Predicting Real World Heat Pump Water Heater Performance

Based on Performance of 14 sites in the Northeast

Carl Shapiro
Steven Winter Associates, Inc.
Building America Innovations

This research is paving the way for key innovations:

• Understanding in-field HPWH performance
• Developing guidelines for industry partners to ensure best practice HPWH installation
Outline

- What are HPWHs and how well do they perform?
- Modeling the real world performance of HPWHs
- Installation issues associated with HPWHs and recommendations
What is a HPWH?

1. Heat pump pulls hot surrounding air in
2. Heat pump transfers heat from air to water
3. Condenser coil heats water in tank
   - Backup electric heating elements
   - Water tank

Heat pump pushes cold/dry air out
New Products
HPWH Monitoring

- Monitored 14 HPWHs at sites in MA and RI for over 1 year
- COPs ranged from 1.0 to 2.6

<table>
<thead>
<tr>
<th></th>
<th>No. Monitored</th>
<th>Capacity (gal)</th>
<th>Energy Factor</th>
<th>First Hour Rating (gal)</th>
<th>COP</th>
<th>% Electric Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO Smith</td>
<td>2</td>
<td>60/80</td>
<td>2.33</td>
<td>68.0/84.0</td>
<td>2.0 - 2.6</td>
<td>0% - 11%</td>
</tr>
<tr>
<td>General Electric</td>
<td>10</td>
<td>50</td>
<td>2.35</td>
<td>63.0</td>
<td>1.0 - 2.1</td>
<td>5% - 78%</td>
</tr>
<tr>
<td>Stiebel Eltron</td>
<td>2</td>
<td>80</td>
<td>2.51</td>
<td>78.6</td>
<td>2.0 - 2.3</td>
<td>2% - 8%</td>
</tr>
</tbody>
</table>
GE: Typical Operation

- 2 adults + 2 kids
- 120°F HW setpoint
- Avg. of 41 gals/day
- Total Calculated COP = 2.0

Standby loss heating:

~622 Wh @ $0.17/kWh = $0.11/day
GE: Cold Basement

2 adults
130°F HW setpoint
Avg. of 64 gals/day
Total Calculated COP = 1.0

Avg. ambient temp = 53°F
Month COP ranges from 0.7-1.6.
GE: Warm Basement

2 adults + 3 kids
140°F HW setpoint
Avg. of 72 gals/day
Total Calculated COP = 1.5

Avg. ambient temp = 76°F
GE: Low HW Use

2 adults
130°F HW setpoint
Avg. of 32 gals/day
Total Calculated COP = 1.4

Avg. ambient temp = 70°F
Minimal electric resistance use over monitoring period.
Dec. 6: 70 gallons, 0% Elec. Res.
Nov. 30: 71 gallons, 81% Elec. Res.
Stiebel-Eltron: High HW Use

2 adults
140°F HW setpoint
Avg. of 41 gals/day
Total Calculated COP = 2.0
Avg. Ambient Temp = 68°F
Model Goals

- Want to develop model to accurately predict COP
  - Identify variables that affect performance
  - Identify best period for analysis
  - Find equation that easily and accurately predicts COP

- Ongoing project
What Affects Performance

- COP depends on:
  - Ambient Temperature
  - Ambient Relative Humidity
  - Setpoint Temperature
  - Mains Temperature
  - Water Draw Profile
    - Total Volume
    - Draw Pattern
Choosing an Analysis Period

- Yearly
  - Sample size too small
  - No discernible patterns from data

- Daily
  - HPWHs have slow recovery and heating can flow into next day
Choosing an Analysis Period

- **20 gals**
  - **1.5 COP**
  - HW Use
  - Heat Pump
  - Electric Resistance

- **35 gals**
  - **1.4 COP**

Energy Used (Wh)

HW Used (Gallons)
Choosing an Analysis Period

- Yearly
  - Sample size too small
  - No discernible patterns from data

- Daily
  - HPWHs have slow recovery and heating can flow into next day

- Solution: find Periods > 4hrs with energy balance = 0
  - Tank Fully Heated -> Fully Heated
60 gals
2.6 COP

27 gals
2.2 COP

53 gals
2.4 COP

44 gals
2.4 COP

70 gals
1.1 COP
Performance Data

DHW Demand (Gallons/Day)

Coefficient of Performance

General Electric
Performance Data

DHW Demand (Gallons/Day)

General Electric

Coefficient of Performance

Electric Resistance Fraction
Performance Data

General Electric

Large Electric Resistance Loads

DHW Demand (Gallons/Day)

Coefficient of Performance

Electric Resistance Fraction
Performance Data

General Electric

Periods with electric resistance fractions < 0.04
Performance Data

General Electric

DHW Demand (Gallons/Day)

Coefficient of Performance

Periods with electric resistance fractions < 0.04
Performance Model Overview

- Model based on first principles and performance curves
- 5 independent variables (previously mentioned)
- 1 dependent variable (COP)
- 4 regression coefficients
  - $a_1, a_2,$ and $a_3$ describe heat pump efficiency$^1$
  - UA describes tank losses

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## Model Regression Results

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model</th>
<th>UA</th>
<th>$a_1$</th>
<th>$a_2$</th>
<th>$a_3$</th>
<th>N</th>
<th>R²</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO Smith</td>
<td>80 gallon</td>
<td>8.72</td>
<td>4.91</td>
<td>-2.85E-2</td>
<td>-2.23E-9</td>
<td>386</td>
<td>0.980</td>
<td>137</td>
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<tr>
<td>AO Smith</td>
<td>60 gallon</td>
<td>6.49</td>
<td>4.31</td>
<td>-2.17E-2</td>
<td>-1.71E-10</td>
<td>247</td>
<td>0.930</td>
<td>56.7</td>
</tr>
<tr>
<td>General Electric</td>
<td></td>
<td>6.14</td>
<td>4.80</td>
<td>-2.78E-2</td>
<td>-5.46E-11</td>
<td>4121</td>
<td>0.917</td>
<td>213</td>
</tr>
<tr>
<td>Stiebel Eltron</td>
<td></td>
<td>15.0</td>
<td>7.49</td>
<td>-4.96E-2</td>
<td>-4.12E-11</td>
<td>742</td>
<td>0.967</td>
<td>148</td>
</tr>
</tbody>
</table>
Model Regression Results

General Electric

DHW Demand (Gallons/Day)

Coefficient of Performance

Ambient Temperature (°F)

Daily Values

- 50°F
- 60°F
- 70°F
- 80°F

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HPWH Performance - Unpredictable

Site 3: COP = 1.4; T = 63.7; RH = 50%; T_{mains} = 54.3; T_{set} = 125;

Site 8: COP = 2.78; T = 64.3; RH = 41%; T_{mains} = 55.9; T_{set} = 125;
Proper HPWH Installation

- Space Requirements
- Tank Volume
- Comfort & Noise
- Managing Condensate
- Mixing Valves and Setpoint Temperature
- Filter Maintenance
- Heat Traps (any tank water heater)
Space Requirements

- Most manufacturers specify 750 to 1000 ft$^3$ of space
- Vents should not be obstructed.

Yes!

No!
Tank Volume

BIGGER IS BETTER
Comfort & Noise

- HPWH cools space – comfort problems in winter.
- Creates more noise than other water heaters.

![Image showing noise levels of different appliances: Refrigerator (~45 dBA), HPWH (~55 dBA), Vacuum (~70 dBA)]
Managing Condensate

- Install condensate pump, if needed
- Place on blocks
- Install drain pan
Unlike most water heaters, increasing the setpoint of HPWHs can increase efficiency.

Mixing Valves are needed if the setpoint is greater than 130°F.

Good practice below 130°F.
Filter Maintenance

- Filters in HPWHs must be regularly cleaned.
- Educating the homeowners is crucial!
Heat Traps

- Heat traps should be installed to prevent thermosiphoning.
- Thermosiphoning can significantly increase thermal losses from tank!
- Insulate your pipes.
Builder Resources

- Code Considerations
  - By 2015, all electric water heaters > 55 gallons must be HPWH.
  - Utilities have rebates (up to $1000)

- References:
  - BA Measure Guideline
  - QI Guideline for Northeast
  - Recent Home Energy Article
    - [www.buildingamerica.gov](http://www.buildingamerica.gov)
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Building America Solution Center
COMING IN JANUARY
Contact Info

Steven Winter Associates, Inc.  
61 Washington St.  
Norwalk, CT  06854  
203-857-0200

Srikanth Puttagunta  
sri@swinter.com

Robb Aldrich  
raldrich@swinter.com

Carl Shapiro  
cshapiro@swinter.com