Project 72577 – Technology Integration
Task 3: Establish Hot Water Draw Profiles, Develop Lab Homes Protocols, and HPWH Baseline Characterization

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Background and Related Projects

► Pacific Northwest HPWH Field Study
  ▪ PNNL Led Project through BTO
  ▪ Project produced a robust Water Heating Dataset
  ▪ Original Project Focus on Characterizing Load Shifting Potential of HPWHs
  ▪ ~150 Heat Pump Water Heater Field Sites
  ▪ ~100 Electric Resistance Water Heater Field Sites
  ▪ 1+ Year of Field Data Collection
  ▪ Customer Survey Data for HPWH Field Sites

► Max Tech Electric HPWH with Low-GWP Halogenated Refrigerant
  ▪ ORNL Led Project through BTO
  ▪ Project Scope to Develop Max Tech HPWH for Specific Design Parameters
  ▪ Project Scope includes Laboratory Testing for Standard Conditions
  ▪ ORNL Project to Hand-Off Max Tech HPWH Proto-types to ORNL and PNNL Teams for Field Assessment in Lab Homes and Occupied Homes
Part A: Using the Pacific Northwest Water Heating Dataset, Establish Representative Hot Water Draw Profiles for examining the Field Performance of the Max Tech HPWH at Lab Homes.


Part C: Using the Pacific Northwest Water Heating Dataset, Characterize Baseline Power Profiles for HPWHs with Survey Data.
Establish Representative Hot Water Draw Profiles
Hot Water Draw Profiles – Dataset

- 98 Field Sites with Electric Resistance Water Heater
- Timeframe: 2017 – 2018; Weekdays (Mon – Fri) Only Considered
- Corrected CTA 2045 Power and Present Energy Data
- Filtered Out Days with Total Hot Water Consumption below 5 Gallons
- Starting Point: 4,925 Total Days of Field Data Collection
- Unknown Occupancy at Electric Resistance Field Sites
- Assumptions for Groundwater Temperature and Water Heater Efficiency used to Determine Hot Water Usage from Power Data
- Daily Median Hot Water Usage Across Field Data was 46 Gallons
Hot Water Draw Profiles – Strategy

Key Characteristics for Hot Water Usage Profile:

- Total Consumption
- Event Distribution
- Profile Shape (Peaks)

Analytical Measures to Identify Representative Day from Field Data:

- Total Daily Consumption
- Hours with Significant Draw (i.e. 5+ Gallons)
- Time (Hours) between AM and PM Peaks
- Ratio of 3-Hour AM and PM Peaks
- Ratio of Daily 3-Hour Peak to Daily Total Consumption

AM and PM Peaks were considered in consecutive 3-hour windows. For example, PM Peak would be largest cumulative hot water usage in 3-hour window from 12PM – 11PM.
Hot Water Draw Profiles – Key Takeaways

- Median Daily Hot Water Usage of 98 Field Sites: ~49 gallons
- 25th Percentile: ~33 gallons; 75th Percentile: ~70 gallons
Hot Water Draw Profiles – Key Takeaways

- Daily 3-Hour Peak in PM with Comparable 3-Hour Peak in AM
- Total Consumption is Proportional to Hours with Draw over 5 Gallons

As shown in figure, lower total daily consumption corresponds with fewer hours with a significant hot water draw (i.e. 5+ gallons), and higher total daily consumption corresponds with more significant draw hours.
Step 1: Determine Median Daily Hot Water Consumption for Each Site
- 98 Field Sites: 98 Median Values
- Provides equal weight for each field site

Step 2: Determine 25th, 50th, and 75th Percentile from Dataset of Step 1
- Percentiles provide Small, Medium, and Large Hot Water Draw Targets

Step 3: Using the Small, Medium, and Large Hot Water Draw Targets ±5 gallons, develop Small, Medium, and Large Data Subset from the 4,925 Days of Field Data
- Data Subsets: Small = 747 Days; Medium = 621 Days; Large = 439 Days

Step 4: Determine Median Values for Four Remaining Analytical Measure (e.g. Hours with a Significant Draw) for Each Data Subset (Small, Medium, Large)
- Results shown in Tables on Slide 6 for “Median of Subset”
Step 5: For Each Small, Medium, and Large Data Subset, Filter Data to Contain:
- Hours with Significant Draw (±1 hour)
- Time between AM and PM Peak (exact interval)
- Days Remaining in Subset: Small = 59 Days; Medium = 59 Days; Large = 37 Days

Step 6: For Remaining Daily Profiles in Each Subset, Conduct Similarity Analysis using the Median Ratio of AM and PM 3-Hour Peaks and Ratio of Daily 3-Hour Peak to Daily Total
- Individual Day closest to Median Values is selected as Representative Day for Dataset
- Results shown in Tables on Slide 6 for “Selected Day”
## Hot Water Draw Profiles – Identification

### Small Draw Profile

<table>
<thead>
<tr>
<th></th>
<th>Total Daily Consumption</th>
<th>Significant Draw</th>
<th>Time Difference AM and PM Peak</th>
<th>Ratio of AM and PM Peaks</th>
<th>Ratio of Daily Peak and Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median of Subset</td>
<td>6,018 Wh</td>
<td>3 Hours</td>
<td>10 Hours</td>
<td>0.84</td>
<td>0.41</td>
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<tr>
<td>Selected Day</td>
<td>5,775 Wh</td>
<td>3 Hours</td>
<td>10 Hours</td>
<td>0.85</td>
<td>0.35</td>
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### Medium Draw Profile

<table>
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<tr>
<th></th>
<th>Total Daily Consumption</th>
<th>Significant Draw</th>
<th>Time Difference AM and PM Peak</th>
<th>Ratio of AM and PM Peaks</th>
<th>Ratio of Daily Peak and Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median of Subset</td>
<td>8,925 Wh</td>
<td>4 Hours</td>
<td>11 Hours</td>
<td>0.77</td>
<td>0.38</td>
</tr>
<tr>
<td>Selected Day</td>
<td>8,706 Wh</td>
<td>5 Hours</td>
<td>11 Hours</td>
<td>0.73</td>
<td>0.39</td>
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</tbody>
</table>

### Large Draw Profile

<table>
<thead>
<tr>
<th></th>
<th>Total Daily Consumption</th>
<th>Significant Draw</th>
<th>Time Difference AM and PM Peak</th>
<th>Ratio of AM and PM Peaks</th>
<th>Ratio of Daily Peak and Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median of Subset</td>
<td>13,500 Wh</td>
<td>6 Hours</td>
<td>11 Hours</td>
<td>0.91</td>
<td>0.35</td>
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<tr>
<td>Selected Day</td>
<td>12,750 Wh</td>
<td>7 Hours</td>
<td>11 Hours</td>
<td>0.96</td>
<td>0.36</td>
</tr>
</tbody>
</table>
Time difference between AM and PM Peak was used as an analytical measure for identifying a representative profile. Separately in analysis, 6:30 AM was determined to be the most common start for hot water draw profile.
Hot Water Draw Profiles – Results

- Small, Medium, and Large Draw Profiles were Identified
- Hot Water Consumption (Gallons) Profiles shown for 15-minute Time Increments

<table>
<thead>
<tr>
<th>Time</th>
<th>Gallons of Hot Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:30 AM</td>
<td>7</td>
</tr>
<tr>
<td>6:45 AM</td>
<td>4</td>
</tr>
<tr>
<td>4:45 PM</td>
<td>5</td>
</tr>
<tr>
<td>5:00 PM</td>
<td>8</td>
</tr>
<tr>
<td>5:15 PM</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Gallons of Hot Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:30 AM</td>
<td>3</td>
</tr>
<tr>
<td>6:45 AM</td>
<td>2</td>
</tr>
<tr>
<td>7:00 AM</td>
<td>1</td>
</tr>
<tr>
<td>7:15 AM</td>
<td>2</td>
</tr>
<tr>
<td>7:30 AM</td>
<td>2</td>
</tr>
<tr>
<td>8:00 AM</td>
<td>5</td>
</tr>
<tr>
<td>10:45 AM</td>
<td>4</td>
</tr>
<tr>
<td>11:00 AM</td>
<td>3</td>
</tr>
<tr>
<td>5:15 PM</td>
<td>3</td>
</tr>
<tr>
<td>5:30 PM</td>
<td>1</td>
</tr>
<tr>
<td>5:45 PM</td>
<td>7</td>
</tr>
<tr>
<td>6:00 PM</td>
<td>7</td>
</tr>
<tr>
<td>6:15 PM</td>
<td>2</td>
</tr>
<tr>
<td>6:30 PM</td>
<td>2</td>
</tr>
<tr>
<td>6:45 PM</td>
<td>1</td>
</tr>
<tr>
<td>7:00 PM</td>
<td>2</td>
</tr>
</tbody>
</table>

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<tr>
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<th>Gallons of Hot Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:30 AM</td>
<td>6</td>
</tr>
<tr>
<td>6:45 AM</td>
<td>1</td>
</tr>
<tr>
<td>7:15 AM</td>
<td>5</td>
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<tr>
<td>7:30 AM</td>
<td>6</td>
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<tr>
<td>7:45 AM</td>
<td>4</td>
</tr>
<tr>
<td>8:00 AM</td>
<td>5</td>
</tr>
<tr>
<td>8:15 AM</td>
<td>2</td>
</tr>
<tr>
<td>8:30 AM</td>
<td>3</td>
</tr>
<tr>
<td>4:15 PM</td>
<td>3</td>
</tr>
<tr>
<td>4:30 PM</td>
<td>5</td>
</tr>
<tr>
<td>4:45 PM</td>
<td>2</td>
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<tr>
<td>5:00 PM</td>
<td>1</td>
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<tr>
<td>5:15 PM</td>
<td>1</td>
</tr>
<tr>
<td>5:30 PM</td>
<td>6</td>
</tr>
<tr>
<td>6:00 PM</td>
<td>3</td>
</tr>
<tr>
<td>6:15 PM</td>
<td>1</td>
</tr>
<tr>
<td>6:30 PM</td>
<td>3</td>
</tr>
<tr>
<td>6:45 PM</td>
<td>6</td>
</tr>
<tr>
<td>7:00 PM</td>
<td>4</td>
</tr>
</tbody>
</table>
Alternative Profile shown is 3-Occupant Profile from Appendix E of Heat Pump Water Heater Model Validation Study. The two field-based profiles have comparable total daily hot water consumption. The alternative profile consists of 5 time intervals with hot water draws more evenly distributed throughout the day.
Protocol Development for Lab Home Evaluation of Max Tech HPWH
Lab Home Testing: Home Characteristics

- Represents Existing Homes
  - 3 BR/2BA 1493-ft² double-wide, factory-built to HUD code
  - 13 SEER/7.7 HSPF heat pump central HVAC
  - R-22 floors, R-11 walls & R-22 ceiling
  - 195.7-ft² (13% of floor) window area
  - Incandescent lighting

- Cold Climate (Winter)

- Hot-Dry Climate (Summer)

- Low-risk Data Collection
  - Equipment Flexibility
  - Controlled Hot Water Draws

- During testing, homes will be identical, except for windows
Lab Home Testing: Home Layout

Water Heater Location

Hot Water Draw Location
Lab Home Testing: Protocol

Water Heating Equipment
- Standard R-134a HPWH
- Low GWP Max Tech HPWH

Imposed Hot Water Draw Profiles
- PNNL Established Profiles in FY19
  - Small (31 daily gallons)
  - Medium (47 daily gallons)
  - Large (67 daily gallons)

Data Analysis
- Performance under Field-Based Draw Profiles
- Performance for Cold and Hot-Dry Climate
Lab Home Testing: Data Acquisition

Planned HWPH Measurements at PNNL Lab Homes

- Hot Water Flow Rate
- Outlet (Hot) Water Temperature
- Inlet (Cold) Water Temperature
- Surrounding Air Temperature and Humidity
  - Semi-Conditioned Closet Space
  - Conditioned Indoor Space adjacent to Closet
- HPWH Power Consumption
  - Backup Electric Heat Usage
  - Operating Performance
Field Testing: FY19 Progress

- Tentative Selection of 2 Field Sites in Portland, OR area
- Field Sites were participates in NW HPWH CTA2045 Study (FY19)
- Over 1 Year of Baseline HPWH Performance Data
  - HPWH Power Consumption
  - Hot Water Delivery Temperature (Pipe Temperature)
  - Air Temperature Surrounding HPWH (Inlet Air)
- Existing HPWH at Selected Field Sites
  - R-134a Refrigerant
  - Standard Industry Efficiency
HPWH Baseline Power Profile Characterization
HPWH Power Profile Characterization

Overall Dataset
- 147 HPWH Sites included in Field Data Monitoring and Survey
- Timeframe: 2017 – 2018; Weekdays (Mon – Fri) Only Considered
- Corrected CTA 2045 Power Consumption Data
- Normal HPWH Operation (No DR Events Included)

Homeowner Survey
- Does at least 1 Adult not work outside of Home for 4+ days of week?
- Number of Occupants in Household
- Manufacturer of HPWH
- Location / Climate

Data Analysis
- 24 Hour Averaged HPWH Power Profile
- Summary Characteristics for Data View: Sample Count, Energy Use, Peak Hour
- Normalized for Each Dataset for Comparison of Profile Shape
HPWH Power Profile Characterization

Does at least 1 Adult not work outside of Home?

Profile Description:
- Graph is an average of Overall Dataset throughout ~1 Year Data Collection
- Comparable AM and PM Peak in both Magnitude and Time Duration
HPWH Power Profile Characterization

Does at least 1 Adult not work outside of Home?

Profile Impact Observation:
- “Yes” or “Home” profile shows broad AM Peak and comparable PM Peak
- “No” or “Away” profile shows narrow and more dominant AM Peak
- Comparable Energy Usage yet Significant Difference in Peak Demands

Summary of Profiles

<table>
<thead>
<tr>
<th></th>
<th>“Yes” - Home</th>
<th>“No” - Away</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Home Count</td>
<td>96</td>
<td>51</td>
</tr>
<tr>
<td>Average Home Occupancy</td>
<td>2.9</td>
<td>3.1</td>
</tr>
<tr>
<td>Daily Energy Usage (Wh)</td>
<td>3,893</td>
<td>3,827</td>
</tr>
<tr>
<td>Hourly Peak Power (W)</td>
<td>242</td>
<td>331</td>
</tr>
</tbody>
</table>
HPWH Power Profile Characterization

Number of Occupants in Household

Profile Impact Observation:
- Both smaller (1, 2) and larger (3, 4, 5, 6) household counts show significant AM Peak
- Larger (3, 4, 5, 6) households show more comparable AM and PM Peak (Dual Peak)
- Smaller (1, 2) households show more dominant AM Peak compared to PM Peak
**Profile Impact Observation:**

- Comparable profile magnitude and profile shape between two represented HPWH manufacturers in field survey.

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<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Sample Home Count*</th>
<th>Average Home Occupancy</th>
<th>Daily Energy Usage (Wh)</th>
<th>Hourly Peak Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>29</td>
<td>3.0</td>
<td>242</td>
<td>3,192</td>
</tr>
<tr>
<td>B</td>
<td>102</td>
<td>2.8</td>
<td>261</td>
<td>3,532</td>
</tr>
</tbody>
</table>

*All 16 sites removed from coldest territory due to disproportionate manufacturer ratio.*
HPWH Power Profile Characterization
Seasonal – Climate

Profile Impact Observation:
• Comparable Winter and Summer Profile Shape
• Expected Increase in Energy Use in Winter due to Decreased Efficiency of HPWH in Colder Ambient Air

Normalized Profile Comparison

Summary of Profiles

<table>
<thead>
<tr>
<th></th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Home Count</td>
<td>147</td>
<td>147</td>
</tr>
<tr>
<td>Average Outdoor Temperature</td>
<td>~45°F</td>
<td>~70°F</td>
</tr>
<tr>
<td>Daily Energy Usage (Wh)</td>
<td>4,971</td>
<td>2,917</td>
</tr>
<tr>
<td>Hourly Peak Power (W)</td>
<td>357</td>
<td>185</td>
</tr>
</tbody>
</table>
Questions or Comments

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