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

Hot water Systems Laboratory

- Evaluated Most Popular Hot Water Systems
- 2012 Evaluated Hybrids
- 2014 More HPWH’s /Hybrids
- 2016 - Present
- PV HPWH
- 2016 - Present
# Summary of HWS Laboratory Electric Water Heating Systems Evaluated since 2010

<table>
<thead>
<tr>
<th>System</th>
<th>Savings (kWh/day)</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV-Driven HPWH</td>
<td>1.2</td>
<td>0.91</td>
</tr>
<tr>
<td>ICS40+ HPWH 50</td>
<td>1.7</td>
<td>0.92</td>
</tr>
<tr>
<td>Sol+Ret HPWH</td>
<td>1.9</td>
<td>0.93</td>
</tr>
<tr>
<td>HPWH - 50 gal</td>
<td>2.8</td>
<td>0.96</td>
</tr>
<tr>
<td>HPWH - 60 gal</td>
<td>2.9</td>
<td>0.97</td>
</tr>
<tr>
<td>HPWH - 80 gal</td>
<td>3.1</td>
<td>0.98</td>
</tr>
<tr>
<td>Sdifi_80/PV Pump</td>
<td>3.0</td>
<td>0.99</td>
</tr>
<tr>
<td>Sdifi_80/AC Pump</td>
<td>3.3</td>
<td>1.00</td>
</tr>
<tr>
<td>ICS40 + E50 gal</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td>Solar80 Polymer</td>
<td>5.1</td>
<td></td>
</tr>
<tr>
<td>Tankless E</td>
<td>7.0</td>
<td>0.94</td>
</tr>
<tr>
<td>E-50 Cap/Ins</td>
<td>7.3</td>
<td>0.95</td>
</tr>
<tr>
<td>Baseline E-50</td>
<td>7.6</td>
<td></td>
</tr>
</tbody>
</table>

*Standard Electric EF=0.91*
FSEC’s PV HPWH: Prototype

- Use Current Generation 190L HPWH
  Electric COP = ~2.5 (Florida)
- Dedicated 620 W PV & micro-Inverters
- Mixing/Anti-scald valve: set @52 °C
- Smart Controls & programmed for added thermal storage above 52 °C
  - Normal thermostat set: 52°C
  - When solar availability = High, Auto-set thermostat to 70 °C
  - Overall COP = 5.2 (Florida)
- Competitive; parts cost ($2041) retail
- Conventional solar water heaters often >$7000- $10,000 installed
- PV-HPWH could be half cost, similar performance
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

<table>
<thead>
<tr>
<th>Component</th>
<th>Model</th>
<th>Price/Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat pump water heater</td>
<td>GE GEH50DEEDSR GeoSpring</td>
<td>$999</td>
<td>$999 (shipping included)</td>
</tr>
<tr>
<td>PV modules (2)</td>
<td>Canadian Solar Quartech MaxPower CS6X-310P</td>
<td>$242 each ($0.78/watt)</td>
<td>$484</td>
</tr>
<tr>
<td>Microinverters (2)</td>
<td>ABB Micro-0.3-I-OUTD, 300W</td>
<td>$148 each ($0.49/watt)</td>
<td>$295</td>
</tr>
<tr>
<td>PV Trunk Cable</td>
<td>ABB AC-Trunk (portrait x2)</td>
<td>$18</td>
<td>$36</td>
</tr>
<tr>
<td>Anti-Scald (Mixing) Valve</td>
<td>Honeywell AM-101 Thermostatic Valve ¾”</td>
<td>$80</td>
<td>$80</td>
</tr>
<tr>
<td>Controls / Communication</td>
<td>GE Green Bean, Raspberry Pi 2, 32 GB MicroSD Card, Miscellaneous</td>
<td>$19, $40, $15, $73</td>
<td>$147, $40, $15, $73</td>
</tr>
</tbody>
</table>

**Total Prototype Equipment Cost:** $2,041

**Note:** Retail costs
Solar PV Costs Plummeting: Predictions by Manufacturer at SPI 2016

On target.....Near Future (2020) Looks even Better!
PV-Driven HPWH Controls and Added Storage
Controls Accomplished by: Greenbean, Raspberry Pi 2 and FSEC-developed Controller

Appliance Control Module (ACM)
FirstBuild Greenbean

Raspberry Pi 2
Running JS Node
Parallel Process
Running GE’s SDK
and FSEC Custom Control Code

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

Control 2-stage Heat Element Control

Dual Stage Heating
RC Power Relays
Time between 12:00 midnight and 8:30 am

No

Time between 8:30 am and 10:30 am

Yes

Set Thermostat to 49 C Night time Standby

Set Thermostat to 49 C Night time Standby

Set Thermostat to 46 C -- Morning setback

No

10:30 am? Resume thermostart baseline setting to 49 C

Yes

PV Power > 260 Watts?

> per 1-minute Avg. <

Set Thermostat to 60 C -- Store Extra Heat!

If PV generated Power > 190W OR > 380W engage low (200W) or high (400W) mode resistance heating element

> 10 sec. decision <

Compressor OFF?

No

Keep thermostat set at 49 C

Yes
Operation Performance Example

PV Driven HPWH August 23, 2016 Cocoa, FL

- Midnight to 8:30 am thermostat set = 49°C
- 8:30 am - 10:30 am Thermostat Setback = 46°C
- 10:30 am Thermostat resume to 52°C OR bump up to 60°C if PV available >265W
- Compressor finished heating to 60°C
- Compressor 550 to 700 W as water is heated
- Added Energy Storage 396 W heating by resistance element
- 192 W heating by resistance

Graph showing net watts, HPWH watts, and PV watts.
Power from Two 310 Watt PV Modules

PV - Microinverter(s) energy production peak at 12:30 pm
= 540 Watts
Daily Performance-Operation Example

At 8:30 am
200+ Watts PV available

At 10:30 am
400+ Watts PV available

Compressor
550 to 700 W
as water is heated
HPWH Electric Load

Compressor 550 to 700 W as water is heated

192 W Heat element

396 W Heat element
PV- HPWH Net Load (Watts)

Compressor 550 to 700 W as water is heated

PV Driven HPWH August 23, 2016 Cocoa, FL
PV Driven HPWH Load

Total daily hot water gallons = 216L
Hot Water Output/Storage - May 2016

Avg daily storage (Apr-Oct) > 52°C = 2.3 kWh/day (no cost)
PV-HPWH Performance September 2016

PV-driven HPWH Performance - Central Florida
September 2016

COP

Daily Solar Radiation (Watt-hours/sq. m)
PV HPWH Performance

FSEC Cocoa, FL, 2016-2017

Average: 1.23 kWh/day (less than a Refrigerator)
Avg. Efficiency COP = 5.4
PV Driven HPWH vs Standard Electric
50 gallon Water Heater

- **Average = 7.18 kWh/day**
  - Hot Water @ 125°F = 54.4 gpd

- **Average = 1.23 kWh/day**
  - Hot water @ 125 °F = 57gpd
PV Electric Daily Production
and Avg. Daily integrated Solar Radiation

FSEC - Cocoa, FL (2016 - 17)

52 deg. Module Tilt
26 deg. Module Tilt
Performance on Cloudy Overcast Days

11/14 (1.28 kWh/m²/day) COP = 3.0; 2.09 kWh

11/15 (1.74 kWh/m²/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 stored
• Morning peak reduced almost 2 kW compared to resistance water heaters
• Daily electricity use less than refrigerator
PV HPWH Demand Compared to 60 (Diversified) Florida Electric Resistance WH’s

- Increased thermal storage
- Previous day carry over
- Thermal storage + Thermostat Setback

- FL 60 Homes
- PVHPWH_FL
PV Electric Generation (Cocoa, FL)

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

Average = 2.3 kWh/day

Small module size = seasonal tilt adjustment simple
PV output is greater under colder conditions = Better match to changing water heating loads
### PV-HPWH Performance Summary

<table>
<thead>
<tr>
<th></th>
<th>kWh/day</th>
<th>Average Monthly COP (Min/Max)</th>
<th>Average Monthly PV Energy Generated</th>
<th>Added storage above 125°F</th>
<th>Average Hot water Max Temp Stored</th>
<th>Average Daily Hot Water Delivered (w/ 52 °C mix valve setting)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electric consumption</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min-Max kWh/day</td>
<td>0.7 – 2.1</td>
<td>5.4</td>
<td>2.3</td>
<td>2.1</td>
<td>62 °C</td>
<td>216</td>
</tr>
<tr>
<td>(4.5 / 7.0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.23</td>
</tr>
</tbody>
</table>

**PV Energy Generated Above 125°F:**
- Average: 1.2 kWh/day
- Min-Max: 0.7 – 2.1 kWh/day
- Average: 5.4 kWh/day
- Max Temp Stored: 62 °C
- Hot Water Delivery: 216 liters
- kWh thermal storage: 6.23 kWh
- Stored kWh: 2.3
Advantages of PV-HPWH

- Similar or superior performance to solar thermal
- Potentially no net-metering agreement
- Much lower cost than (perhaps half solar thermal)
- Simple & fast install: No plumbing, light weight modules
- Better winter performance: no freeze protection
  - PV output higher in winter, no piping losses
- Solid state = More reliable/longer life
  - lower maintenance than solar thermal
- Stores 2.3 kWh thermal/day above set@ no cost
- Better future performance available
  - HPWH COPs now 2.5 – 3.4 vs. prototype compressor (2.2)
  - PV module efficiencies increasing = smaller module footprint
    - Seasonal tilt tracking possible given small size
Questions?

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

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

Thank You
## Storage: Above 140 °F

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