Zero and Beyond

Marc Rosenbaum, PE – South Mountain Company – Martha's Vineyard, MA

Overview

- Basis
- Where the energy goes
- Production and consumption
- Solar electric (PV) components, guidelines, issues
- Battery storage

Basis

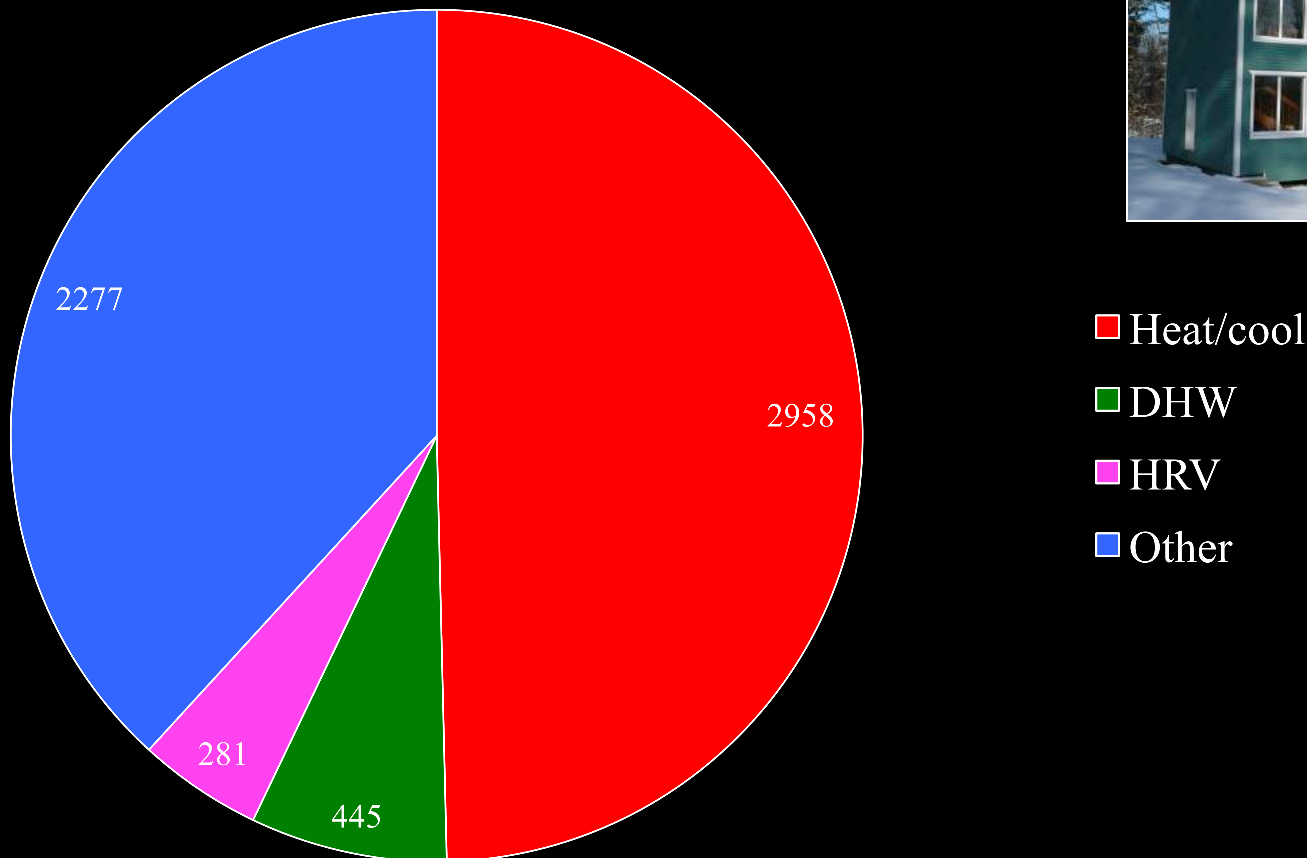
- Zero (or better!) net annual site energy
- All electric buildings using air source heat pumps
- Renewable energy is from grid-interconnected, on-site PV
- Experience from MA, NH, and VT superinsulated houses
- Data logging from either monthly reading of glass front meters or eMonitor

Where the Energy Goes

- Data from 13 homes, 2-4 occupants
- Superinsulated houses, 1,200 to 1,600 sf, new and DER
- One house is a PH and is 2,400 sf
- All minisplit HPs
- Electric DHW, solar DHW, and HPWH

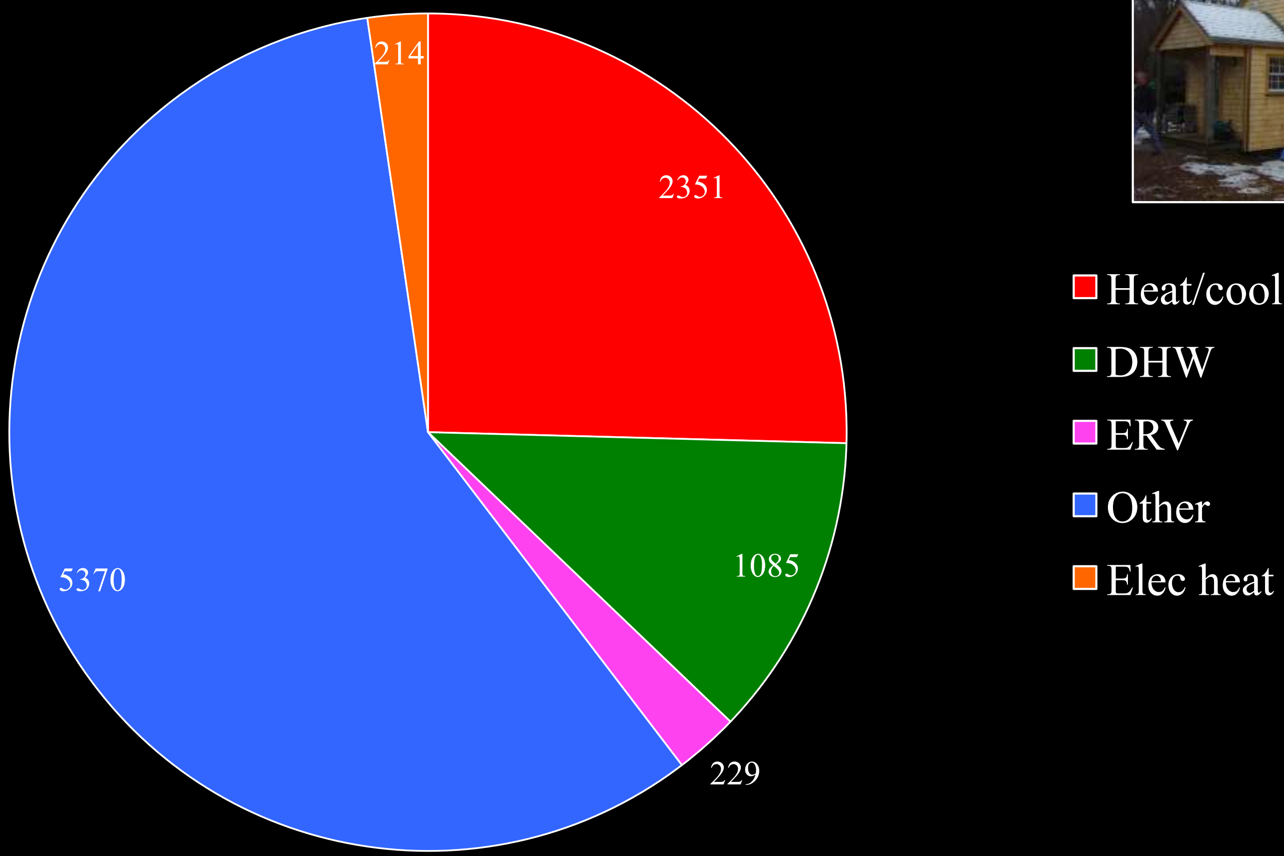
VT PH

kWh by End Use, 3 Years
Annualized 5961 kWh

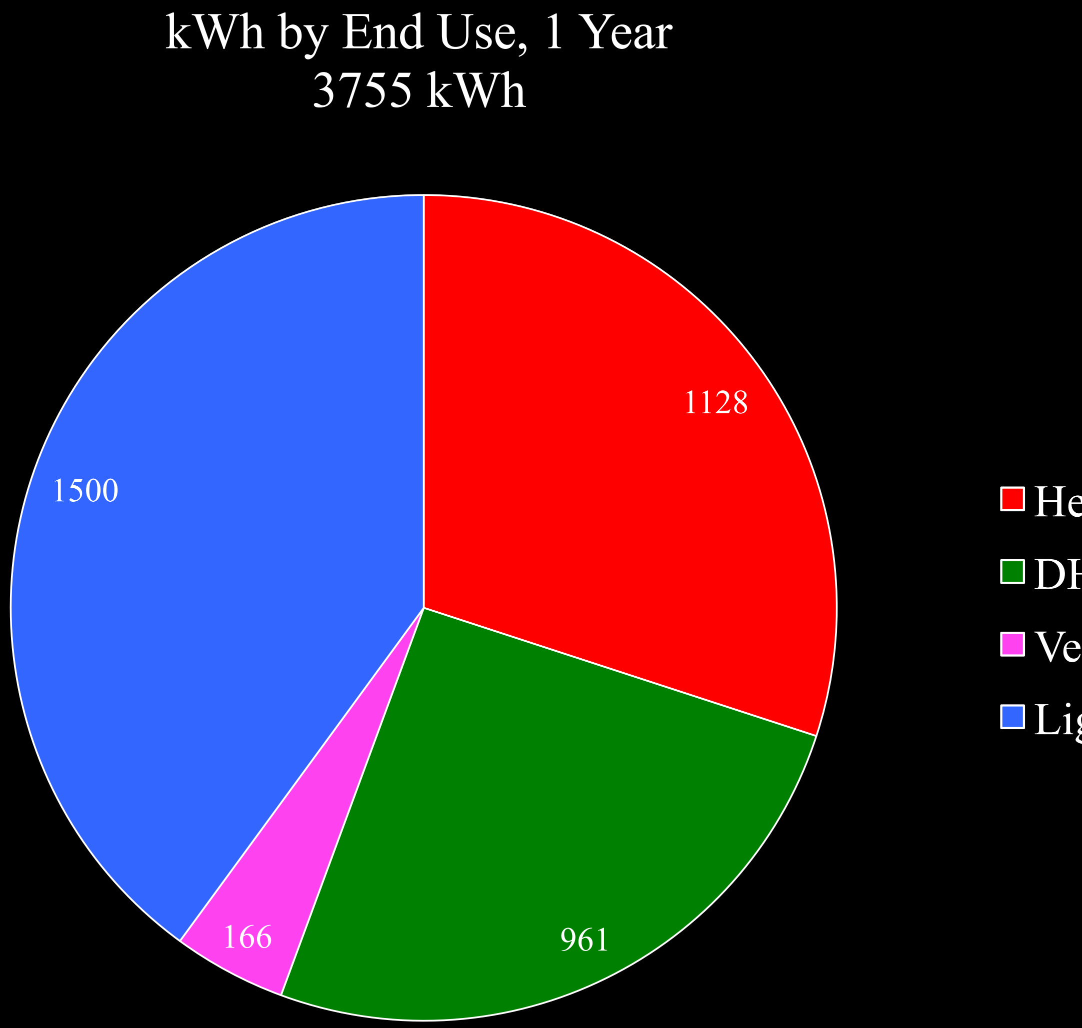


MV DER 1

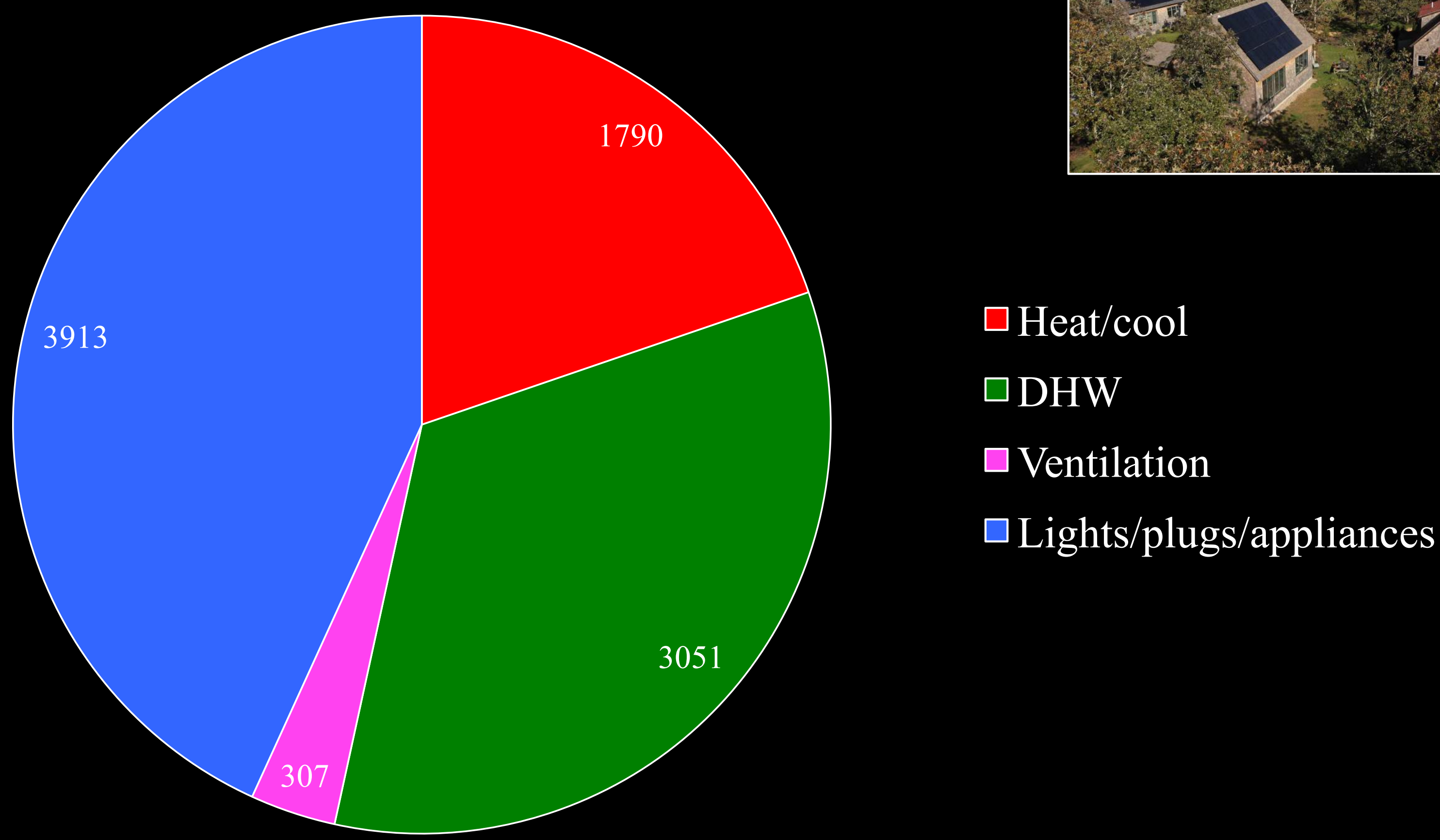
kWh by End Use, 3 Years
Annualized 9249 kWh



MV Shallow ER

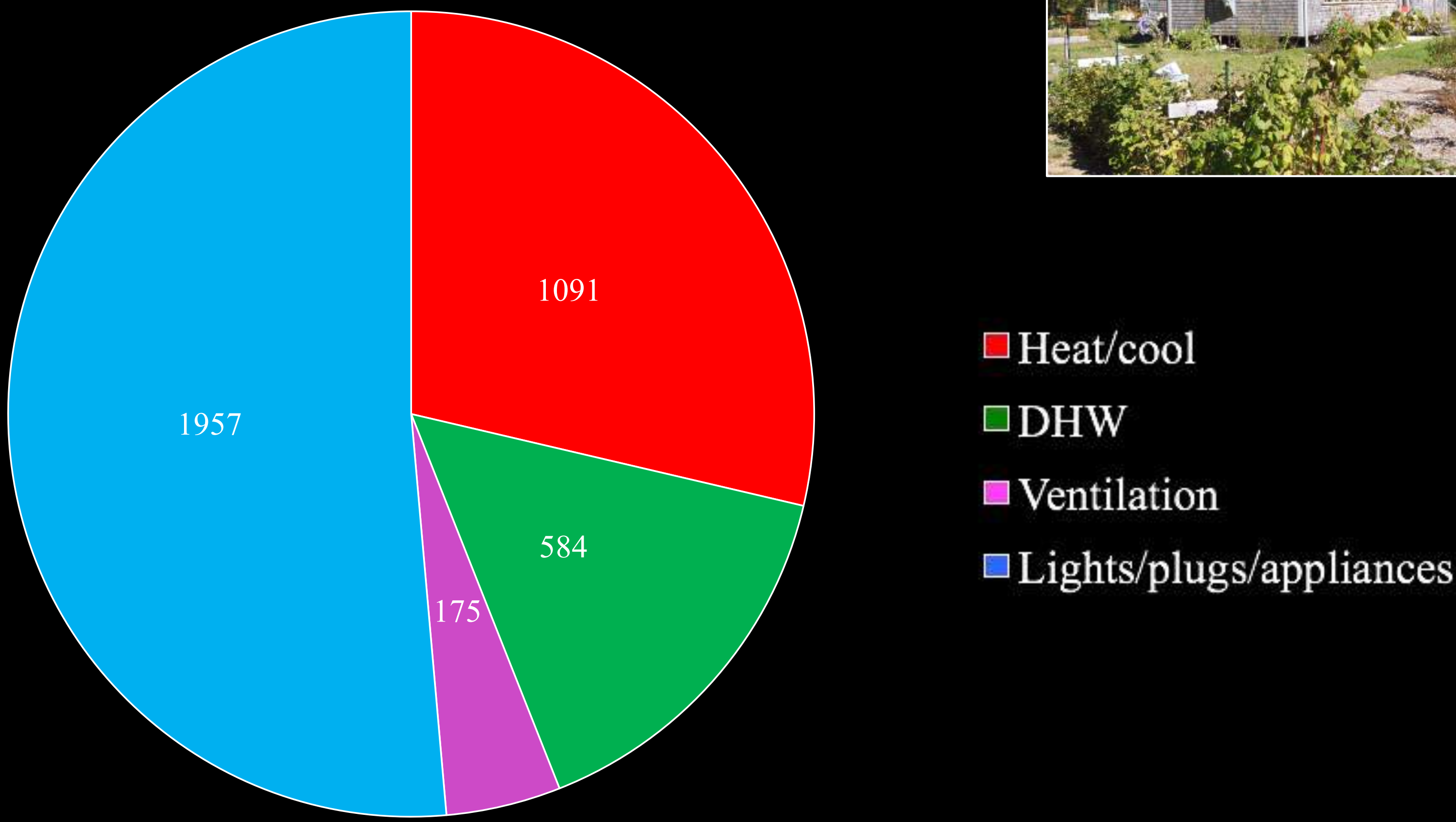


8 MV Houses

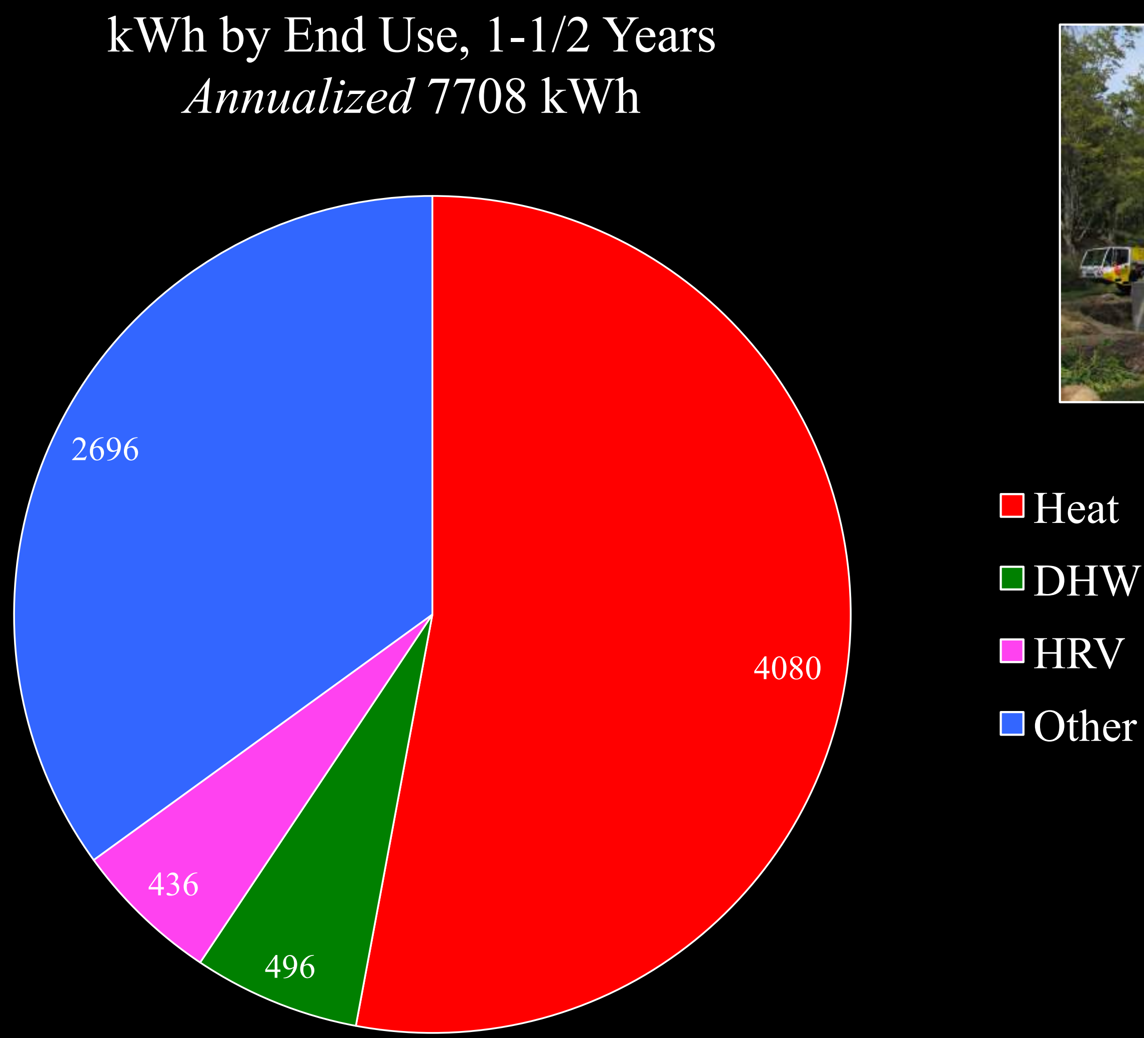

kWh by End Use, 8 Households, 4 Years
Annualized Average 9051 kWh
1790
3051
307
3913
Heat/cool
DHW
Ventilation
Lights/plugs/appliances

MV DER 2

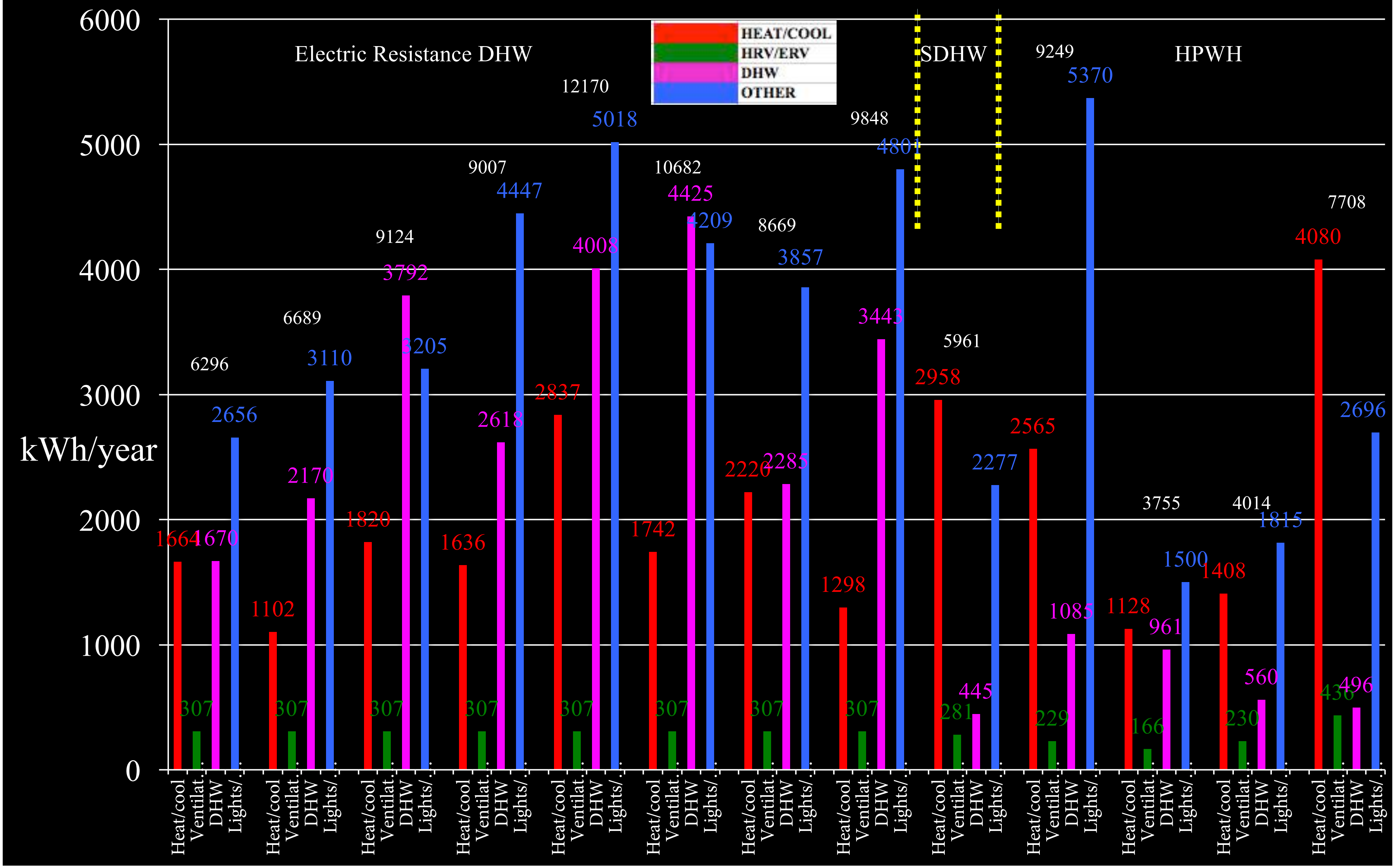
kWh by End Use, 3 Years
Annualized 3808 kWh



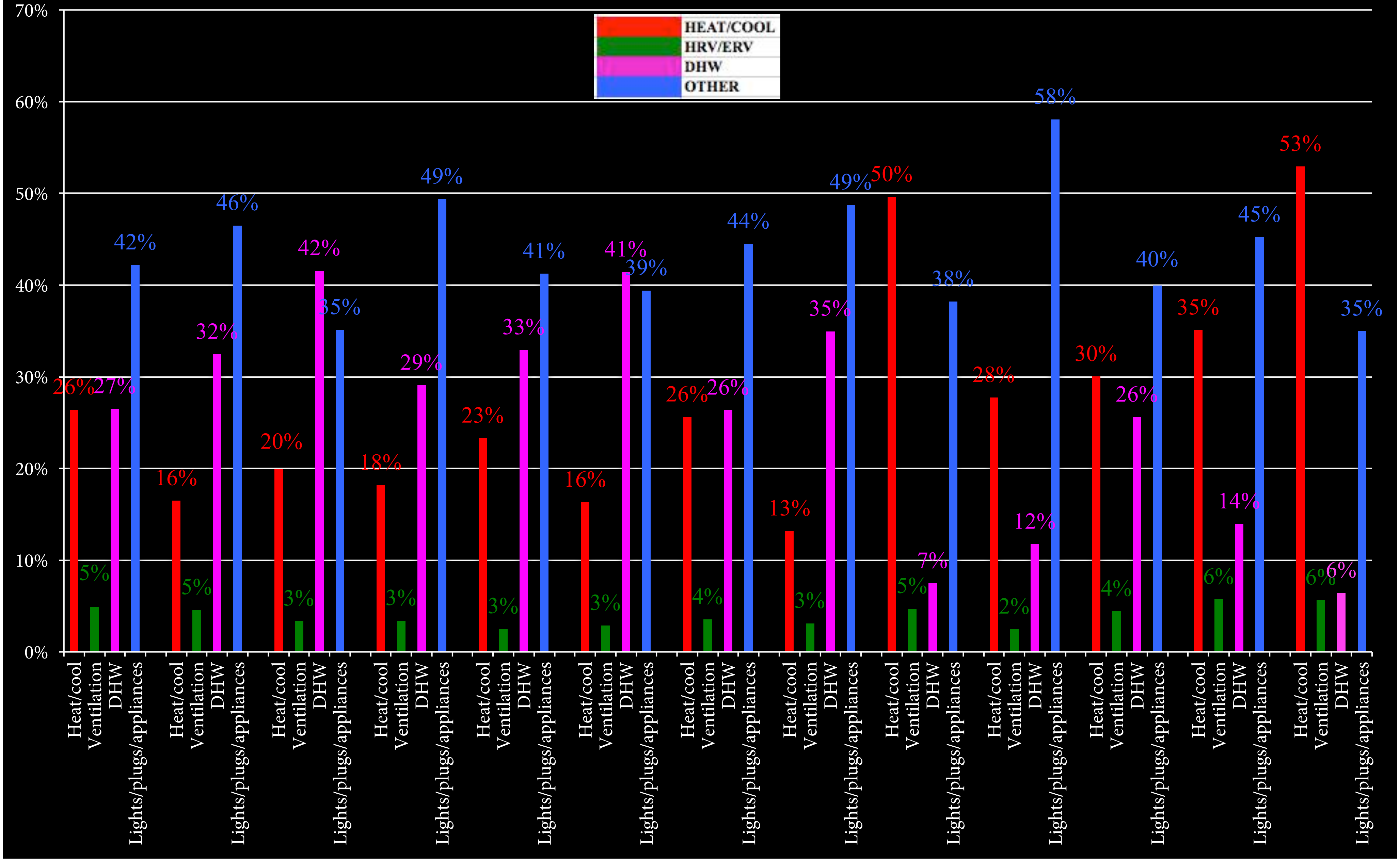
VT DER


kWh by End Use, 1-1/2 Years
Annualized 7708 kWh
2696
4080
436
496
Heat
DHW
HRV
Other

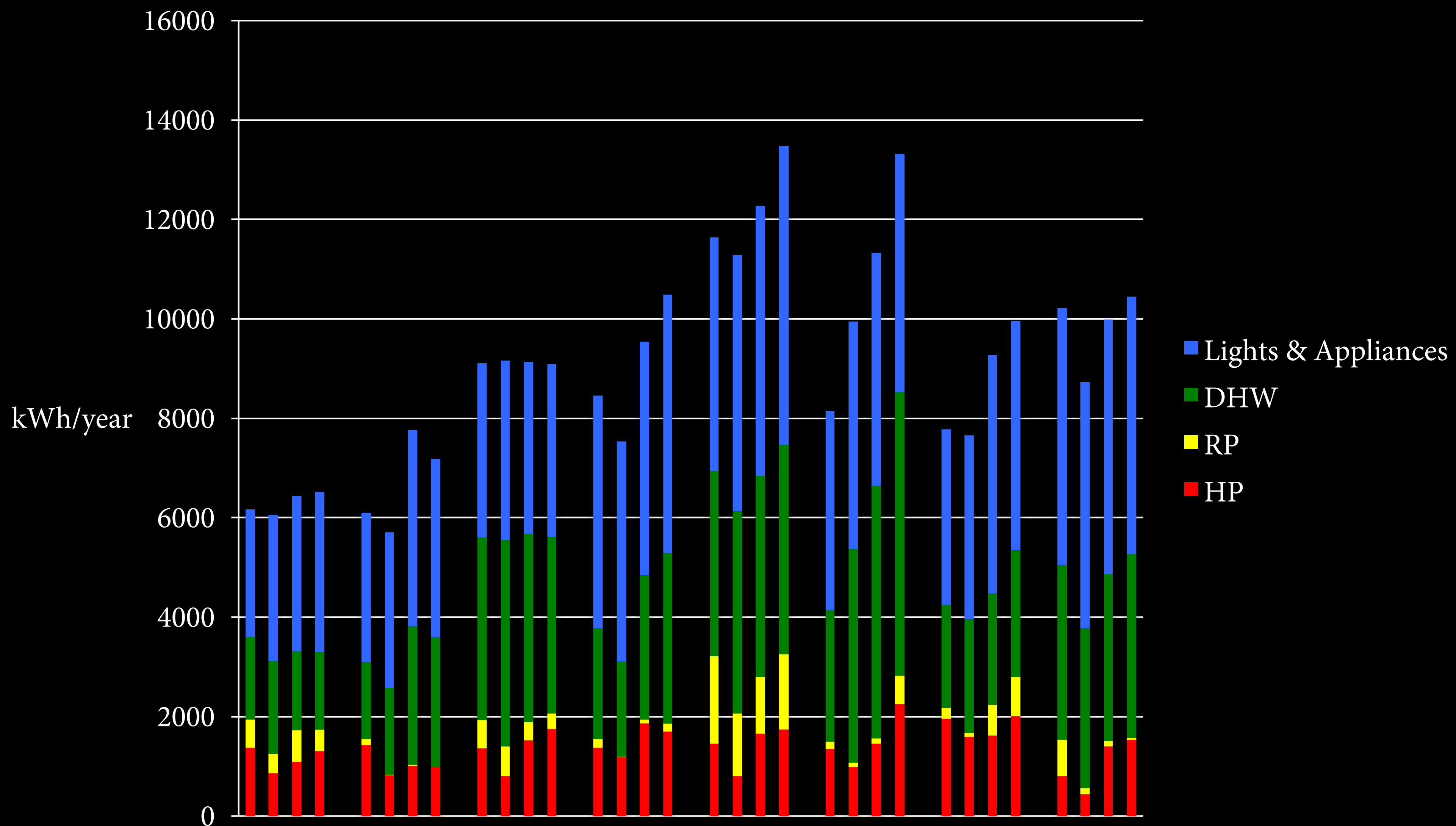
All 13 Households



All 13 Households



8 Households – 4 Year Trends



PV vs. Enclosure

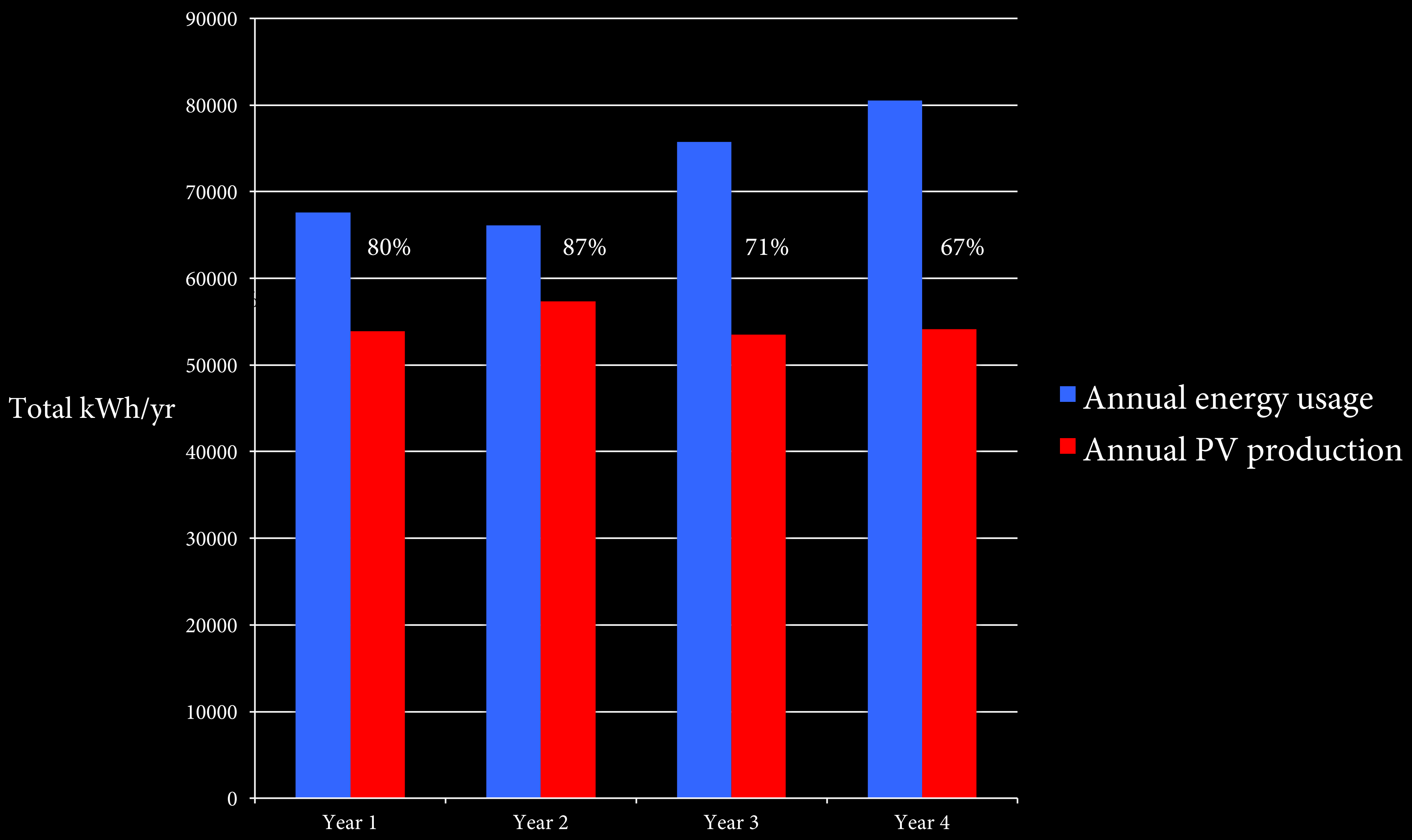
R-31 Wall, R-50 Roof,
R-20 Basement
Triple glazed FG windows
154 CFM50
5 kW PV

~2X PH AHD limit (2BR model)

1329 kWh/year heat 1st 2 years

Need 500W PV to cover difference

8 Households – 4 Year Trends



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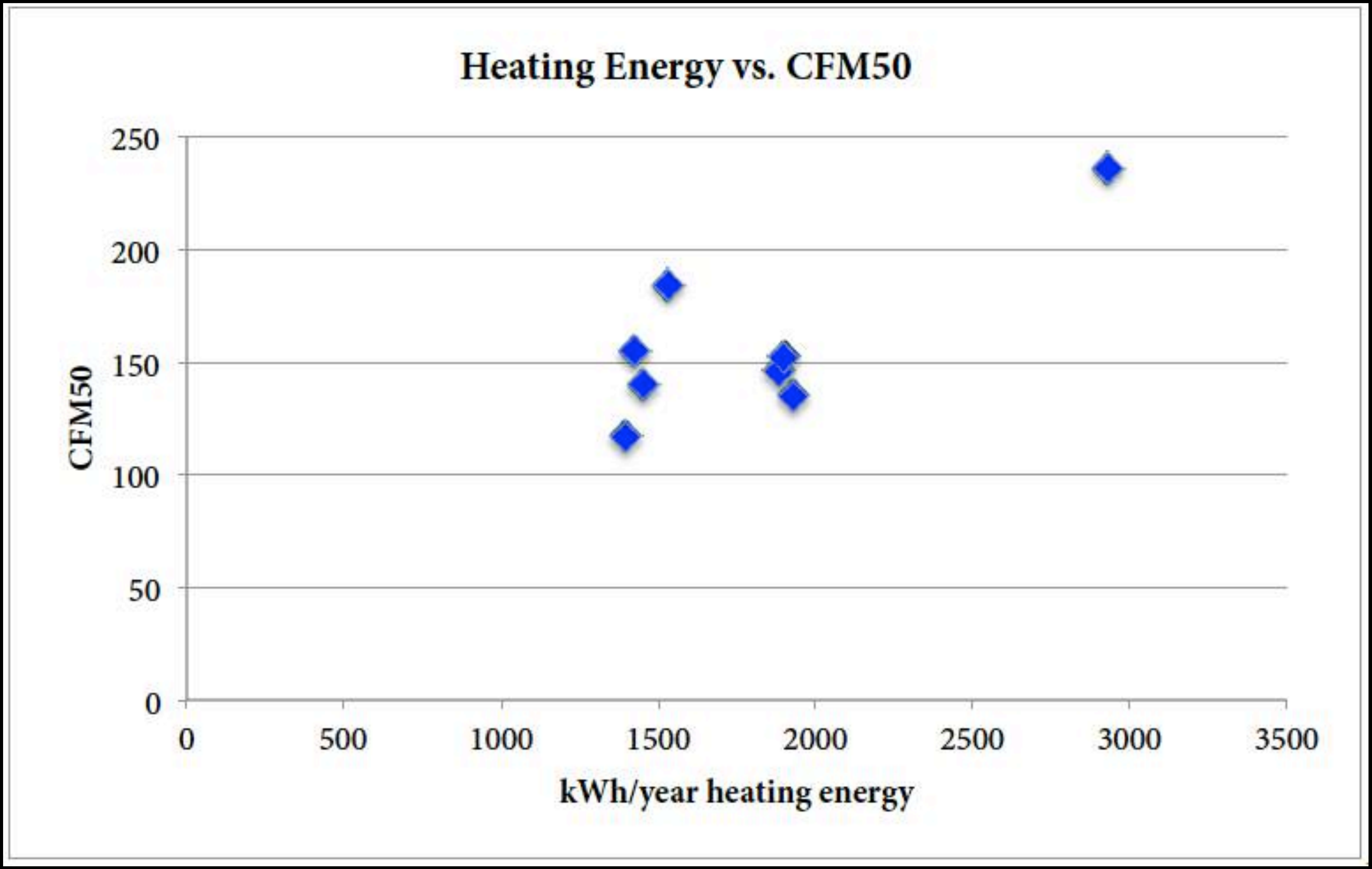
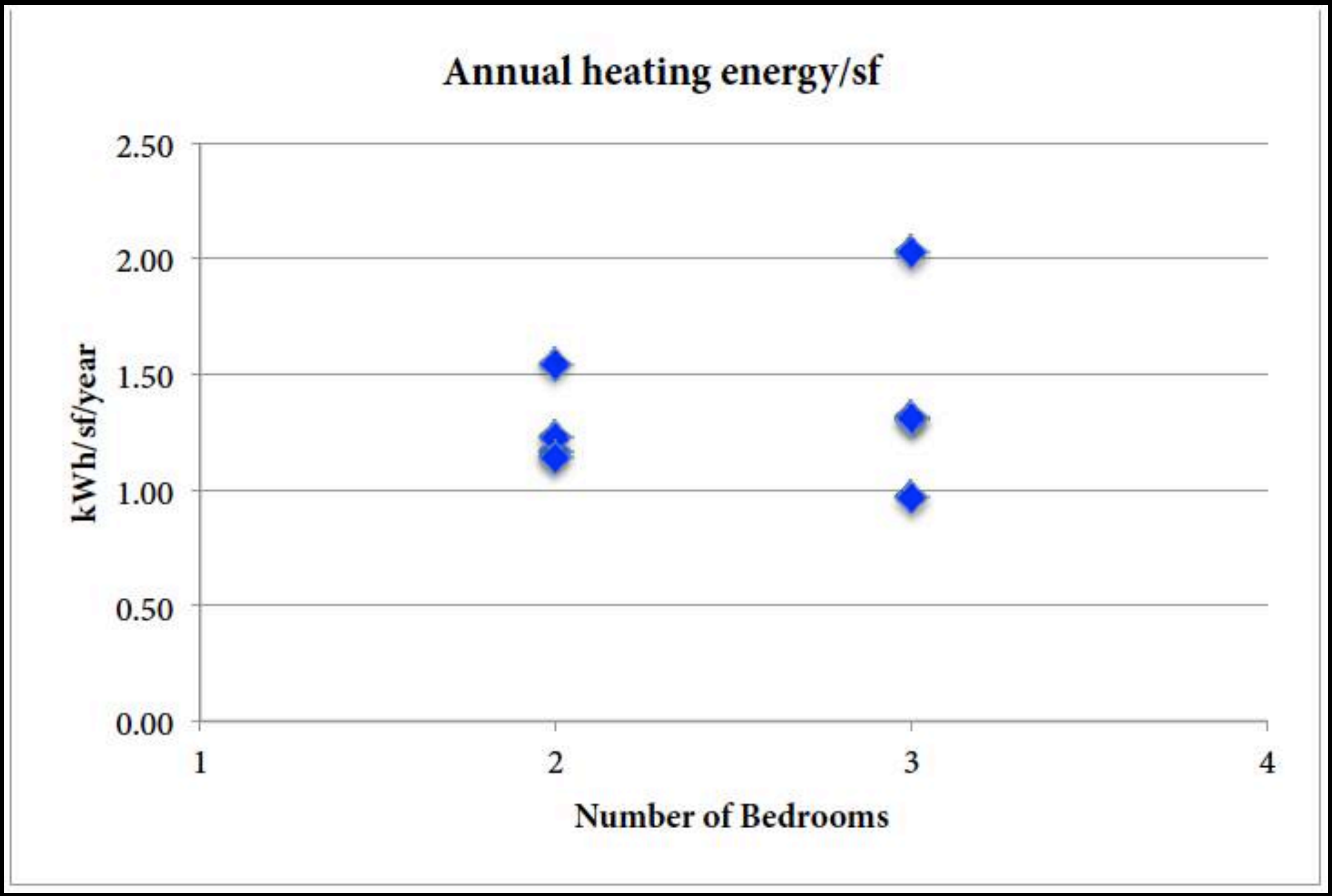
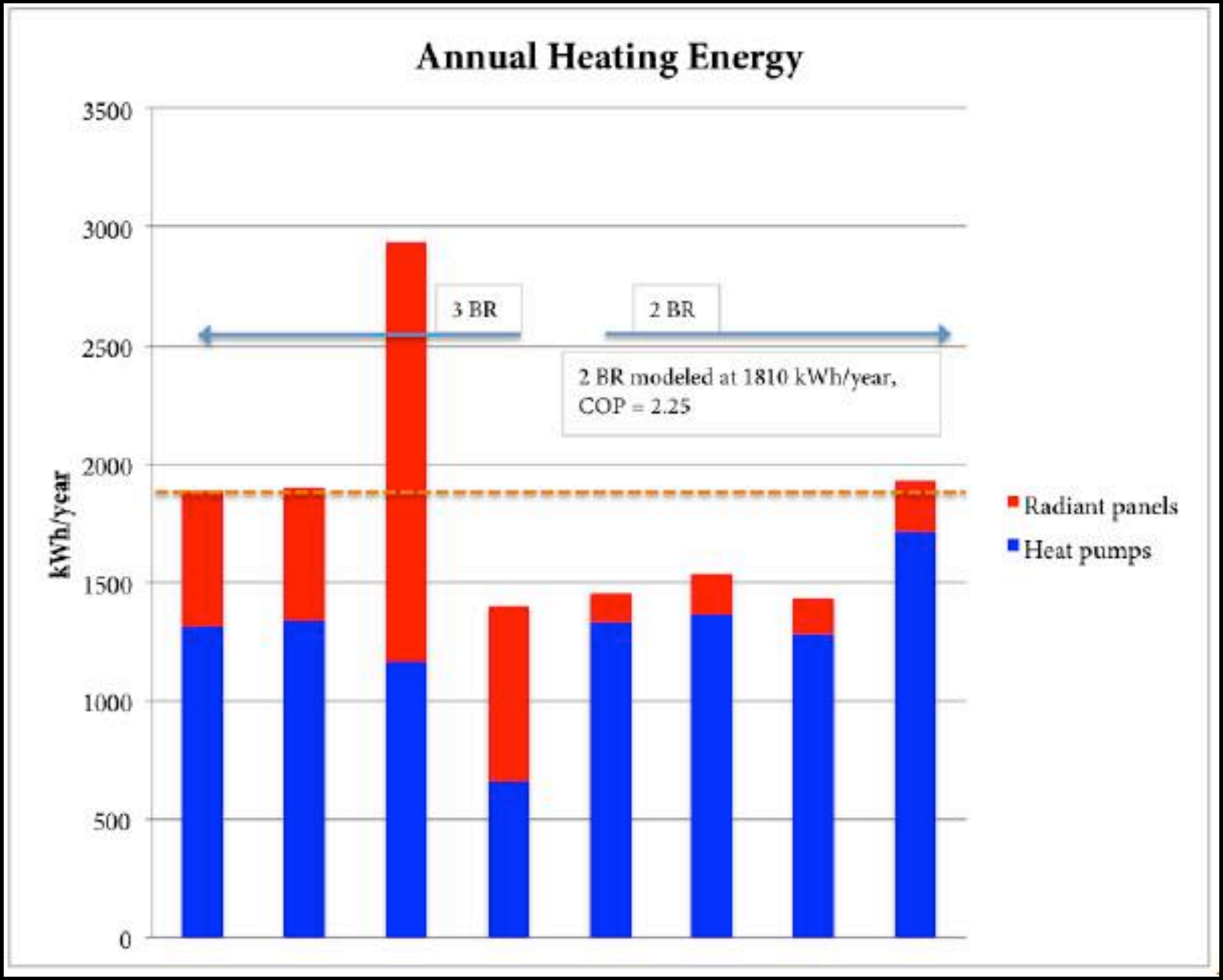
8 Households – Heat vs. CFM50



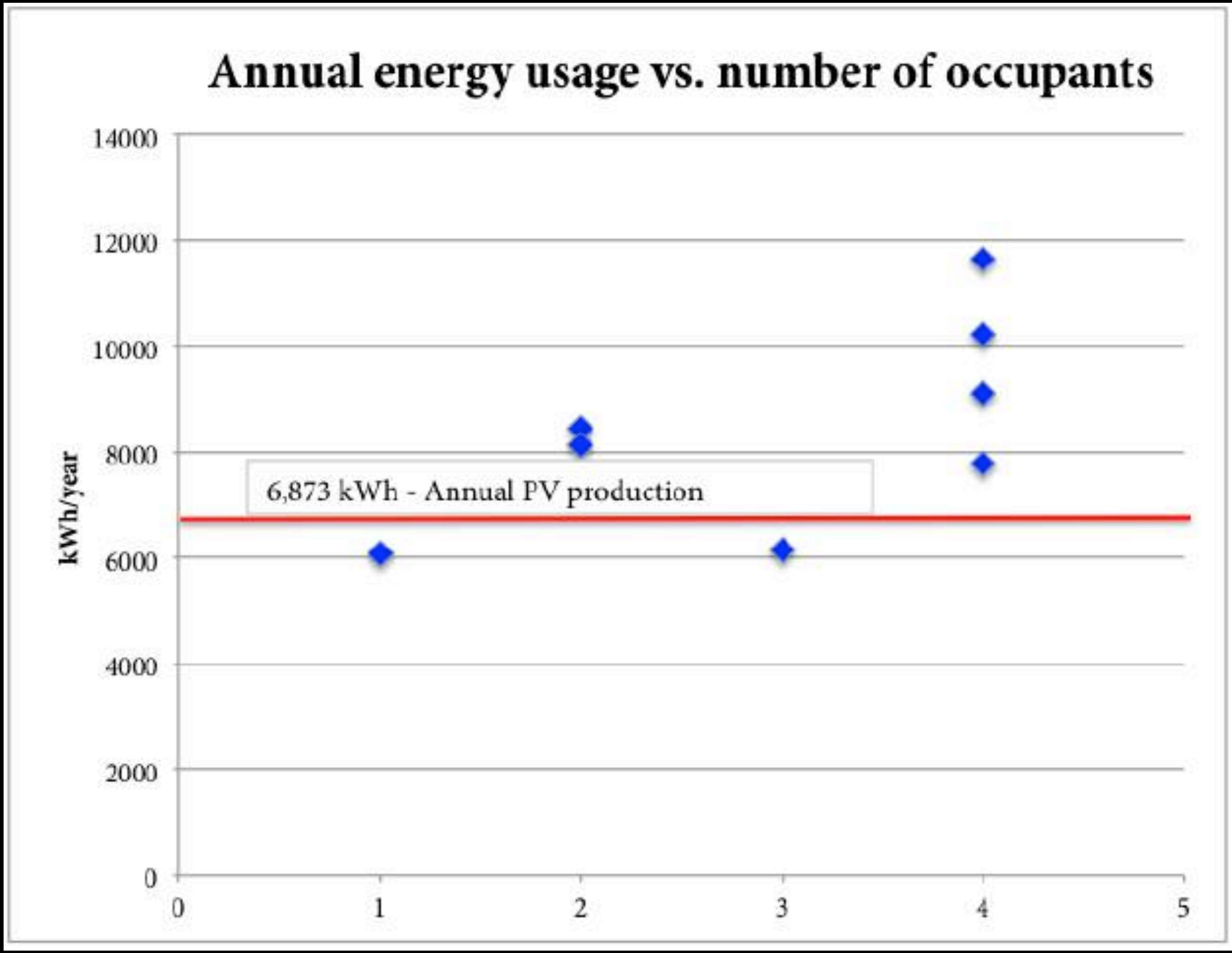
8 Households – Heat vs. Floor Area



8 Households – Heat vs. BRs



8 Households – Energy vs. Occupancy



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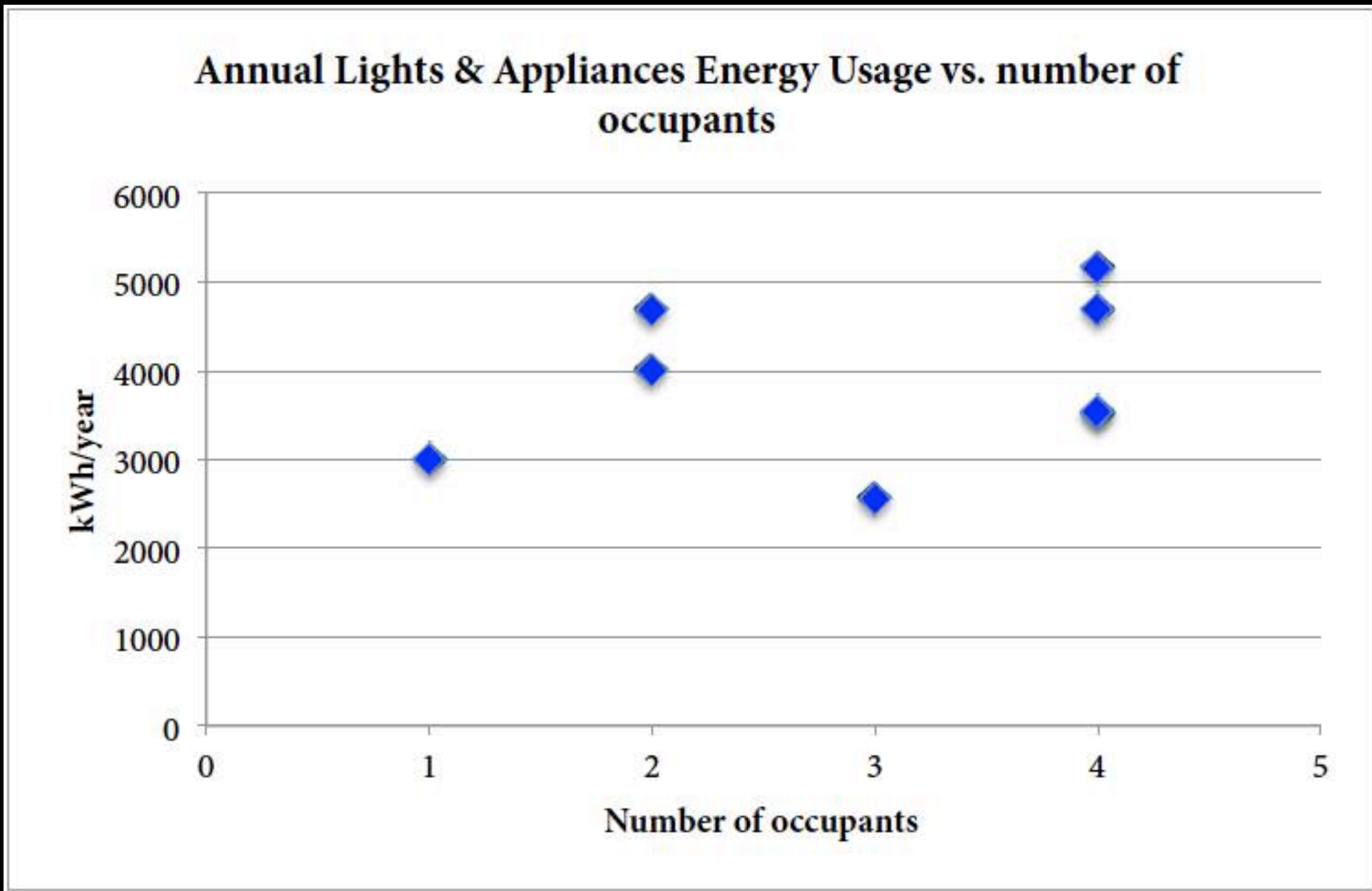
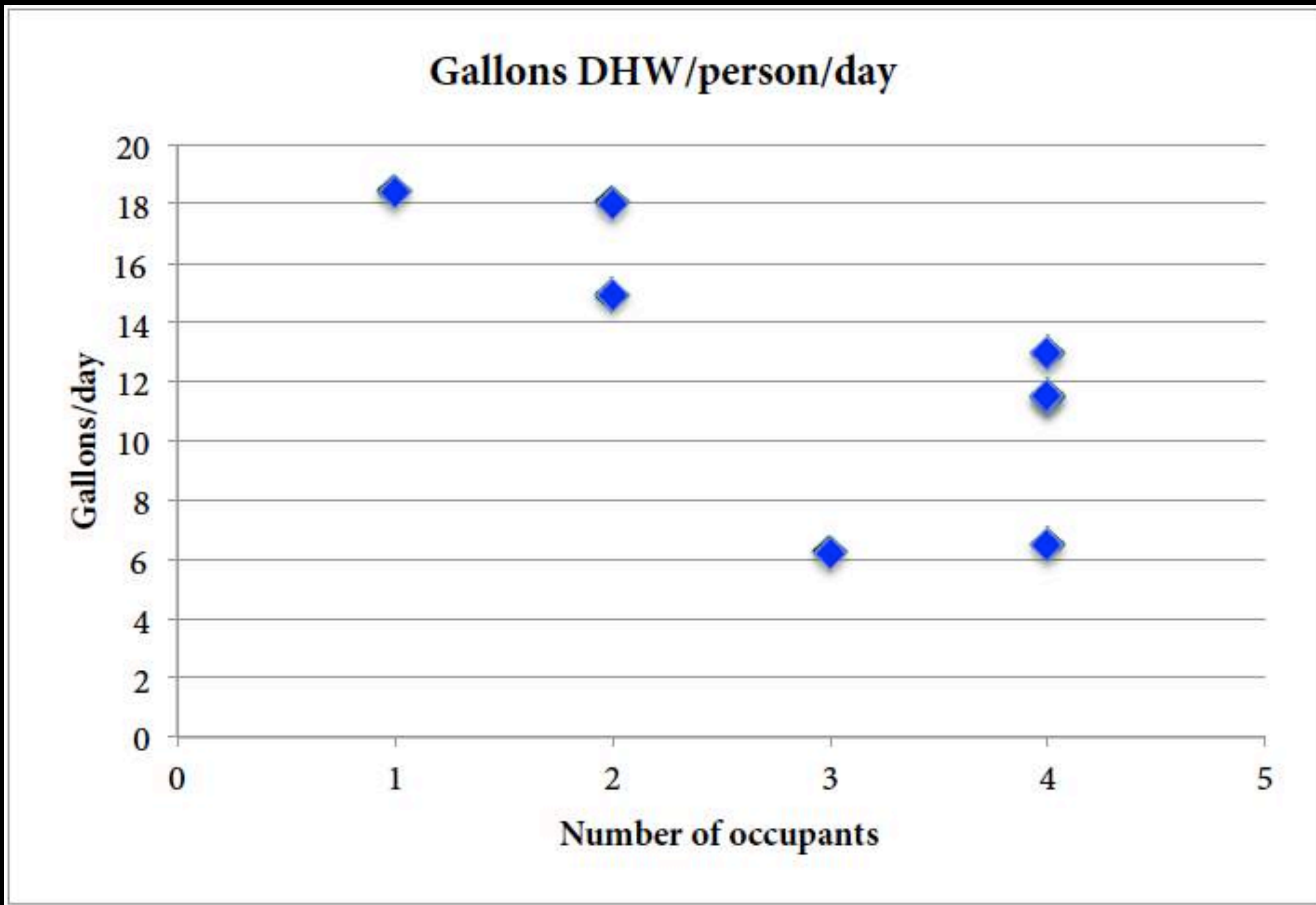
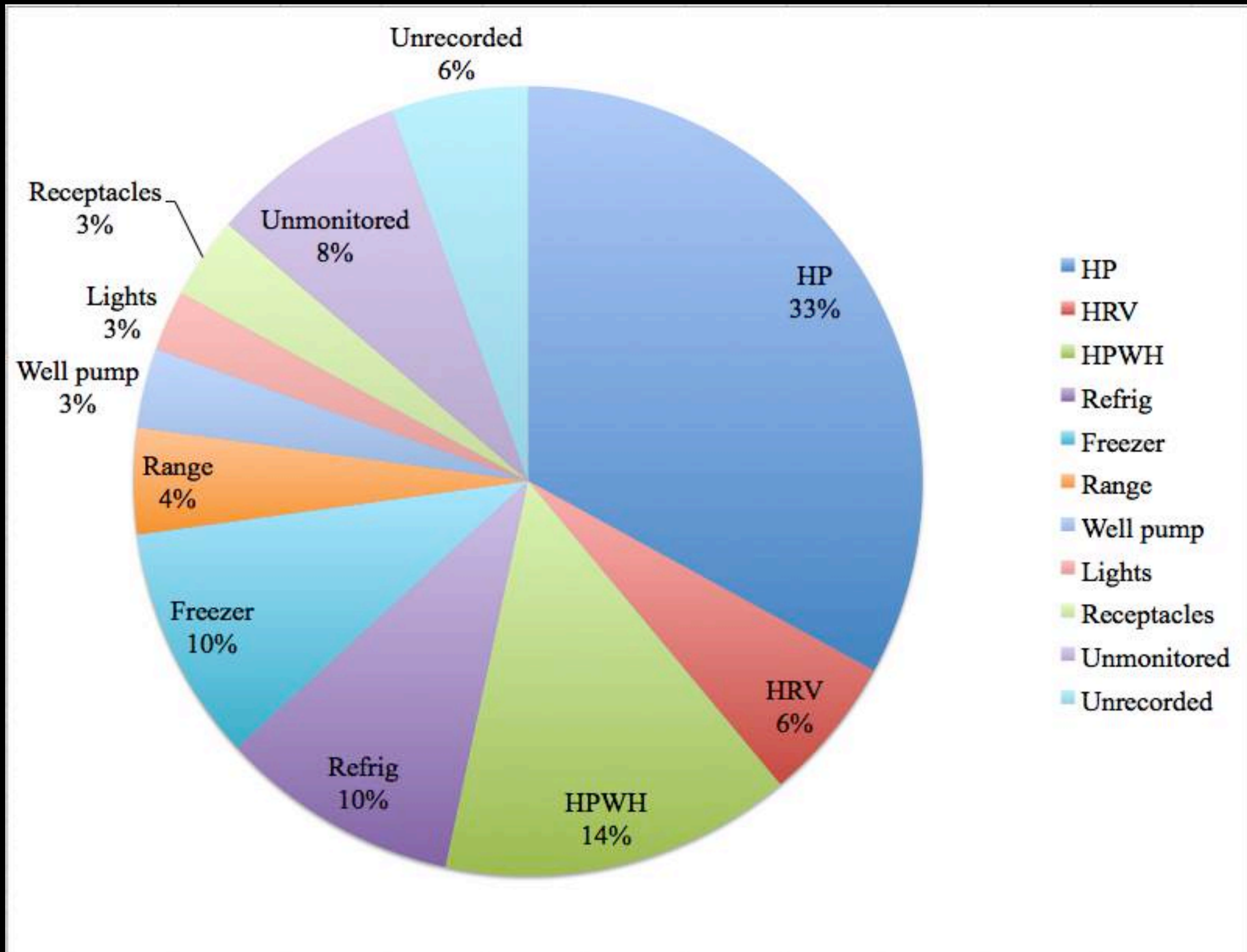
8 Households – Other vs. Occupancy



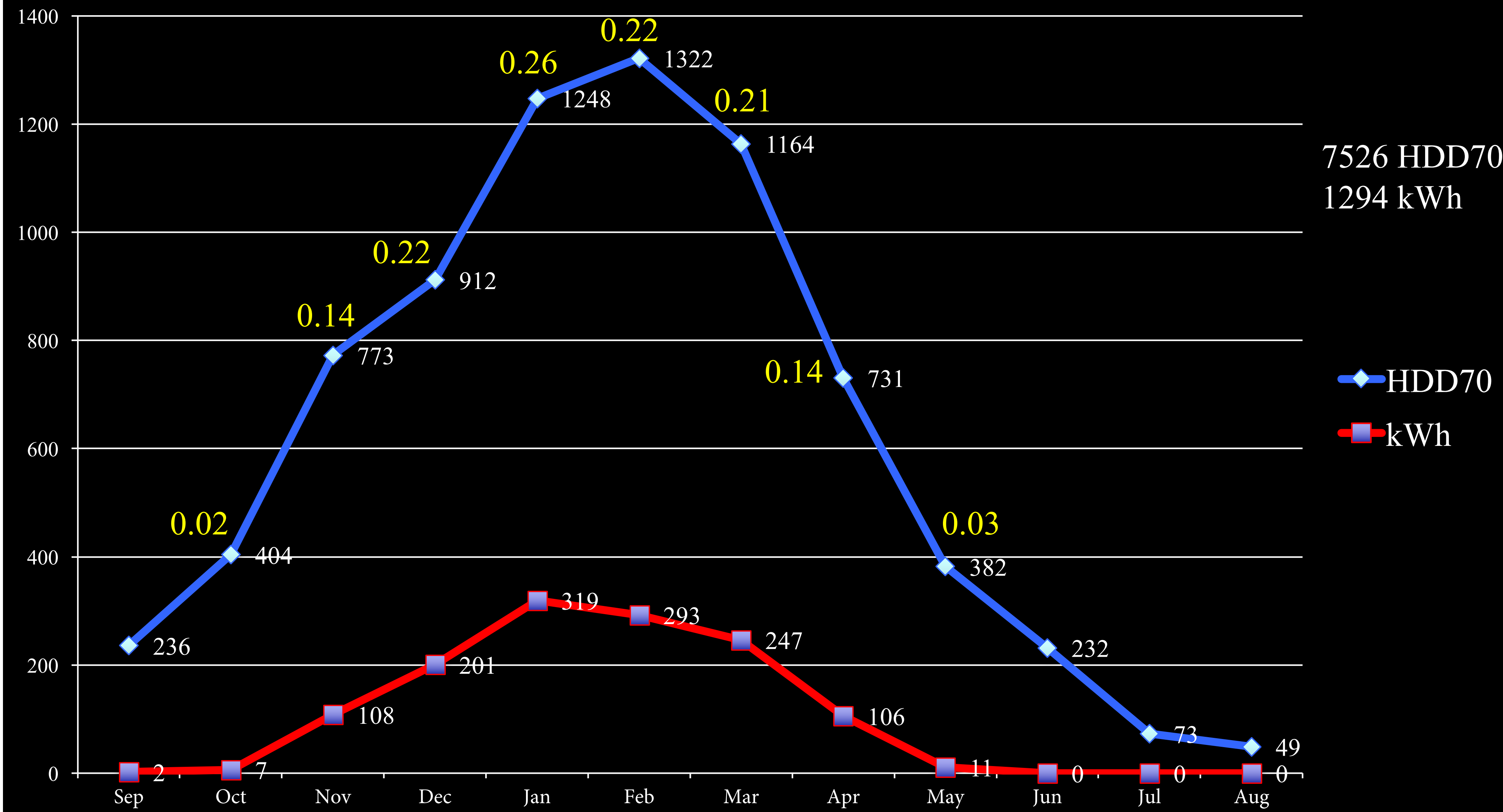
8 Households – DHW/person/day



MV DER 2 End Use Breakdown



Heat Pump kWh vs. HDD70



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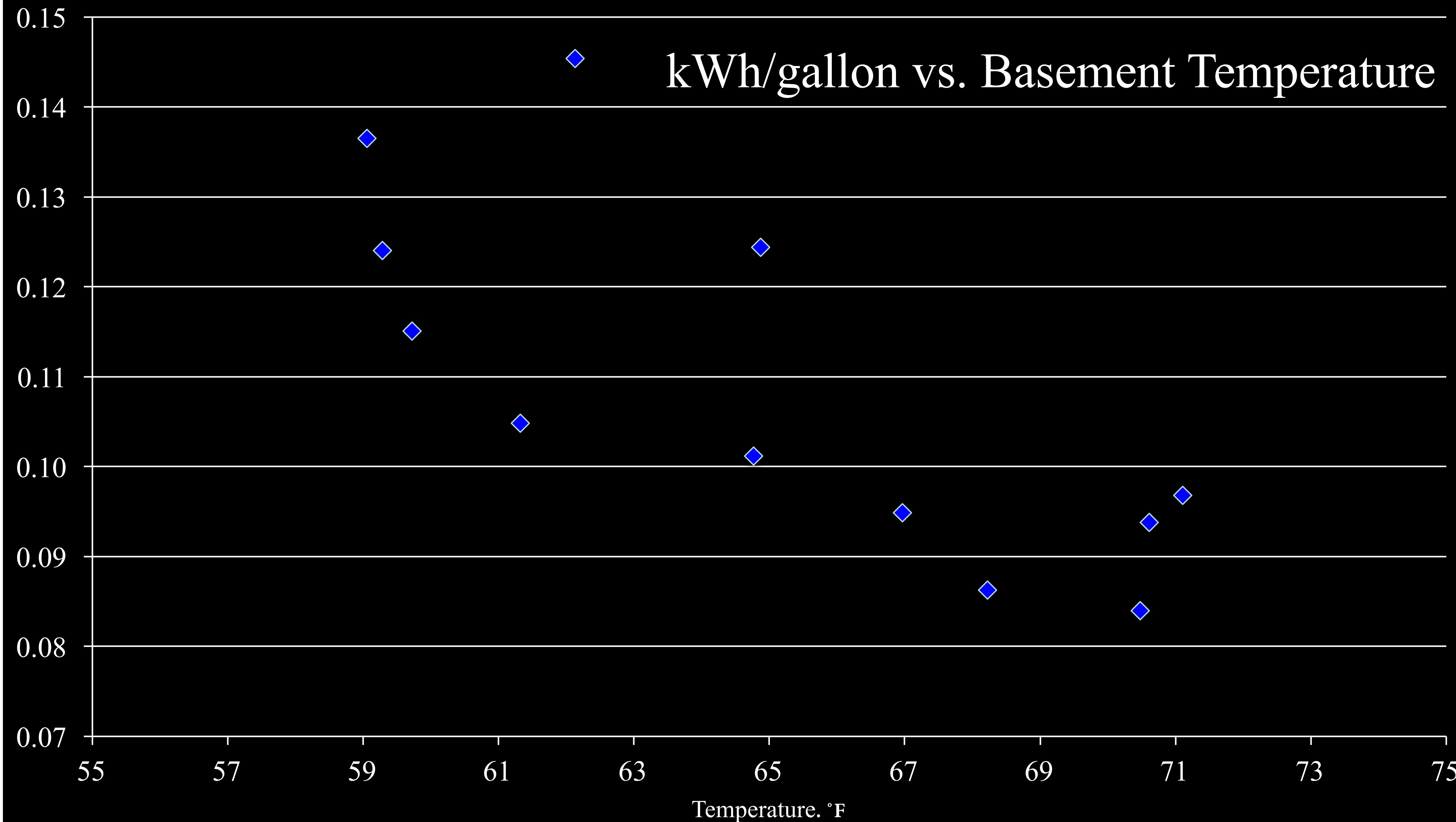
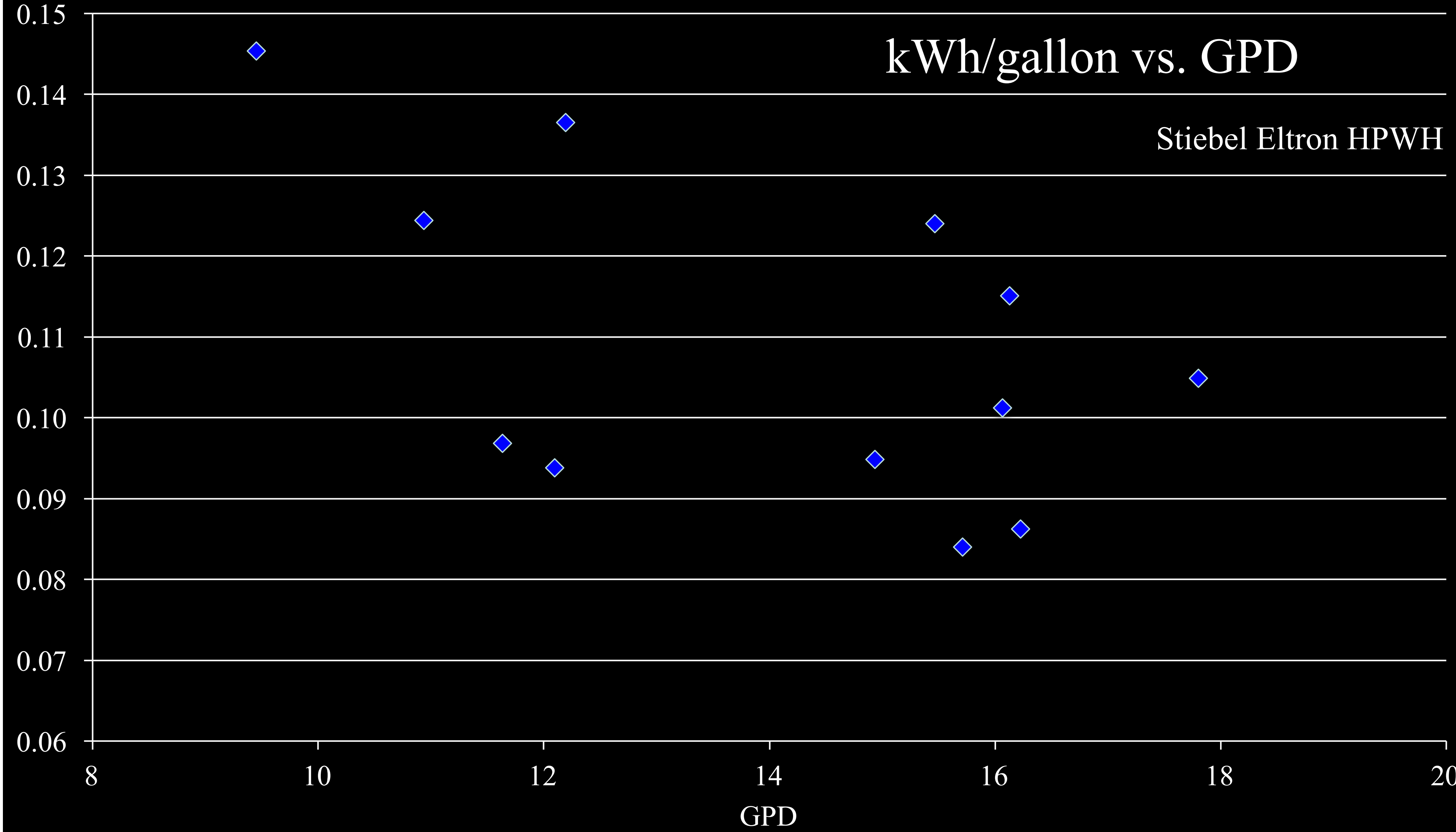
DHW kWh/gallon vs. Temp



DHW kWh/gallon vs. GPD



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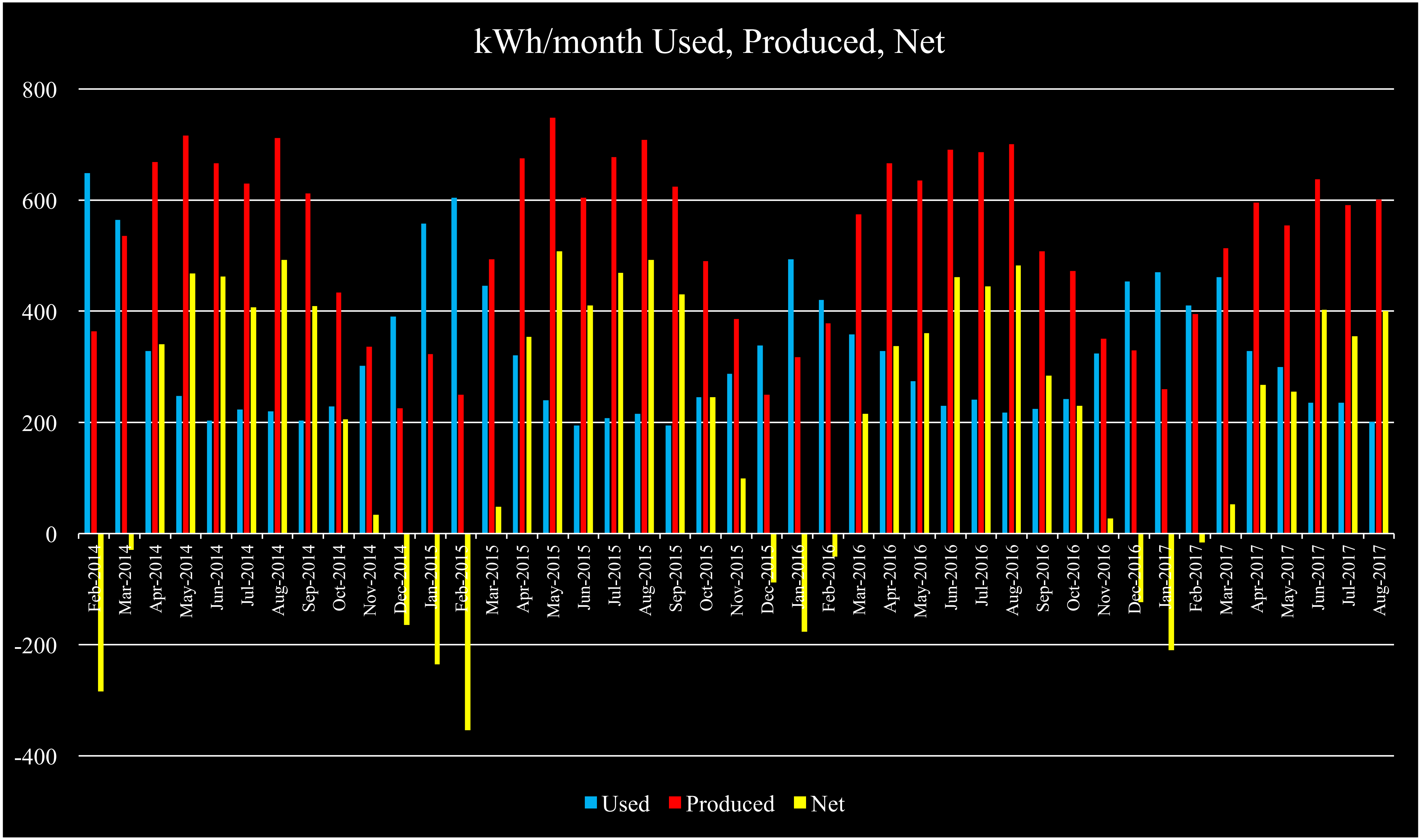
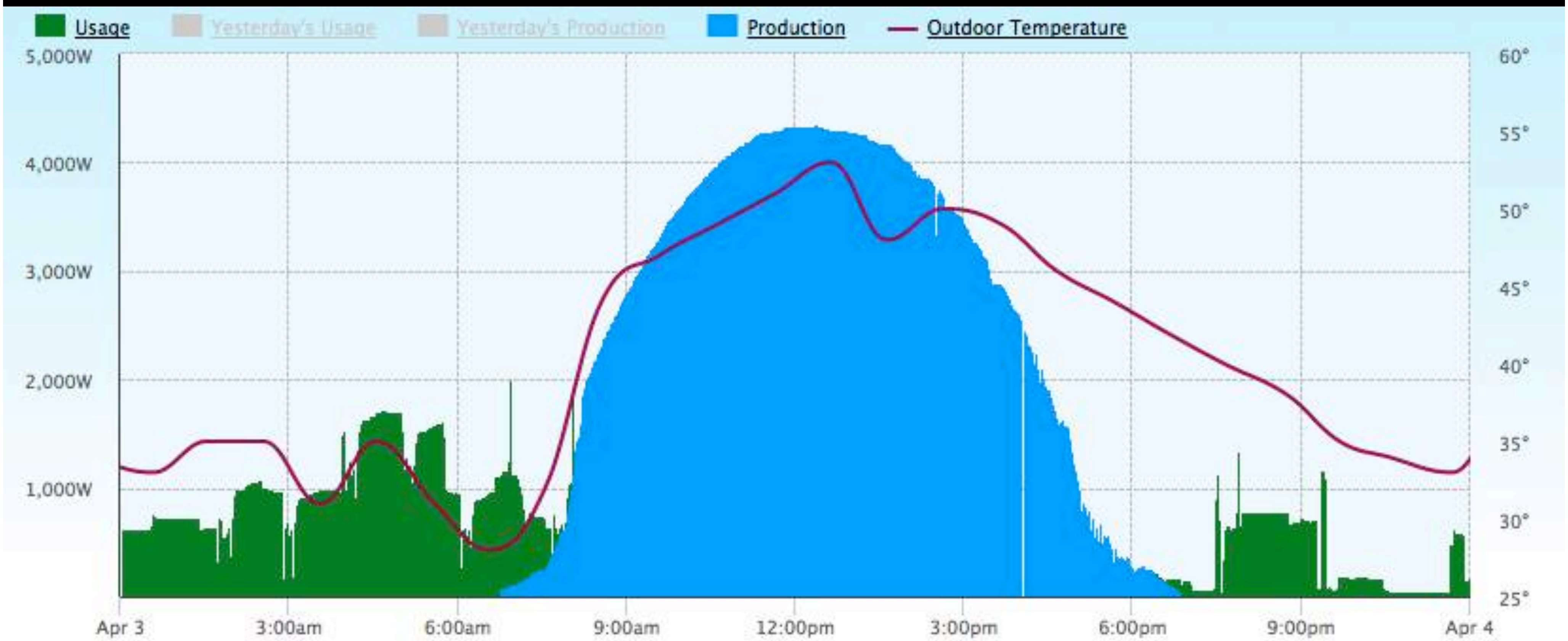
Net Energy Flows



Daily Usage vs. Generation

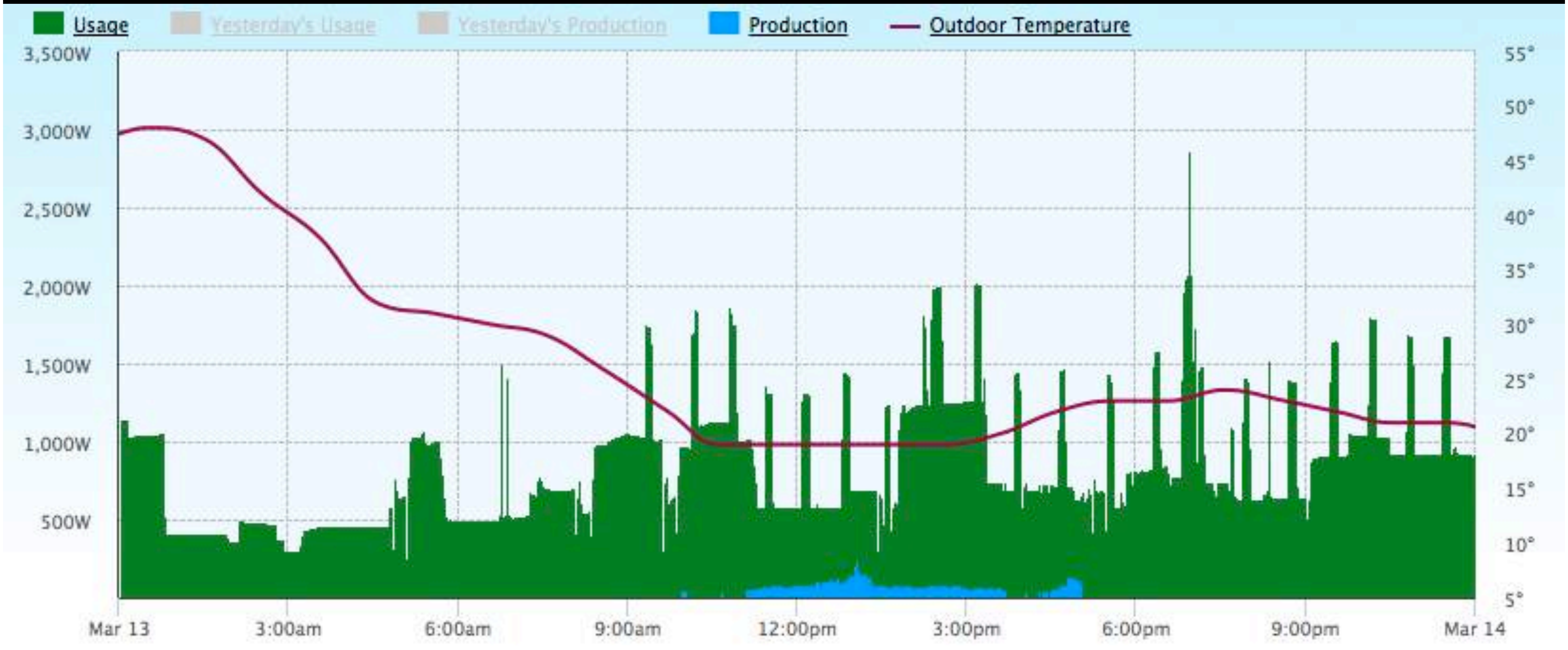
April 3rd 2014

Usage 12.3 kWh, Generation 31.7 kWh



Daily Usage vs. Generation

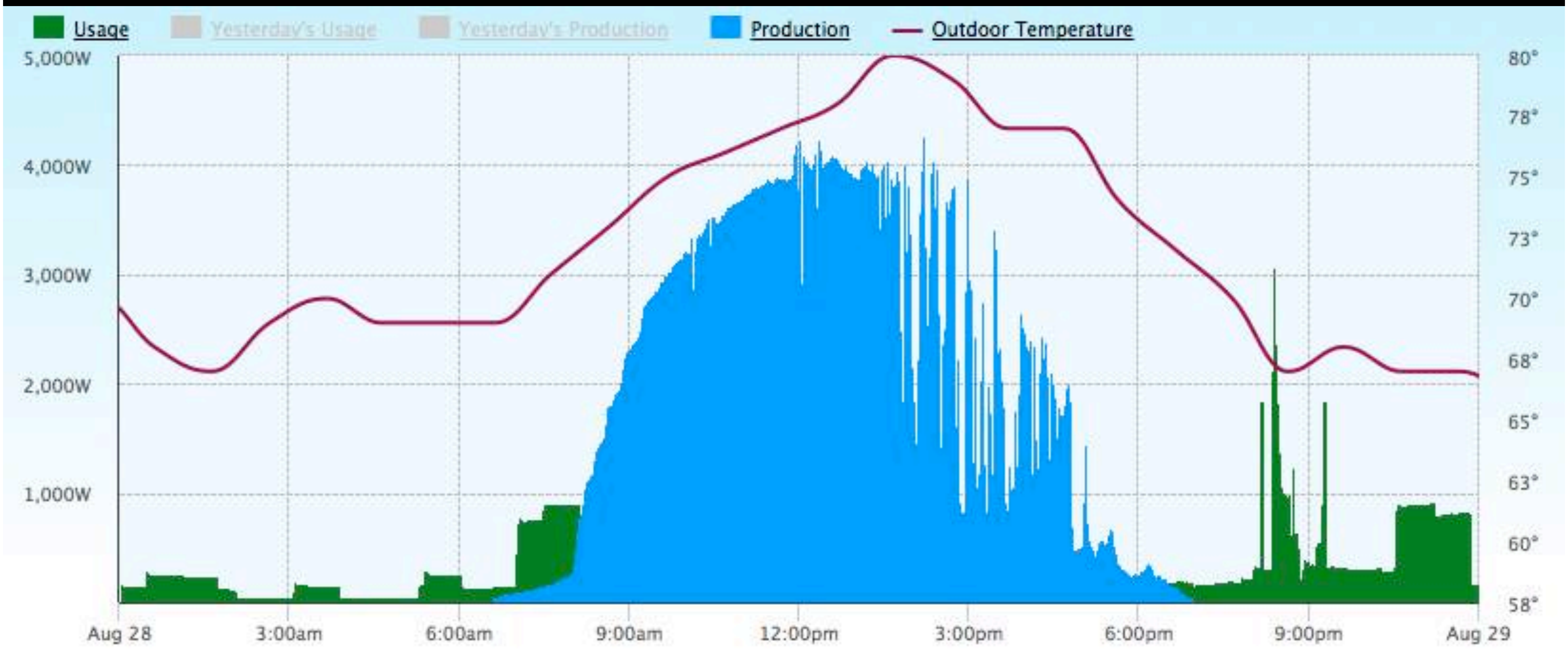
March 13th 2014
Usage 20.1 kWh, Generation 0.4 kWh (snow)



Daily Usage vs. Generation

August 28th 2014

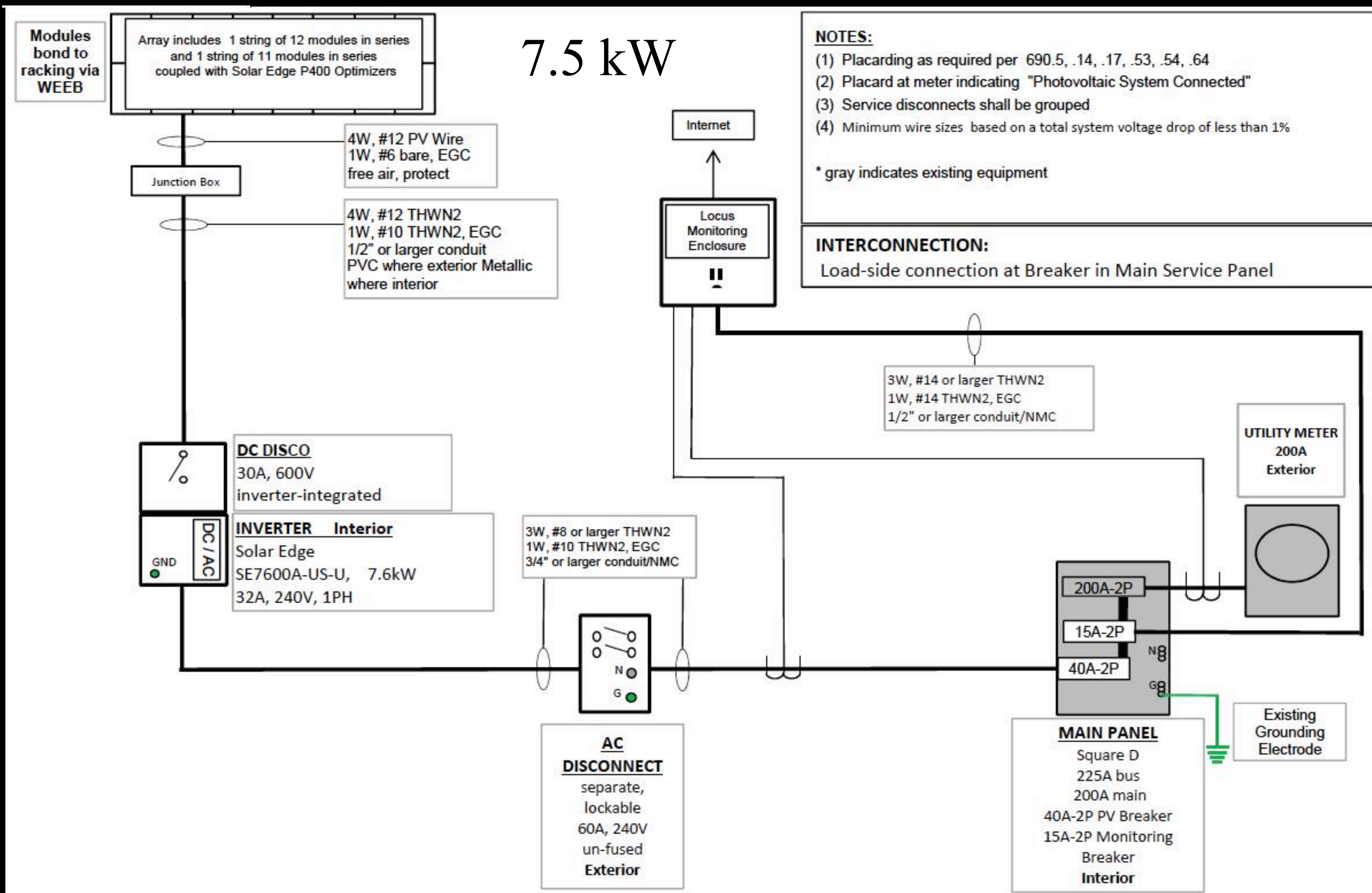
Usage 6.5 kWh, Generation 25.4 kWh



Grid-interconnected PV Systems

- Principal components are solar electric panels and inverters
- The panels produce direct current (DC)
- The inverter(s) convert that to 240V alternating current (AC)
- Inverters can be *micro-inverters*, mounted on each panel, in which case each panel produces AC, or
- *string inverters*, in which case a string of panels, or multiple strings in parallel, are wired in series to produce several hundred volts DC as input to the inverter
- The AC inverter output is wired into the main utility panel, where it can either serve loads in the house, or if the generation exceeds the house load the power is exported to the grid. No grid, no PV.

One line diagram

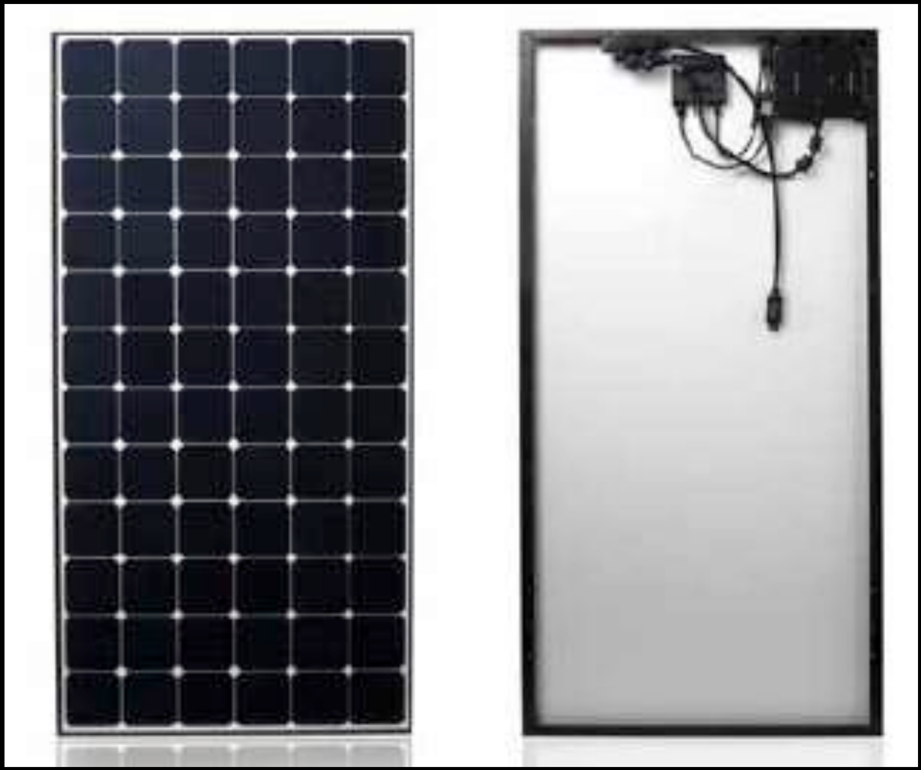


String Inverters

- >95% efficient
- They make some noise and heat
- Service life expected to be shorter than the panels – 10 year warranty is common

Micro-inverters

- Per panel conversion to AC
- Good for shaded or multiple facing arrays
- Per panel monitoring



Guidelines

- Monocrystalline panels are 14-20W/sf
- Annual output in kWh/Kw depends on location, orientation, and shading – in the northeast the range is 1,000 – 1,400 kWh/kW/yr
- Annual output from an unshaded roof or ground mounted system is 14-26 kWh/sf/yr
- A free easy-to-use online estimating tool is PVWATTS, which gives a monthly estimate of kWh generated given location and system inputs

PV Watts


PVWatts® Calculator
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Get Started:
Enter a Home or Business Address
GO »
Release Notice (?)
HELP
FEEDBACK
ALL NREL SOLAR TOOLS
NREL's PVWatts® Calculator
Estimates the energy production and cost of energy of grid-connected photovoltaic (PV) energy systems throughout the world. It allows homeowners, small building owners, installers and manufacturers to easily develop estimates of the performance of potential PV installations.
What's New
Follow @PVWatts
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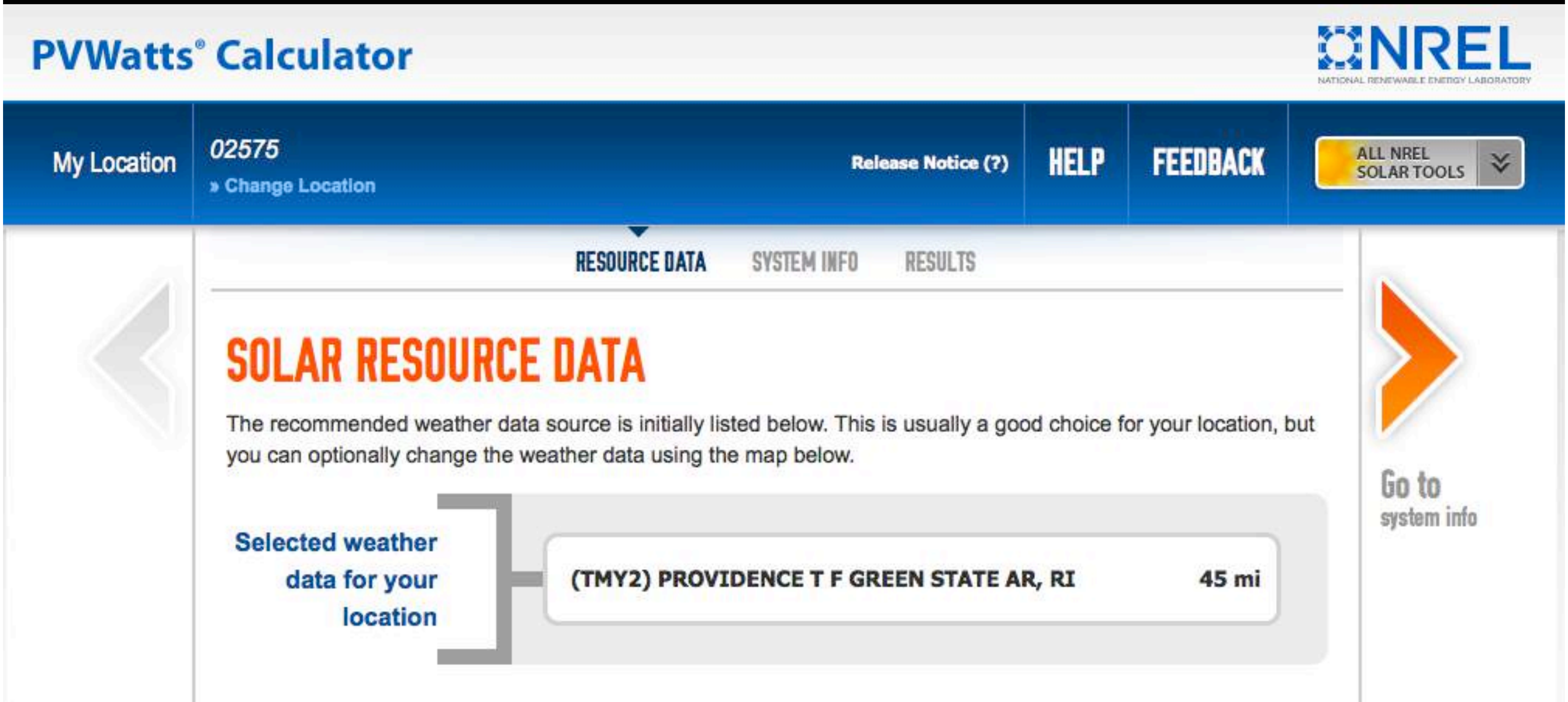
PV Watts

Type your zip code or location, then click Go

PV Watts



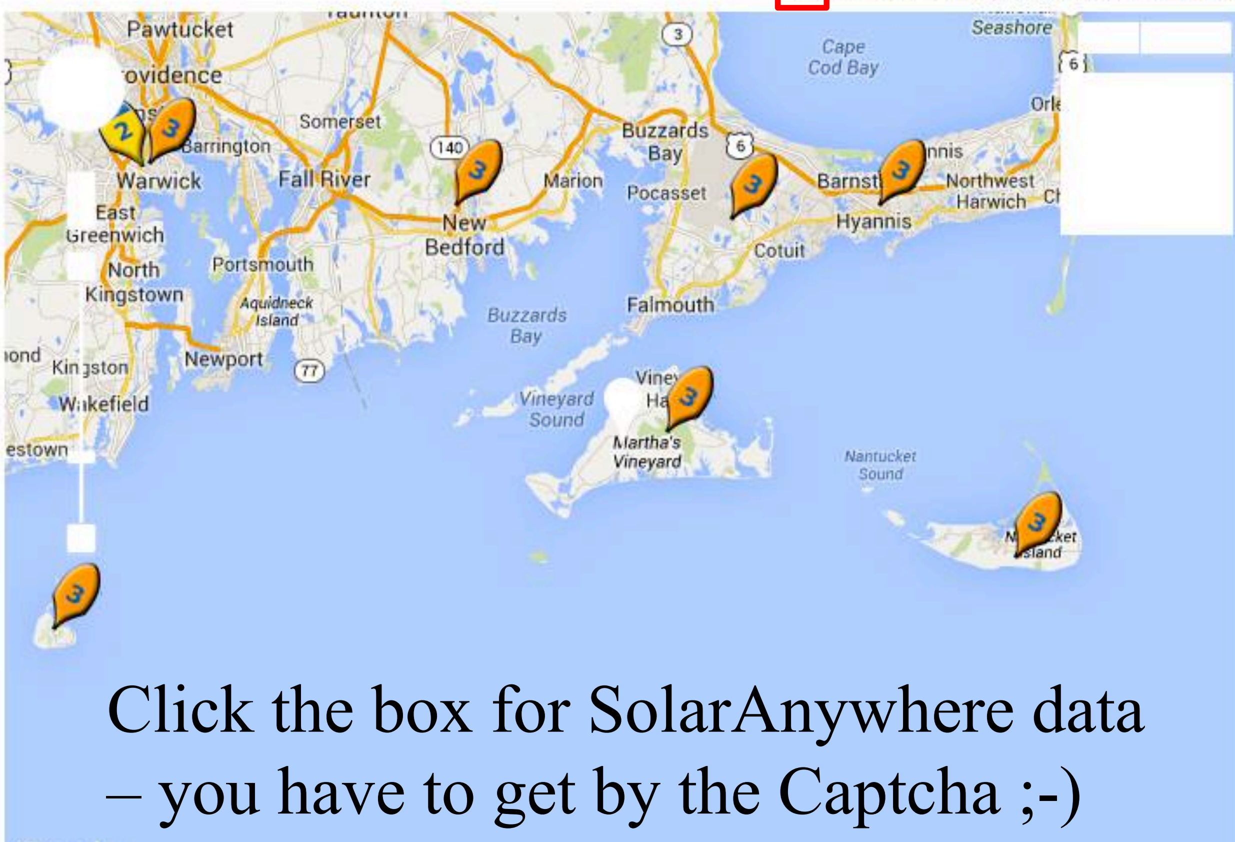
PV Watts selects the appropriate weather file.
Next, click on Go to system info
OR

PV Watts

Optionally, Select Different Weather Data

Currently, PVWatts® defaults to the closest TMY2 weather file (or international file). This will be the standard for the foreseeable future. We also offer the TMY3 locations and a 10 km gridded data set from SolarAnywhere®. We will not be including the older 40 km gridded data from PVWatts Version 2 as the other datasets are superior. The selected weather source pin is wrapped with a blue background. Click a different pin to select that source. If you enable SolarAnywhere® data for the continental US, then **double-click** anywhere on the map to select that grid cell (it must be enabled for each location). Refer to Help for more detailed information.

☐ Enable SolarAnywhere® Gridded Data



Click the box for SolarAnywhere data – you have to get by the Captcha ;-)

PV Watts

Optionally, Select Different Weather Data

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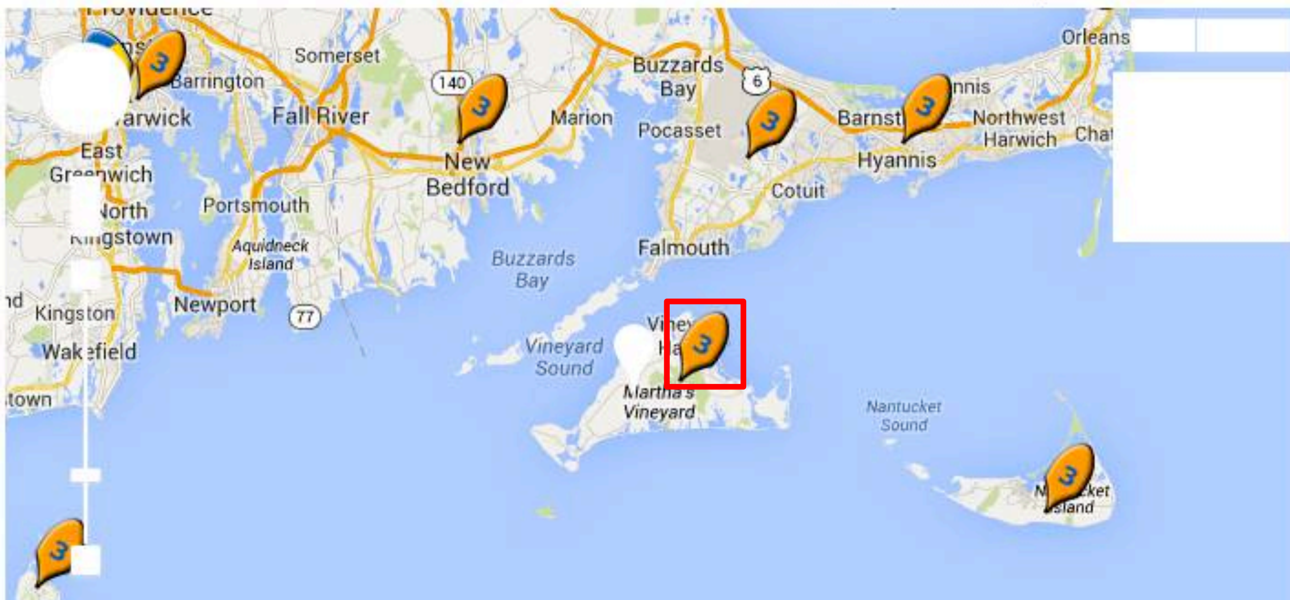
☑ Enable SolarAnywhere® Gridded Data



I click on the icon on Martha's Vineyard, where I live

PV Watts

SOLAR RESOURCE DATA

The recommended weather data source is initially listed below. This is usually a good choice for your location, but you can optionally change the weather data using the map below.

Selected weather data for your location

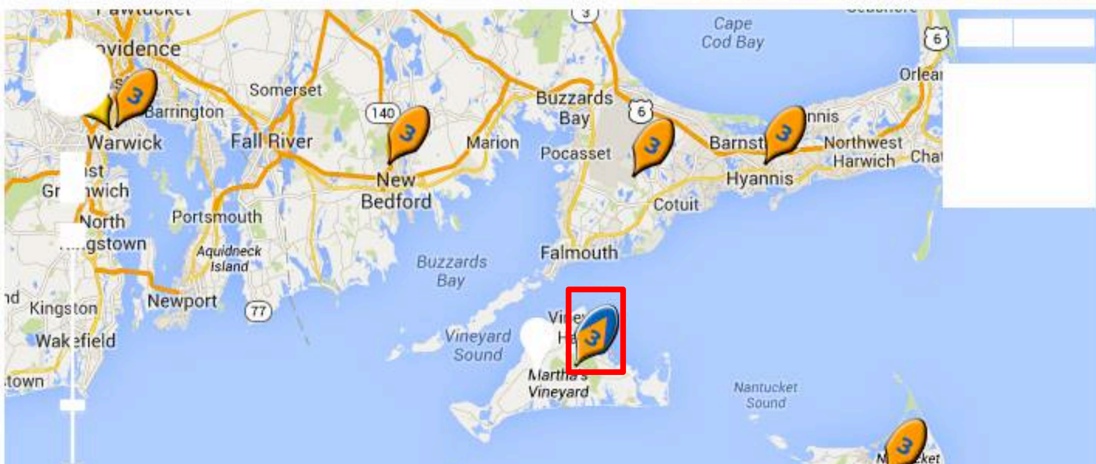
(TMY3) MARTHAS VINEYARD, MA	**3.6 mi**

Go to system info

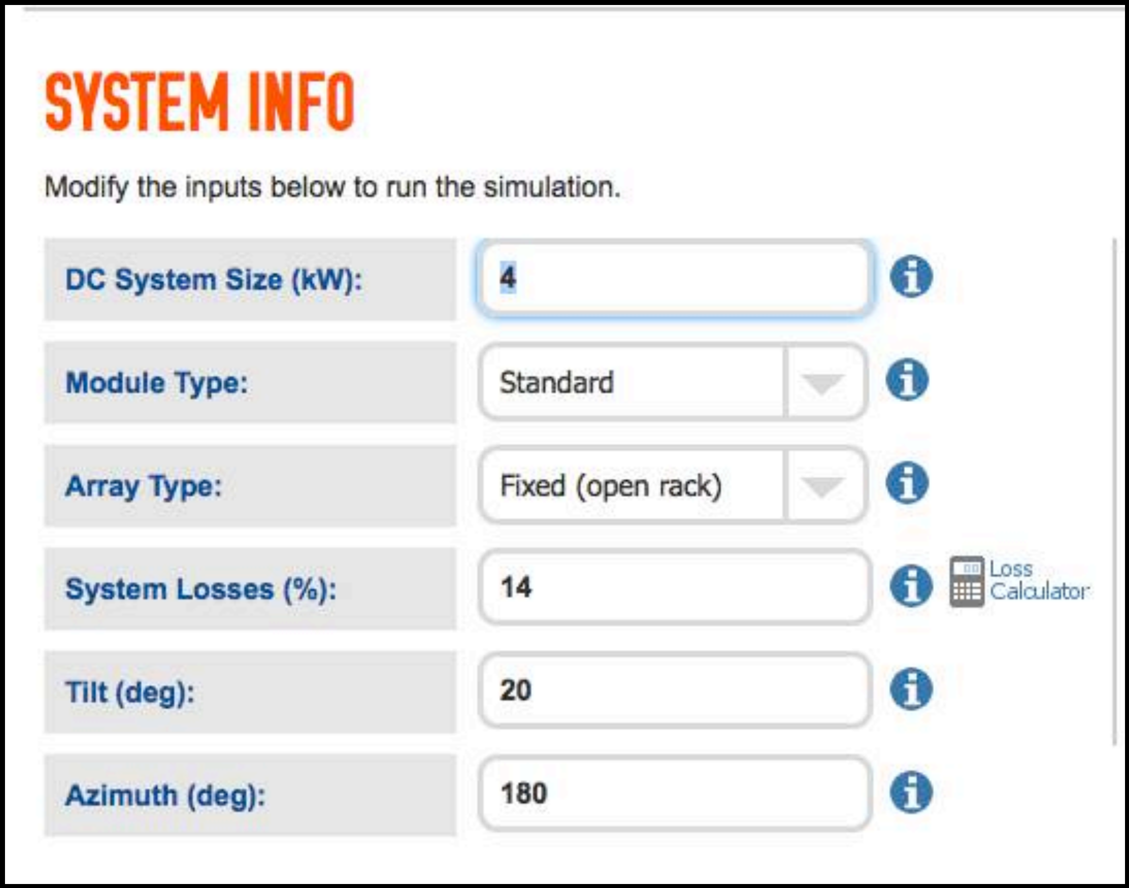
Optionally, Select Different Weather Data

Currently, PVWatts® defaults to the closest TMY2 weather file (or international file). This will be the standard for the foreseeable future. We also offer the TMY3 locations and a 10 km gridded data set from SolarAnywhere®. We will not be including the older 40 km gridded data from PVWatts Version 2 as the other datasets are superior. The selected weather source pin is wrapped with a blue background. Click a different pin to select that source. If you enable SolarAnywhere® data for the continental US, then **double-click** anywhere on the map to select that grid cell (it must be enabled for each location). Refer to Help for more detailed information.

☑ Enable SolarAnywhere® Gridded Data



PV Watts



This brings up a page with these inputs (and other stuff you can explore). For now, I will enter my system size, array type, and the tilt and azimuth of the array, and leave the PV Watts defaults for Module Type and System Losses.

PV Watts

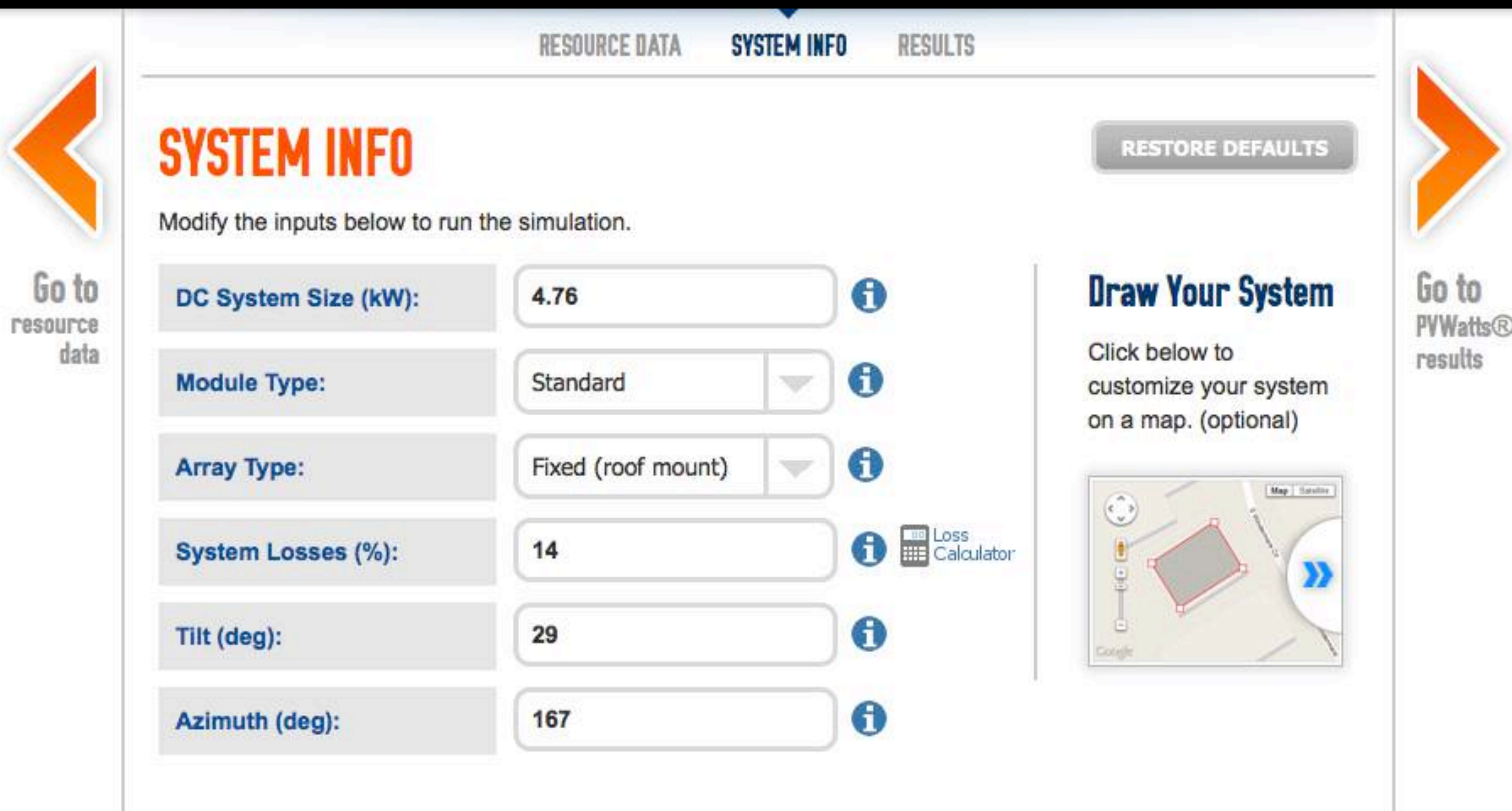
SYSTEM INFO

Modify the inputs below to run the simulation.

DC System Size (kW):	4.76
Module Type:	Standard
Array Type:	Fixed (roof mount)
System Losses (%):	14
Tilt (deg):	29
Azimuth (deg):	167

Loss Calculator

PV Watts



Click on Go to PVWatts results arrow

PV Watts

RESULTS

Print Results

5,336 kWh per

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy ($
January	2.47	311	4
February	2.41	278	4
March	4.00	495	7
April	4.09	485	7
May	4.67	550	8
June	4.04	449	6
July	5.21	592	8
August	5.99	667	9
September	4.37	484	7
October	2.93	344	5
November	3.17	374	5
December	2.41	307	4
Annual	3.81	5,336	$ 7

User Comments

Optionally, add comments to include in the print out.

Download Results: Monthly | Hourly

Find A Local Installer

RESULTS

Print Results

6,481 kWh per Year *

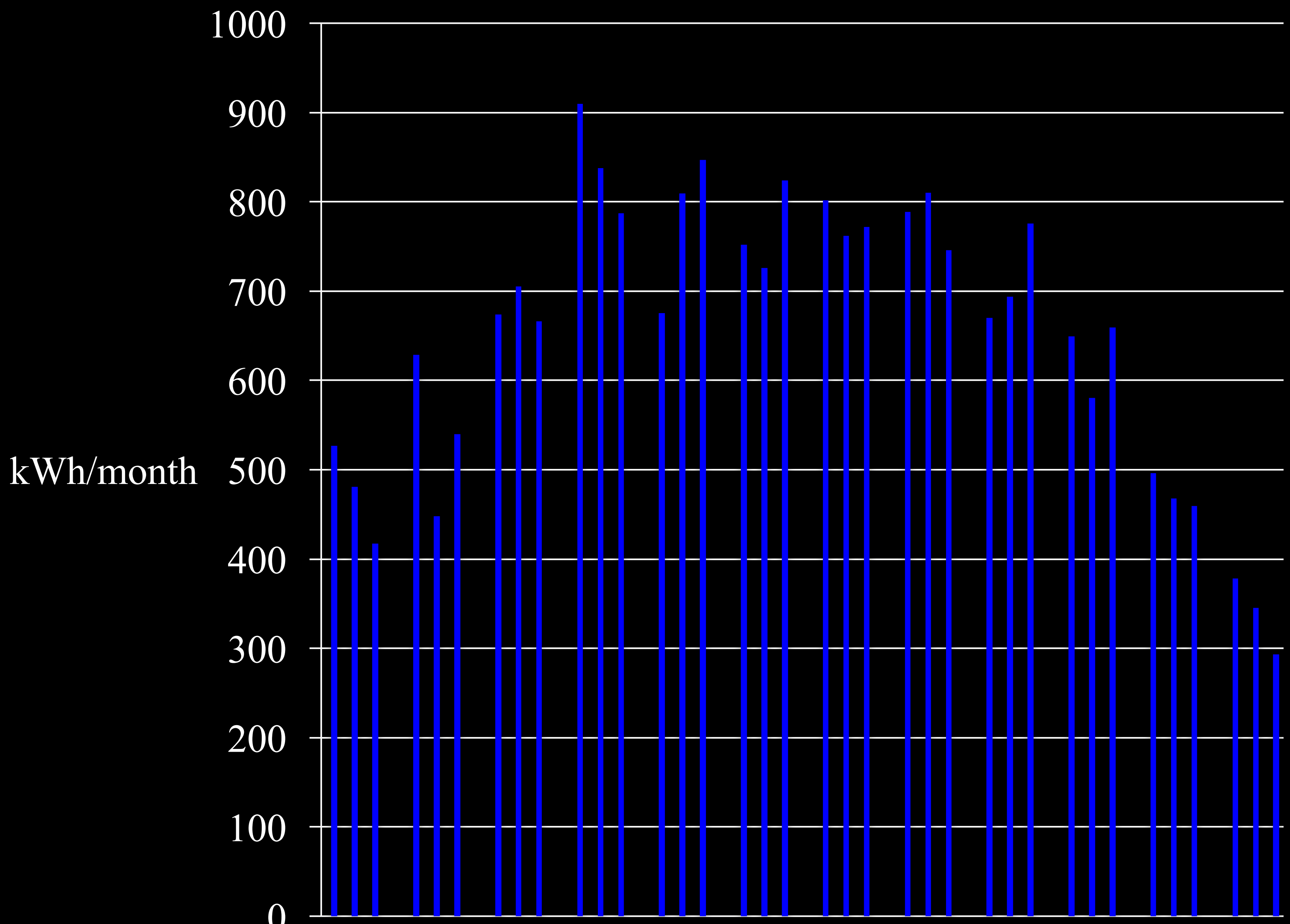
Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value ($)
January	3.00	391	58
February	3.92	455	68
March	4.75	595	89
April	5.38	635	95
May	5.69	670	100
June	6.00	664	99
July	6.24	699	104
August	5.92	666	99
September	4.63	516	77
October	4.26	510	76
November	2.97	358	53
December	2.51	321	48
Annual	4.61	6,480	$ 966

Las Vegas **8,359** kWh per Year

Rough Sizing Exercise

- Estimated annual energy consumption of 7,000 kWh/yr
- Generation of 1,300 kWh/kW/yr given location/tilt/azimuth
- Minimum required = 5.4 kW
- Panel output 18W/sf, so aperture required is 300 sf
- Install more to account for unpredictability of usage, seasonal weather and insolation variation, and electric transportation

Year on Year Variation



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Shading

8:59 am 238W
9:01 am 1519W
1,000W
500W
6:30am
7:00am
7:30am
8:00am
8:30am
9:00am
9:30am

Daily Usage vs. Generation

Delivered	Received	PV produced	Net	PV used on site	PV % used on site
5758	10189	12300	-4431	2111	17%

- Over close to two years, the PV system generated 12,300 kWh
- 10,189 kWh was exported, and 5,758 kWh was imported
- Usage was 7,869 kWh, for a net export of 4,431 kWh
- 2,111 kWh of PV generated energy was used on site
- This was only 17% of PV generated energy
- Consider thermal storage and electricity storage so more of the generation will be used on site

Battery storage

- Storage useful for:
  - Demand charge reduction
  - Time of day rate cost savings / arbitrage
  - Back-up power
  - “Self-generation”, especially as net metering is compromised
- Most promising in the near term are lithium-based batteries
- Integrated products with 4-16 kWh storage and integrated inverter and controls
- Tesla is apparently shipping their product…we haven’t seen one

St. Croix example

19 kWh lithium iron phosphate battery
16 3V 400Ah cells

Outback inverter and charge controllers – Option to not export to the grid

Sonnenbatterie Eco10

10 kWh (4-16) lithium iron phosphate battery   7 kW inverter

Sonnenbatterie Eco10

- AC coupled
- Programmable
- Built-in transfer switch
- Can be used to increase self-consumption
- Can be used for back-up
- Can be used for arbitrage

PV Autonomy Model

Storage capacity, kWh	0	Heat multiplier	1.43	1294	1850	30%
Depth of discharge	0.80	All except heat multiplier	1.75	2445	4278	70%
Useful storage capacity, kWh	0	PV multiplier	1.00	3739	6128	16.8
Storage round trip efficiency	0.90					

PV generated, kWh	Total used, kWh	Heat, kWh	Not Heat, kWh	Served directly by PV, kWh	Load not served by PV, kWh	Potential stored PV, kWh	Stored PV, kWh	Used from Storage, kWh	Imported from grid, kWh	% of load served by PV - no Net Metering	% of load served by PV - with Net Metering	PV generated / load
6139	6126	1850	4276	1637	4489	4052	0	0	4489	27%	100%	100%

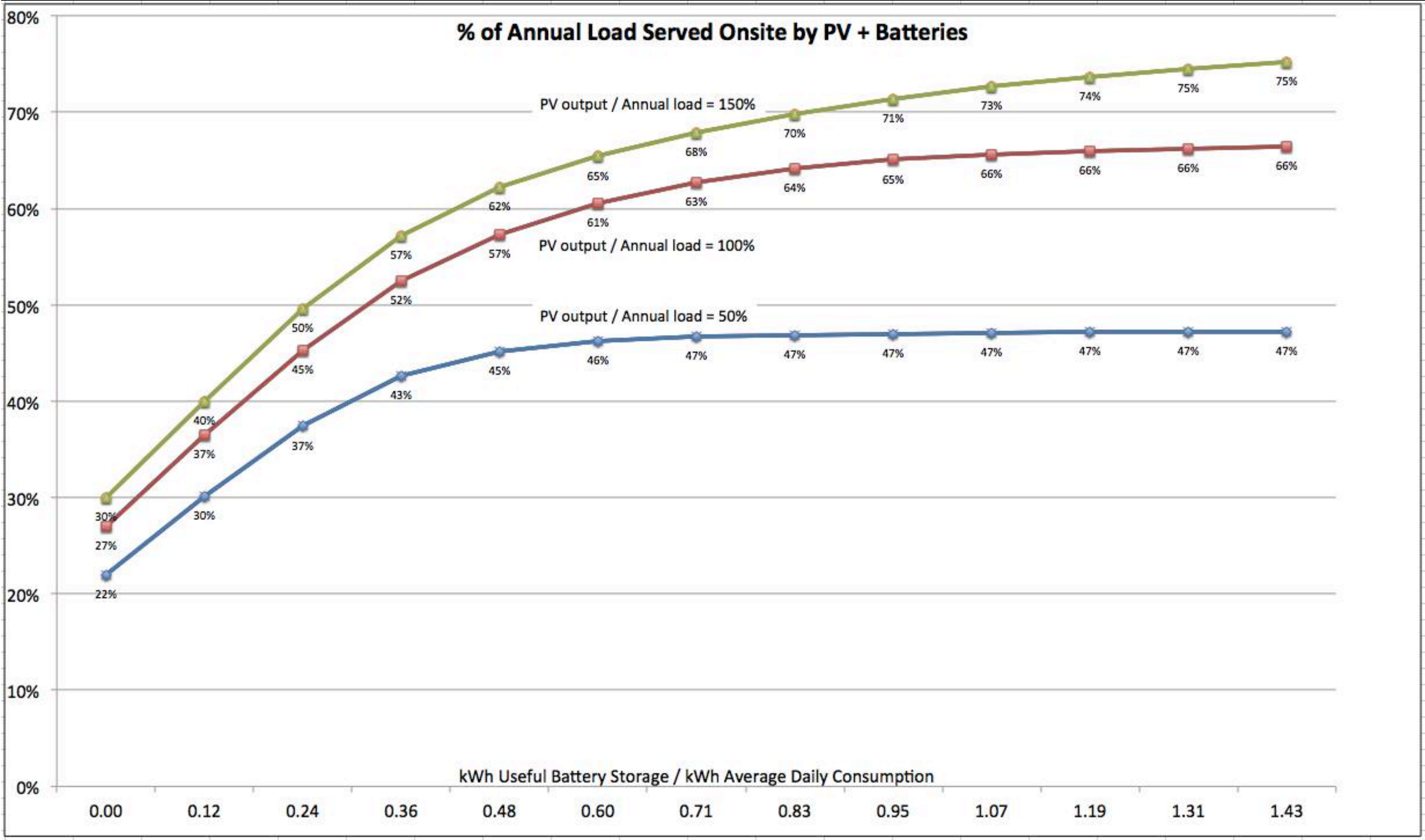
Date/Time	Net Utility	PV	Use	Heat	All except heat	Adjusted Use	Adjusted PV	Surplus PV	Potential stored PV	Net use after PV
12/3/2014 11:00	-238	-384	146	16	130	250	384	134	120	0
12/3/2014 12:00	-179	-592	413	262	151	639	592	0	0	47

Add Battery Storage

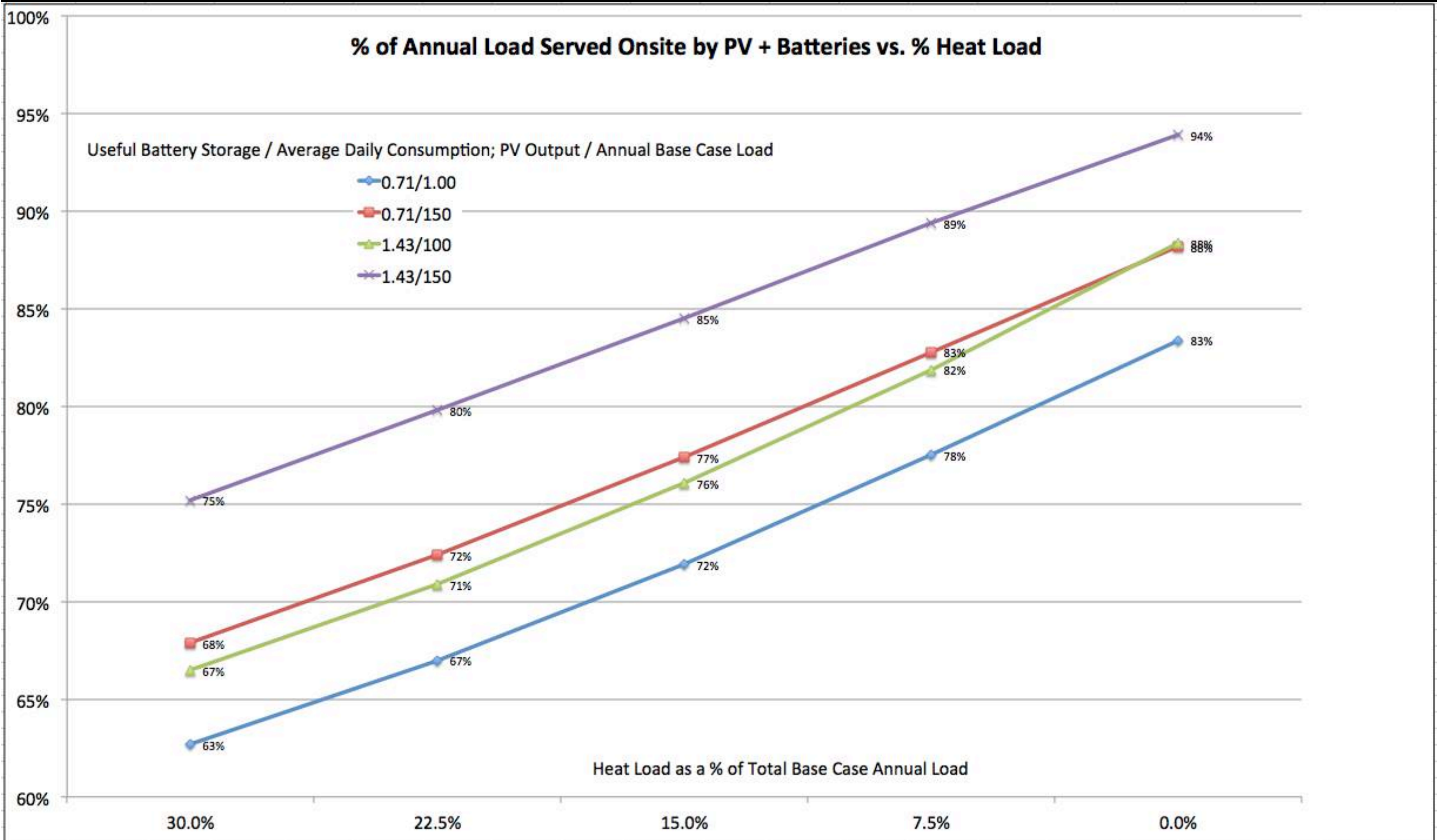
Storage capacity, kWh	15	Heat multiplier	1.43
Depth of discharge	0.80	All except heat multiplier	1.75
Useful storage capacity, kWh	12	PV multiplier	1.00
Storage round trip efficiency	0.90		

PV generated, kWh	Total used, kWh	Heat, kWh	Not Heat, kWh	Served directly by PV, kWh	Load not served by PV, kWh	Potential stored PV, kWh	Stored PV, kWh	Used from Storage, kWh	Imported from grid, kWh	% of load served by PV - no Net Metering	% of load served by PV - with Net Metering	PV generated / load
6139	6126	1850	4276	1637	4489	4052	3159	2205	2284	*63%*	100%	100%

Varying Storage and PV Size



Varying Heat Load



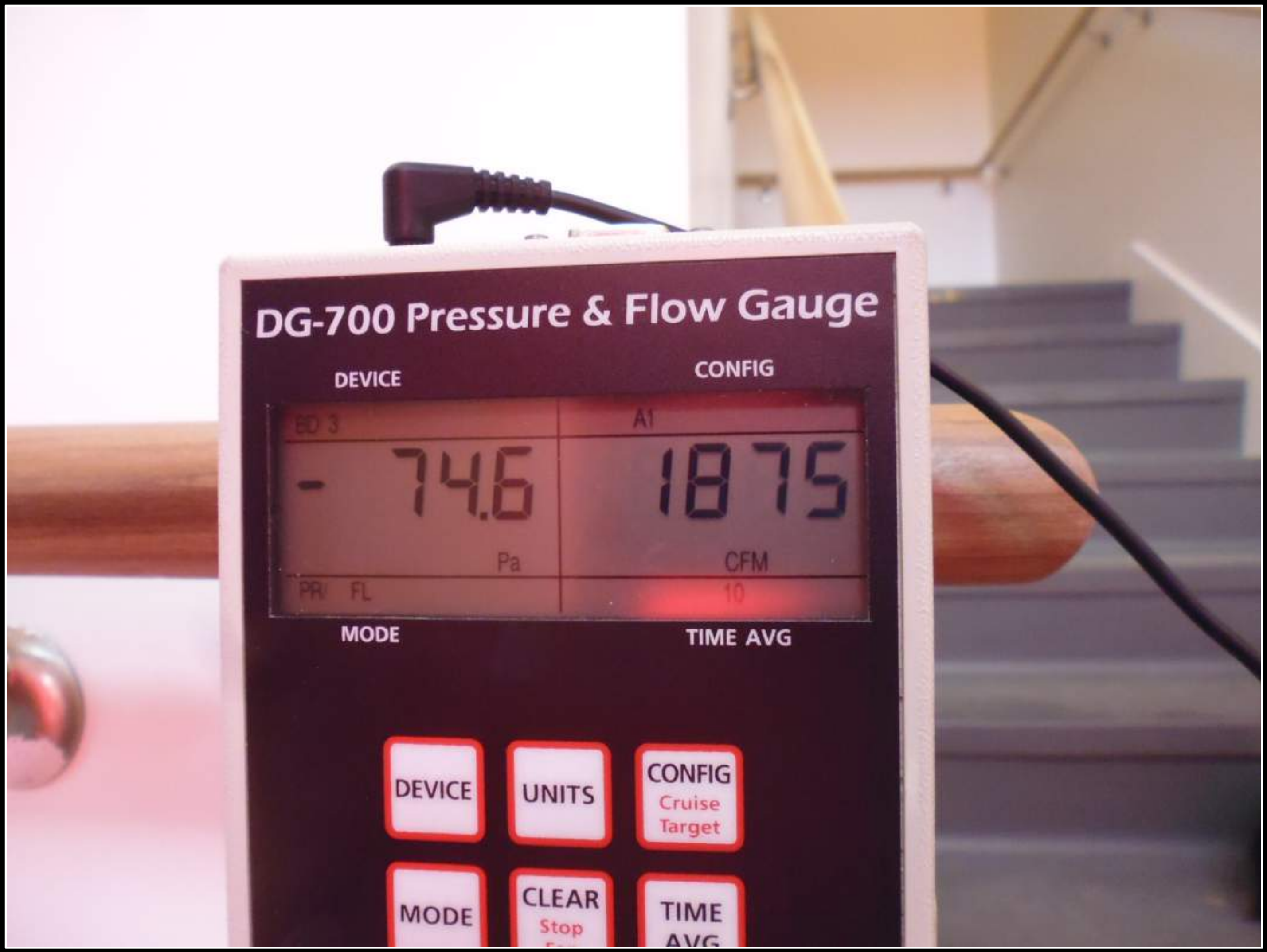
Emissions

- New England eGrid value for CO_2 emissions is 0.578 lb/kWh
- Getting 6,128 kWh from the grid = 3,542 lbs/year CO_2
- A Honda generator = +/- ¼ gallon gasoline/kWh (25% load)
- This makes 4.9 lbs/kWh of CO_2, 8.5 times the grid
- 3,542 lbs/year CO_2 from a generator = 183 gallons = 730 kWh
- If off-grid, one needs PV + storage to reach 88% of the annual 6,128 kWh/year load to break even on emissions compared with using the grid

Case Study – Kern Center

Hampshire College Bruner Cott Wright Builders

Case Study – Kern Center



0.046 CFM50/sf; 0.060 CFM75/sf of enclosure

Case Study – Kern Center

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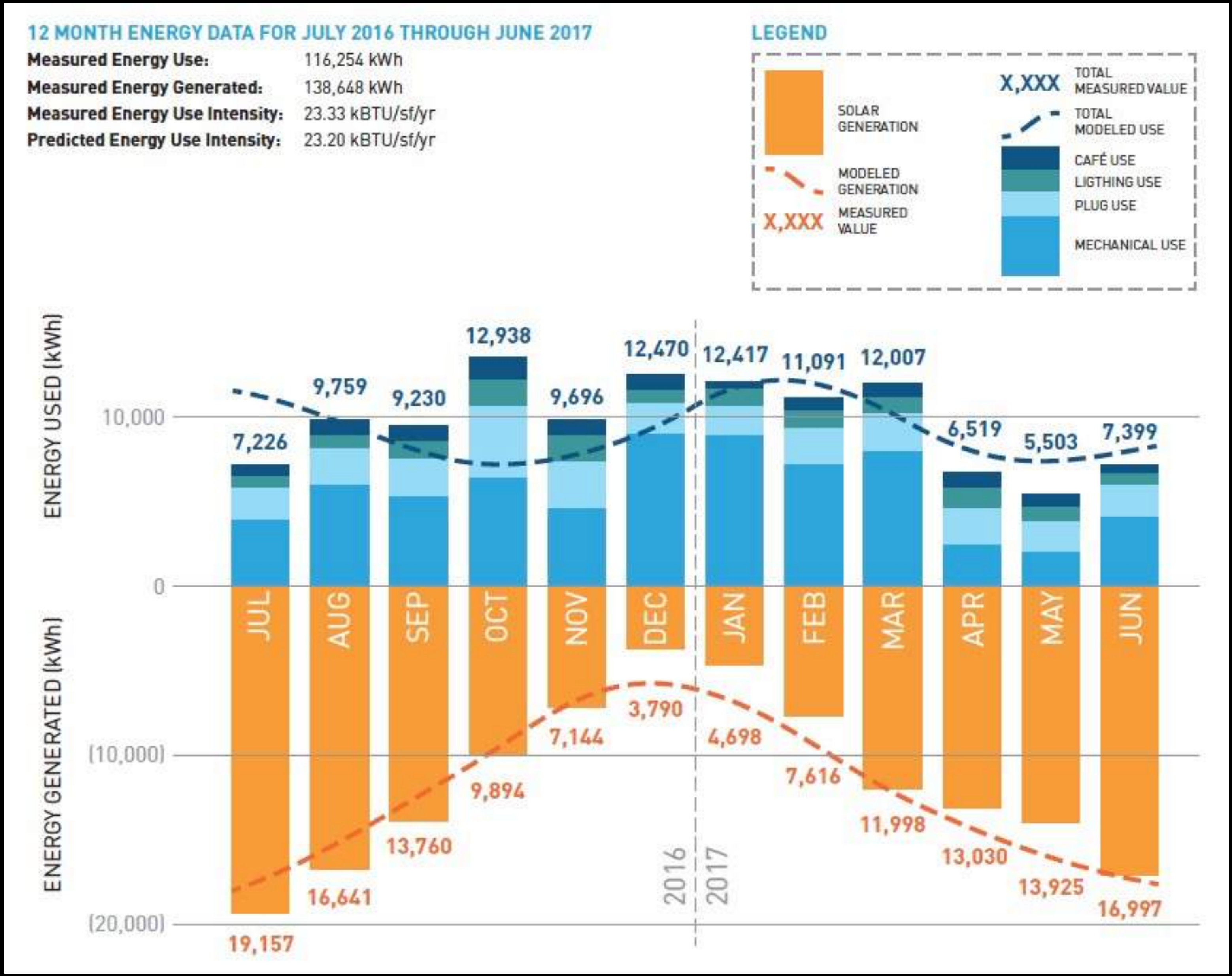


Case Study – West Tisbury Art Barn

Case Study – West Tisbury Project

- 3,000 ft2 multipurpose building – art gallery, shop, greenhouse, solar electricity
- Not heated, but high quality thermal envelope and very tight construction (0.05 CFM50/ft2 shell)

Solar applications include solar electricity, solar greenhouse with remote thermal storage, daylighting

Solar Electricity

- Estate usage of 36,000 kWh/year and objective of net zero electricity
- Buildings are heated with propane; swimming pool converted from propane to a heat pump pool heater
- Objective of providing power when the grid is down led to a bi-modal system with SMA grid-tied and off-grid inverters with battery banks
- 35 kW of Sunpower panels mounted on the standing seam roof – annual output of ~ 45,000 kWh

Solar Electricity

Solar Thermal

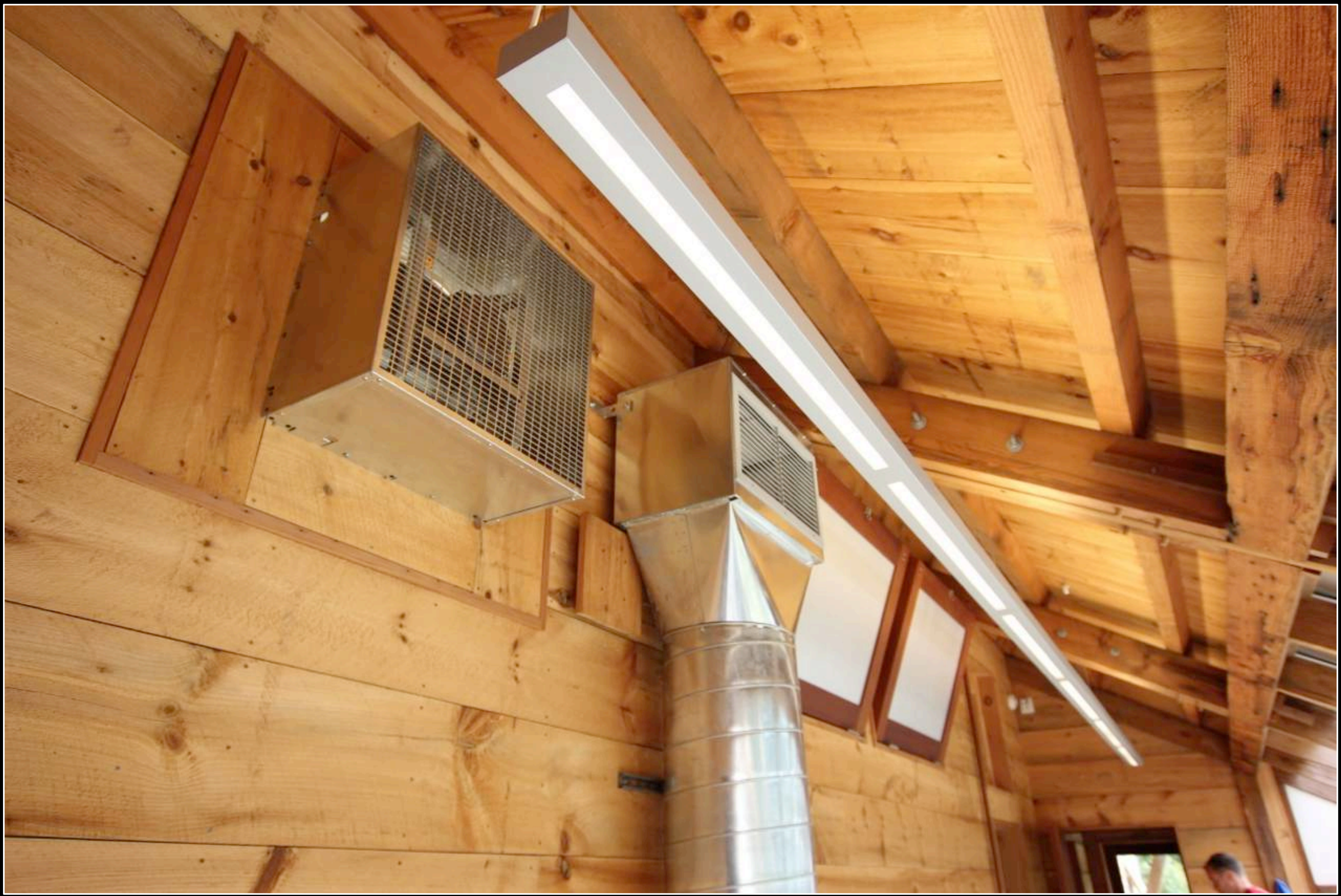
- Solar greenhouse designed to keep plants at 50F or more through the winter without heating
- Glazing is double low-e argon Cardinal 180
- When greenhouse temperature is greater than thermal storage temperature a blower turns on to transport heated air from the greenhouse to the basement level thermal storage
- Heat retrieval during cold night time conditions is via passive natural convection

Solar Thermal

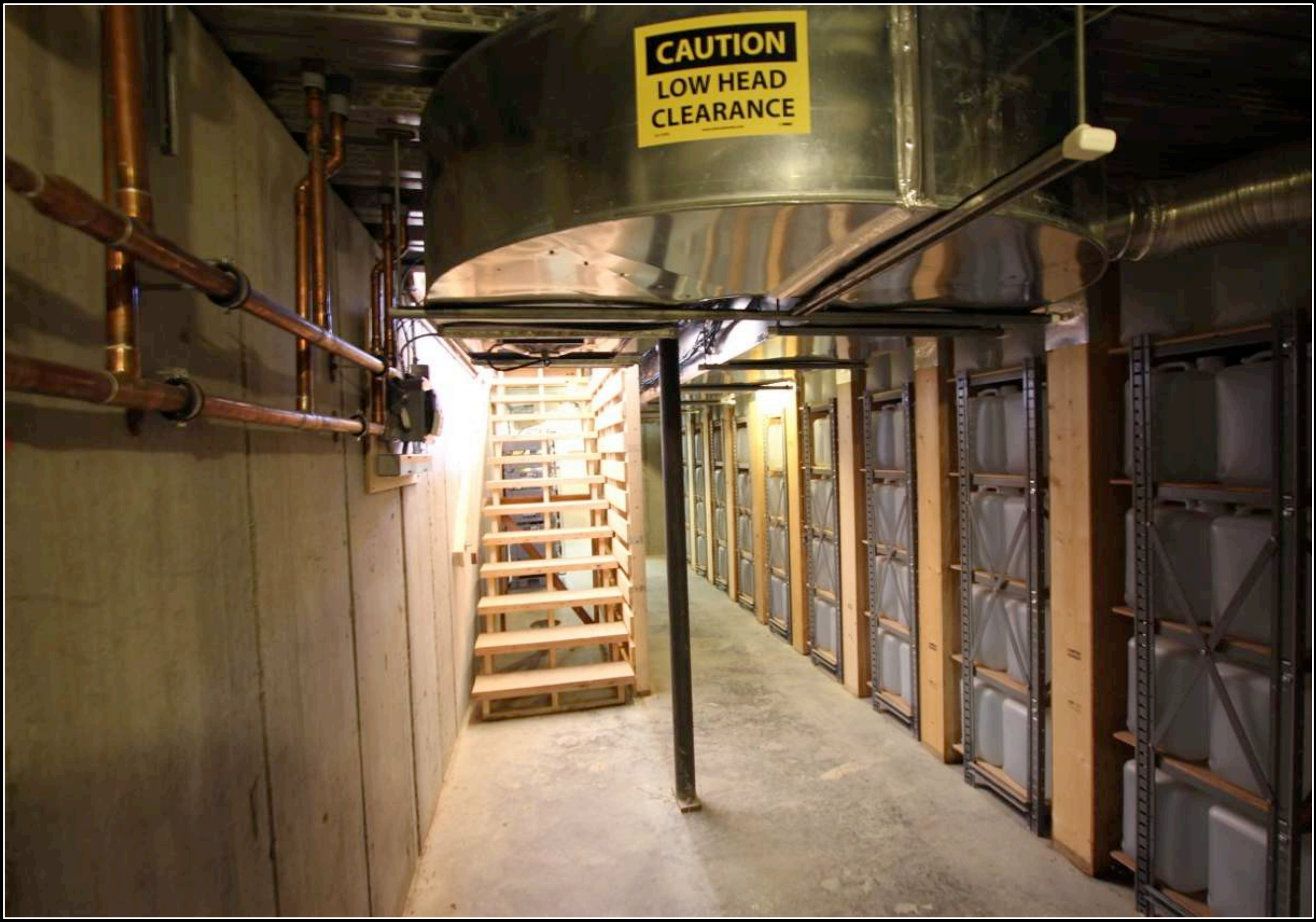
- Clear day calculations on vertical and horizontal glazing to assess thermal storage need – final design has 300 five gallon water containers that store 125,000 BTU over a 10˚F rise – concrete in the basement adds significant additional storage
- Peak hourly net gain calculation to size the blower

Solar Thermal

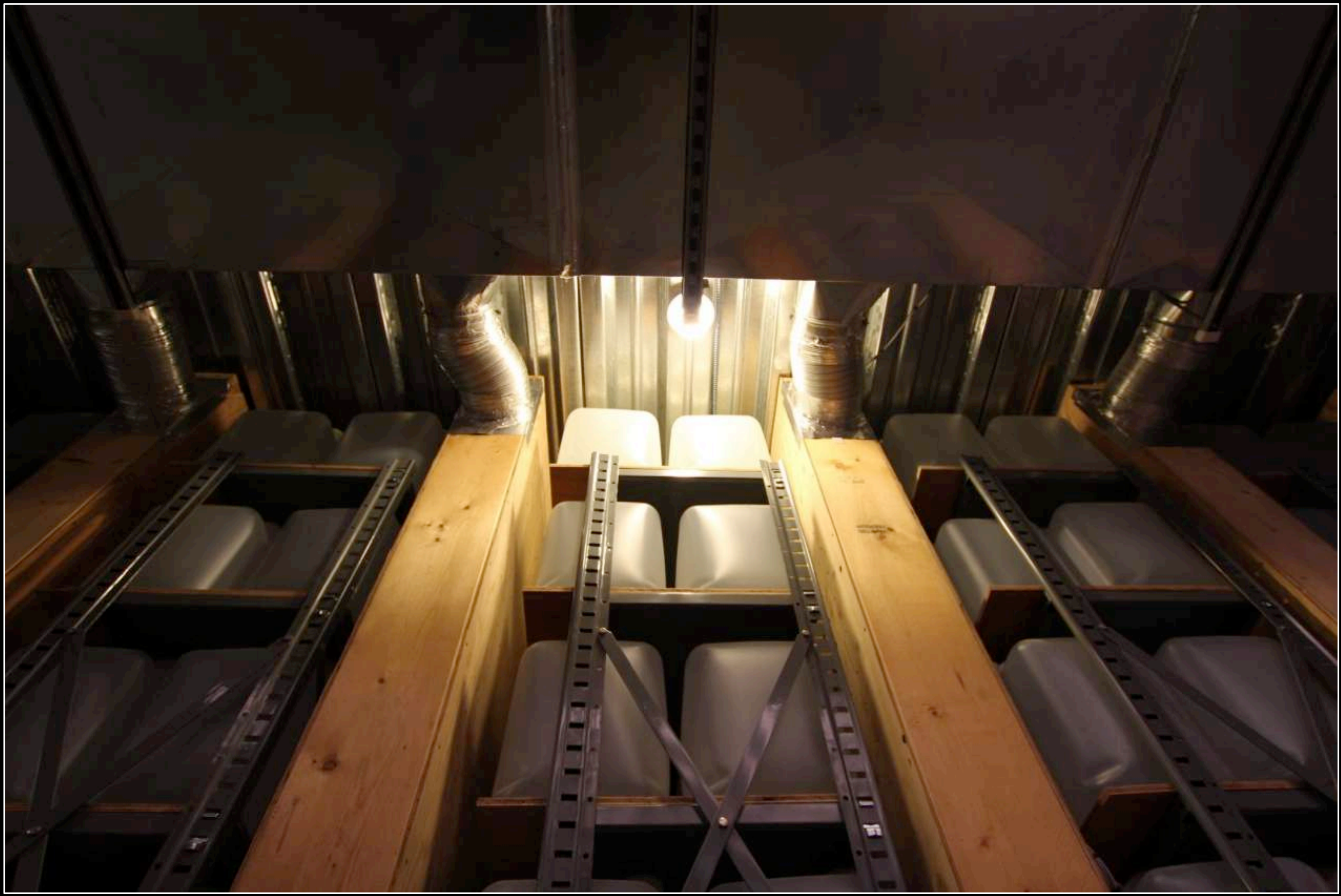
Solar Thermal



Solar Thermal



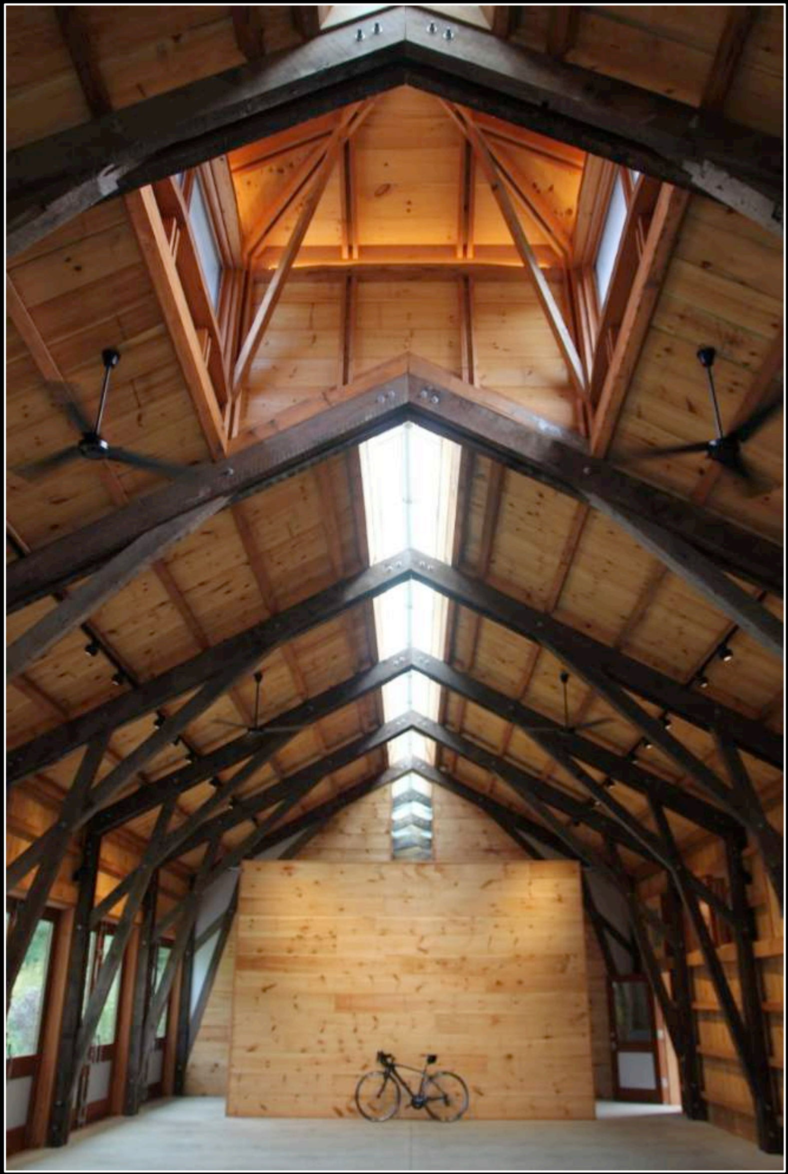
Solar Thermal



Daylighting

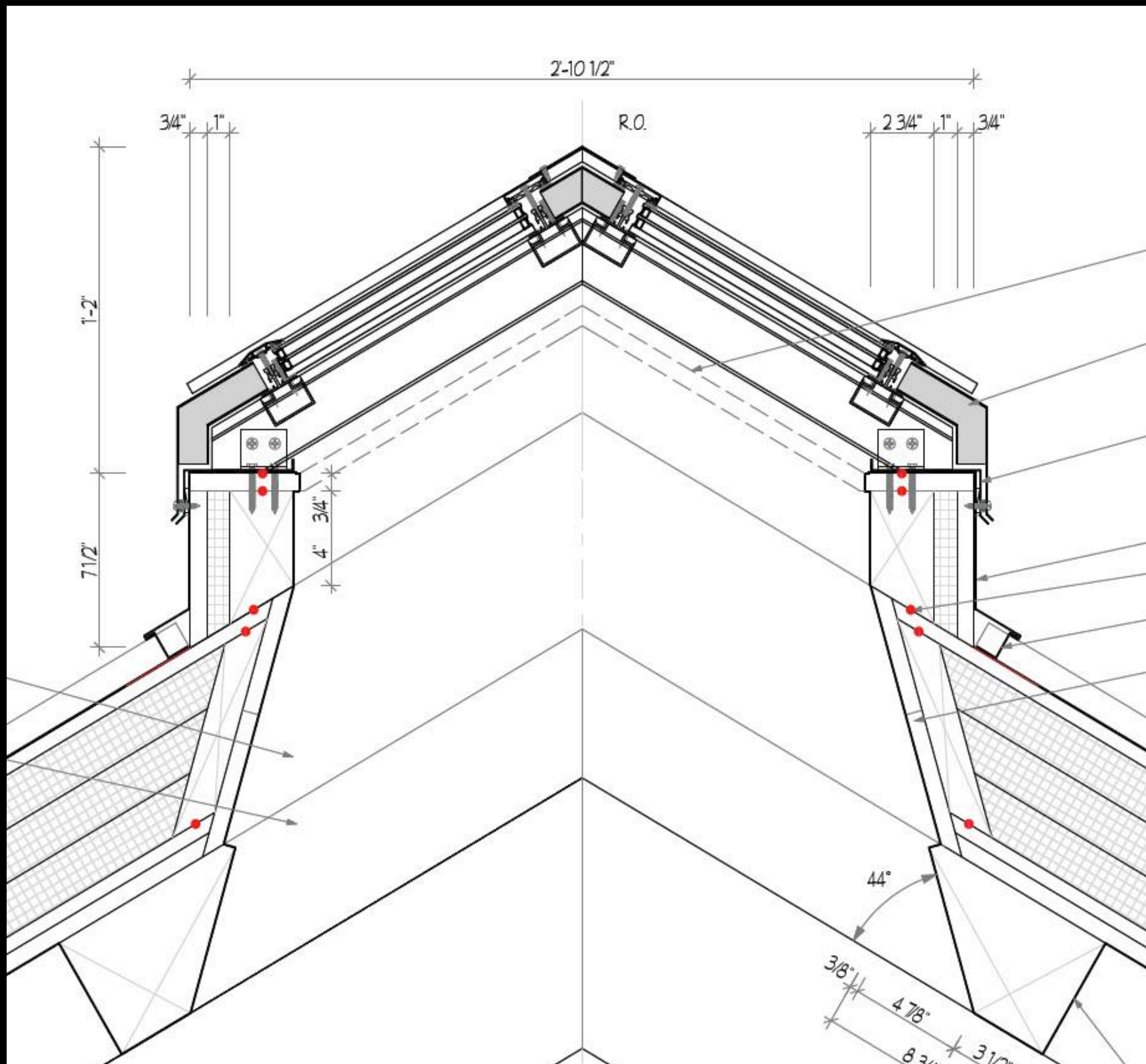
- Both gallery and shop were designed with little sidewall glazing
- Toplighting via a continuous ridge skylight was chosen to daylight these spaces
- A Daylight Factor of 2% was the target
- Glazing is triple low-e argon Cardinal 272 – VLT is 56%

Daylighting



Daylighting

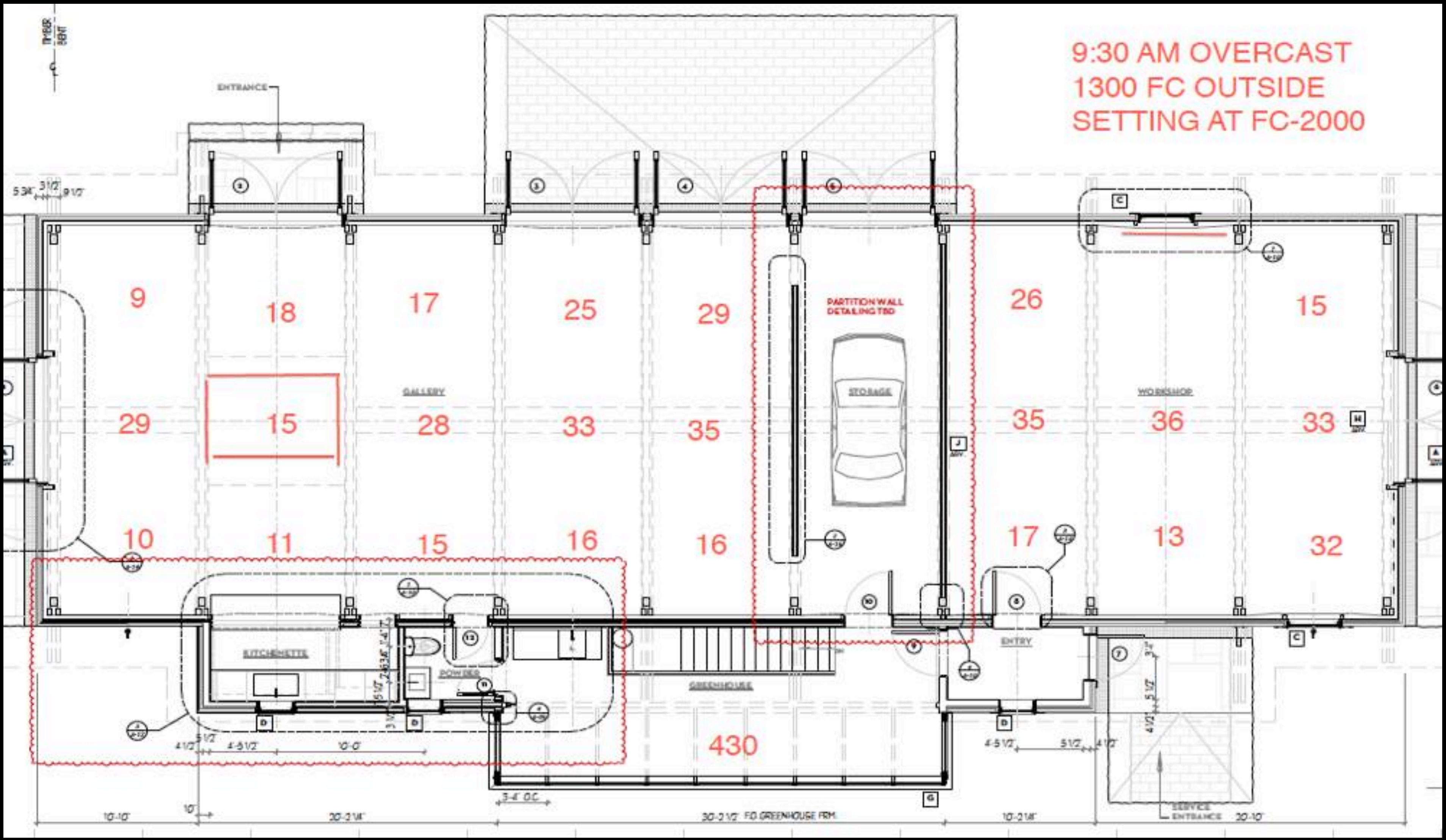
Daylighting



Daylighting

Skylight to floor ratio	7.1%
VLT	0.56
Well Factor	0.6
Dirt/Screen Factor	0.85
Effective aperture	2.0%
Outdoor fc	1300
Indoor fc	27

Daylighting



Thank You!

Marc Rosenbaum, P.E.
South Mountain Company
West Tisbury, MA