Update on Advanced Heat Pump Water Heater Research

Presented by Ken Eklund
Passive House California 2015
HupWah!

(HPHW)
Four Projects on Advanced HPWH

• TIP 292—Performance as a Water Heater
• TIP 302—Demand/Response Potential of Split and Unitary Systems
• TIP 326—Combination Space and Water Heating
• TIP 338—Combined Space and Hot Water in Existing Homes
All Projects Fit Together

Discoveries Lead to New Questions

Experience of Project Team Allows Greater Project Size and Complexity
Schematic shamelessly borrowed from Sanden brochure
Transcritical CO₂

Diagram from Rolf Christensen-Alfa Laval
Specific Heat of Transcritical CO$_2$

Diagram from Rolf Christensen-Alfa Laval
TIP 292

WATER HEATER PERFORMANCE
## Compare Water Heaters

<table>
<thead>
<tr>
<th>Standard</th>
<th>ER</th>
<th>Std. HPWH</th>
<th>CO2 HPWH</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Hour Rating (Gal)</td>
<td>32.1</td>
<td>50.0</td>
<td>97.8</td>
</tr>
<tr>
<td>Energy Factor (DOE)</td>
<td>0.93</td>
<td>2.0</td>
<td>3.4</td>
</tr>
<tr>
<td>Northern Climate EF</td>
<td>2.0</td>
<td>2.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Delivery Rating</td>
<td>3.0</td>
<td></td>
<td>7.5</td>
</tr>
<tr>
<td>kWh per Gallon</td>
<td>.23</td>
<td>.11</td>
<td>.05</td>
</tr>
</tbody>
</table>
High Efficiency Lab Test

Performance vs. Outside Temperature

$y = 0.033x + 1.196$
Field Sites

- 4 homes from the coast to Montana
- Minimum family size of 4—up to 7
- Billing history of at least 3 years with electric resistance water heat
- Avista, ETO, Ravalli Electric, and Tacoma Power found sites
Weekly Field Energy Factor With Temperature (excludes freeze protection)

Proxy Temperatures used for Portland and Addy (from installation to 10/06/2014)
AVERAGE ENERGY/GALLON \leq .05 \text{kWh}
Compare Performance

- Resistance Heat Tank: 23 kWh/100 gallons
- GeoSpring Garage: 13 kWh/100 gallons
- Voltex Garage: 10 kWh/100 gallons
- Any Integrated HPWH Interior: 8 kWh/100 gallons
- Addy: 5 kWh/100 gallons
- Corvallis: 4 kWh/100 gallons
- Portland: 4 kWh/100 gallons
- Tacoma: 4 kWh/100 gallons
Cost Effective!

• Inputs
  – Savings: 2,436 kWh/yr
  – Life: 20 years
  – Credit for ER Heater $800
  – Discount Rate 5%
  – Installed Cost $4,200
  – Energy Cost 10¢ per kWh
  – Annual Capacity Value $40

• Outputs:
  – Simple Payback = 12 Years
  – Benefit to Cost Ratio = 1.04
Climate Impact

COMPARISON TO OTHER REFRIGERANTS
Why CO₂? – It’s only Natural

- Zero ozone depletion potential
- Minimal global warming potential

- Source: [http://www.epa.gov/ozone/snap/subsgwps.html](http://www.epa.gov/ozone/snap/subsgwps.html)
ppt is parts per trillion
CO₂ is currently ~400ppm
Current anthropogenic forcing from refrigerants is 1-2% of total
  - Possible to increase to 9-19% of CO₂ forcing by 2050
    - (Velders 2009) http://www.pnas.org/content/early/2009/06/19/0902817106.abstract
What is GWP?

• Used to compare radiative forcing of different chemical species
• By definition $\text{CO}_2$ is set to a GWP of 1
• GWP Depends on:
  – Infrared absorption spectra
  – Spectral location of absorbing wavelengths
  – Atmospheric lifetime
# Atmospheric Lifetimes

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Lifetime (yrs)</th>
<th>GWP - 100 year time horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{CO}_2$</td>
<td>5-200</td>
<td>1</td>
</tr>
<tr>
<td>(carbon cycle makes lifetime variable)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-12</td>
<td>100</td>
<td>10,900</td>
</tr>
<tr>
<td>R-22</td>
<td>12</td>
<td>1,810</td>
</tr>
<tr>
<td>R-134a</td>
<td>14</td>
<td>1,430</td>
</tr>
<tr>
<td>R-32</td>
<td>5</td>
<td>675</td>
</tr>
<tr>
<td>R-125</td>
<td>29</td>
<td>3,500</td>
</tr>
<tr>
<td>R-410a</td>
<td>17</td>
<td>2,088</td>
</tr>
<tr>
<td>(50/50 blend of 32 &amp; 125)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
things go better with CO$_2$

“Transitioning to the HFC-free CO$_2$ refrigerant in cold drink equipment is of the highest priority to Coca-Cola.”
Coke Vending Machines Go CO$_2$

The company’s goal is to replace all 10 million of its vending machines worldwide with CO$_2$ refrigerant vending machines avoiding the equivalent of 58,000 tons of CO$_2$ injected into the atmosphere annually.
TIP 302

DEMAND RESPONSE POTENTIAL
DEMAND RESPONSE

PNNL Lab Home

Unitary System
SPLIT SYSTEM
Extreme Oversupply Mitigation Test

Water Heater Off at 1 pm
To Make Room to Absorb Off-Peak Wind Energy

Split System (80 Gallons)  Unitary System (40 Gallons)

Note: the top point on the chart is water temperature – the bottom point is the cooled pipe temperature between draws and not relevant to delivery
DR Improves Performance!

Spokane

Portland

![Graph showing the performance of DR in Spokane and Portland](image)

- **Demand Response**
  - Yes
  - No

- **Tank Volume**
  - 40 Gallons
  - 80 Gallons

- **COP**

- **Number of Persons**

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27
TIP 326

COMBINATION SPACE AND WATER HEATING
THE ZONE 3 EXPERIENCE

House is at 4,250 ft. in Montana

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Graph showing HPWH Energy Use during a 9-day cold weather period (Montana) with corresponding outside air temperature and dates. The energy usage values are: 75.2g, 32.3g, 91.7g, 66.0g, 61.5g, 12.7g, 14.1g, 93.1g, 60.3g.
The Performance Field Tests showed the HPWH met water heating loads with minimal operation even in cold weather.

The system was off 75% of the time showing the power of system heating capacity.
First Field Site

- In Bellingham, WA
- Passive Solar House
- Design Load = 21,160 Btu/hr
- First data obtained in December 2014
- Backup Heat ≈ 5 kWh
System View
Heat Distribution: Radiant Floor, Fan Coil, Baseboard Radiator

X-Pump Block Heat Exchanger

Backup Electric Resistance

Sanden Heat Pump

Sanden Hot Water Storage Tank

Tempering Valve

Hot Water

City Water Supply
Full Field Install Schematic

GENERAL NOTES

1. Insulate all potable hot water lines for energy code.

2. Strap tanks to wall with seismic strapping.
Space and Water Heating Event

Overnight: Outside Air Reaches 40F

Call for heat from radiant loop

Tank Loop Pump Engages

Showers

Heat Pump Operation

Midnight March 2

Midnight March 3
Bellingham Solar

Bellingham Solar 2015

Solar Radiation in W/m²

Hour of Day

January

February

March

month
January
February
March
High Solar Days Are Low kWh

Bellingham Sanden Site - 5 Day Averages

5-Day Running Average Heat Pump Input kWh vs. 5-Day Running Average Temperature

Average Solar W/m²

- 120
- 50
- 20
Impact of Stratification

![Graph showing the impact of stratification on COP (Coefficient of Performance) with water temperature at gas cooler as a variable. The graph includes data points for different temperatures: SandenGAU 17F, SandenGAU 35F, SandenGAU 50F, SandenGAU 67F, and SandenGAU 95F. The COP decreases as the water temperature increases.]
Combi Project Overview

• 10 Homes:
  – 7 in Heating Zone 1 – Bellingham, Olympia, Portland, Tacoma and Seattle
  – 1 in Heating Zone 2 – Coeur d’Alene, Idaho
  – 2 in Heating Zone 3 – McCall, Idaho

• Average Design Load ≈ 16,000 Btu

• Status: 8 systems installed, 7 houses complete, 8 monitoring systems installed
Product Availability

• HPWH with standard refrigerants are offered by GE (GeoSpring), AO Smith (Voltex), Rheem, Stiebel Eltron (Accelera) and other manufacturers

• Mitsubishi has prototype ductless heat pump plus water heating that WSU will field test

• Sanden expects to have a UL listing for its CO₂ split system this fall and to have product available in December, 2015

• CO₂ heat pumps are made by all major Japanese HVAC manufacturers including Sanyo, Mayekawa, Daikin and Panasonic—most are not yet available in North America
CONCLUSION

• As a water heater is 4x as efficient as electric resistance water heating and uses about half current HPWH energy
• HPWH Have High Performance DR potential
• CO$_2$ impact on climate is minimal
• Combined space and water heating is still under development
Thanks

To Adria Banks, WSU lead analyst
To Ben Larson, Jonathan Heller, Nick Kvaltine and Colin Grist, Ecotope
To Melinda Spencer, WSU technical editor
To Bruce Carter, Fred Gordon, Rem Husted, Tom Lienhart, & Jim Maunder—utility partner reps
To PNNL’s Graham Parker, Joe Petersen & Sarah Widder & Greg Sullivan, Efficiency Solutions
To Mark Jerome, Clear Result, lead installer
To David Hales, WSU lead monitoring installer
To Janice Peterson, BPA project manager
To Dave Kresta & Charlie Stephens, NEEA
To Maho Ito, John Miles, & Charles Yao, Sanden International
To the Regional Advanced HPWH Advisory Task Force
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DISCUSSION