ELECTRIC HEAT PUMP
WATER HEATER
PERFORMANCE SIMULATION

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Research Question

Significant questions/confusion about heat pump water heater (HPWH) performance:

- Has evolved dramatically over last 10 years
- Varies by air and water temperature, tank size, technology, installation location…

- What performance should policy makers expect from HPWH?
Project Overview

**Inputs**
- 50-state TMY data
- Water draw profiles

**Simulation**
- HPWHsim* (HPWH performance model)
- SEEM (whole house energy model)

**Outputs**
- Annual coefficient of performance (aCOP)
  - By state / CA climate zone
  - By tank size
  - By household size
  - By technology

HPWHsim Validation:
## Project Overview

<table>
<thead>
<tr>
<th>Water Heater Type</th>
<th>Details</th>
</tr>
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</table>
| Conventional electric resistance (baseline) | • **Generic electric resistance (ER)**  
                                        | • EF=0.96                                                               
                                        | • 50 gal. and 80 gal.                                                   |
| Hybrid heat pump                          | • **GE GeoSpring 2014**, EF=3.25                                         
                                        | • 50 gal. and 80 gal. tank sizes                                        
                                        | • Hybrid HP-ER                                                          
                                        | • Unitary form factor                                                   |
| Pure heat pump                            | • **Sanden SanCO2 2016**, EF=3.35                                        
                                        | • 39.6 gal. and 83.2 gal. tank sizes                                    
                                        | • CO2 refrigerant, pure HP                                               
                                        | • Split system                                                          |
## Project Overview

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<tr>
<th>Water Heater Type</th>
<th>Details</th>
<th>Modeled Installation Locations</th>
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</thead>
<tbody>
<tr>
<td>Conventional electric resistance (baseline)</td>
<td>• Generic electric resistance (ER)</td>
<td>Indoor</td>
</tr>
<tr>
<td></td>
<td>• EF=0.96</td>
<td>✓</td>
</tr>
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<td></td>
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<td></td>
</tr>
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* Did not model hybrid HPWH indoor due to interactive effects with HVAC
More on Methodology

- **Typical Meteorological Year (TMY):**
  - Simulations run for all TMY locations, then aggregated by population across each state (and by climate zone in CA)

- **Water draw profiles:**
  - Representative weekly draw profiles with event clusters, from NEEA HPWH validation study (100 households)
  - Specific to household size (1 to 5+)
  - Scaled down to CA building code draws for drought states (CA, AZ, NM, NV)

- **3 temperature variables:**
  1. Evaporator air temperature
  2. Tank air temperature (different for split system)
  3. Inlet water temperature (generated from outdoor air temperature, per NEEA HPWH validation study)

- **Tank set point:**
  - Default settings: 125F for GeoSpring, 149F for Sanden + mixing valve
Key Findings

- Hybrid HPWH more than 2x as efficient as electric resistance (ER) in coldest US climates, and up to nearly 3x in warmest

- CO2 heat pump 3x to 3.5x as efficient as ER

- Efficiency varies by household size, installation location, tank size
All 50 States, Hybrid Models

Annual COP of Hybrid Models per U.S. State

- Bigger is often better for HPWH, particularly in colder climates (and larger households)
- This chart is for all household sizes combined, best installation location for each state
Household size effects efficiency in two opposing ways:

1. Increased use of electric resistance element by larger draws
2. Increased relative standby losses for smaller draws
Effect of Installation Location

COP by Installation Location in Home, 50-gal Hybrid Model

- Best installation location varies by climate:
  - Basements (unconditioned) are best in cold and intermediate climates
  - Vented closets and garages better in warm climates
### How Significant is Each Factor?

#### Annual COP Sensitivity Analysis

<table>
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<tr>
<th>Factor</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure heat pump 40-gal</td>
<td>+40%</td>
</tr>
<tr>
<td>Hybrid 80-gal</td>
<td>+15%</td>
</tr>
<tr>
<td>Cold climate (ND)</td>
<td>-9%</td>
</tr>
<tr>
<td>Hot climate (FL)</td>
<td>+31%</td>
</tr>
<tr>
<td>Garage location</td>
<td>-7%</td>
</tr>
<tr>
<td>1 person household</td>
<td>-6%</td>
</tr>
<tr>
<td>5+ persons hh, 80-gal</td>
<td>+6%</td>
</tr>
<tr>
<td>Electric resistance</td>
<td>-58%</td>
</tr>
</tbody>
</table>

**Base case:**
- Hybrid 50-gal
- Intermediate climate (NY)
- Basement location
- 3-person household

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Limitations and Further Research Opportunities

- **Latest HPWH model** have a higher energy factor (3.5) than the 2014 GeoSpring used in this study (3.25)

- **Water draw profiles and inlet temperature**: improve accuracy

- **Superheating** (higher set point + mixing valve) would reduce use of electric resistance, but increase standby losses and affect heat pump efficiency. Needs further study.
How about gas water heaters?

- **Electric resistance (COP 0.96)**
- **Gas, storage tank (COP 0.6)**
- **Gas, tankless condensing (COP 0.95)**
- **Gas heat pump (COP 1.4)**

**Electric heat pump in heat-pump only mode (COP 3.5)**

Note: does not include fugitive methane emissions.
Generally better, but it all depends on time of use (avoiding ER on peak) ⇒ grid-connectivity is key!

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- Electric resistance (COP 0.96)
- Gas, storage tank (COP 0.6)
- Gas, tankless condensing (COP 0.95)
- Gas heat pump (COP 1.4)
- Hybrid heat pump operating area
- Electric heat pump in heat-pump only mode (COP 3.5)

% Renewable electricity as marginal build

( Electric resistance (COP 0.96) )
( Gas, storage tank (COP 0.6) )
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THANK YOU! - QUESTIONS?

Full results and analysis available at https://www.nrdc.org/experts/pierre-delforge/very-cool-heat-pump-water-heaters-save-energy-and-money