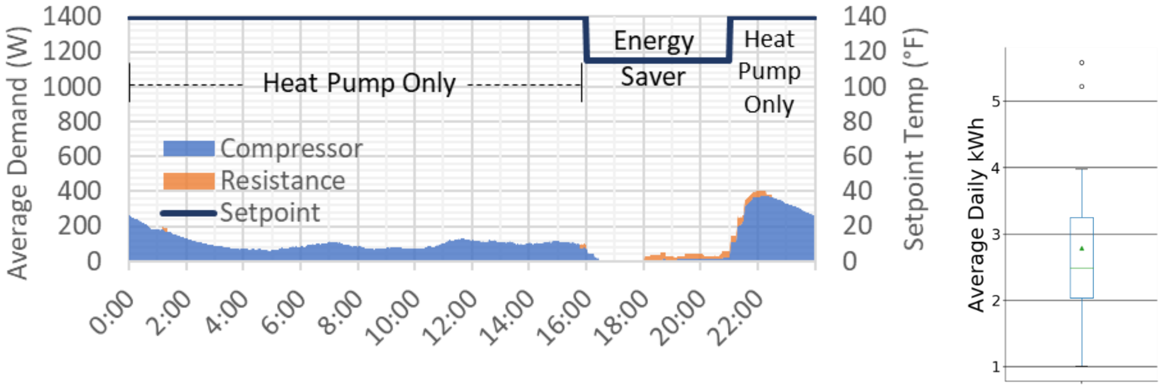


Table E-10: Experiment 1o (Test #16): 5/22–6/12/20 (21 days)

Stage	Start Time	End Time	Set Point (°F)	Mode
Shed	4:00 pm	9:00 pm	115	Energy Saver
Recovery	9:00 pm	4:00 pm	140	Heat Pump

Intent: Test peak shifting from 4–9 pm, similar to 1e, but during more favorable summer conditions.

Results: This experiment was largely successful and only one unit incurred any resistance during the shed period. Compared to similar winter schemas, this was far more successful by all metrics.

Figure E-24: Experiment 1p Variation of 1o with Extended Shed Period

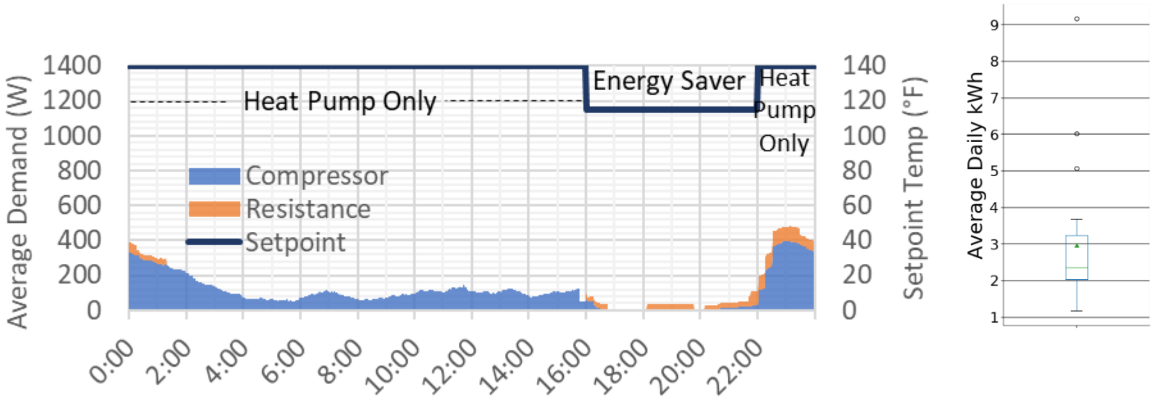


Table E-11: Experiment1p (Test #17): 6/12–6/22/20 (10 days)

Stage	Start Time	End Time	Set Point (°F)	Mode
Shed	4:00 pm	10:00 pm	115	Energy Saver
Recovery	10:00 pm	4:00 pm	140	Heat Pump

Intent: Iterate on experiment 1o, extending the shed period by an hour to 10 pm.

Results: This experiment was marginally less successful than experiment 1o, as tanks became depleted for some apartments with significant hot water demand. Post-shed recovery had a stronger and more abrupt peak than in experiment 1o.

Figure E-25: Experiment 1q Was a Summer Comparison to 1j (7 days)

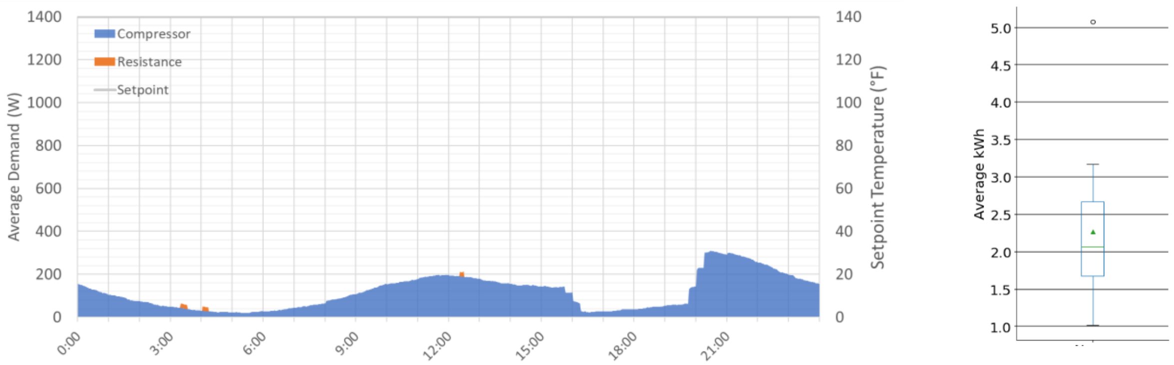


Table E-12: Experiment 1q (Test #18): 6/22–7/10/20 (10 days)

Stage	Start Time	End Time	Set Point (°F)	Mode
Shed	N/A	N/A	140	Heat Pump

Intent: This experiment was largely meant to provide a summer comparison to experiment 1j, which was undertaken during the winter.

Results: This experiment resulted in almost no resistance. Higher COPs and lower thermal losses resulted in lower total energy consumption than in the winter experiment, 1j. Total electrical consumption was similar to experiments 1o and 1p, but with greater peak demand resulting from no attempts at load shifting.

Thermal Storage Modeling Exercise

The model was then used to evaluate the effect of load shifting between the hours of 5 pm and 9 pm for each bedroom type and each HPWH heating modes (hybrid and heat pump only). The analysis was completed for a 50 gallon, 65 gallon, and 80 gallon

RHEEM ProTerra. Table E-13 summarizes the occurrence the HPWHs cannot provide adequate hot water for each bedroom type with load shifting logic applied.

Table E-13: Load Shifting Analysis 50 Gallon, 65 Gallon, 80 Gallon, RHEEM ProTerra at 140°F Set Point with Mixing Valve set to 125°F

	50 Gallon RHEEM ProTerra Hybrid Mode	50 Gallon RHEEM ProTerra Heat Pump Only Mode	65 Gallon RHEEM ProTerra Hybrid Mode	65 Gallon RHEEM ProTerra Heat Pump Only Mode	80 Gallon RHEEM ProTerra Hybrid Mode	80 Gallon RHEEM ProTerra Heat Pump Only Mode
2 Bedroom Average Occurrence HPWH Cannot Provide Hot Water	2.90%	7.16%	1.29%	3.22%	0.55%	1.46%
3 Bedroom Average Occurrence HPWH Cannot Provide Hot Water	2.51%	7.16%	0.89%	3.57%	0.35%	1.58%
4 Bedroom Average Occurrence HPWH Cannot Provide Hot Water	9.85%	25.49%	5.33%	18.17%	2.84%	13.74%

HVAC

Daily runtimes, even for apartments that consistently heat or cool daily, were low. Runtimes were generally longer in the summer. There was little demand for heating or cooling below an average daily temperature of 60°F (Figure E-26). Average runtimes and variance in runtimes across apartments was greater in the winter, but varied greatly in response to short-term weather patterns. When the baseload was removed, the low runtimes became evident as shown in comparison of Figure E-27 with baseload to Figure E-28 without baseload. Seasonal demand patterns were as expected and shoulder seasons were relatively flat (Figure E-29)

Figure E-26: Daily Runtime for All Units as Function of Temperature

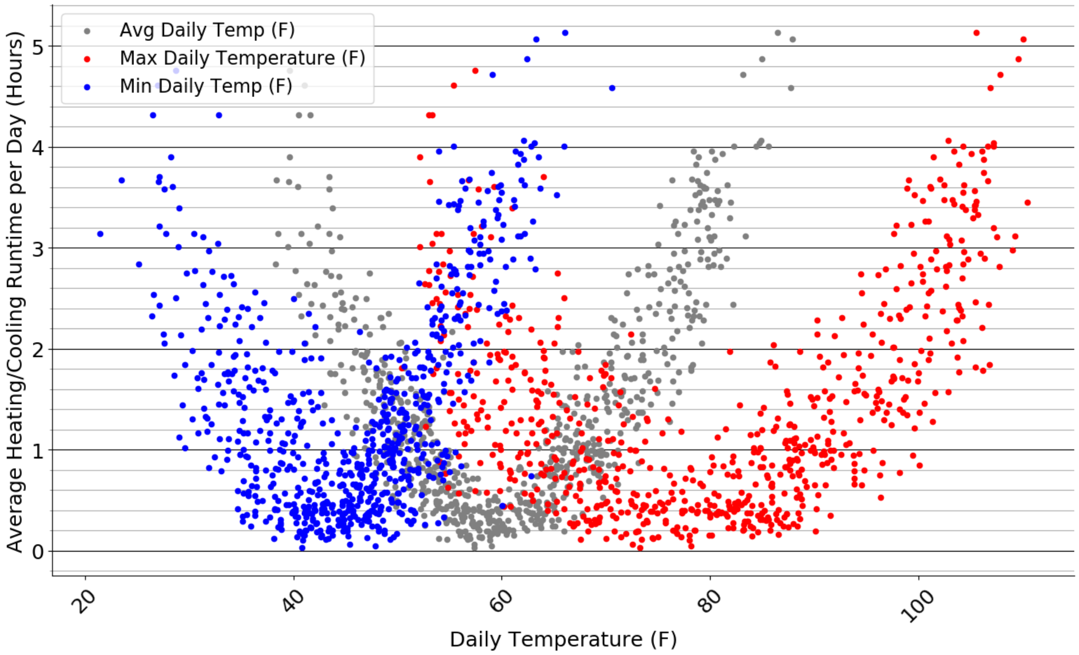


Figure E-27: Average Annual Heating Loads by Apartment Including Base Load

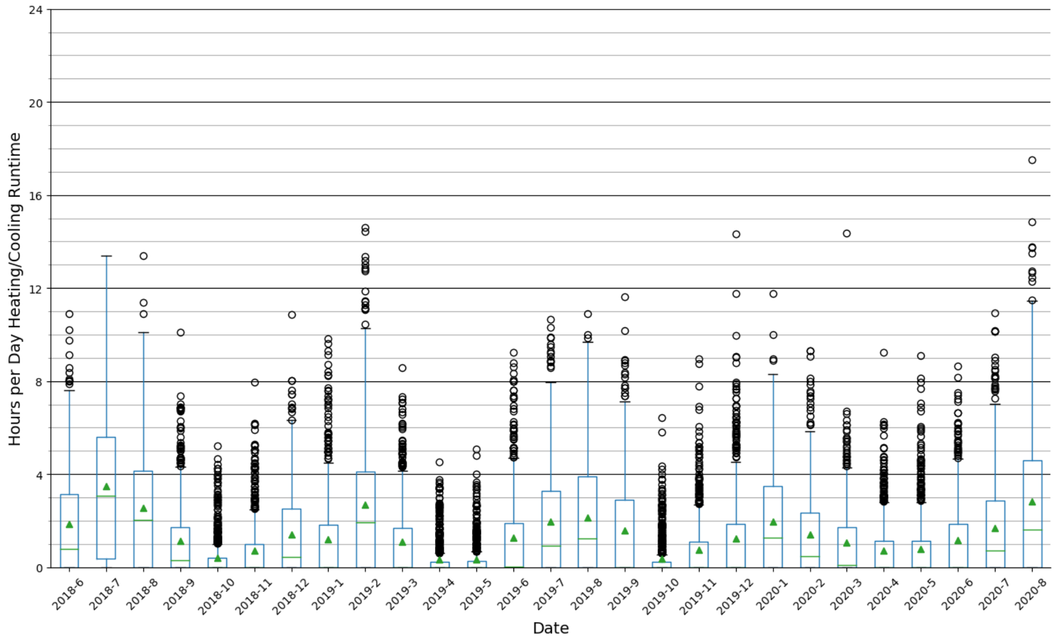


Figure E-28: Average Annual Heating Loads by Apartment Excluding Base Load

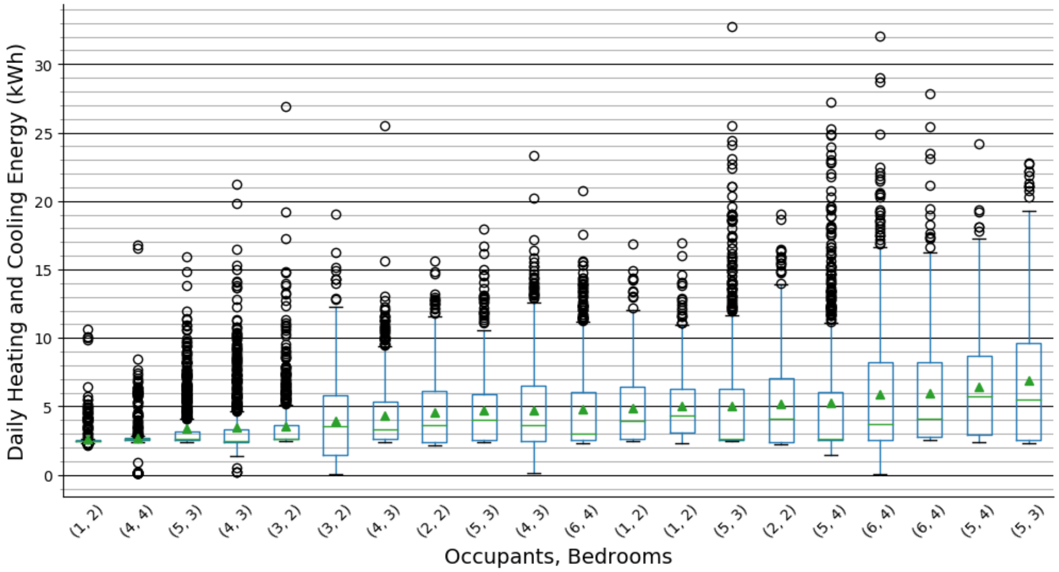


Figure E-29: Hourly Demand by Month

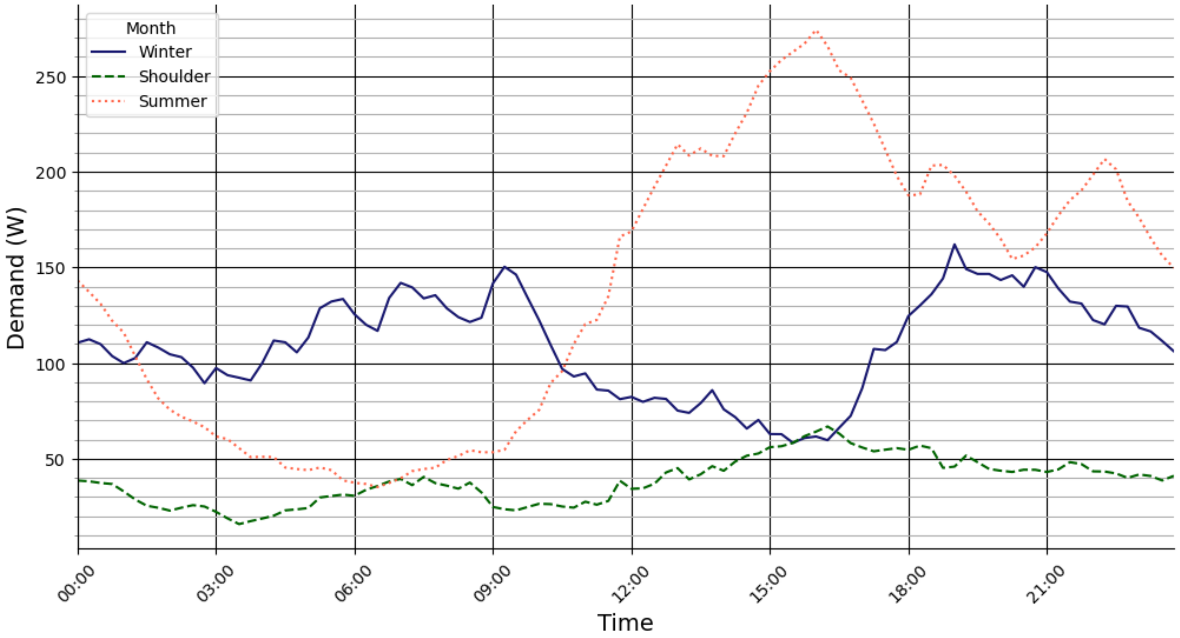
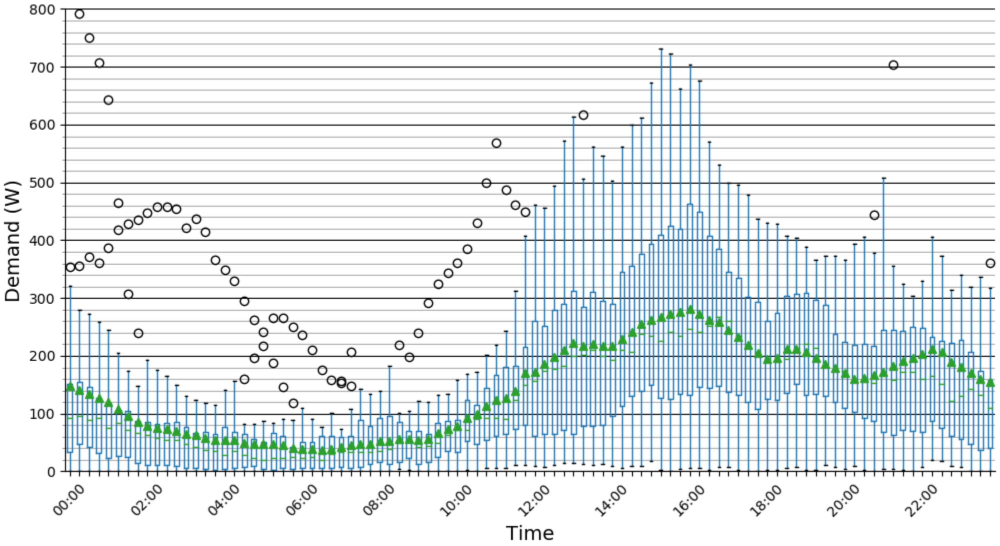
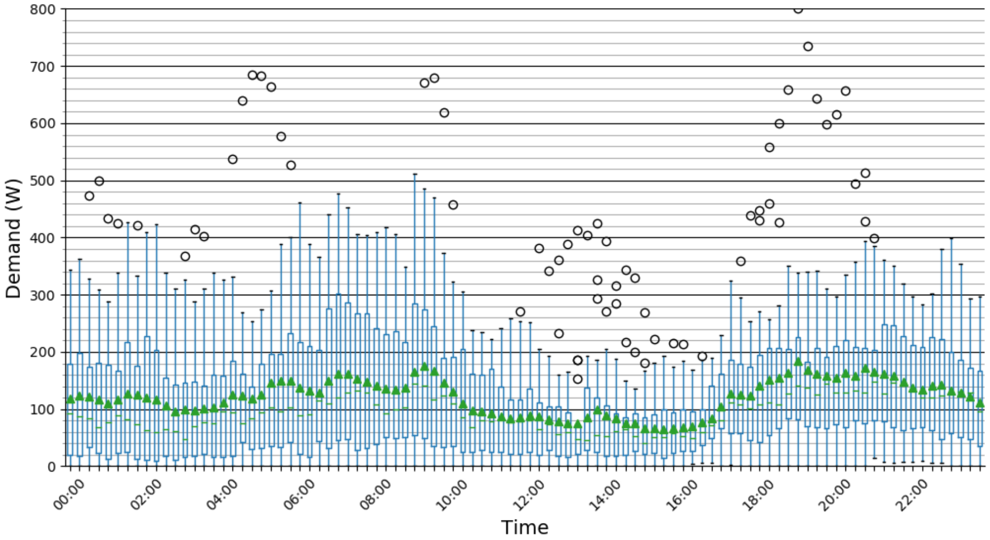
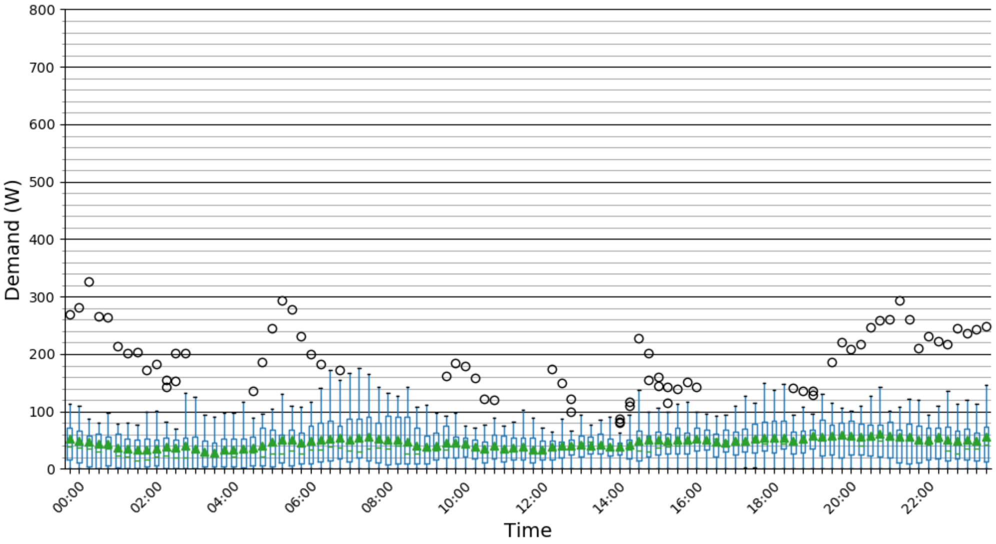


Figure E-30 shows variance in demand during summer, winter, and shoulder seasons, respectively. Summer loads clearly are dominant demand.

Figure E-30: Seasonal demand by summer (top), winter (middle) and shoulder (bottom) seasons

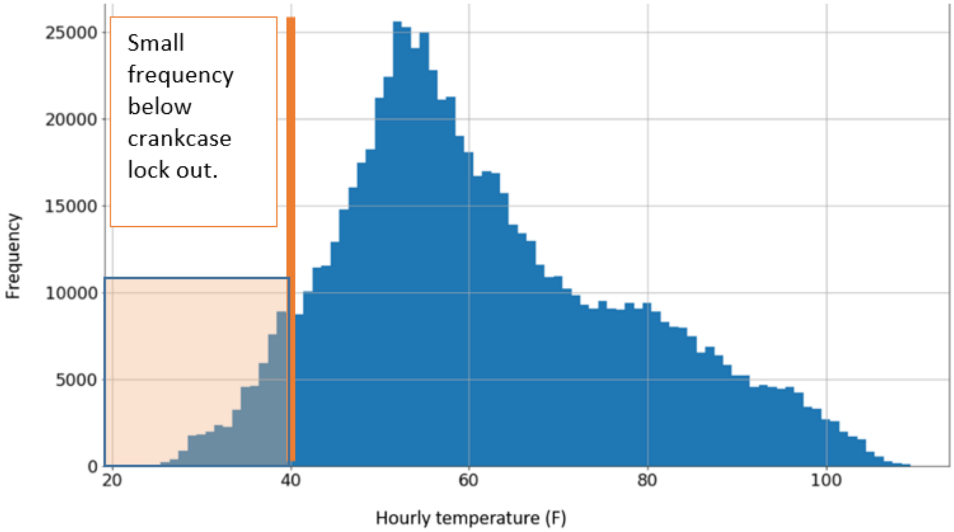





Demand (W)
800
700
600
500
400
300
200
100
0
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time

The crankcase heater for the high performance condensing unit operated 24/7, even when there was no call for space conditioning. The total baseload uses approximately 2.5 kWh a day, even though the primary need for a crankcase heater in these units is when air temperatures drop below 40°F, less than 10 percent of annual operating hours (Figure E-31).

Figure E-31: Histogram of Crankcase Operation across Hourly Temperatures



Cooking usage tracks with occupancy, as show in other studies (Figure E-32). Seasonally, daily cooking energy (averaged across all apartments) varied by roughly 0.25 kWh (June, 1.78 kWh; December, 2.03 kWh), less than other similar complexes studied (Figure E-33). Cooking demand increased by 12 percent from summer to winter and manifested itself between the hours of 4 to 7 pm. There was a shift in peak demand in the morning between summer and winter seasons (Figure E-34). Weekly trends also were present, with consistently lower cooking energy on weekends (Friday–Sunday) (Figure E-35).

Figure E-32: Daily Average Range Energy Consumption by Occupants Shows Correlation to Occupancy

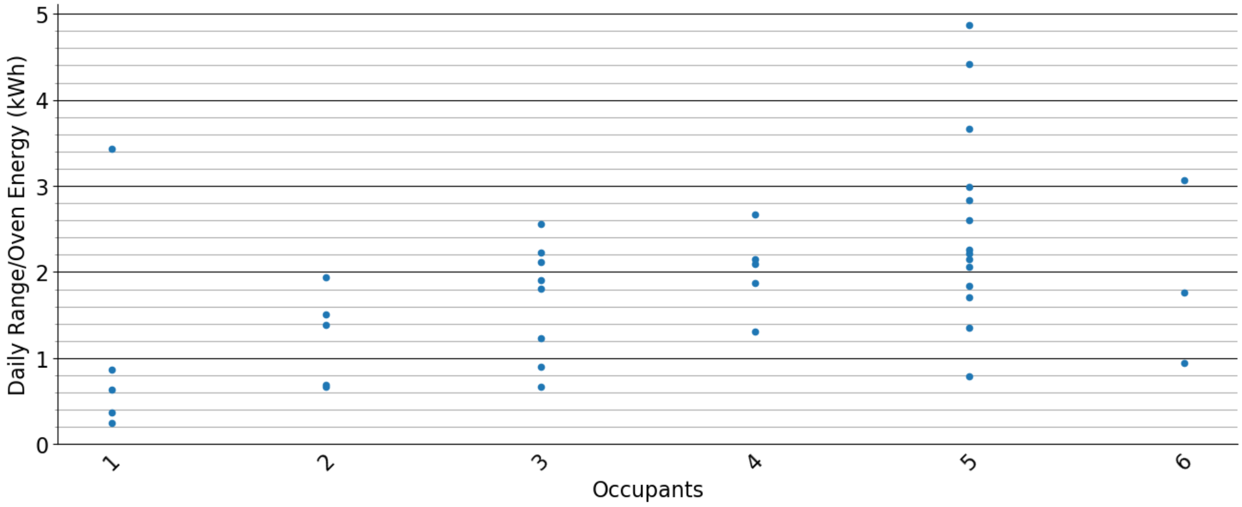


Figure E-33. Variance across Apartments in Daily kWh of Cooking Consumption

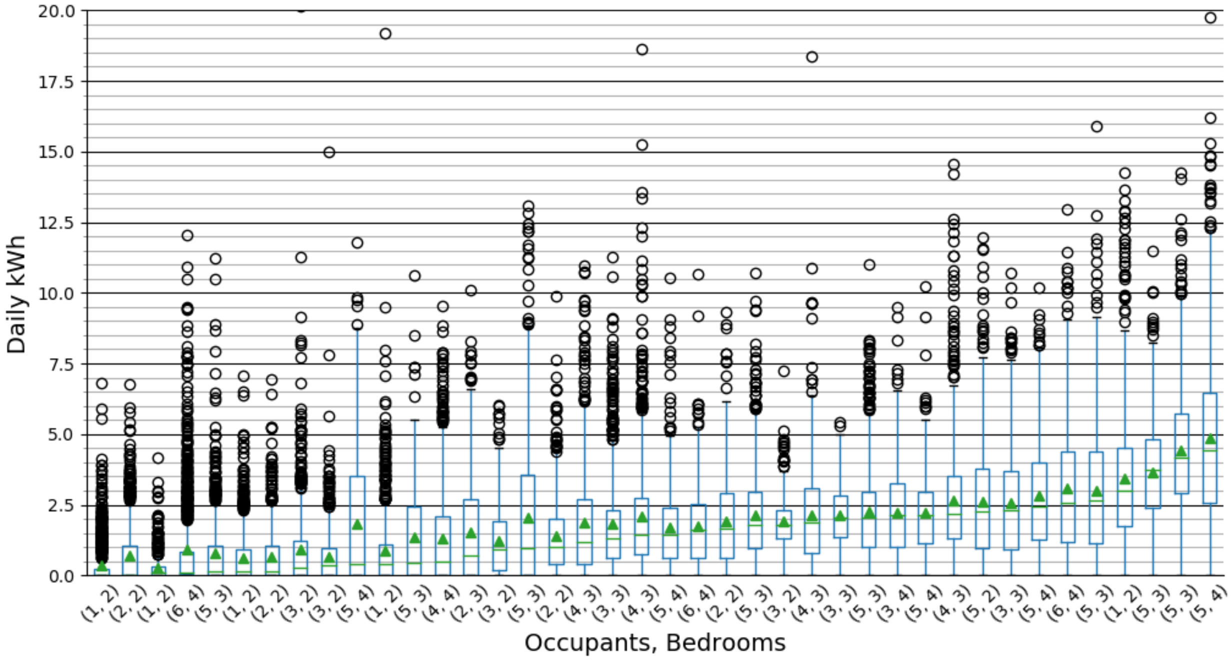


Figure E-34. Hourly Load Profile by Month Showing Earlier Morning Peaks in the Summer and Higher Evening Peaks in the Winter, and Cooking Increases 12% in winter

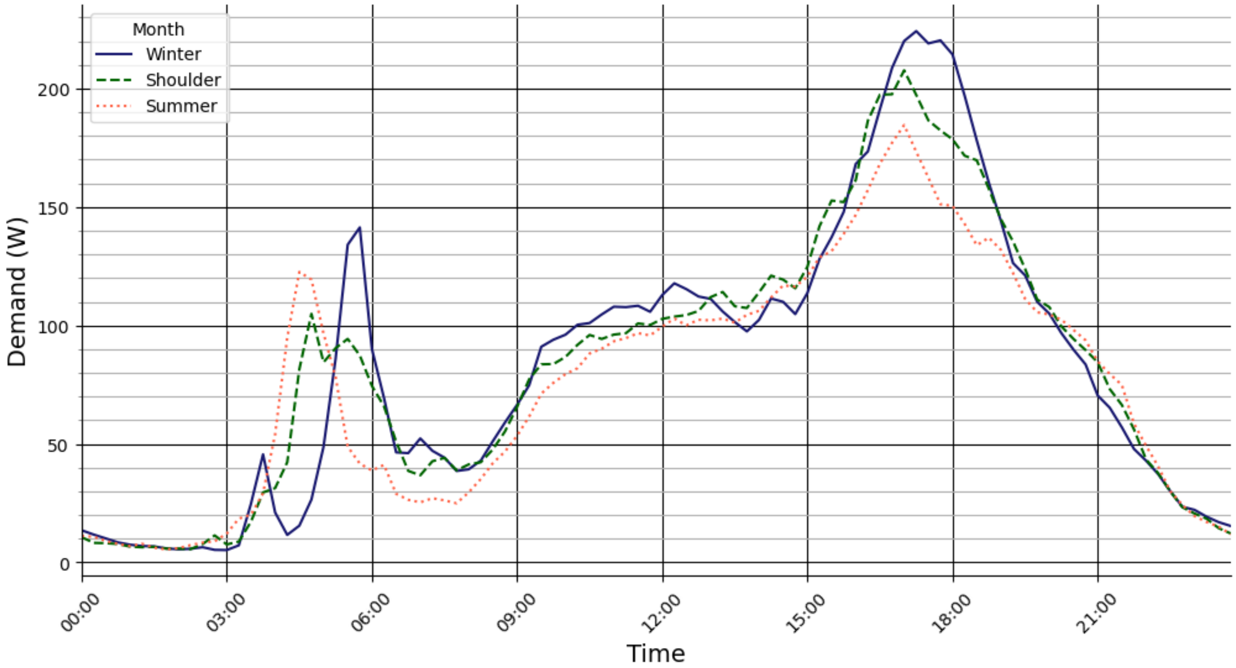
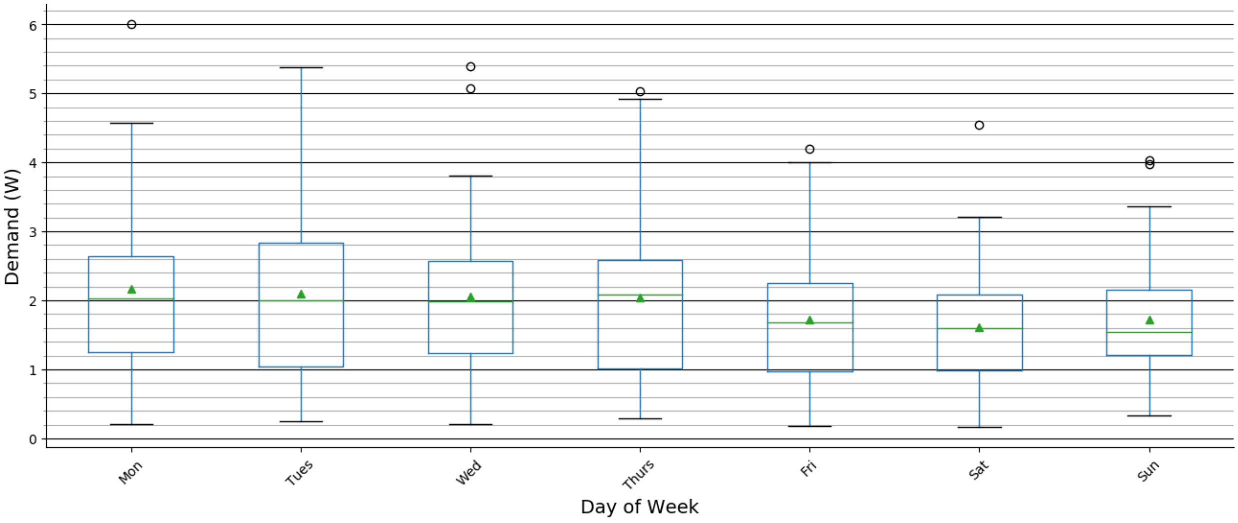


Figure E-35. Variance by Day of the Week with Less Cooking Occurring on Weekends



Range Hood Usage

The range hood use was minor compared to other loads, representing only 47 kWh on average across apartments. No seasonal or occupancy-based correlations were present. In general, hood use paralleled cooking demand. Average daily runtime for range hood fans was only 6 minutes, with a maximum average of 19 minutes (Figure E-36). Simultaneous cooking range and range hood runtimes have an average 14.5 percent (ranging from 1.9 percent to 33.2 percent) of total time that cooking takes place (Figure E-37). This did not align completely with survey results, wherein most tenants reported always or usually using the hood while cooking.

Figure E-36. Range Hood Runtime Variance Across Apartments

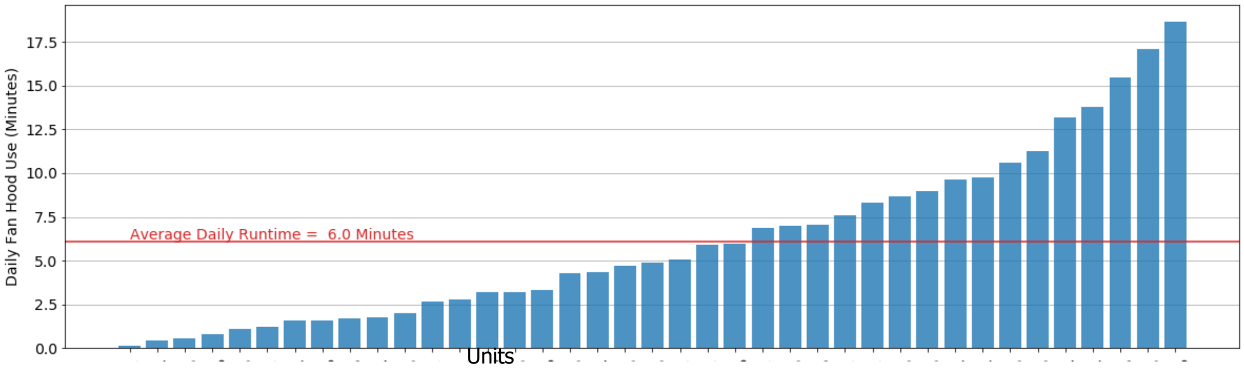
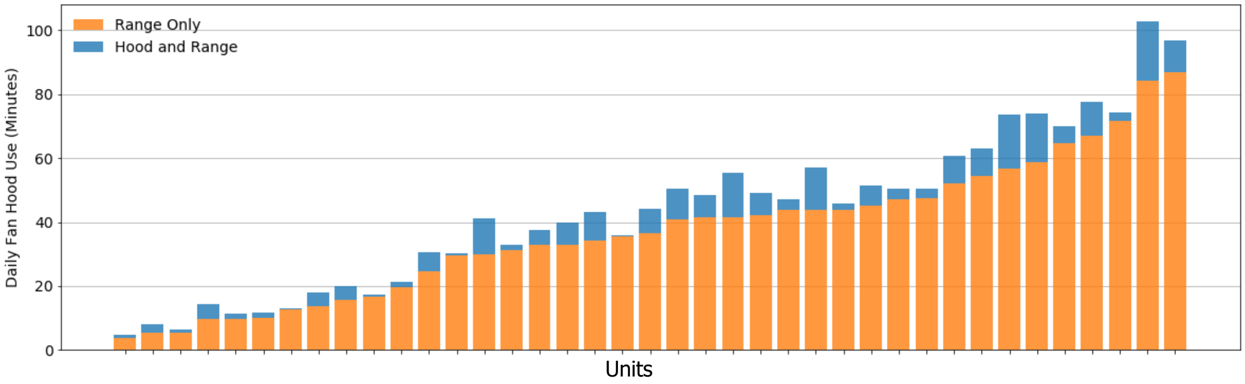


Figure E-37: Range Only and Hood and Range Operation Times Demonstrate Frequency of Coincident Use



Refrigerator total energy was more variable than expected (Figure E-38) in the 20 units metered.). There is strong seasonal variation to average refrigerator energy. Not only does consumption decrease from summer to winter (25%, roughly 1 kWh in July to

0.75 kWh in Jan), but there is a strong correlation between daily average ambient outdoor temperatures and refrigerator energy consumption. Indoor temperatures are expected to rise and fall to some degree with outdoor temperatures, and higher indoor temperatures lead to increased heat loss from refrigerators. On average, an increase of 0.1 kWh/day for every 10°F above daily mean temperature of 40°F was recorded (Figure E-39).

Figure E-38: Variance of Refrigerator Consumption by Apartment Type for Sample of Apartments

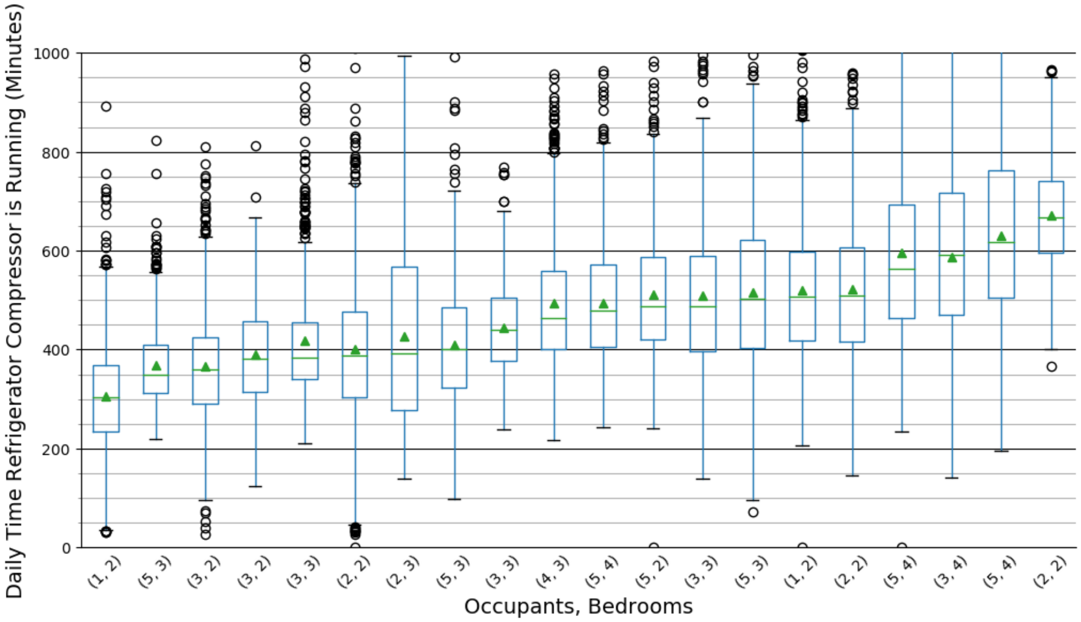
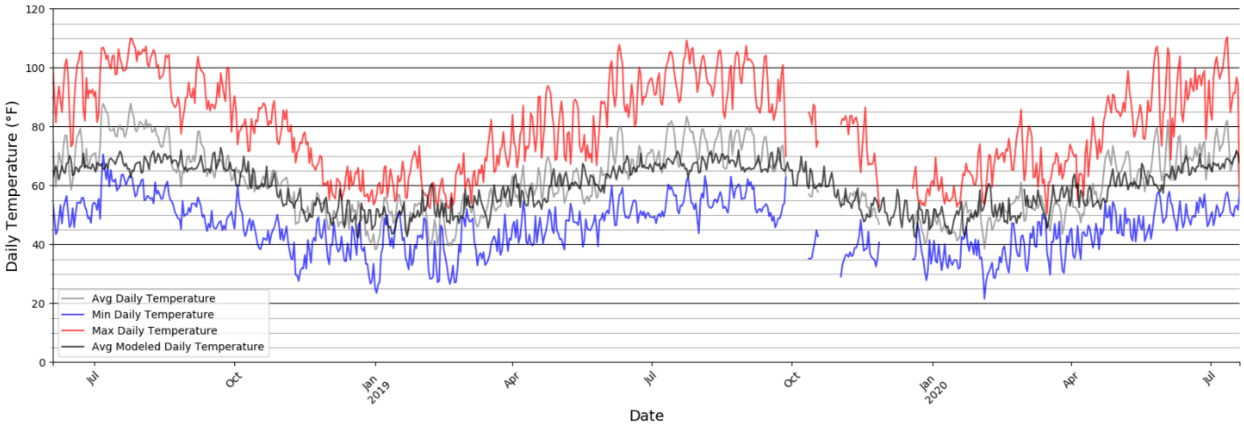


Figure E-39: Average Temperatures Compared to Modeled Daily Temperatures

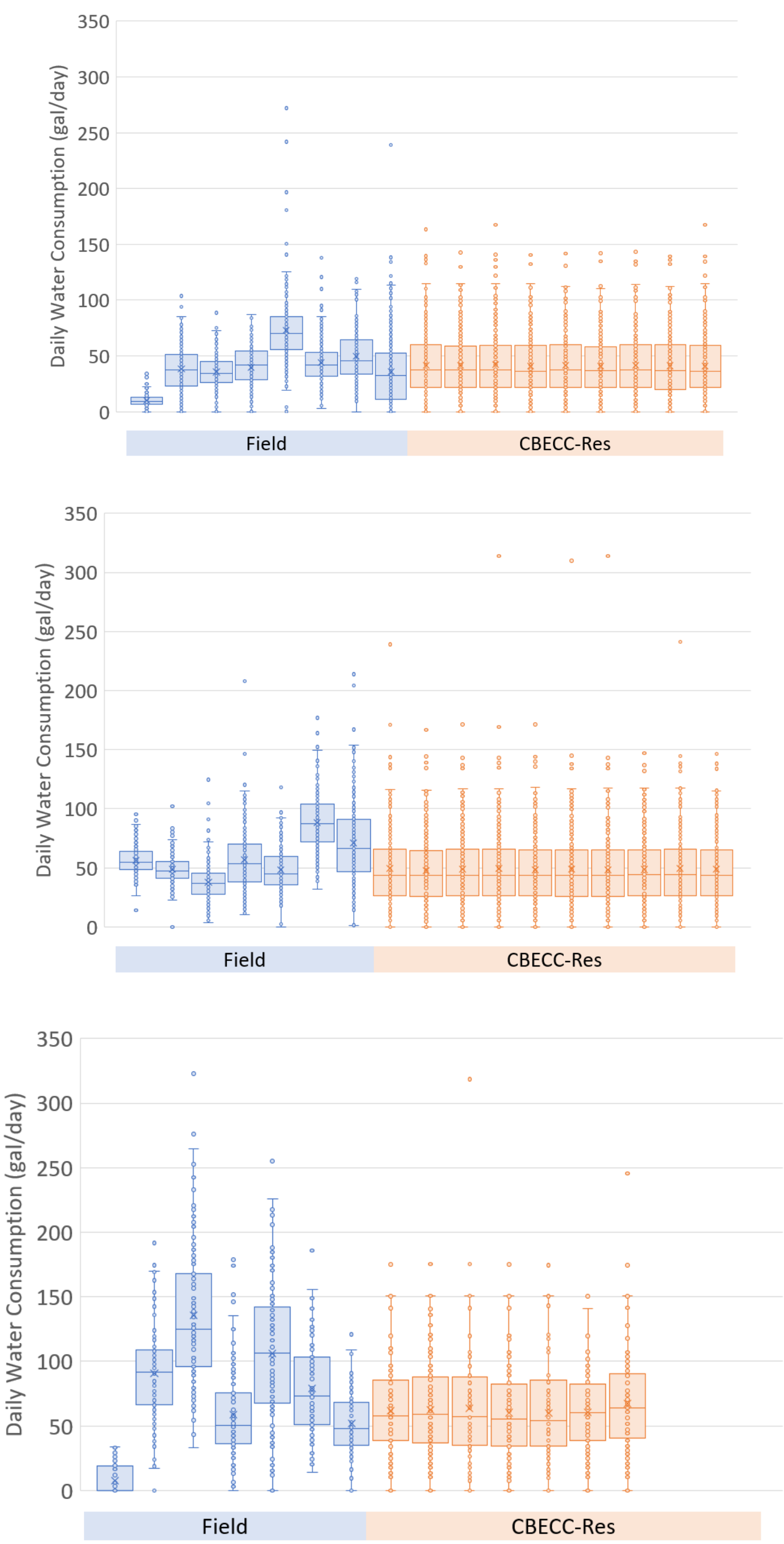


Hot Water Use

Three different methods were used to estimate the actual water use. The first was using the average gal/person/day, the second was using the average gal/unit/day, and the third was using gal/unit/day but for each bedroom size. All these methods have similar yearly total water use for the Atascadero site: 1.20, 1.21, and 1.2 million gal/year respectively. These estimates are similar to the modeled estimate, but on average are roughly 200,000 gal/year more.

Figure E-40 below looks closer at the individual apartments: 2-bedrroom, 3-bedroom, and 4-bedroom. The CBECC draws include some high daily uses that are a similar magnitude of the field data. For example, the four-bedroom CBECC draw had nine high-end outliers, ranging from 150 to 320 gal/day, and the field draws had 10 outlier draws ranging from 120 to 320 gal/day. These somewhat random high usage days are important to include in modeled draws to properly simulate heat pump water heater performance and potentially increase in electrical resistance. At Atascadero there were some high-volume users that did not necessarily follow the trend of higher water use with higher number of bedrooms. For example, there was a two-bedroom unit that used a high of 270 gal/day and on average used water more like a four-bedroom unit of about 70 gal/day.

Figure E-40: The Daily Hot Water Use by Apartment Type, 2- (top), 3- (middle), and 4- (bottom) Bedroom Units



Appendix F: Sunnyvale Performance Data

With Sunnyvale, the sample size was reduced compared to the other three sites. Similar to the other sites, there are correlations with consumption and occupancy.

Whole house consumption is largely sensitive to both individual behavior and seasonality. That said, since tenant loads did not include DHW, there was less impact of seasonality and occupancy impacts. Consumption was sensitive to occupancy (Figure F-1) more so than bedroom type (Figure F-2) as seen in the other developments, but not as strongly as Atascadero, given the lack of DHW loads. Individual behavior also was a primary driver in energy consumption.

Figure F-1: Sunnyvale Daily kWh Based on Occupancy Shows Correlation.

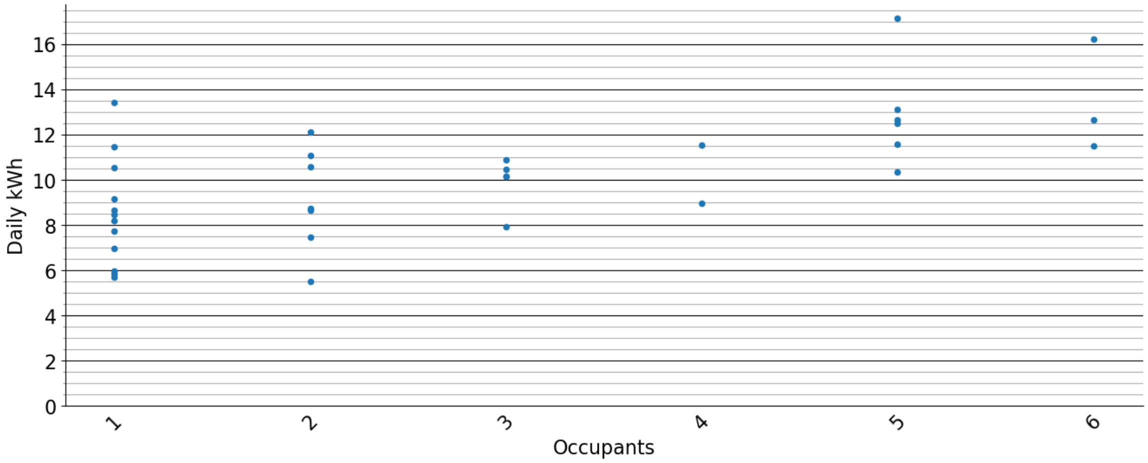
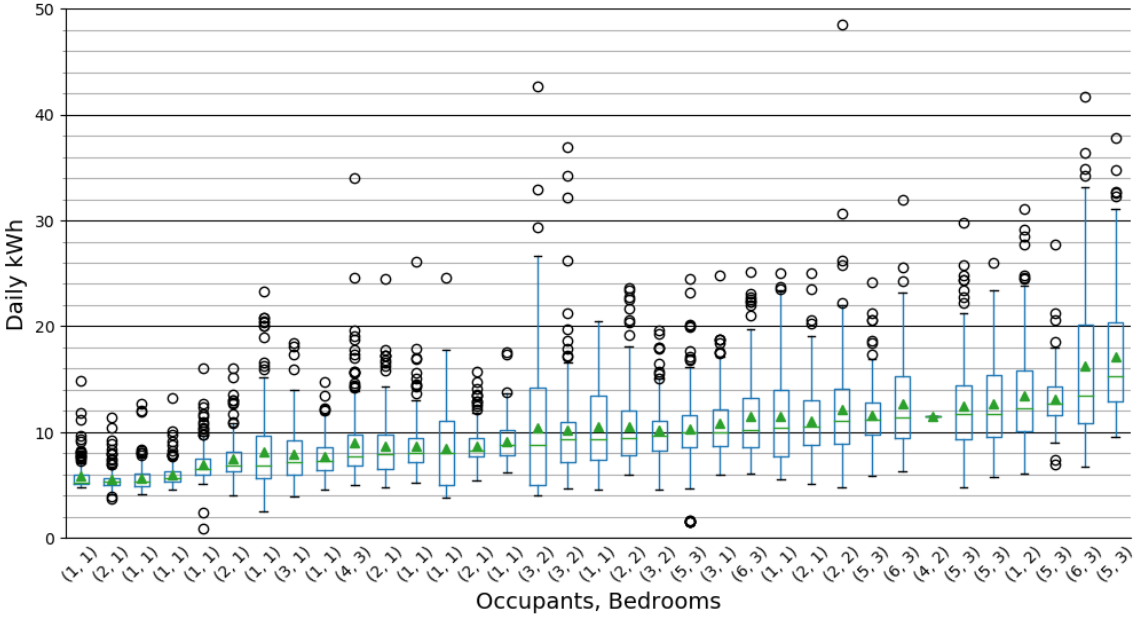


Figure F-2: Sunnyvale Daily kWh Based on Bedroom Type Show a Similar Correlation with Consumption as Occupancy.

Average daily consumption ranged from 5.5 to 17.1 kWh/day (an average of 10.1 kWh) and is normally distributed across apartments as shown in Figure F-3.

Figure F-3: Average Daily Usage Was Relatively Normally Distributed Across Apartments with No Clear Outliers.



Average consumption was reasonably flat across the six months with HVAC driving seasonal differences as shown in Figure F-4.

Figure F-4: Seasonality Seen in Total Loads in this Graph is Attributed to HVAC Loads

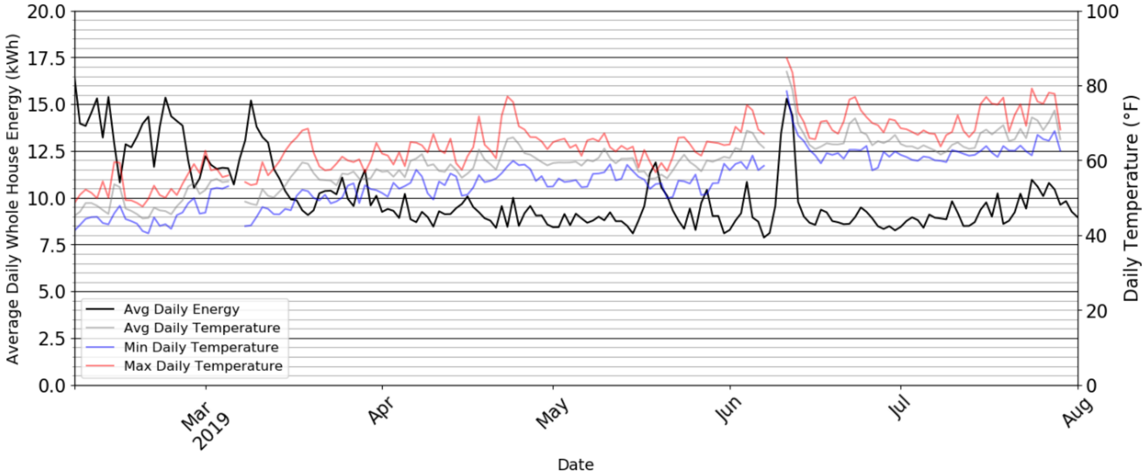


Table F-1 shows the calculated COP of the plants and plant components, and efficiency of the plants.

Table F-1: Sunnyvale Central DHW Plant: Monthly COP by Component

	COP								Plant Efficiency		Temp		
Month	Tank 1	Tank 2	Tank 3	Tank 4	Recirc WH 1/2	Recirc WH 3	Plant 1/2	Plant 3	W1/ 2	W3	OAT	Garage -HP location	Boiler Room - Recirc
January	3.82	3.97	3.75	4.51	2.03	2.28	3.13	4.86	2.72	5.39	50.8	47.9	57.4
February	3.83	3.46	3.59	4.17	1.95	2.18	3.00	4.81	2.90	4.48	53.7	56.0	62.4
March	3.99	3.83	3.74	4.54	2.00	2.40	3.24	4.83	3.10	4.89	54.4	57.0	63.5
April	4.17	4.03	3.99	4.34	2.02	2.49	3.65	4.98	3.37	3.73	58.3	61.8	67.0
May	4.30	4.15	4.05	4.37	2.02	2.48	3.51	4.73	5.00	4.25	61.4	64.9	70.1
June	4.28	4.14	4.17	4.40	2.02	2.70	3.67	4.93	5.90	4.07	66.9	69.9	74.4
July	4.23	4.16	4.29	4.32	1.94	2.69	3.59	4.87	4.86	4.07	66.3	69.9	74.6
August	4.31	4.20	3.93	4.34	1.90	2.90	3.61	4.91	6.66	6.16	70.6	73.2	77.1
September	4.48	4.14	4.47	4.41	1.95	2.76	3.49	5.06	3.32	6.53	68.0	70.6	75.0
October	4.57	4.07	4.31	4.28	1.85	2.57	3.23	4.95	3.07	5.41	62.0	64.6	69.4
November	4.38	4.12	3.91	4.26	2.04	2.35	3.25	5.07	3.22	5.87	57.1	58.3	64.9
December	4.37	4.39	3.78	4.42	2.01	2.18	3.21	4.99	3.05	4.95	53.3	54.3	61.4
Annual Avg	4.23	4.06	4.00	4.36	1.98	2.50	3.38	4.92	3.93	4.98	60.2	62.4	68.1

DHW demand by way of cold water makeup flow was analyzed from both plants to determine the 99th percentile for specific intervals, excluding the 1 percent characterized by outlier events. Peak one-hour, two-hour, and three-hour intervals were used to inform continued demand events versus short large events, which would affect the recovery capacity needed. Twenty-four hour demand was included for comparison, to understand if the demand event was a one-time event occurring during an otherwise low or normal usage or sustained usage throughout the days. **Error! Reference source not found.** includes results for all intervals. Based on the 99 percent peaks for the 16-month monitoring period (April 2019 to August 2020), the ASHRAE Low demand profile was the closest match to actual Sunnyvale demand, but it provided no additional safety factor. Low-Medium provided at least 24 percent safety factor across all demand lengths, while Medium resulted in a system with 127 percent safety factor under even the highest measured peak demand periods.

Table F-2: 99th Percentile 1-Hr, 2-Hr, 3-Hr, and Daily Peak Demand for System Capacity Sizing

System Peak	Measured 15-month 99% Peak (Gallons)	Ecosizer-Based – Benner DHW System Capacity					
		Demand Profiles					
		Low		Low-Medium		Medium	
		Peak Rating (Gallons)	Safety Factor	Peak Rating (Gallons)	Safety Factor	Peak Rating (Gallons)	Safety Factor
Wings 1 and 2 1 Hr	362	687	1.90	870	2.40	1,812	5.01
Wings 1 and 2 2 Hr	567	809	1.43	1,021	1.80	2,082	3.67
Wings 1 and 2 3 Hr	**774**	**931**	**1.20**	**1,171**	**1.51**	**2,351**	**3.04**
Wings 1 and 2 24 Hr	2,915	3,488	1.20	4,330	1.49	8,009	2.75
Wing 3 1 Hr	311	489	1.57	611	1.96	1,005	3.23
Wing 3 2 Hr	484	566	1.17	707	1.46	1,239	2.56
Wing 3 3 Hr	**650**	**643**	**0.99**	**803**	**1.24**	**1,473**	**2.27**
Wing 3 24 Hr	2,108	2,264	1.07	2,827	1.34	6,386	3.03

The average daily DHW consumption was 21.8 gallons per occupant, which was reasonably stable over the course of the year as shown in Figure F-5.

Figure F-5: Average Daily DHW Consumption per Month per Wing and Total Building

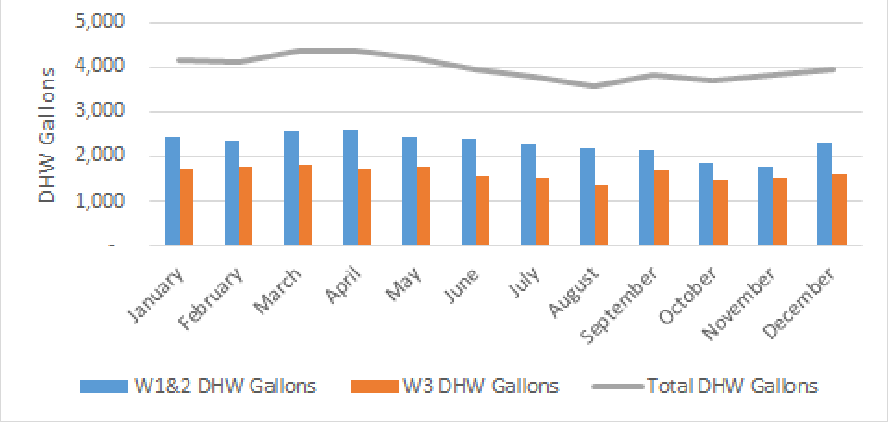
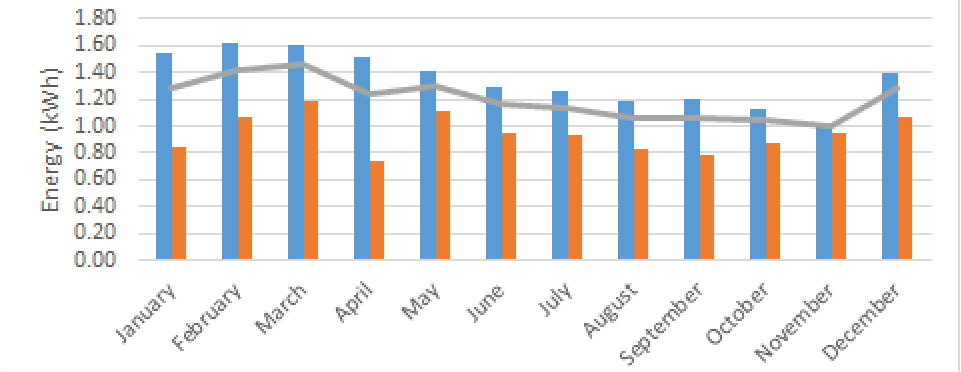


Table F-3 and Figure F-6 show quantified energy consumption of the DHW plants on a per occupant basis, demonstrating increased consumption in winter months as well as corresponding energy consumption.

Table F-3: Daily Average DHW Load per Occupant per Season

Season	Plant 1/2 (kWh)	Plant 3 (kWh)	Total DHW (kWh)	W1/2 Recirc	W3 Recirc
Winter (Dec–Feb)	2.30	1.50	1.99	1.07	0.52
Spring (Mar–May)	1.51	1.02	1.33	0.67	0.30
Summer (Jun–Aug)	1.25	0.90	1.12	0.61	0.25
Fall (Sept–Nov)	1.12	0.87	1.03	0.54	0.18
Annual Daily Average	1.55	1.07	1.37	0.72	0.31

Figure F-6: Average Daily kWh Consumption over 14 Months per Occupancy



As designed, the Sanden heat pumps in each bank are meant to see equal flow, and therefore be able to share the DHW production load equally. There were a number of issues with this control strategy, however (mostly how it was implemented), that yielded unequal operation and runtime of the heat pumps within each bank, as discussed and shown in Table F-4.

Table F-4: Average Percent Runtime of Each Heat Pump per Plant

	HP 1-1 (%)	HP 1-2 (%)	HP 1-3 (%)	HP 1-4 (%)	HP 2-1 (%)	HP 2-2 (%)	HP 2-3 (%)	HP 2-4 (%)	HP 3-1 (%)	HP 3-2 (%)	HP 3-3 (%)	HP 3-4 (%)	HP 4-1 (%)	HP 4-2 (%)	HP 4-3 (%)	HP 4-4 (%)
Full Monitoring Period	6	15	5	75	2	13	78	18	18	58	30	30	77	38	0	47
1/20/19–2/28/19	3	44	13	93	2	36	69	1	46	34	46	17	89	100	0	29
3/1/19- 3/14/19	14	47	8	83	0	0	100	0	32	44	57	68	87	100	0	67
3/15/19–6/2/20	5	12	5	79	2	8	80	15	15	60	33	33	75	39	0	50
6/4/20–8/24/20	13	17	0	46	0	25	72	45	18	63	7	18	84	0	0	43

The average recirculation load (pump energy, recirculation heater, losses) was calculated in watts per apartment per hour of the day to compare to design standards of 100 W per apartment. Table F-5 contains the average recirculation load shown from the period of late November 2019 to early April 2020.

Table F-5: Average Recirculation Load per Hour – December 2019 to April 2020

Hour	W1&2 Avg W/Apt Recirc Load	W3 Avg W/Apt Recirc Load
0	99.63	46.35
1	101.03	45.64
2	101.98	44.61
3	102.28	45.37
4	102.72	46.11
5	101.96	47.19
6	94.67	45.61
7	95.81	40.34
8	95.27	45.43
9	92.34	43.71
10	92.93	44.09
11	91.62	43.13
12	91.72	42.04
13	92.02	41.02
14	93.38	41.06
15	92.81	40.69
16	90.43	40.22
17	86.12	39.14
18	84.41	39.28
19	83.94	40.03
20	86.05	39.24
21	87.57	41.48
22	94.10	44.82
23	98.31	45.56

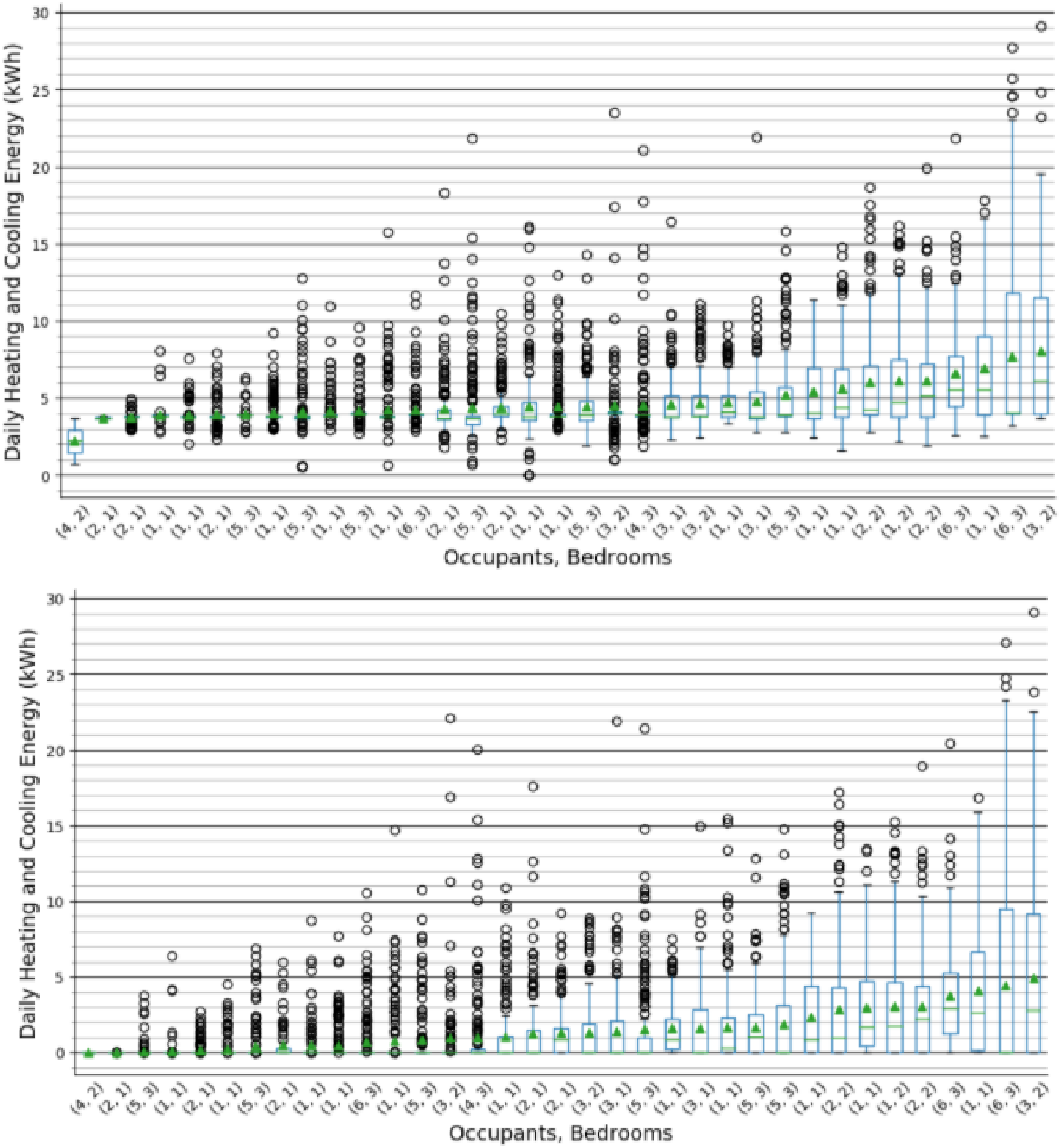
COP was calculated for the thermal storage experiment periods. Despite energy consumption being reduced, there was also a small reduction in the COP of both bank 1 and of the overall plant. This reduction in average COP per heat pump bank and DHW plant was somewhat surprising given the coincident energy reduction during the same time period (Figure F-6). The cause of this is not completely evident but may have been partially attributed to reduced water consumption.

Table F-6: COP Reduction Pre- and Post-Thermal Load Shifting Commencement

Date Range	Bank 1 COP	Bank 2 COP	Bank 3 COP	Plant 1/2 COP	Bank 1 COP % Redux	Bank 2 COP % Redux	Bank 3 COP % Redux	Plant 1/2 COP % Redux	CWMU - DHW Gal	CWMU - DHW Gal % Redux
5/17–6/2	4.00	4.08	4.03	3.52					2,598	
6/4–6/20	3.84	4.00	3.97	3.39	-4.4%	-2.0%	-1.5%	-3.8%	2,544	-2.1%

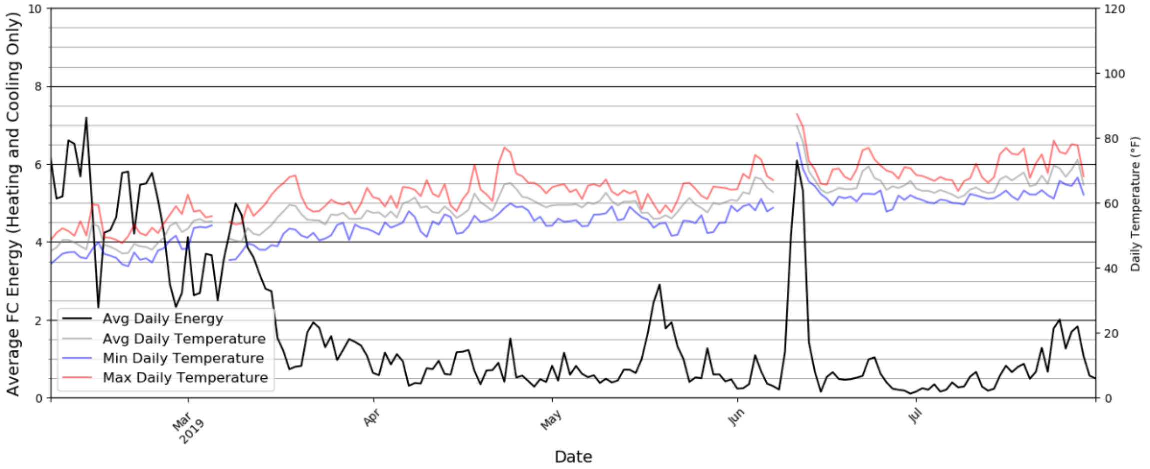
Overall heating and cooling loads were low, with heating being the dominant load. Through monitoring the research identified a baseload. Figure F-7 shows total loads with baseloads included in the upper graph compared lower graph where baseloads are omitted.

Figure F-7: The Average Daily Consumption Is Overall Low For All Apartments, Yet the Upper Graph Includes Baseload and the Lower Graph Has This Baseload Omitted



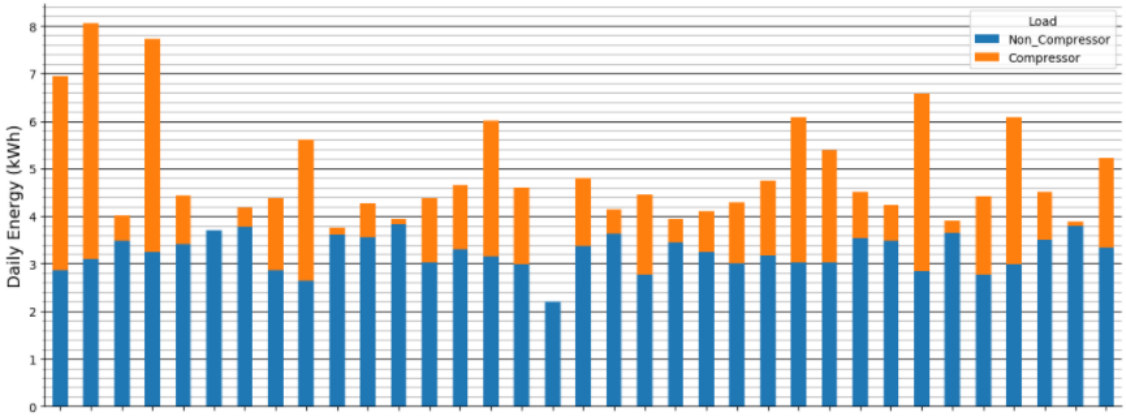
Averages and variance in runtimes across apartments was greater in the winter, but varied greatly in response to short-term weather patterns (Figure F-8).

Figure F-8: The HVAC Load Are Subject to Higher Consumption in Response to Peak Events of Outdoor Temperature



The load was relatively evenly distributed across apartments as shown in Figure F-9.

Figure F-9: The Baseload Is Relatively Consistent Across All Apartments, Ranging from 3–3.5 kWh.



To investigate the phantom baseload from HVAC operation brought to light by HVAC monitoring data, electrical performance testing was conducted on a Mitsubishi ductless mini-split heat pump unit installed in a different building and intended to be completed on one installed at Sunnyvale. The evaluation included measured current draw in different modes of operation and without power as a baseline. The testing measured current draw in amps of the equipment during different modes of operation, both for the outdoor compressor unit and the indoor head units. Power was turned off at the circuit breaker to initiate the test; both the indoor and outdoor units measured no current. The breaker was turned back on and current was measured at the indoor head units and outdoor compressor unit prior to any call for conditioning. Both heating and cooling were enabled in stages, and current at each of the indoor units and at the outdoor unit was measured at each stage of the specified conditioning. Results of this evaluation has not been completed, due to limited access to data and to sites.

Appendix G: Customer Satisfaction Survey Results

	N
Atascadero	25
Calistoga	30
Cloverdale	24
Sunnyvale	

CATEGORY	QUESTION	SUB QUESTION	Q #	SUB Q#		1	2	3	4	5	6	7	8	9	Did Not Answer	n
Air Quality	To what extent are you satisfied or dissatisfied with the indoor air quality in your home? Think about odors, air circulation or movement. ?		Q1		Atascadero	0	0	0	0	2	0	0	4	19	0	25
					Calistoga	3	0	0	0	12	0	3	3	9	0	30
					Cloverdale	2	0	0	0	6	0	2	1	12	1	23
					Sunnyvale	0	0	0	0	0	0	0	0	0	0	0
	How would you rate the outdoor air quality near where you live?		Q2		Atascadero	1	0	0	0	9	0	2	1	12	0	25
					Calistoga	0	0	0	0	10	0	1	2	17	0	30
					Cloverdale	2	0	0	0	5	0	1	0	15	1	23
					Sunnyvale	0	0	0	0	0	0	0	0	0	0	0
	How would you rate your home in protecting you from outdoor air pollution?		Q3		Atascadero	2	0	0	0	4	1	0	1	17	0	25
					Calistoga	0	0	0	0	8	0	2	3	17	0	30
					Cloverdale	1	0	0	0	8	0	1	0	13	1	23
					Sunnyvale	0	0	0	0	0	0	0	0	0	0	0
Noise	To what extent are you satisfied or dissatisfied with the noise level inside your home?		Q4		Atascadero	2	0	0	0	12	0	1	3	7	0	25
					Calistoga	0	0	0	0	8	0	1	4	17	0	30
					Cloverdale	0	0	1	0	7	0	3	0	13	0	24
					Sunnyvale	0	0	0	0	0	0	0	0	0	0	0
	To what extent are you satisfied or dissatisfied with the noise level outside (not including traffic) in your home?		Q5		Atascadero	3	0	0	0	6	0	3	3	10	0	25
					Calistoga	1	0	0	0	8	0	2	8	11	0	30
					Cloverdale	0	1	0	1	7	0	3	2	9	1	23
					Sunnyvale	0	0	0	0	0	0	0	0	0	0	0
Comfort	What temperature do you keep your thermostat at:	Winter Warmth	Q6	a	Atascadero											
					Calistoga											
					Cloverdale											
					Sunnyvale											
	What temperature do you keep your thermostat at:	Summer Cooling	Q6	b	Atascadero											
					Calistoga											
					Cloverdale											
					Sunnyvale											

						Rarely or Never	Few Times a Month	Few Times a Week	Every Day	Did Not Answer	n
Winter	In **WINTER**, how often do the following conditions affect the comfort of occupants in your home?	Too Hot in some rooms	Q7	a	Atascadero	11	2	3	2	7	18
					Calistoga	23	3	1	2	1	29
					Cloverdale	16	3	3	2	0	24
					Sunnyvale	0	0	0	0	0	0
	In **WINTER**, how often do the following conditions affect the comfort of occupants in your home?	Too cold in some rooms	Q7	b	Atascadero	14	3	1	0	7	18
					Calistoga	26	1	0	3	0	30
					Cloverdale	13	5	5	1	0	24
					Sunnyvale	0	0	0	0	0	0
	In **WINTER**, how often do the following conditions affect the comfort of occupants in your home?	Too much air movement.	Q7	c	Atascadero	16	1	1	0	7	18
					Calistoga	27	2	0	1	0	30
					Cloverdale	18	4	2	0	0	24
					Sunnyvale	0	0	0	0	0	0
	In **WINTER**, how often do the following conditions affect the comfort of occupants in your home?	Not enough air movement.	Q7	d	Atascadero	17	1	0	0	7	18
					Calistoga	26	1	3	0	0	30
					Cloverdale	17	4	3	0	0	24
					Sunnyvale	0	0	0	0	0	0
	In **WINTER**, how often do the following conditions affect the comfort of occupants in your home?	Indoor air is too dry.	Q7	e	Atascadero	16	0	1	1	7	18
					Calistoga	26	1	2	0	1	29
					Cloverdale	19	2	2	0	1	23
					Sunnyvale	0	0	0	0	0	0
	In **WINTER**, how often do the following conditions affect the comfort of occupants in your home?	Indoor air is too damp.	Q7	f	Atascadero	15	3	0	0	7	18
					Calistoga	22	4	2	1	1	29
					Cloverdale	19	4	1	0	0	24
					Sunnyvale	0	0	0	0	0	0
	In **WINTER**, how often do the following conditions affect the comfort of occupants in your home?	Indoor air has musty odor.	Q7	g	Atascadero	17	1	0	0	7	18
					Calistoga	25	2	0	3	0	30
					Cloverdale	20	3	1	0	0	24
					Sunnyvale	0	0	0	0	0	0
	In **WINTER**, how often do the following conditions affect the comfort of occupants in your home?	Does not warm up fast enough.	Q7	h	Atascadero	18	0	0	0	7	18
					Calistoga	23	2	1	4	0	30
					Cloverdale	18	1	4	1	0	24
					Sunnyvale	0	0	0	0	0	0

Summer	In **SUMMER**, how often do the following conditions affect the comfort of occupants in your home?	Too Hot in some rooms	Q8	a	Atascadero	16	3	1	4	1	24
					Calistoga	17	1	4	8	0	30
					Cloverdale	8	7	3	2	4	20
					Sunnyvale	0	0	0	0	0	0
	In **SUMMER**, how often do the following conditions affect the comfort of occupants in your home?	Too cold in some rooms	Q8	b	Atascadero	18	3	3	0	1	24
					Calistoga	27	1	1	1	0	30
					Cloverdale	12	4	3	1	4	20
					Sunnyvale	0	0	0	0	0	0
	In **SUMMER**, how often do the following conditions affect the comfort of occupants in your home?	Too much air movement.	Q8	c	Atascadero	23	0	0	1	1	24
					Calistoga	28	1	0	1	0	30
					Cloverdale	16	3	1	0	4	20
					Sunnyvale	0	0	0	0	0	0
	In **SUMMER**, how often do the following conditions affect the comfort of occupants in your home?	Not enough air movement.	Q8	d	Atascadero	23	1	0	0	1	24
					Calistoga	22	1	0	6	1	29
					Cloverdale	16	2	1	1	4	20
					Sunnyvale	0	0	0	0	0	0
	In **SUMMER**, how often do the following conditions affect the comfort of occupants in your home?	Indoor air is too dry.	Q8	e	Atascadero	21	1	1	1	1	24
					Calistoga	21	1	3	5	0	30
					Cloverdale	18	1	0	1	4	20
					Sunnyvale	0	0	0	0	0	0
	In **SUMMER**, how often do the following conditions affect the comfort of occupants in your home?	Indoor air is too damp.	Q8	f	Atascadero	22	2	0	0	1	24
					Calistoga	25	2	0	3	0	30
					Cloverdale	16	2	0	0	6	18
					Sunnyvale	0	0	0	0	0	0
	In **SUMMER**, how often do the following conditions affect the comfort of occupants in your home?	Indoor air has musty odor.	Q8	g	Atascadero	22	2	0	0	1	24
					Calistoga	24	2	0	4	0	30
					Cloverdale	17	2	0	0	5	19
					Sunnyvale	0	0	0	0	0	0
	In **SUMMER**, how often do the following conditions affect the comfort of occupants in your home?	Does not warm up fast enough.	Q8	h	Atascadero	23	0	1	0	1	24
					Calistoga	20	2	1	7	0	30
					Cloverdale	16	1	0	2	5	19
					Sunnyvale	0	0	0	0	0	0

						Always	Most of the time	Sometimes	Rarely	Never	Don't Know	Did Not Answer	n
Indoor	How often is the kitchen range hood or kitchen exhaust fan used when cooking on the range?		Q9		Atascadero	12	7	5	1	0	0	0	25
					Calistoga	19	6	4	1	0	0	0	30
					Cloverdale	13	8	1	0	0	1	1	23
					Sunnyvale	0 x	0	0	0	0	0	0	0
	If the kitchen range hood or kitchen exhaust fan is NOT always used, what are the reasons for not using it? Select all that apply.	Forget to turn it on	Q10	a	Atascadero	1							
					Calistoga	1							
					Cloverdale	2							
					Sunnyvale	0							
	If the kitchen range hood or kitchen exhaust fan is NOT always used, what are the reasons for not using it? Select all that apply.	not needed for what is being cooked	Q10	b	Atascadero	2							
					Calistoga	11							
					Cloverdale	5							
					Sunnyvale	0							
	If the kitchen range hood or kitchen exhaust fan is NOT always used, what are the reasons for not using it? Select all that apply.	Too noisy	Q10	c	Atascadero	0							
					Calistoga	0							
					Cloverdale	0							
					Sunnyvale	0							
	If the kitchen range hood or kitchen exhaust fan is NOT always used, what are the reasons for not using it? Select all that apply.	Doesn't seem to remove cooking fumes or odors	Q10	d	Atascadero	0							
					Calistoga	0							
					Cloverdale	0							
					Sunnyvale	0							
	If the kitchen range hood or kitchen exhaust fan is NOT always used, what are the reasons for not using it? Select all that apply.	Open window instead	Q 10	e	Atascadero	1							
					Calistoga	5							
					Cloverdale	3							
					Sunnyvale	0							
	If the kitchen range hood or kitchen exhaust fan is NOT always used, what are the reasons for not using it? Select all that apply.	Uses too much energy	Q 10	f	Atascadero	0							
					Calistoga	0							
					Cloverdale	0							
					Sunnyvale	0							
	If the kitchen range hood or kitchen exhaust fan is NOT always used, what are the reasons for not using it? Select all that apply.	Other, please describe	Q 10	g	Atascadero	0							
					Calistoga	0							
					Cloverdale	0							
					Sunnyvale	0							

					Fewer than 8 hours per day	8 to 12 hours per day	12 to 16 hours per day	16 to 20 hours per day	More than 20 hours per day	Did Not Answer	n
On average, how many hours per day is your home occupied by at least one person, including day and night hours?	Weekday	Q 11	a	Atascadero	2	3	2	2	16	0	25
				Calistoga	1	6	1	3	19	0	30
				Cloverdale	4	4	3	2	10	1	23
				Sunnyvale	0	0	0	0	0	0	0
On average, how many hours per day is your home occupied by at least one person, including day and night hours?	Weekend	Q 11	b	Atascadero	3	4	3	3	12	0	25
				Calistoga	1	4	1	8	16	0	30
				Cloverdale	3	2	3	2	12	2	22
				Sunnyvale	0	0	0	0	0	0	0

					0 Hour per day	1 to 2 hours per day	2 to 8 hours per day	8 to 16 hours per day	More than 16 hours per day	Did Not Answer	n
On average, how many hours per day are your windows open in your house? (summer)	Summer	Q 12	a	Atascadero	5	12	7	1	0	0	25
				Calistoga	5	8	12	4	1	0	30
				Cloverdale	4	4	5	2	6	3	21
				Sunnyvale	0	0	0	0	0	0	0
On average, how many hours per day are your windows open in your house? (Fall)	Fall	Q 12	b	Atascadero	12	7	5	0	0	1	24
				Calistoga	9	8	8	3	2	0	30
				Cloverdale	3	7	8	2	2	2	22
				Sunnyvale	0	0	0	0	0	0	0
On average, how many hours per day are your windows open in your house? (winter)	Winter	Q 12	c	Atascadero	13	7	3	1	0	1	24
				Calistoga	16	11	3	0	0	0	30
				Cloverdale	4	10	5	3	1	1	23
				Sunnyvale	0	0	0	0	0	0	0
On average, how many hours per day are your windows open in your house? (spring)	Spring	Q 12	d	Atascadero	7	5	13	0	0	0	25
				Calistoga	8	11	7	4	0	0	30
				Cloverdale	2	7	7	3	3	2	22
				Sunnyvale	0	0	0	0	0	0	0

						0 times per week	1 to 2 times per week	3 to 4 times per week	5 to 6 times per week	7 times per week	Did Not Answer	n				
	On average, how often do you leave your bedroom windows open at night when you sleep? (Summer)	Summer	Q 13	a	Atascadero	12	6	1	1	5	0	25				
					Calistoga	9	2	6	0	13	0	30				
					Cloverdale	3	6	4	3	6	2	22				
					Sunnyvale	0	0	0	0	0	0	0				
	On average, how often do you leave your bedroom windows open at night when you sleep? (Fall)	Fall	Q 13	b	Atascadero	13	5	2	1	3	1	24				
					Calistoga	14	5	5	1	5	0	30				
					Cloverdale	5	9	2	1	5	2	22				
					Sunnyvale	0	0	0	0	0	0	0				
	On average, how often do you leave your bedroom windows open at night when you sleep? (Winter)	Winter	Q 13	c	Atascadero	19	3	2	0	0	1	24				
					Calistoga	24	3	1	0	2	0	30				
					Cloverdale	11	7	1	1	3	1	23				
					Sunnyvale	0	0	0	0	0	0	0				
	On average, how often do you leave your bedroom windows open at night when you sleep? (Spring)	Spring	Q 13	d	Atascadero	13	4	5	1	2	0	25				
					Calistoga	13	5	3	2	7	0	30				
					Cloverdale	4	9	3	0	6	2	22				
					Sunnyvale	0	0	0	0	0	0	0				
	On average, how often do you leave your bedroom door open at night when you sleep?		Q 14		Atascadero	16	2	1	0	6	0	25				
					Calistoga	17	2	0	0	11	0	30				
					Cloverdale	10	1	1	2	9	1	23				
					Sunnyvale	0	0	0	0	0	0	0				
						1Surprisingly Low	2	3About Right	4	5Too High	Did Not Answer	n				
Energy Use	Do you feel like your bill is surprisingly low, about right, or too high?		Q 15		Atascadero	5	3	15	1	1	0	25				
					Calistoga	14	1	13	0	2	0	30				
					Cloverdale	4	1	16	0	1	2	22				
					Sunnyvale	0	0	0	0	0	0	0				
						1Not Aware	2	3	4	5Neutral	6	7	8	9Very Aware	Did Not Answer	n
	How aware were you of how you used energy in your home before the NEXI (lighting display) was installed?		Q 16		Atascadero	13	0	0	0	5	0	1	2	4	0	25
					Calistoga	8	0	1	0	5	1	1	4	10	0	30
					Cloverdale	8	0	0	0	0	0	2	0	5	9	15
					Sunnyvale	0	0	0	0	0	0	0	0	0	0	0
	With the presence of the light display, do you feel more connected/aware of your energy use?		Q 17		Atascadero	4	0	0	0	0	0	0	0	13	8	17
					Calistoga	1	0	0	0	0	0	0	2	21	6	24
					Cloverdale	2	0	0	0	0	0	0	0	9	13	11
					Sunnyvale	0	0	0	0	0	0	0	0	0	0	0

			Never	Once	Twice	Three to Five	More than five times	Did Not Answer	n
How many times do you notice the monitor per day?	Q 18	Atascadero	5	1	7	4	7	1	24
		Calistoga	3	2	7	3	15	0	30
		Cloverdale	1	2	12	6	2	1	23
		Sunnyvale	0	0	0	0	0	0	0

			1Decreased	2	3	4	5Neutral	6	7	8	9Increased	Did Not Answer	n
How has your utility bill changed since you moved in?	Q 19	Atascadero	16	0	0	0	9	0	0	0	0	0	25
		Calistoga	21	0	0	0	9	0	0	0	0	0	30
		Cloverdale	13	0	0	1	0	0	1	0	0	9	15
		Sunnyvale	0	0	0	0	0	0	0	0	0	0	0

			1Rarely or Never	2	3Every other Month	4	5Every Month	Did Not Answer	n
How often are you surprised by your energy bill since the NEXI was installed?	Q 20	Atascadero	11	2	7	1	4	0	25
		Calistoga	16	2	3	1	8	0	30
		Cloverdale	6	1	7	0	8	2	22
		Sunnyvale	0	0	0	0	0	0	0

			Yes	No	Did Not Answer	n
Is your energy display currently plugged in and illuminated?	Q 21	Atascadero	24	1	0	25
		Calistoga	30	0	0	30
		Cloverdale	21	0	3	21
		Sunnyvale	0	0	0	0

			1Not At All	2	3	4	5Somewhat	6	7	8	9Significant	Did Not Answer	n
How much has the presence of the lighting display influenced your behavior?	Q 22	Atascadero	4	0	1	0	12	0	0	0	7	1	24
		Calistoga	6	1	0	0	7	0	2	1	13	0	30
		Cloverdale	1	0	1	0	9	1	1	0	8	3	21
		Sunnyvale	0	0	0	0	0	0	0	0	0	0	0

						Rarely or Never	Few Times a Month	Few Times a Week	Every Day	Did Not Answer	n
Domestic Hot Water	n **SUMMER**, how often do the following conditions affect your satisfaction with your hot water?	Too hot at some fixtures.	**Q 23**	**a**	Atascadero	20	4	0	1	0	25
					Calistoga	23	2	1	4	0	30
					Cloverdale	15	1	1	1	6	18
					Sunnyvale	0	0	0	0	0	0
	n **SUMMER**, how often do the following conditions affect your satisfaction with your hot water?	Wait too long for hot water at some fixtures.	**Q 23**	**b**	Atascadero	18	5	1	1	0	25
					Calistoga	28	2	0	0	0	30
					Cloverdale	17	2	0	0	5	19
					Sunnyvale	0	0	0	0	0	0
	n **SUMMER**, how often do the following conditions affect your satisfaction with your hot water?	Flow is too low at some fixtures.	**Q 23**	**c**	Atascadero	23	1	0	1	0	25
					Calistoga	29	0	0	1	0	30
					Cloverdale	18	0	1	0	5	19
					Sunnyvale	0	0	0	0	0	0
	n **SUMMER**, how often do the following conditions affect your satisfaction with your hot water?	Not hot enough at some fixtures.	**Q 23**	**d**	Atascadero	23	2	0	0	0	25
					Calistoga	30	0	0	0	0	30
					Cloverdale	19	0	1	0	4	20
					Sunnyvale	0	0	0	0	0	0
	In **WINTER**, how often do the following conditions affect your satisfaction with your hot water?	Too hot at some fixtures.	**Q 24**	**a**	Atascadero	22	1	0	1	1	24
					Calistoga	25	2	0	3	0	30
					Cloverdale	21	1	0	1	1	23
					Sunnyvale	0	0	0	0	0	0
	In **WINTER**, how often do the following conditions affect your satisfaction with your hot water?	Wait too long for hot water at some fixtures.	**Q 24**	**b**	Atascadero	14	7	2	1	1	24
					Calistoga	21	4	3	2	0	30
					Cloverdale	20	2	1	0	1	23
					Sunnyvale	0	0	0	0	0	0
	In **WINTER**, how often do the following conditions affect your satisfaction with your hot water?	Flow is too low at some fixtures.	**Q 24**	**c**	Atascadero	23	0	0	1	1	24
					Calistoga	28	1	0	1	0	30
					Cloverdale	22	1	0	0	1	23
					Sunnyvale	0	0	0	0	0	0
	In **WINTER**, how often do the following conditions affect your satisfaction with your hot water?	Not hot enough at some fixtures.	**Q 24**	**d**	Atascadero	22	2	0	0	1	24
					Calistoga	23	4	2	1	0	30
					Cloverdale	23	0	0	0	1	23
					Sunnyvale	0	0	0	0	0	0

				0Not at All	1	2	3	4	0	6	7	8	9	10Extremely Likely	Did Not Answer
General	How likely would you be to recommend living in your community based on noise, air quality, comfort, energy use, and hot water delivery?	**Q 25**	Atascadero	1	0	0	0	1	1	0	1	3	2	13	3
			Calistoga	0	0	0	0	0	0	2	0	3	3	20	2
			Cloverdale	0	0	0	0	0	0	0	0	1	3	17	3
			Sunnyvale	0	0	0	0	0	0	0	0	0	0	0	0

Appendix H: Team Members

Association for Energy Affordability

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Monitoring Plan