Advanced Heat Pump Water Heater Research Update

Conducted by WSU Energy Program
Funded by Bonneville Power Administration
BPA Technology Innovation Projects 292, 302 and 326
Current Status

Pacific Northwest CO\textsubscript{2} HPWH Research

- Lab test of Sanden French manufactured unitary 40 gallon HPWH sponsored by NEEA
- Lab test of Sanden Australian manufactured split 84 gallon HPWH sponsored by BPA
- Field test of split system at 4 sites
- Demand Response assessment of Sanden unitary and split systems currently underway sponsored by BPA
- Field test for combined space and water heat in Next Step Homes sponsored by NEEA and BPA and lab test sponsored by BPA
Project Teams
(For All Projects)

WSU
• Ken Eklund, Principal Investigator and General Project Manager
• David Hales, Field Monitoring Installation and Maintenance
• Adria Banks, Data Analyst

Lab Tests
• Ben Larson, Ecotope, Test Manager and Analyst
• Kumar Banerjee, Cascade Engineering, Lab Test Director

Field Installations
• Mark Jerome, Clear Result, System Installation Coordinator

BPA
• Janice Peterson, Project Manager
• Stephanie Vasquez, Project Technical Representative

Sanden
• Maho Ito, CO₂ Product Line Manager
• Charles Yao, Project Engineer
Project Teams Continued

Demand Response Controlled Field Study (TIP 302)
- Graham Parker, PNNL – Lab Homes Project Lead
- Joe Petersen, PNNL – Technical Lead
- Greg Sullivan, Efficiency Solutions – Technical Consultant
- Austin Winkelman, PNNL – Engineering Intern
- Tony Koch, BPA – Demand Response Engineer
- Frank Brown, BPA – Demand Response and Efficiency
- Thor Hinckley, BPA – Smart Grid and Demand Response

Combi System Research
- Charlie Stephen, NEEA – Project Manager
- Thomas Anreise and Dan Wildenhaus, Clear Result – Next Step Home site analysis and recruitment
TIP 292 Project Overview

Performance test of split system CO$_2$ refrigerant Heat Pump Water Heater manufactured by Sanden Lab test to DOE and Northern Climate Specification Field test in partnership with NEEA and:

- Avista Heating Zone 2
- Energy Trust of Oregon Heating Zone 1
- Ravalli Electric Coop Heating Zone 3
- Tacoma Power Heating Zone 1

One install in each territory. 12-18 month monitoring.
TIP 302 Project Overview

Demand Response tests of Sanden unitary and split system Heat Pump Water Heater

Controlled Field Study at PNNL Lab Homes in Richland, WA – Currently underway

Demand Response Lab tests at Cascade Engineering Services in Redmond, WA – Protocol under development by Ben Larson
Combi System Research

WSU, NEEA and BPA are engaged in research in the use of the Sanden split system unit for combination space and water heating in highly efficient Next Step Homes.

The partners are currently recruiting builders and sites through the Next Step Home project. NEEA will provide all the monitoring plus incentives. BPA has agreed to fund the lab test and analysis and reporting of data from both the field and lab research.
Quick Specifications

Equipment currently built and sold in Australia
Outdoor Unit Model: GAU-A45HPA
Power Input: 240V, 15 A circuit
Tank Model: GAU-315EQTA
Storage Capacity: 315L (83 gallons)
Tank Set Point: 65°C (149°F) – not adjustable

Outdoor unit has a variable speed inverter driven compressor, fan and pump

Water is heated at the outdoor unit. A pump circulates water from the bottom of the tank, to the outdoor unit heat exchanger, heating the water in one pass, and re-injecting the hot water near the top of the tank

No resistance heating element
CO₂ Refrigerant Function

Source: Rolf Christensen, ATMOsphere 2014
Performance vs. Temperature

- Linear fit of EF to temperature
- Use TMY temperature bins to calculate an annual EF:

<table>
<thead>
<tr>
<th>Outside Air Temperature (F)</th>
<th>Energy Factor (EF)</th>
<th>COP</th>
<th>Output Capacity (kW)</th>
<th>Input Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>1.74</td>
<td>2.1</td>
<td>4.0</td>
<td>1.9</td>
</tr>
<tr>
<td>35</td>
<td>2.21</td>
<td>2.75</td>
<td>3.6</td>
<td>1.3</td>
</tr>
<tr>
<td>50</td>
<td>3.11</td>
<td>3.7</td>
<td>4.0</td>
<td>1.1</td>
</tr>
<tr>
<td>67</td>
<td>3.35</td>
<td>4.2</td>
<td>4.1</td>
<td>0.97</td>
</tr>
<tr>
<td>95</td>
<td>4.3</td>
<td>5.0</td>
<td>4.6</td>
<td>0.93</td>
</tr>
</tbody>
</table>

![Graph showing performance vs. outside temperature with a linear fit equation: \( y = 0.0331x + 1.1958 \).]

<table>
<thead>
<tr>
<th>Climate</th>
<th>Annual EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boise</td>
<td>2.9</td>
</tr>
<tr>
<td>Kalispell</td>
<td>2.6</td>
</tr>
<tr>
<td>Portland</td>
<td>3.0</td>
</tr>
<tr>
<td>Seattle</td>
<td>2.9</td>
</tr>
<tr>
<td>Spokane</td>
<td>2.8</td>
</tr>
</tbody>
</table>
Installation-Tacoma-10-15-13
TIP 292 Field Site Characteristics

<table>
<thead>
<tr>
<th>Site Location</th>
<th>Site HDD</th>
<th>Climate Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland, OR</td>
<td>4,461</td>
<td>Western Oregon</td>
</tr>
<tr>
<td>Tacoma, WA</td>
<td>4,696</td>
<td>Puget Sound</td>
</tr>
<tr>
<td>Addy, WA</td>
<td>6,842</td>
<td>Inland Washington</td>
</tr>
<tr>
<td>Above Corvallis, MT</td>
<td>8,156</td>
<td>Mountain Region</td>
</tr>
</tbody>
</table>

- Each site has at least 4 occupants
- At least 3 years of electric hot water use
- Represents a climate within the Pacific Northwest
## Climate Data

From Installation through March 31, 2014

<table>
<thead>
<tr>
<th>Site</th>
<th>Minimum OAT (F)</th>
<th>Mean OAT (F)</th>
<th>Standard Deviation (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland</td>
<td>17.89</td>
<td>44.23</td>
<td>± 8.88</td>
</tr>
<tr>
<td>Tacoma</td>
<td>22.20</td>
<td>43.35</td>
<td>± 5.33</td>
</tr>
<tr>
<td>Addy</td>
<td>2.08</td>
<td>34.17</td>
<td>± 8.64</td>
</tr>
<tr>
<td>Montana</td>
<td>-15.68</td>
<td>32.96</td>
<td>± 11.74</td>
</tr>
</tbody>
</table>
Average Cold Water Temp

![Box plot showing the distribution of average cold water supply temperature for Addy, Montana, Portland, and Tacoma cities.](image)
Average Hot Water Supply Temp

![Boxplot showing average hot water supply temperatures for Addy, Montana, Portland, and Tacoma.](chart.png)
Average Tempered Water Temp
## Water Use Per Site

<table>
<thead>
<tr>
<th>Site</th>
<th>Total Cold Water Supply Water (Gal/day)</th>
<th>Calculated Total Water added to Tempering Valve (Gal/day)</th>
<th>Total Household Hot Water (Gal/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addy</td>
<td>77.6</td>
<td>26.5</td>
<td>104.0</td>
</tr>
<tr>
<td>Montana</td>
<td>50.5</td>
<td>12.4</td>
<td>62.6</td>
</tr>
<tr>
<td>Portland</td>
<td>44.0</td>
<td>12.2</td>
<td>55.9</td>
</tr>
<tr>
<td>Tacoma</td>
<td>64.7</td>
<td>15.8</td>
<td>79.5</td>
</tr>
</tbody>
</table>
Daily Water Flow and Energy

Slope: 0.07227

Slope: 0.05602

Slope: 0.07028

Slope: 0.04100
Field Energy Factor

• Is the Energy Contained in Total Useful Hot Water / Total Energy In

• Contains all the invested energy including compressor and freeze protection

• Also includes the energy losses from the tank and the piping

• Plus variable such as the ground water temperature—which varied significantly
Field Energy Factor & Outside Air Temp.

Weekly Field Energy Factor (including Freeze Protection) and Temperature

Performance vs. Outside Temperature

\[ y = 0.033x + 1.196 \]
Interim Conclusions
From Installation Through March 31, 2014

• The largest performance factors appear to be amount of daily water use and outside air temperature

• The Sanden system is capable of providing 150°F water in minus zero weather and can operate to minus 15.7°F

• The weekly Field Energy Factors ranged from 1.1 during a week averaging below 10°F OAT to 2.5 at 40°F OAT
Next Steps

Performance Research
• Second Interim Report
  – Data from April 1 through July 31, 2014
  – Report due September 30, 2014
• Final Analysis and Report
  – Data through February, 2015
  – Report due summer, 2015

Demand Response Research
• Complete PNNL study, analyze and report
• Finalize lab protocol, conduct test, analyze and report

Combi System Research
• Recruit, qualify, install systems and monitoring at NSH sites
• Collect data for at least one year, analyze and report