FLORIDA SOLAR ENERGY CENTER™

Creating Energy Independence

Ultra High Efficiency PV System Integrated Non-Grid-Tied Hot Water Energy Storage

American Council for an Energy Efficient Economy

ACEEE Hot Water Forum– Feb. 26-28, 2017

Carlos J. Colon
carlos@fsec.ucf.edu

FSEC™

A Research Institute of the University of Central Florida

Florida Solar Energy Center – Research Institute of University of Central Florida (UCF)

(Cocoa, FL : East Central Coast)

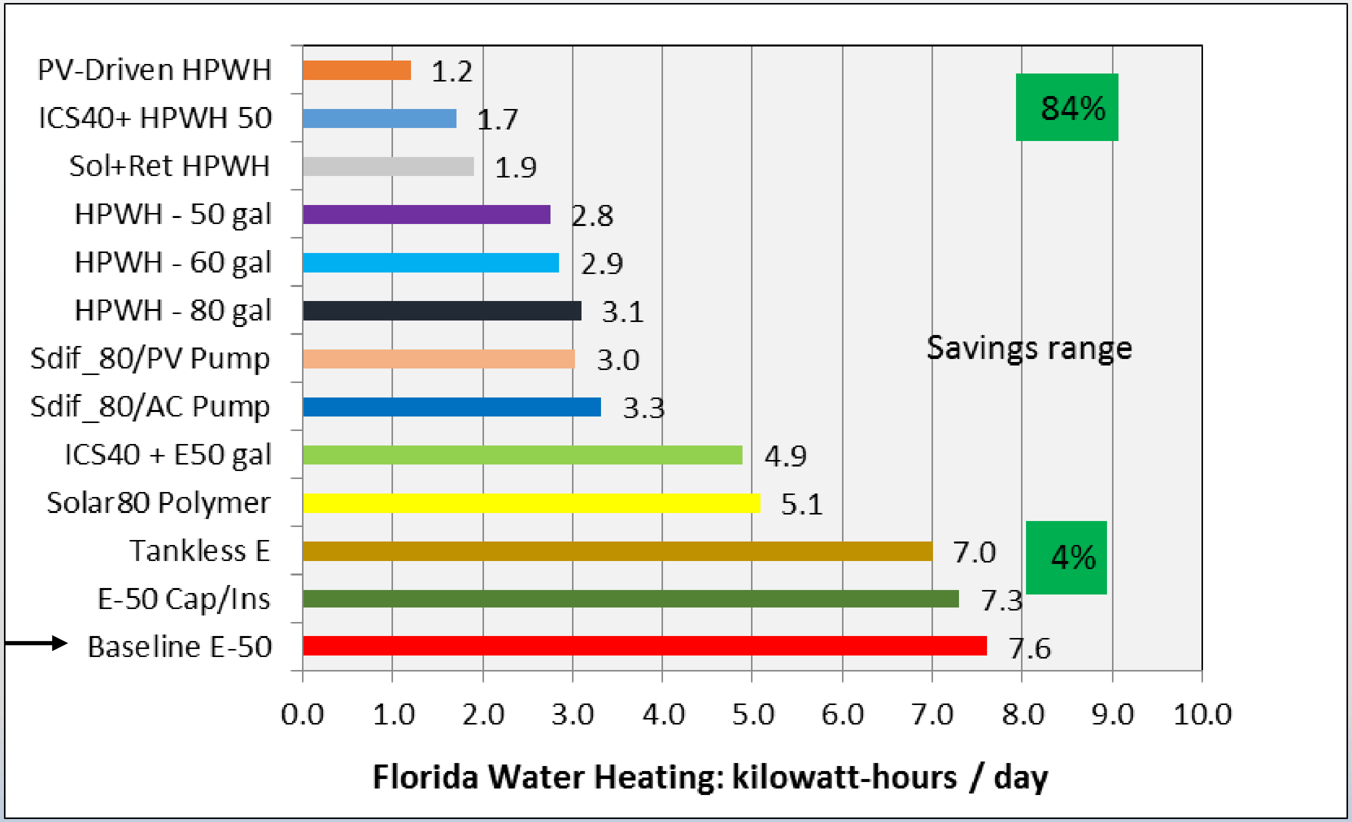
FSEC™

Florida Solar Energy Center – Research Institute
University of Central Florida (UCF)

Hot water Systems Laboratory 2010

Summary of HWS Laboratory Electric Water Heating Systems Evaluated since 2010

#1



Standard Electric EF=0.91

FSEC's PV HPWH: Prototype

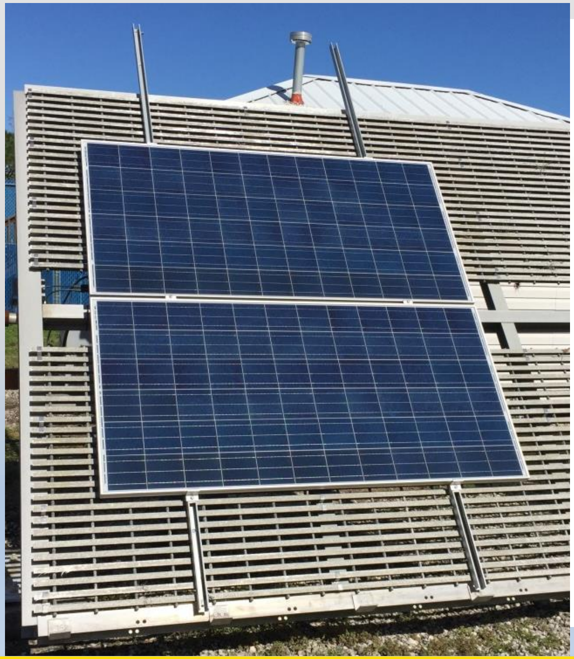
- Use Current Generation 50 Gal HPWH
  Electric COP = ~2.5 (Florida)
- Add dedicated 620 Watts Photovoltaics & micro-Inverters
- Use Mixing/Anti-scald valve: set @125 ^{o}F
- Add Smart Controls & Program for Additional thermal storage above 125 ^{o}F
  - -Normal thermostat set: 125 ^{o}F (52C)
  - -When solar availability = High, Auto-set thermostat to 140 ^{o}F (70 C)
  - -Use of electric resistance past 140 ^{o}F
- Overall COP = 5.2 (Florida)
- Competitive total parts cost ($2041) Retail

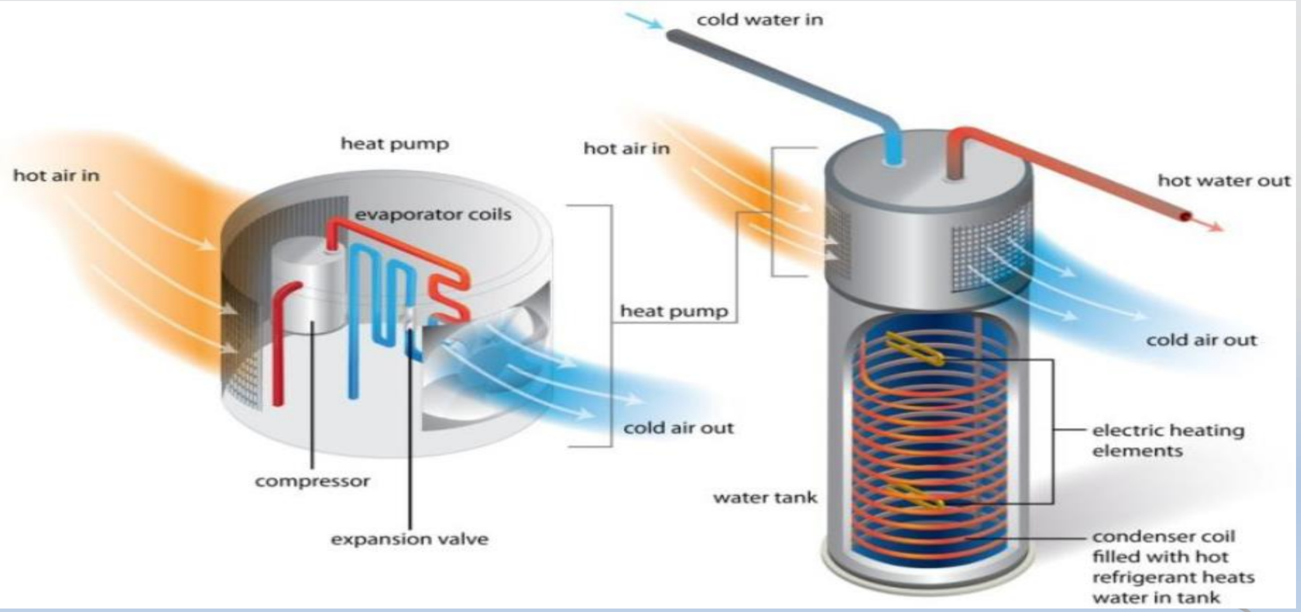
Project Goals/Targets

Target Performance and Cost:

The PV-assisted HPWH project has the following low-cost and high-performance targets for typical U.S. climates:

- $1,200 incremental system cost in existing homes at large market scale
- 60-85% energy savings over electric resistance water heaters
- 10-15 year product lifetime with high system and component reliability and performance





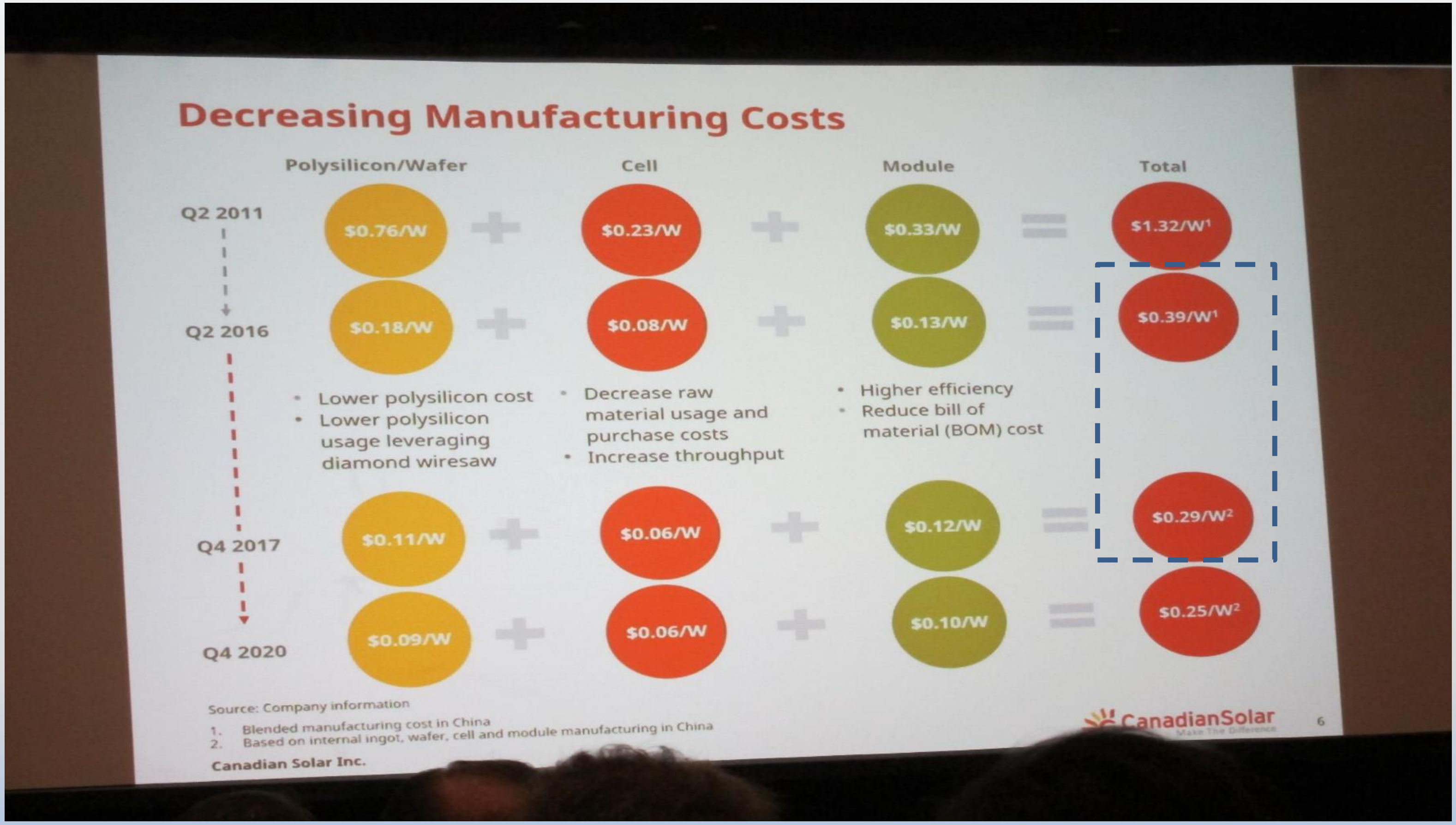
Prototype PV-assisted HPWH Costs

Component	Model	Price/Unit	Cost
Heat pump water heater	GE GEH50DEEDSR GeoSpring	$999	$999 (shipping included)
PV modules (2)	Canadian Solar Quartech MaxPower CS6X-310P	$241.80 each ($0.78/watt)	$483.60
Microinverters (2)	ABB Micro-0.3-I-OUTD, 300W	$147.52 each ($0.49/watt)	$295.04
PV Trunk Cable	ABB AC-Trunk (portrait x2)	$18.08	$36.16
Anti-Scald (Mixing) Valve	Honeywell AM-101 Thermostatic Valve ¾”	$80	$80
Controls / Communication	GE Green Bean, Raspberry Pi 2, 32 GB MicroSD Card, Miscellaneous	$19 $39.95 $14.95 $73.17	$147.07

Total Prototype Equipment Cost: $2,041

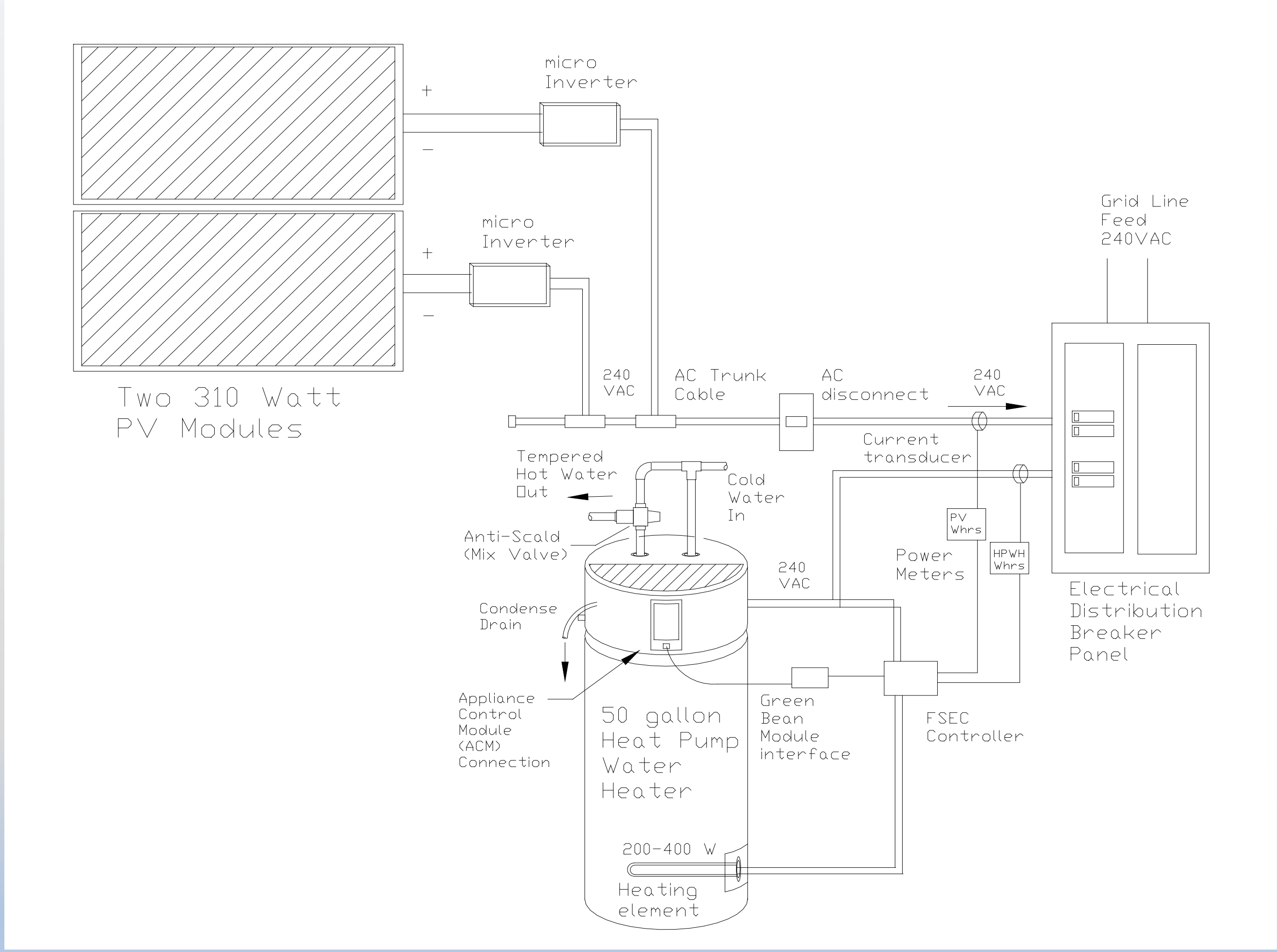
Note: Retail costs

Predictions on Solar PV Cost by Manufacturer at SPI 2016

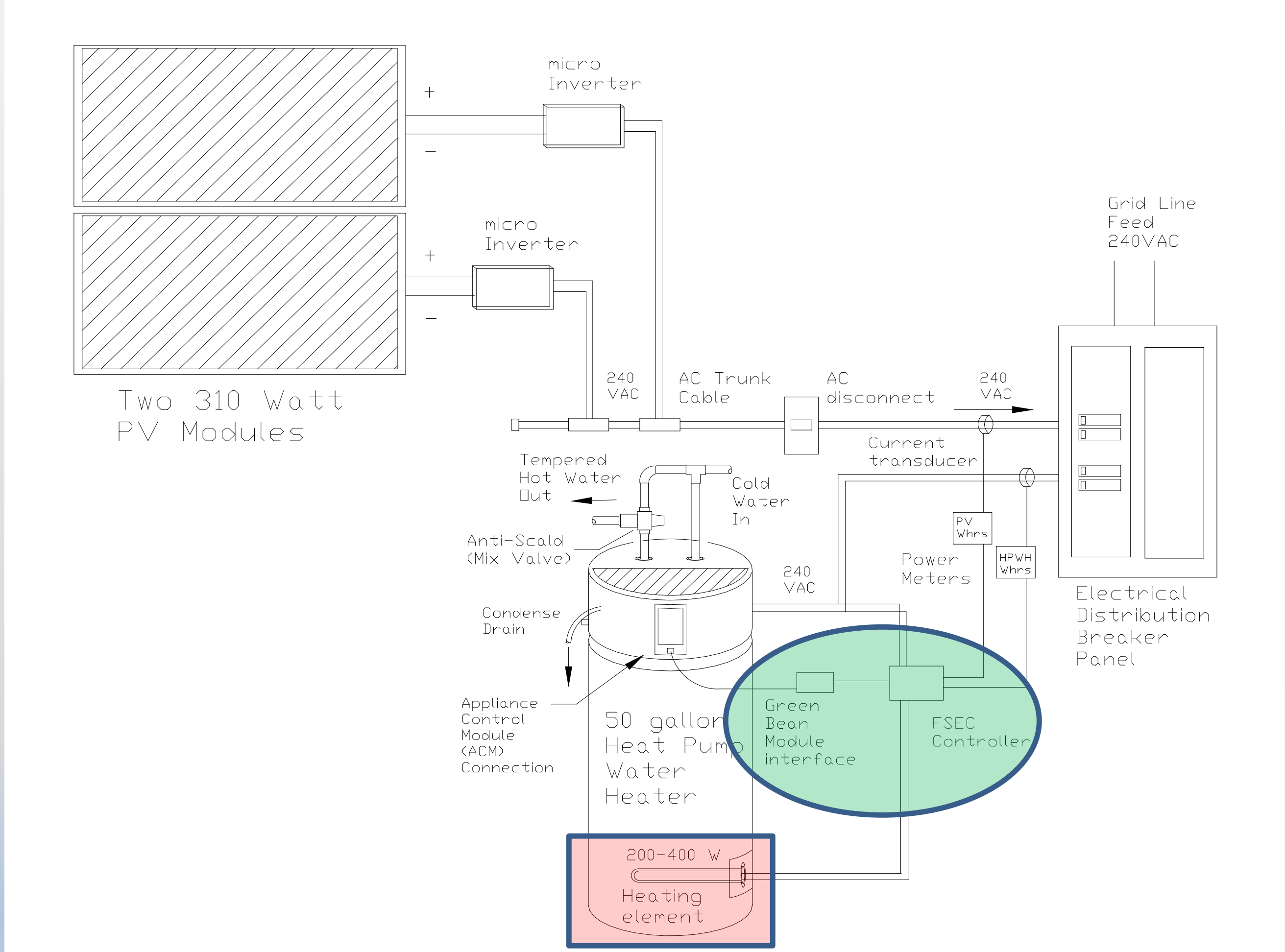


On target…..Near Future (2020) Looks even Better!

FSEC's PV-Driven HPWH Prototype

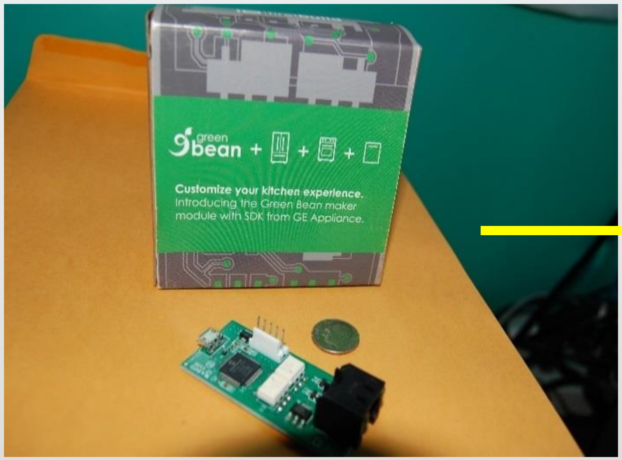


PV-Driven HPWH Controls and Added Storage

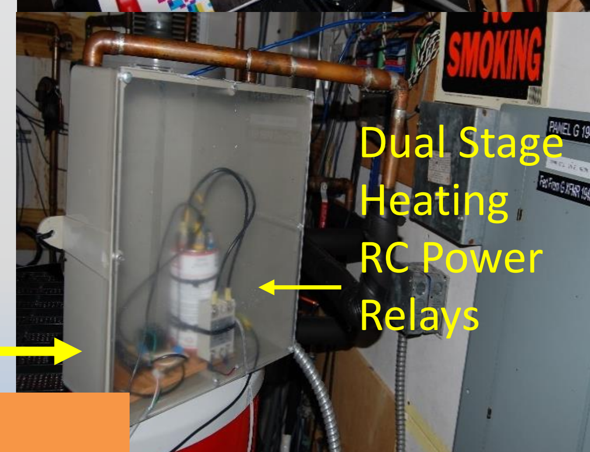


Controls Accomplished by: : Greenbean, RaspberryPi2 and FSEC Controller

Appliance Control Module (ACM)
FirstBuild Greenbean

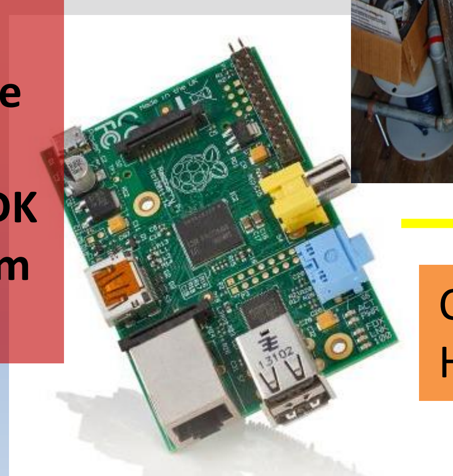


Determines Solar
Electric production near real time
and decide thermostat setting
or element activation



Dual Stage
Heating
RC Power
Relays

Raspberry Pi 2
Running JS Node
Parallel Process
Running GE's SDK
and FSEC Csutom
Control Code



Control 2-stage
Heat Element Control

FSEC™

Electric Resistance Heating Elements

OHM METER READING FOR ELEMENTS

WATTS	VOLTS	OHMS	VOLTS	OHMS
600	118	23.2	120	24
750	118	18.5	120	19.2
1000	118	13.9	120	14.4
1250	118	11.1	120	11.5
1500	118	9.3	120	9.6
2000	118	6.9	120	7.2
600	236	92.8	240	96
750	236	74.2	240	76.8
1000	236	55.6	240	57.6
1250	236	44.5	240	46
1500	236	37.1	240	38.4
2000	236	27.8	240	28.8
2500	236	22.2	240	23
3000	236	18.5	240	19.2
3500	236	15.9	240	16.4
4000	236	13.9	240	14.4
4500	236	12.3	240	12.8
5000	236	11.1	240	11.5
6000			240	9.6
3000	208	14.4		
4500	208	9.6		
5000	208	8.6		
4000	480	57.6		
5000	480	46.08		
6000	480	38.4		

Formula for R (Ohms) =

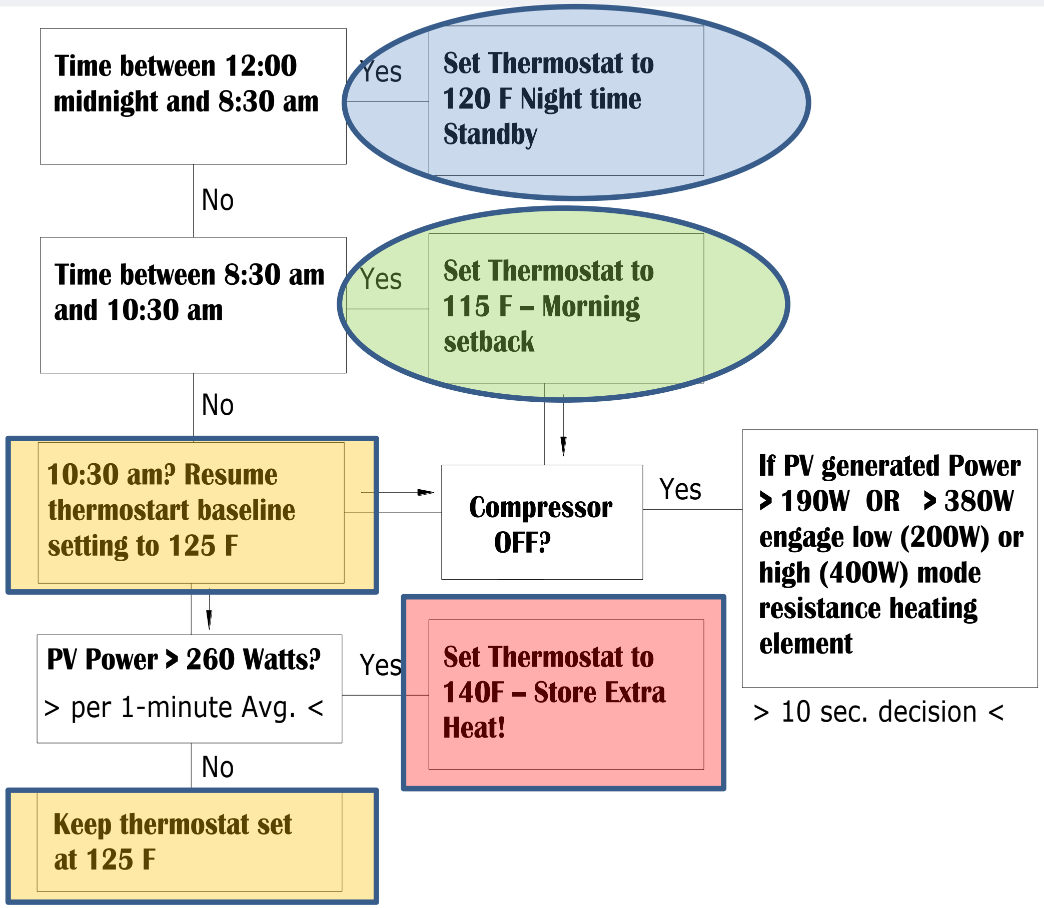
$$\frac{(\text{Rated Voltage})^2}{\text{Rated Wattage}} \pm 2\%$$

Reduced Power to Heat Element using Capacitive Reactance

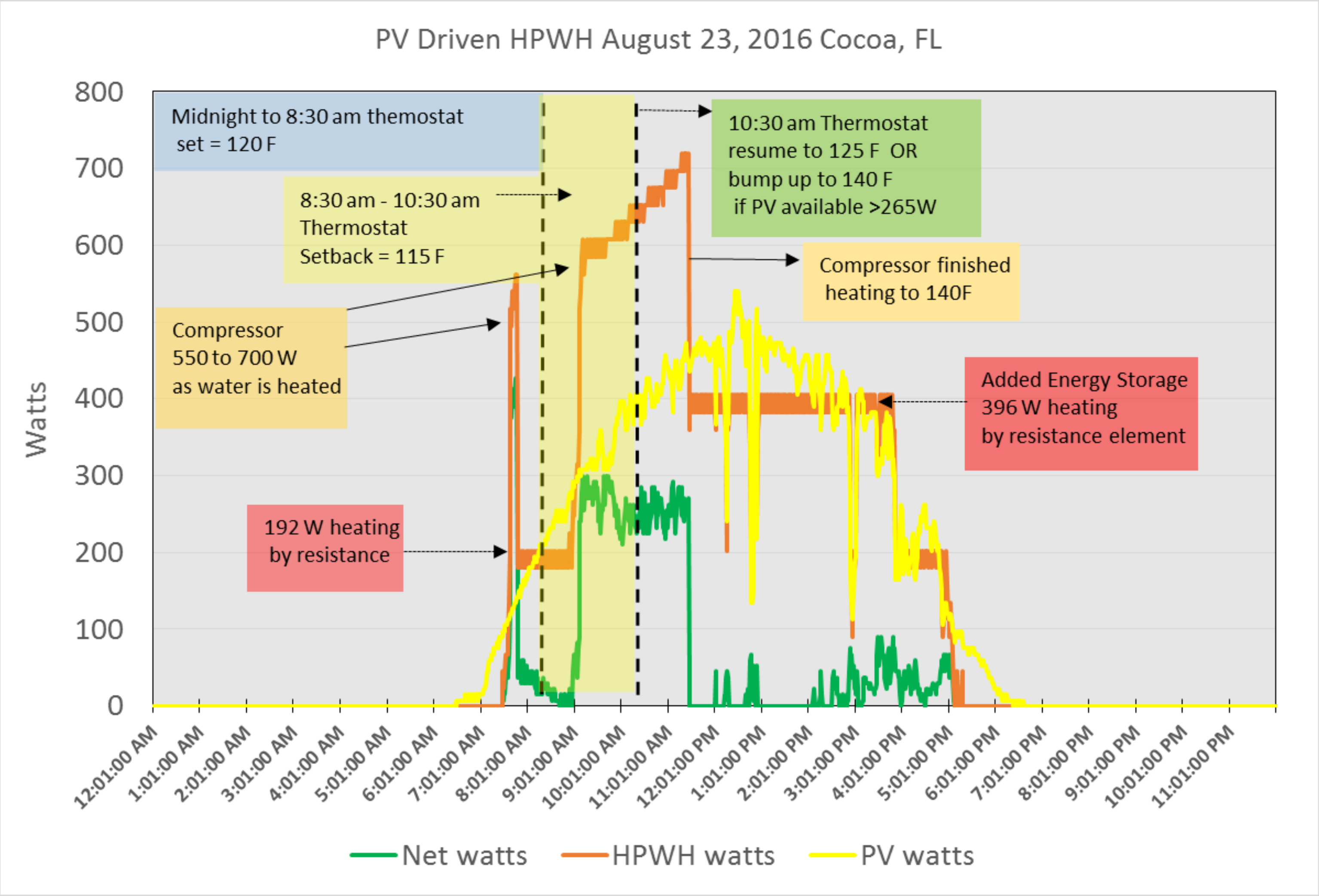
30 uf 400VAC Capacitor
Voltage across heating element
154.6 VAC; Current 2.037 Amps
315 watts

240 VAC Heat element replaced: 75 ohms (750W)

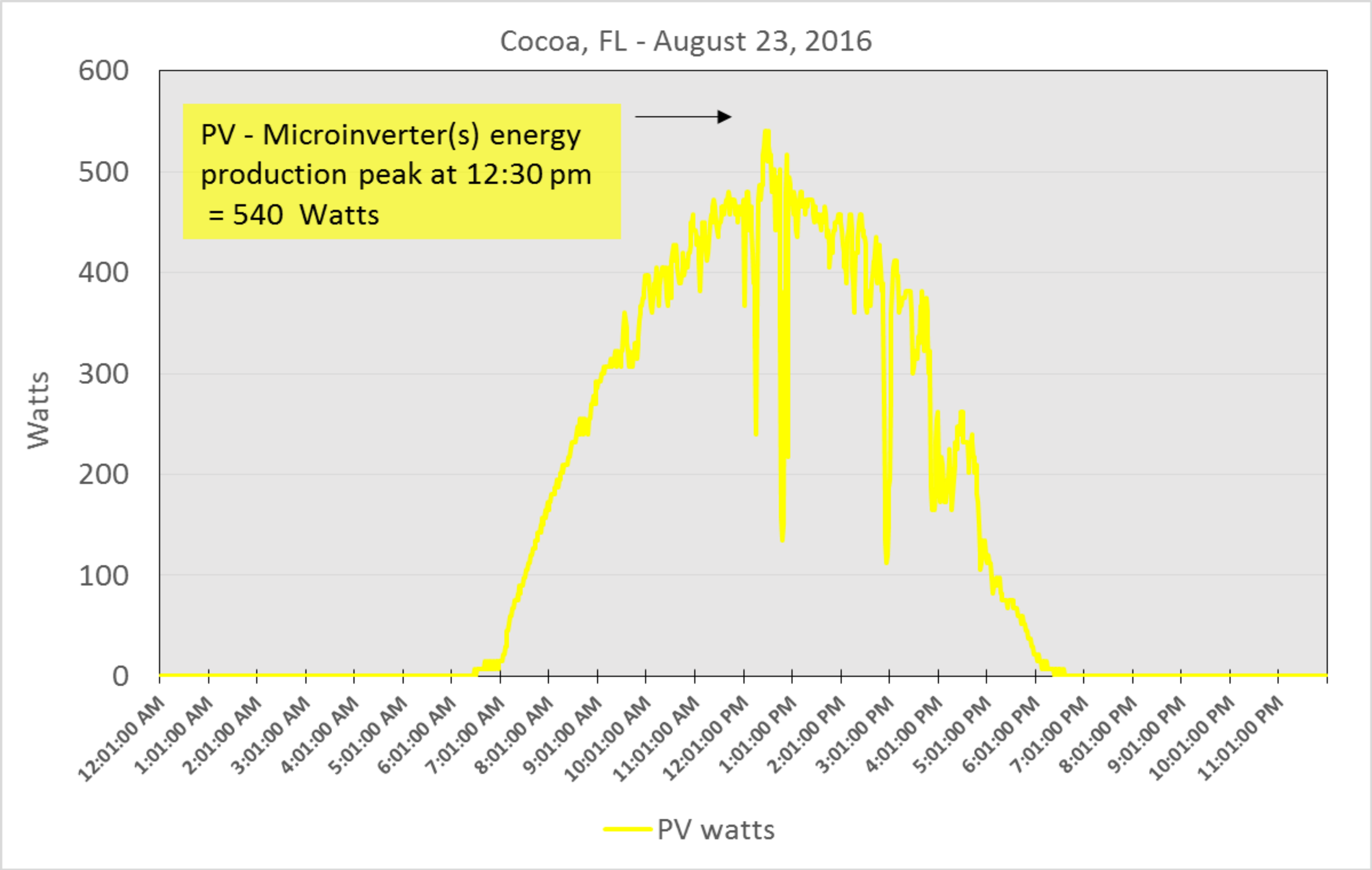
PV HPWH Control Logic



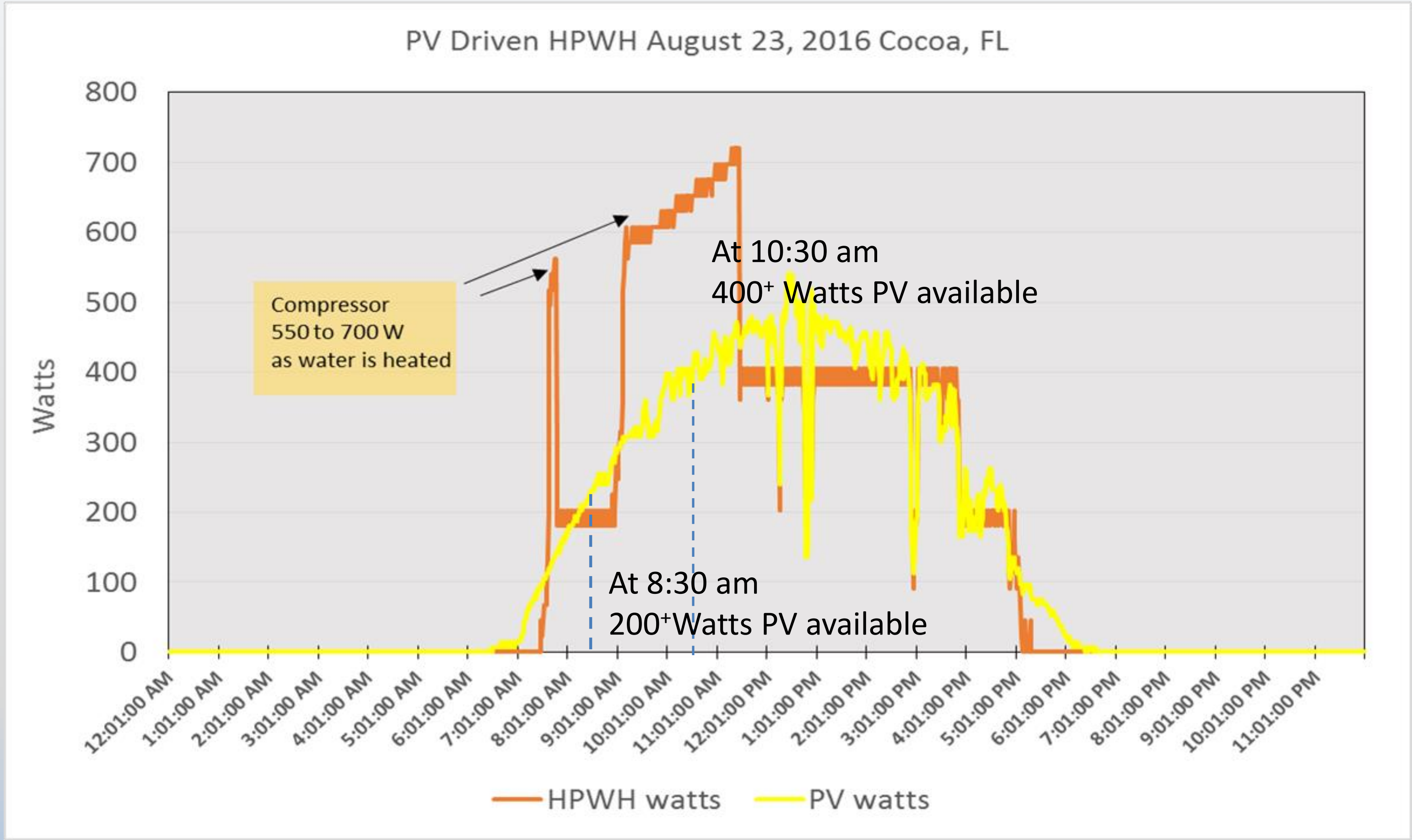
Operation Performance Example



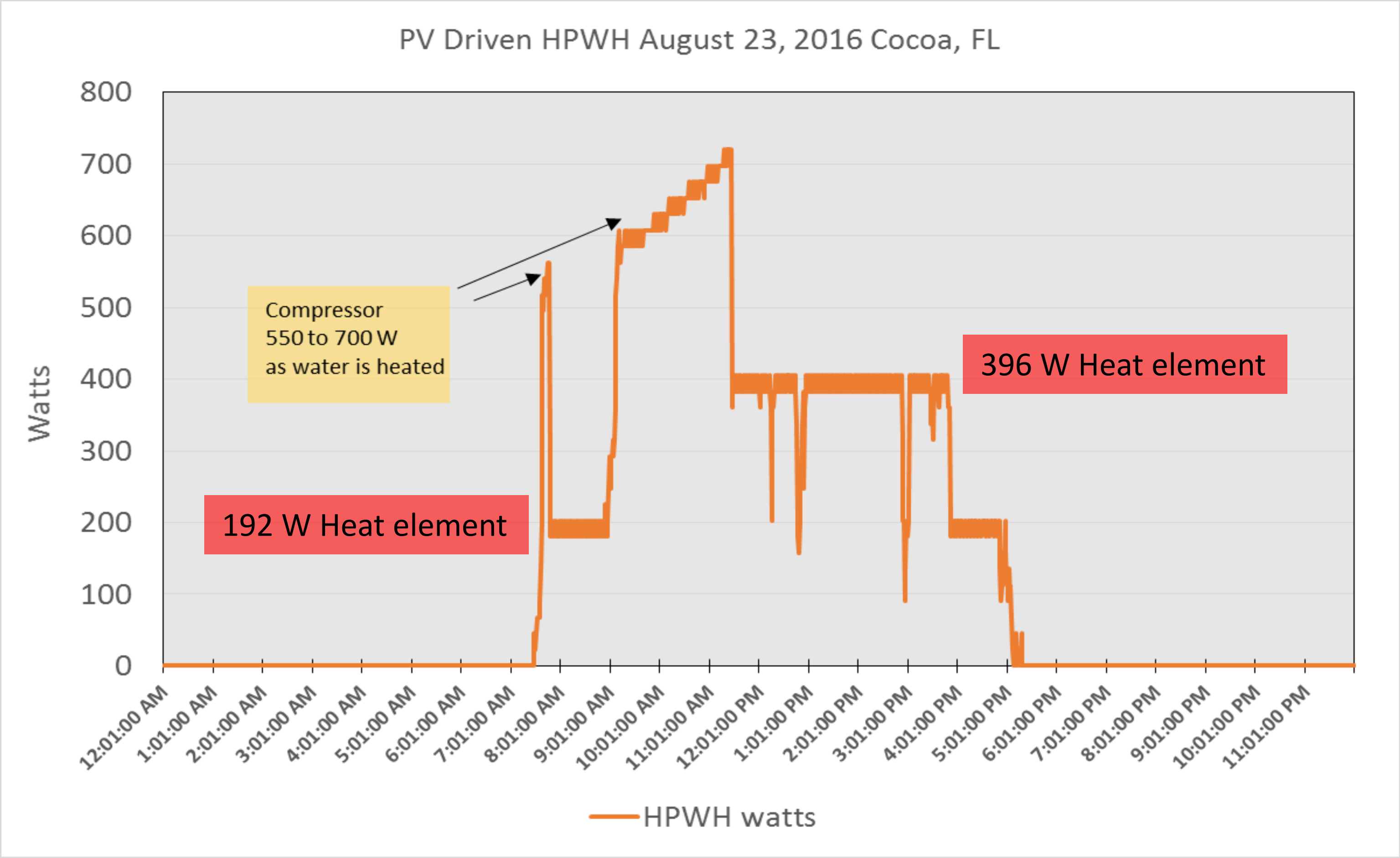
Power from Two 310 Watt PV Modules



Daily Performance-Operation Example

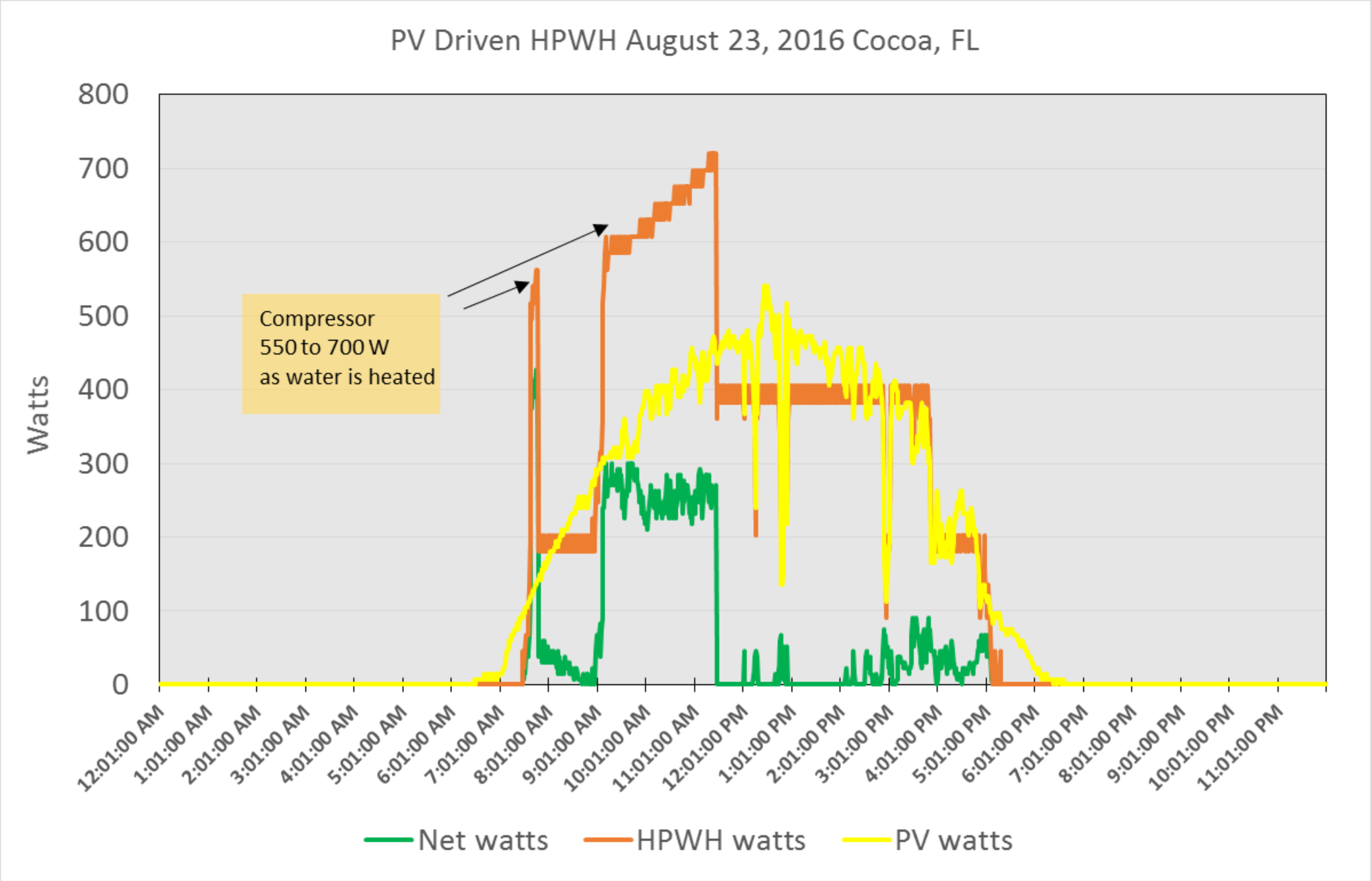


HPWH Electric Load

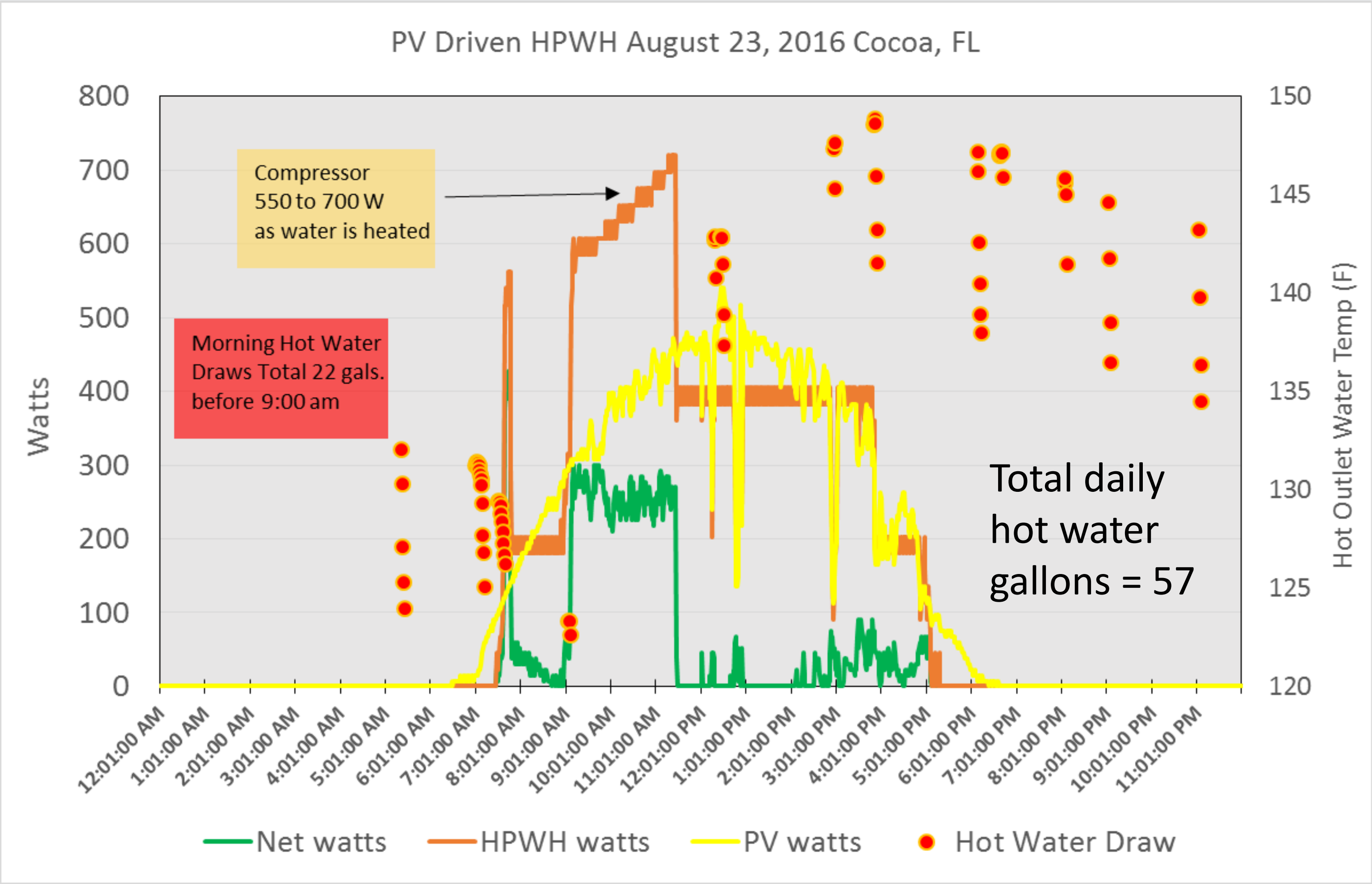


FSEC

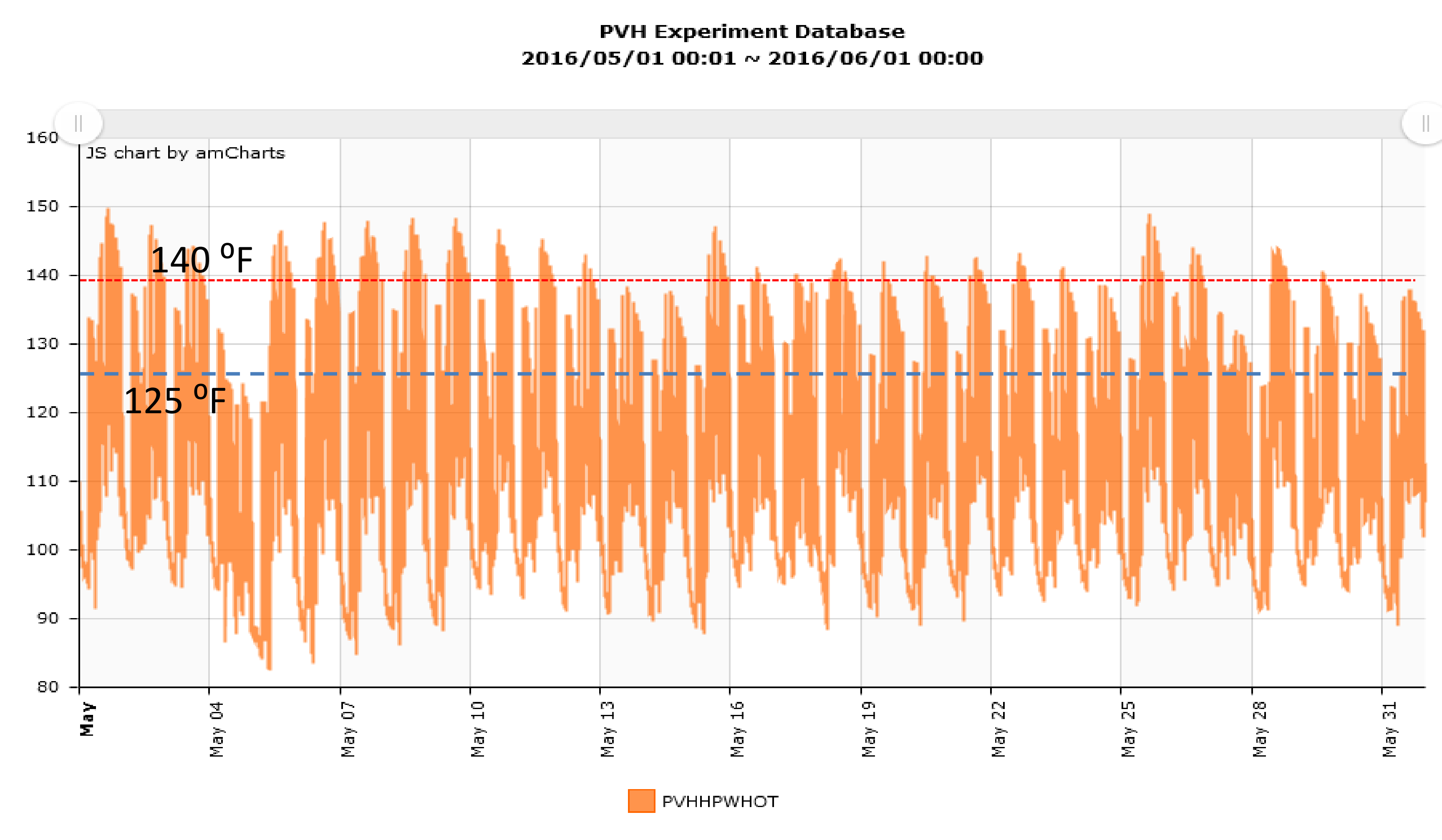
PV Driven HPWH Net Load (Watts)



PV Driven HPWH Load



Hot Water - May 2016



Storage: Above 140 ^oF

	Maximum Hot outlet temperature recorded (F)	Average Max Hot Water Temperature for days above 140 ^oF	Equivalent Extra storage Energy above 140 ^oF (kWh)	# Days in Month reaching over 140 ^oF and percentage of instance for Month (%)
April	147.67	143.5	0.407	19/23 (82.6%)
May	149.71	145.1	0.604	23/31 (74.2%)
June	147.49	143.4	0.394	16/30 (53.3%)
July	148.75	146.1	0.721	27/31 (87.1%)
Aug	149.81	144.2	0.496	27/31 (87.1%)
Sep	147.24	143.3	0.387	23/30 (76.7%)
Oct	146.26	142.5	0.293	15/24 (62.5%)
Average		144.0	0.472	150/200 (75%)

FSEC

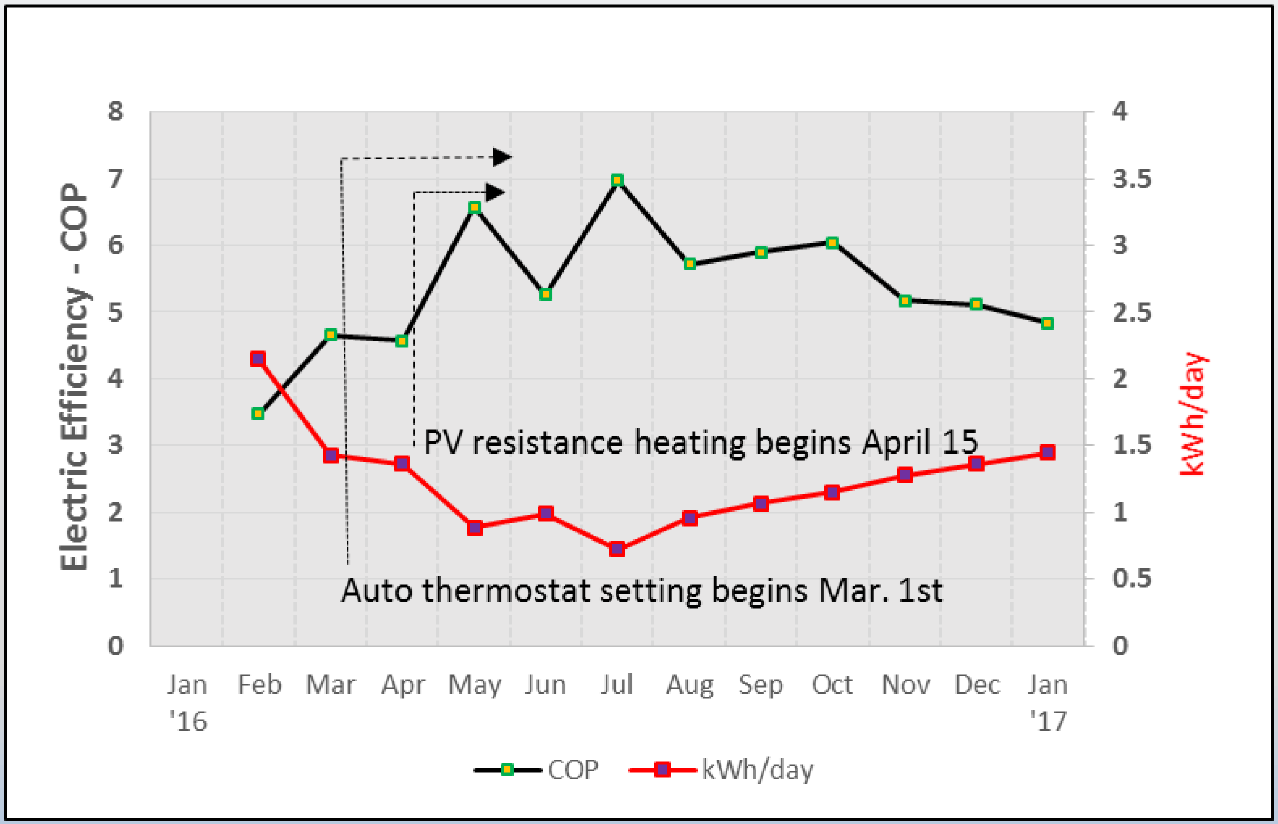
Insulation and Tank Losses

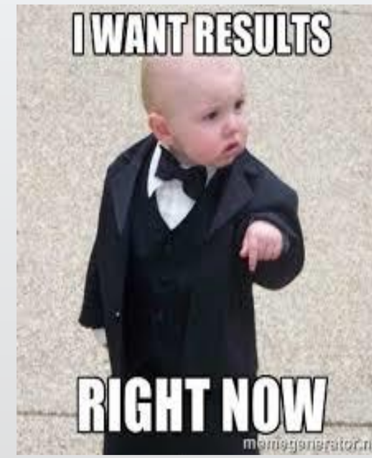
Insulation: Single layer double bubble wrap (R= 1.01) with ½" air space
Total R = < 2.0

May 2-3 and May3 -4	No Wrap Insulation	After Wrap Insulation
Hot temp prior to standby (23:03 pm)	135.0 ^{o}F	134.2 ^{o}F
Temp after standby (5:21 am)	130.1 ^{o}F	129.1 ^{o}F
Overnight Hot water temperature loss (ΔT)	4.9 ^{o}F	5.1 ^{o}F
Ambient to tank temp differential (ΔT)	57.27 ^{o}F	64.27 ^{o}F
Losses (BTU/hr).	324	377
U (Btu/hr F)	5.65	5.25

PV HPWH Performance

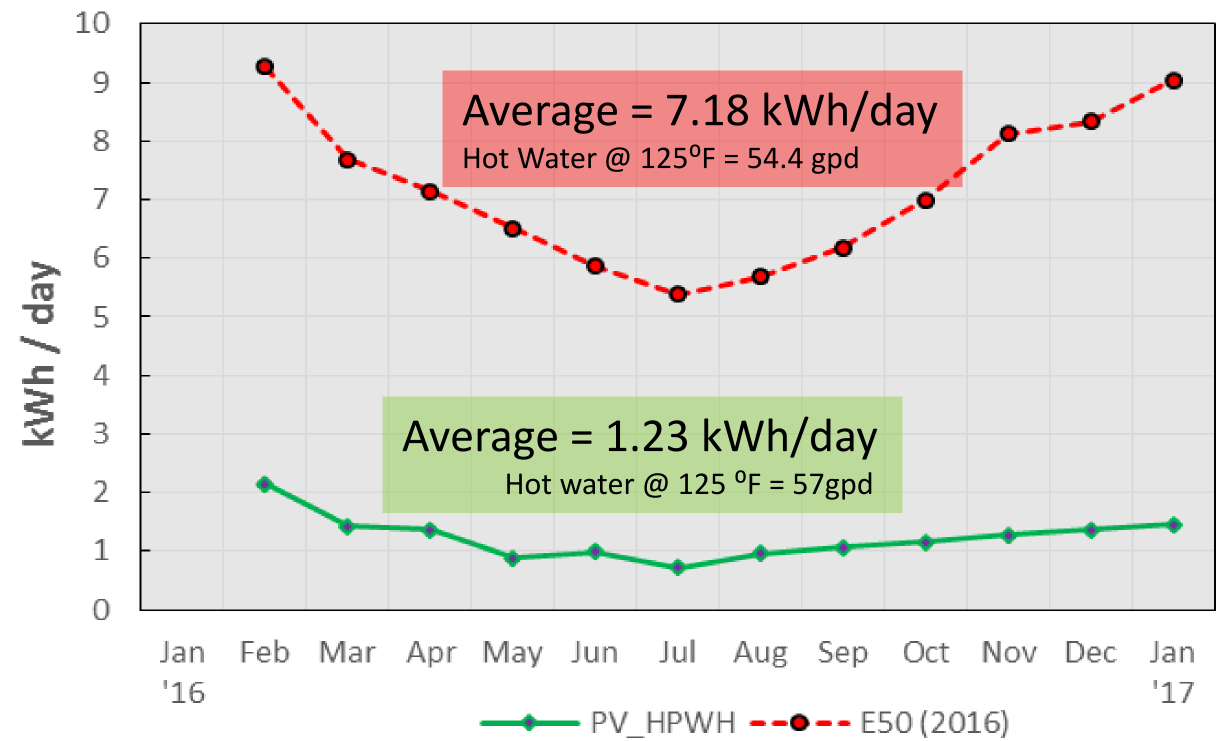
FSEC Cocoa, FL, 2016-2017



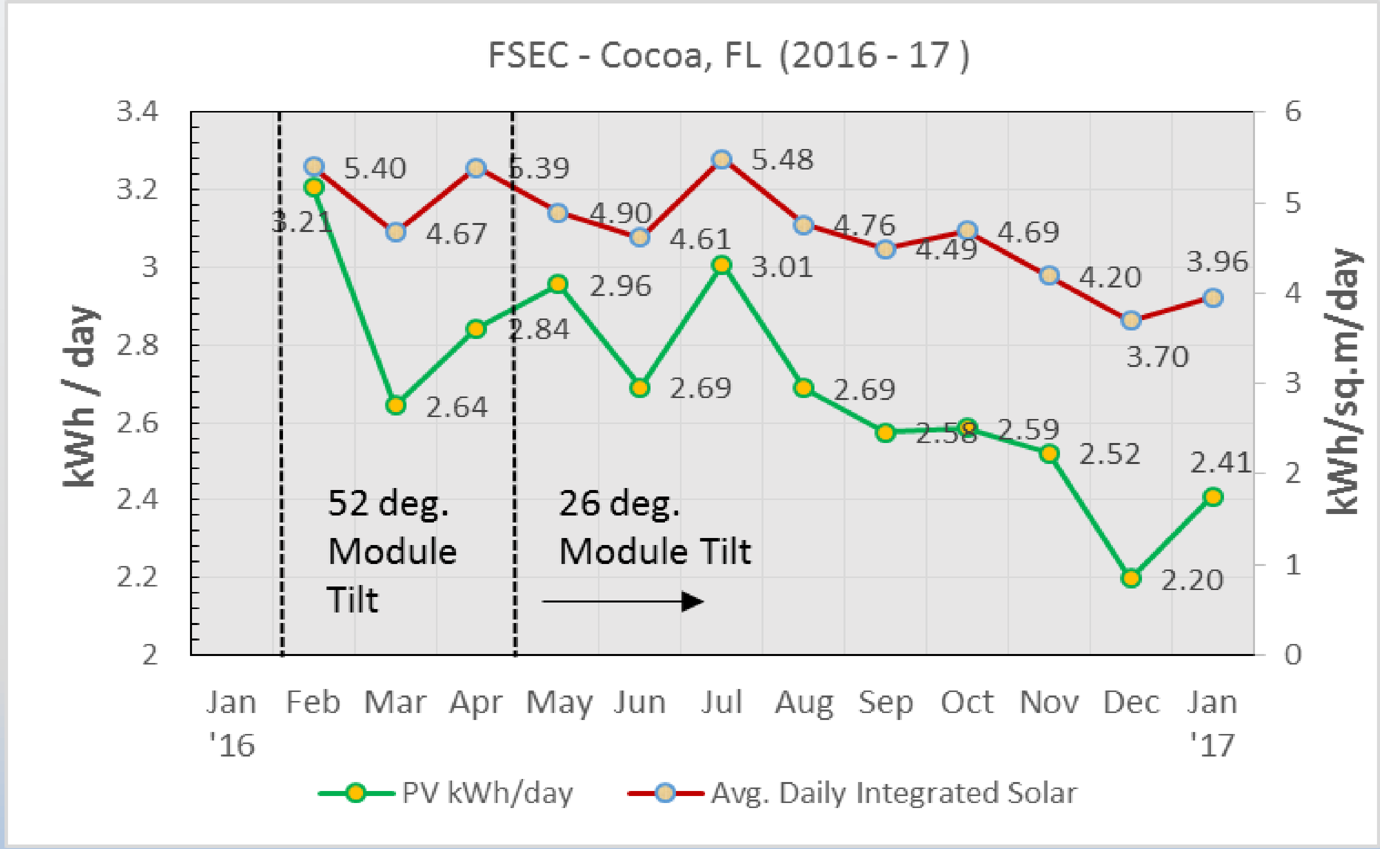


Average:
1.23 kWh/day
Avg. Efficiency
COP = 5.4

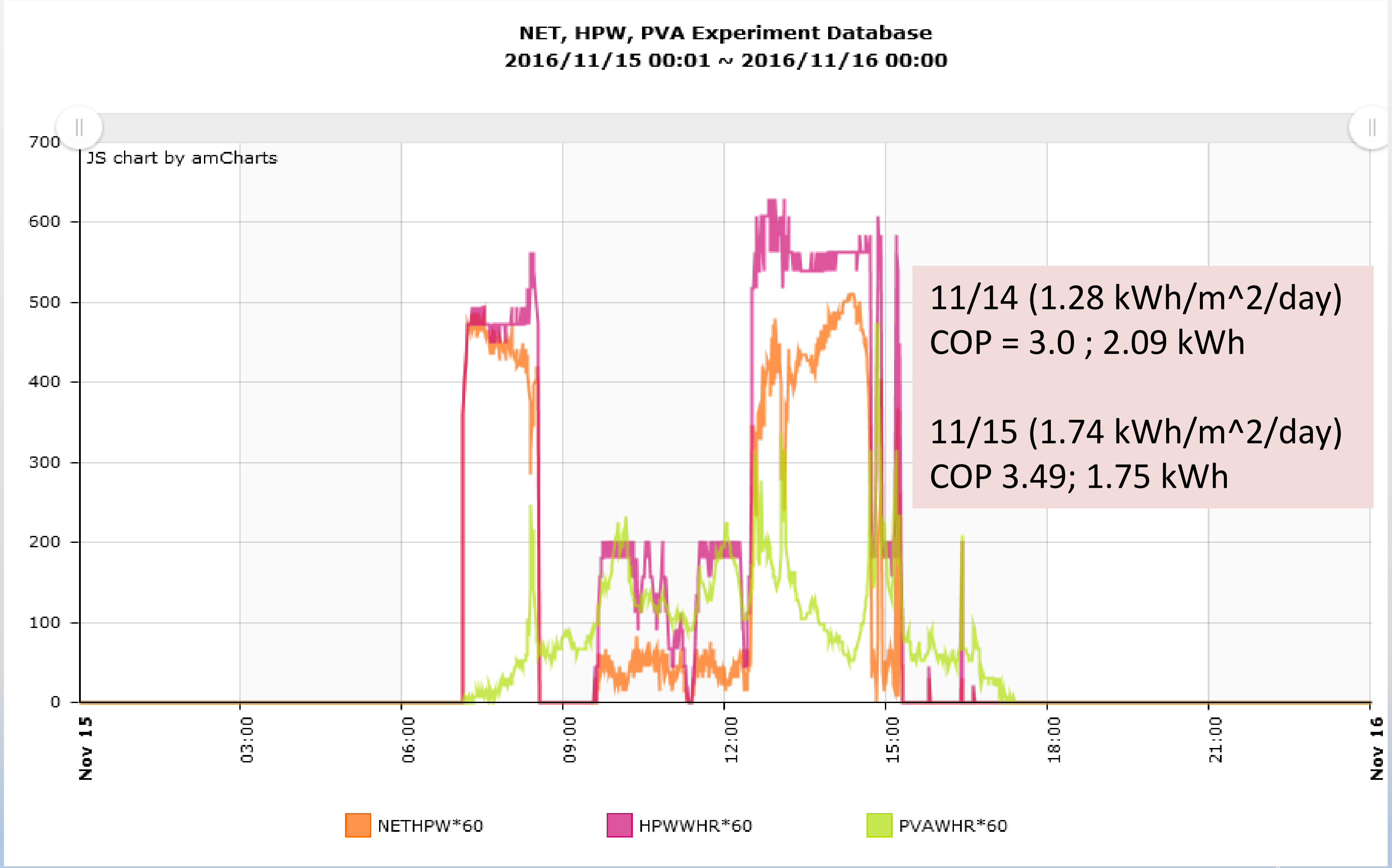
PV Driven HPWH vs Standard Electric 50 gallon Water Heater



PV-Microinverter Electric Daily Production and Average Daily integrated Solar Radiation



Performance on Cloudy Overcast Days

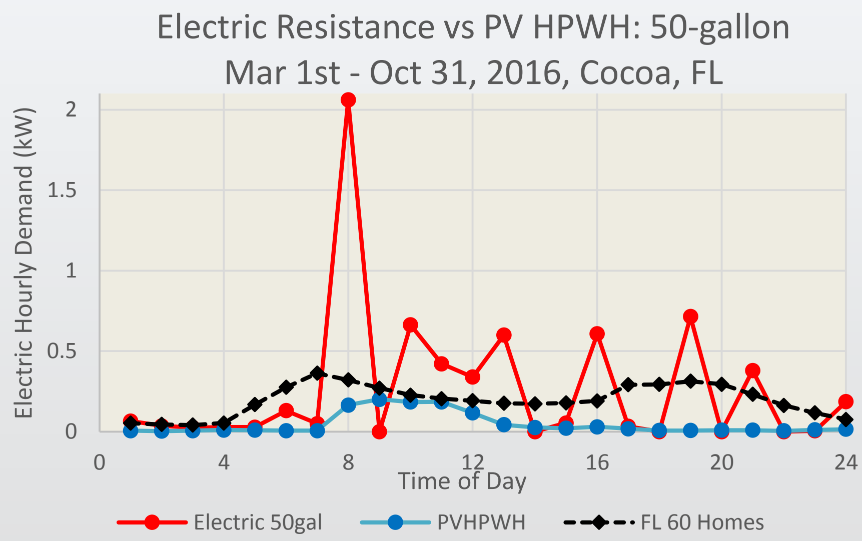


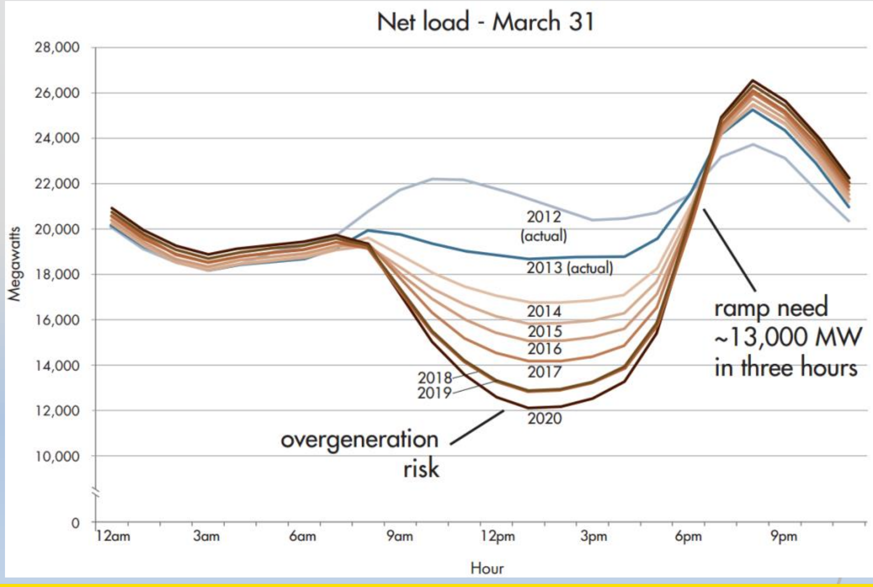
11/14 (1.28 kWh/m^2/day)
COP = 3.0 ; 2.09 kWh

11/15 (1.74 kWh/m^2/day)
COP 3.49; 1.75 kWh

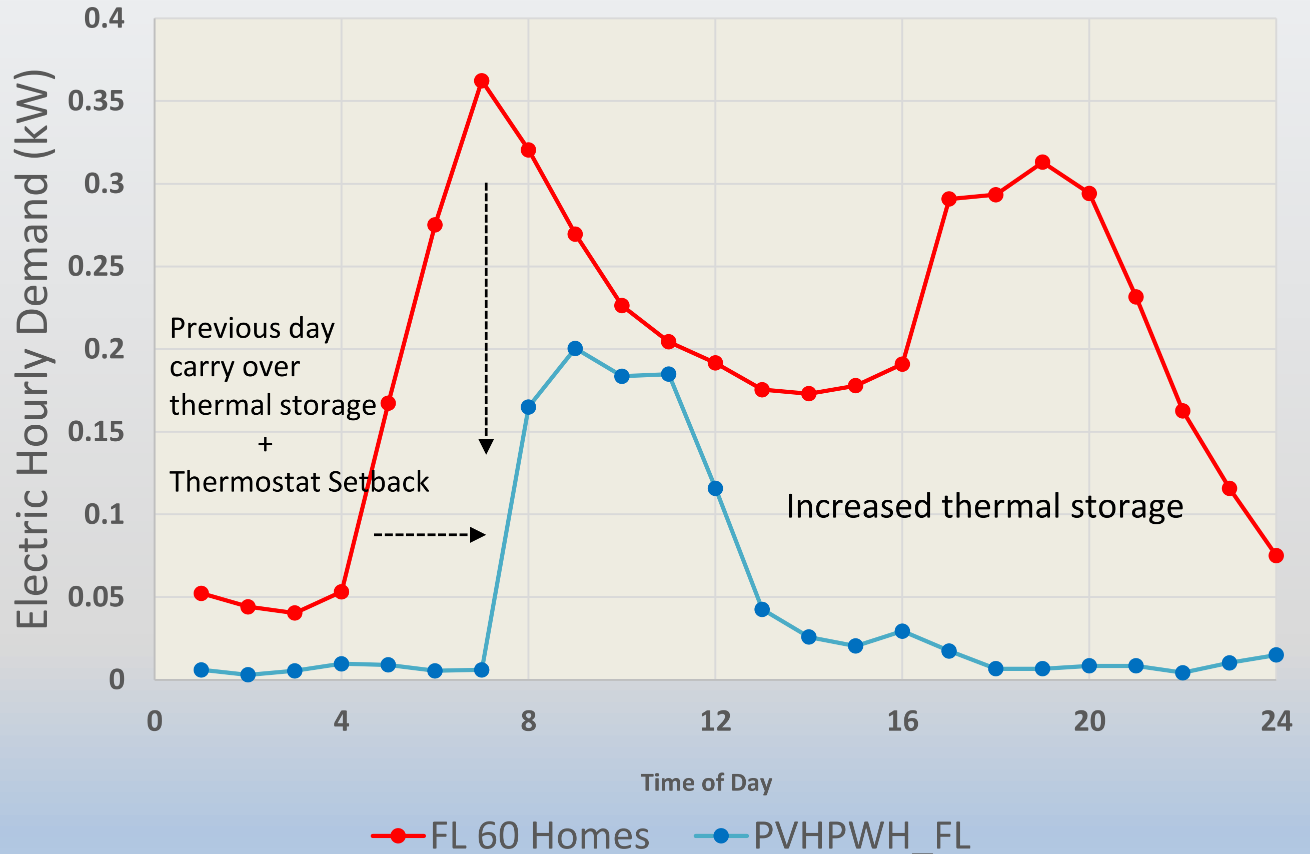
Reduces TOD Demand & PV Grid Impact

- PV energy is used by the HPWH compressor, and backup electric elements
- Flattens the "duck curve" as no PV energy is supplied to the grid during the day
- Requires some grid energy when hot water use is high – typically in the early morning
- Morning peak reduced almost 2 kW compared to electric resistance water heaters



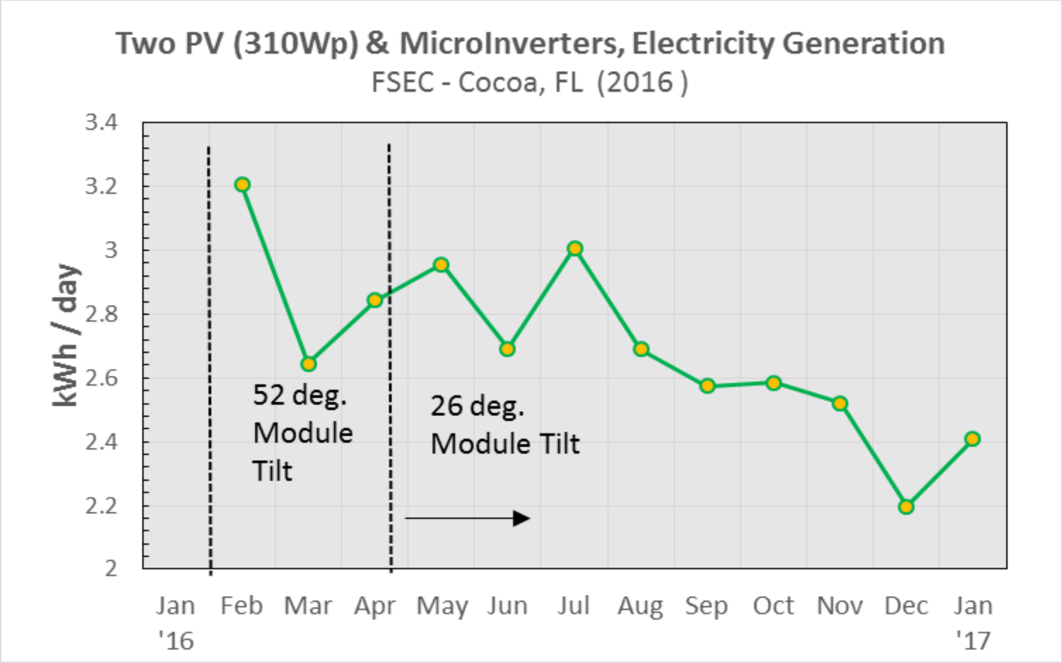


PV HPWH Demand Compared to 60 (Diversified) Florida Electric Resistance WH's



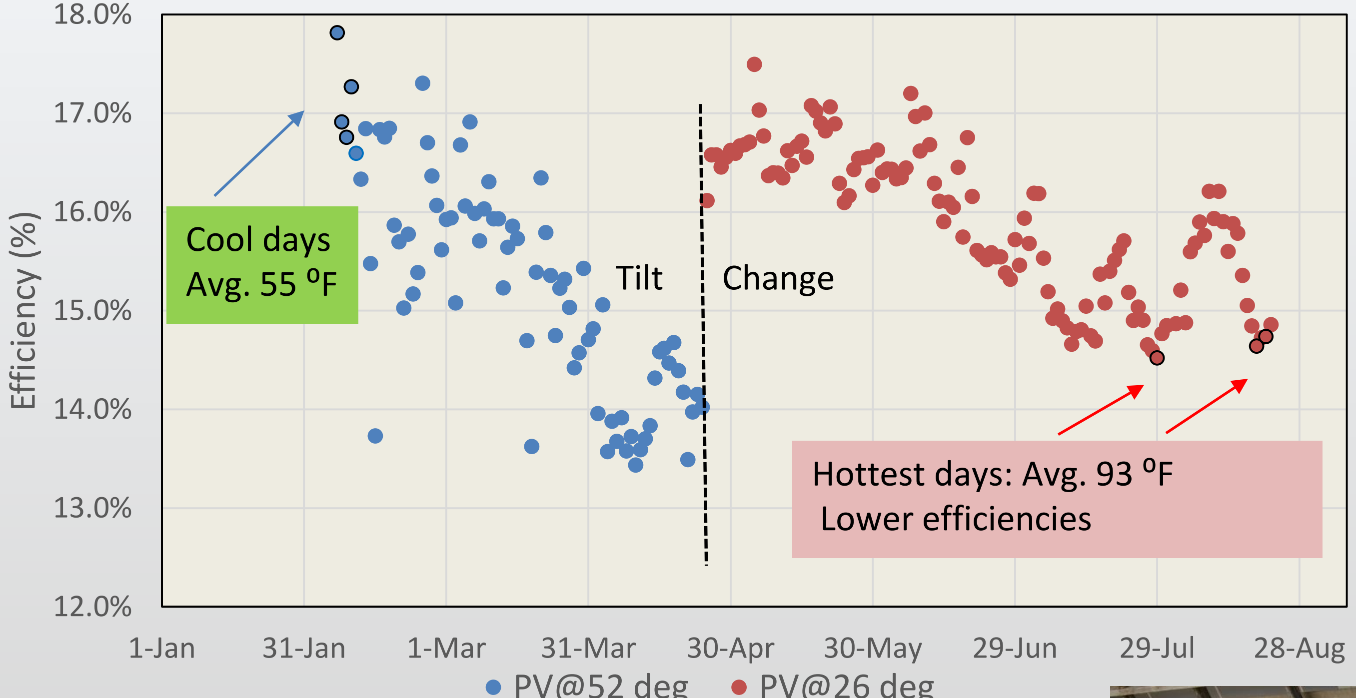
PV & Microinverter Electric Generation (Cocoa, FL)

Two Polycrystalline Modules 310Wp:
620Wp, 72 cell, 16% efficiency



Average = 2.3 kWh/day

PV + Micro-Inverter Efficiencies



Cons and Pros of PV HPWH

- Cons:
- Premium cost $1590 over $450 Std ER WH or $1040 over a HPWH ($999) – Simple Payback: 8 to 4 Yrs. vs electric resistance

  Based on : Equipment cost only @ $0.11 to $0.25/kWh
- Net metering agreement for only 600W PV?
- Accelerated Anode Rod depletion/Warranty

Cons and Pros of PV HPWH (Cont.)

- Pros:
- Compared to Solar Thermal: No Circulation Lines or Solar freeze protection needed
- Programmable to suit schedule / Avoid high TOU electric rate
- Solar PV may last 20+ Yrs. -- Continue use PV after replacing HPWH
- May utilize auxiliary cooling byproduct of HPWH due to longer run times.

PV-driven HPWH Performance Summary

Average Monthly Daily Electric consumption		Average Monthly COP (Min/Max)	Average PV Energy Generated	Added storage above 125^{0}F	Average Hot water Max Temp Stored	Average Daily Hot Water Delivered (w/ 125 ^{0}F mix valve setting)		
kWh/day	Min-Max kWh/day		kWh/day	kWh/day		Gal.	Btu's	kWh
1.2	0.7 – 2.1	5.4 (4.5 / 7.0)	2.3	2.1	144 ^{0}F	57	21,261	6.2

Questions?

This Research was funded and in Collaboration with the National Renewable Laboratory (NREL)

FSEC:
C. Colon, D. Parker
carlos@fsec.ucf.edu, dparker@fsec.ucf.edu

NREL: Tim Merrigan (Program manager)
Jeff Maguire (TRNSYS Simulations)

Thank You ?