U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Max Tech HPWH Field Study

ORNL and PNNL

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Project Summary

Timeline:

Start date: 10/1/2018

Planned end date: 9/30/2020

Key Milestones

1. Results from duct configuration evaluation; 9/2019
2. Final report on field/lab home evaluation; 9/2020

Budget:

Total Project $ to Date:

- DOE: ORNL: 200k, PNNL: 158k

Total Project $:

- DOE: ORNL: 400k, PNNL: 400k

Key Partners:

Pacific Northwest NATIONAL LABORATORY

AO Smith Innovation has a name.

Project Outcome:

A market-ready, high-efficiency, low-GWP heat pump water heater with field-validated performance and uniform energy factor (UEF) greater than 3.0.

Team

Oak Ridge National Laboratory

- Baseline and Max Tech HPWH evaluation in research house; FY19/20
- Evaluation of integration possibilities with ducting; FY19

Pacific Northwest NATIONAL LABORATORY

- Develop water draw profiles based on field test data; FY19
- Field test of Max Tech HPWH in occupied homes; FY20
- Baseline and Max Tech HPWH evaluation in lab homes; FY20

Jeff Munk
Experience: 10 years of lab and field testing experience, 10+ studies on water heating equipment performance

Kashif Nawaz, PhD
Experience: Design and optimization of heat pumps with alternative refrigerants

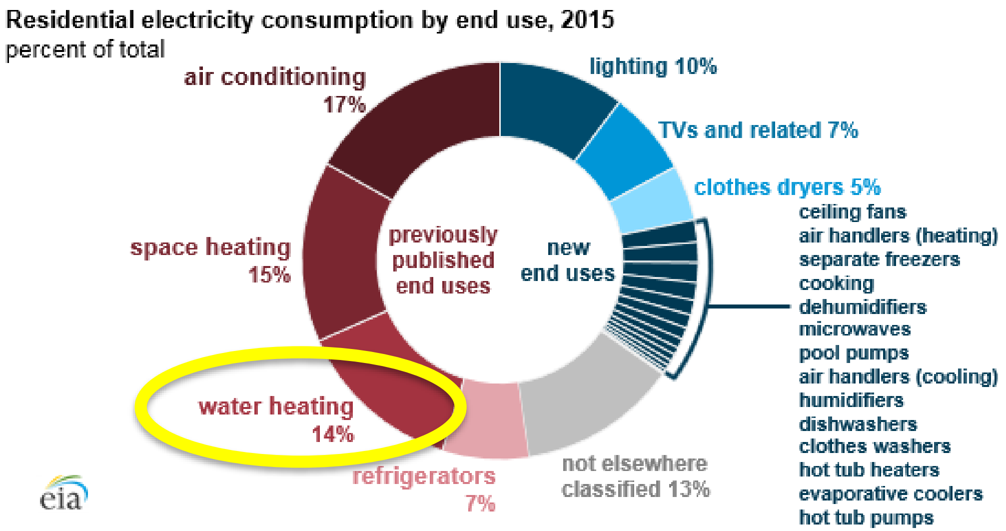
Cheryn Metzger, PE PMP LEED AP
Experience: ~10 years of lab and field experience, with multiple projects related to heat pump water heaters

Walt Hunt, PE
Experience: ~10 years experience with lab and field experiments using heat pump equipment

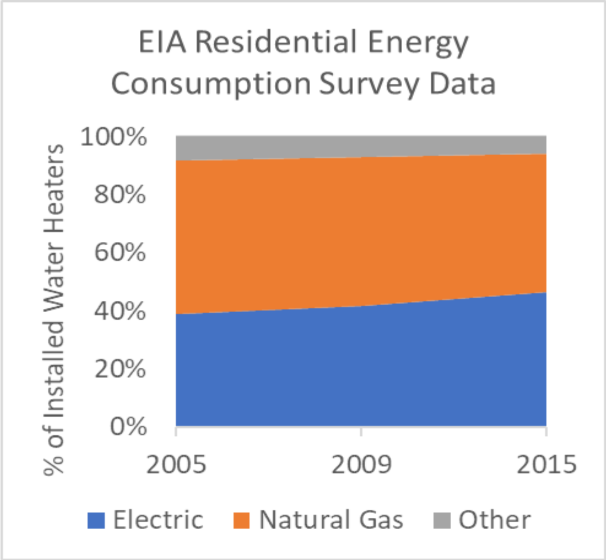
Challenge

Problem Definition:

- Residential water heating accounts for 14% of electricity consumption in homes
- There is a trend for electrification of water heating and increased adoption of heat pump water heaters
- The automotive industry has already begun the phase out of R-134a refrigerant (typically used in heat pump water heaters) with refrigerants having lower global warming potential



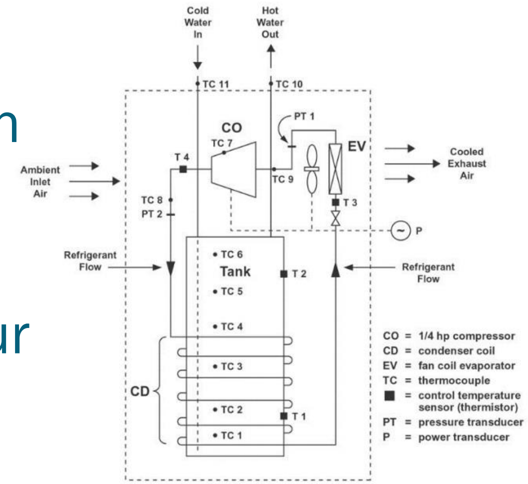
EIA. 2015 Residential Energy Consumption Survey. U.S. Energy Information Agency. https://www.eia.gov/todayinenergy/detail.php?id=36412



EIA. Residential Energy Consumption Survey. U.S. Energy Information Agency. https://www.eia.gov/consumption/residential/index.php

Approach

- Emerging Technology project at ORNL to develop lower GWP high efficiency HPWH
- Focus on maximizing uniform energy factor (UEF) and first hour rating (FHR)



- Residential Building Integration project with ORNL and PNNL
- Validate performance in real buildings and compare to existing R-134a HWPH
- Evaluate potential for demand-side load management
- Evaluate integration with building/equipment for mutual benefit

Approach

FY19

Baseline HPWH testing in unoccupied research house

Develop hot water use profiles from field data

Evaluation of ducting configurations that may improve installed efficiency of HPWH or other building equipment

FY20

Max Tech HPWH testing in unoccupied research homes

Max Tech HPWH testing in up to three occupied homes

Approach

- **Research house performance evaluation**
  - Performance mapping; varying hot water use, set point, mode
  - Demand-side load flexibility; power use under various conditions, recovery rate, and tank losses
- **Occupied home performance evaluation**
  - Measured performance under real-world conditions
  - Feedback from homeowners on performance differences compared to prior HPWH
- **Update hot water use profiles**
- **Ducting configurations in research house**
  - Improve performance of HPWH
    - Pull air from warm/humid areas (bathroom with shower, attic)
  - Improve performance of other equipment
    - Deliver cool exhaust to the refrigerator to reduce condenser temperature and reduce heat gain through case

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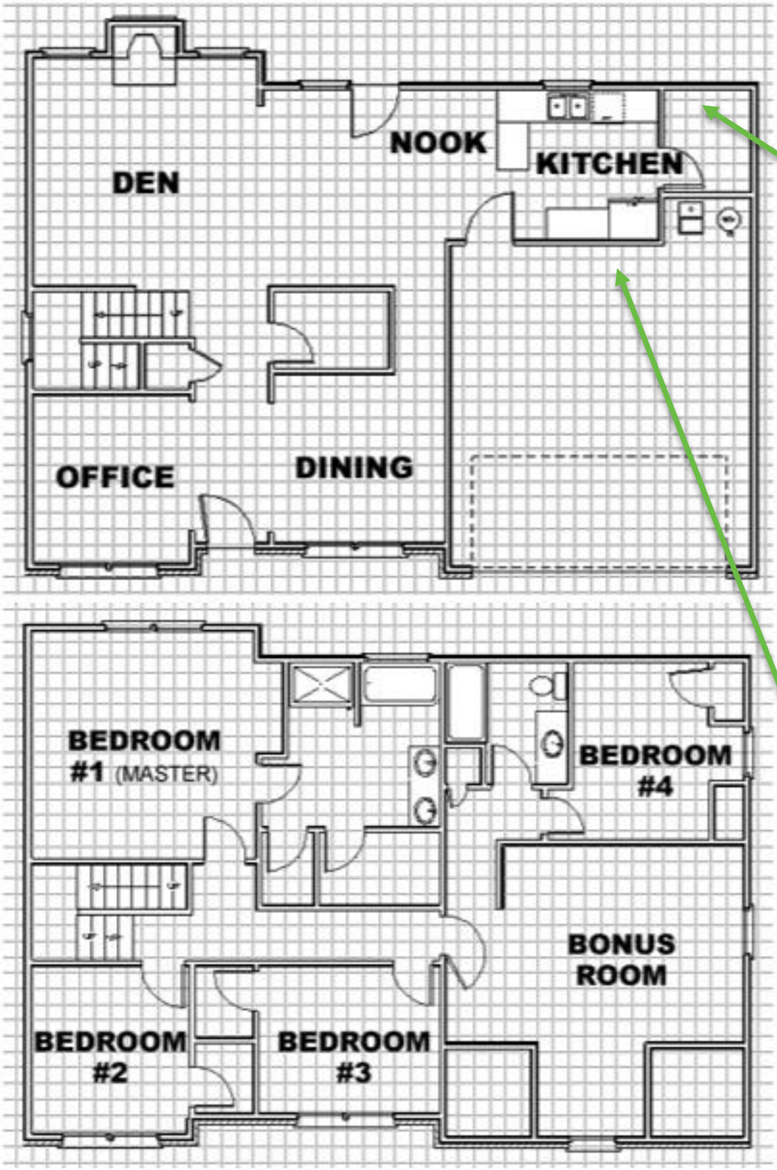
ORNL Approach – Research House

- 2-story, 2,400 ft^2 home built in 2013
- Located in Knoxville, Tennessee
- Mixed-humid climate
- Unoccupied, but with simulated occupancy using heaters, humidifiers, and programmable hot water use
- 2-stage heat pump
- 2-zones
- Slab foundation
- Vented attic
- R-13 walls
- R-38 attic

ORNL Approach – Research House



Water heater installed in garage; no insulation in exterior walls

High temperature: ~85ºF

Low temperature: ~42ºF

PNNL Approach — Lab Homes

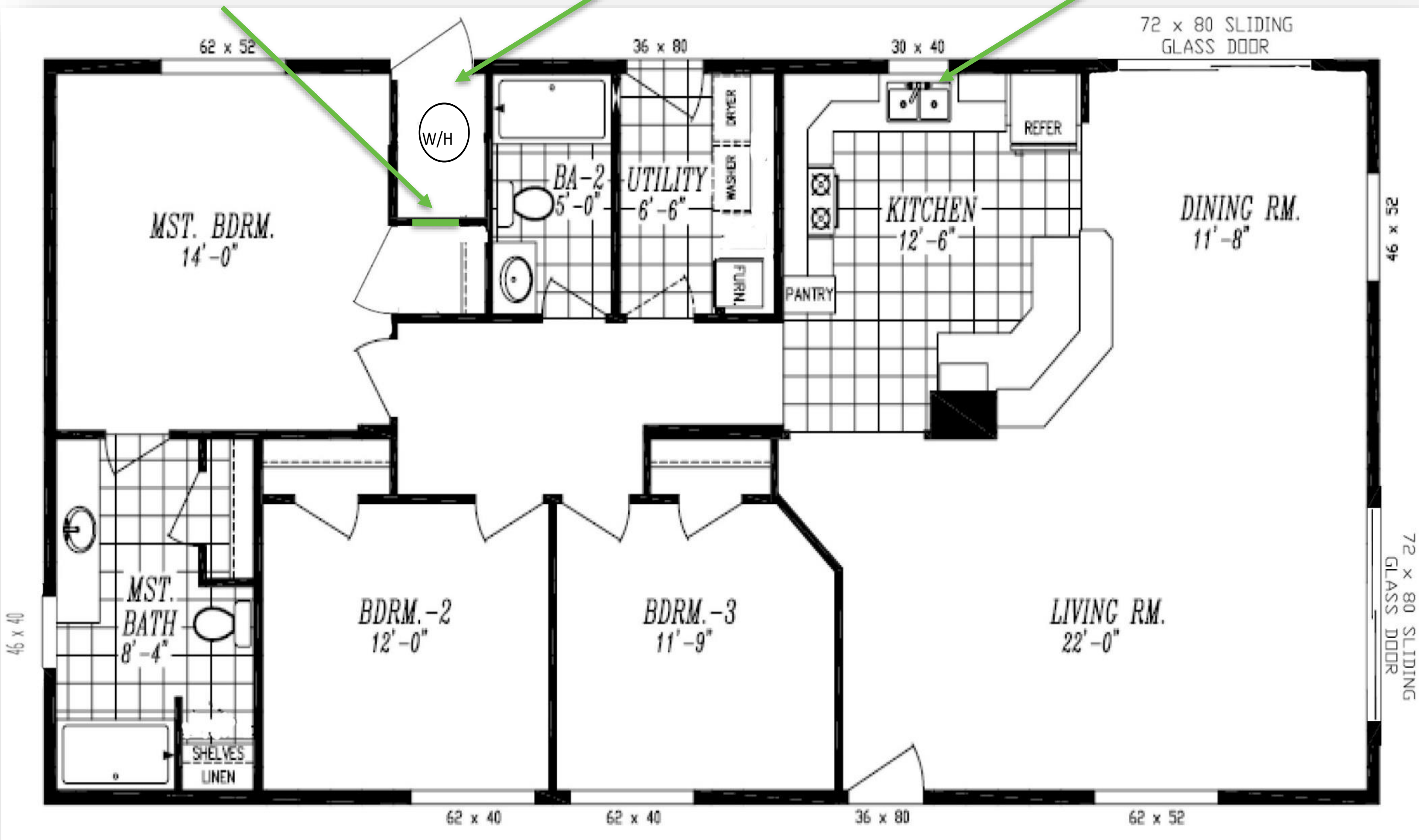
- **Represent existing homes**
  - 3 BR/2BA 1493-ft^2 double-wide, factory-built to HUD code
  - All-electric with 13 SEER/7.7 HSPF heat pump central HVAC + alternate Cadet fan wall heaters throughout
  - R-22 floors, R-11 walls & R-22 ceiling
  - 195.7-ft^2 (13% of floor) window area
  - Incandescent lighting
- **Cold climate**
- Electric vehicle charging station
- Some connected infrastructure
- Low-risk project data collection
- Equipment flexibility
- In this case, homes will be the same, except for windows

PNNL Approach — Lab Homes

Louvered slots to master bedroom meet manufacturer installation specifications

Water Heater Closet

Water draw location



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PNNL Approach — Field Testing

- Leveraging previous field study
  - Existing AO Smith HPWHs
  - Previously collected baseline data

- Research Questions:
  - What is the customer experience with the Max Tech HPWH?
  - What is the field performance of the water heater?
  - How does the field performance compare to the lab performance?

Approach

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PNNL Approach — Update Hot Water Use Profiles

Field Data Sources

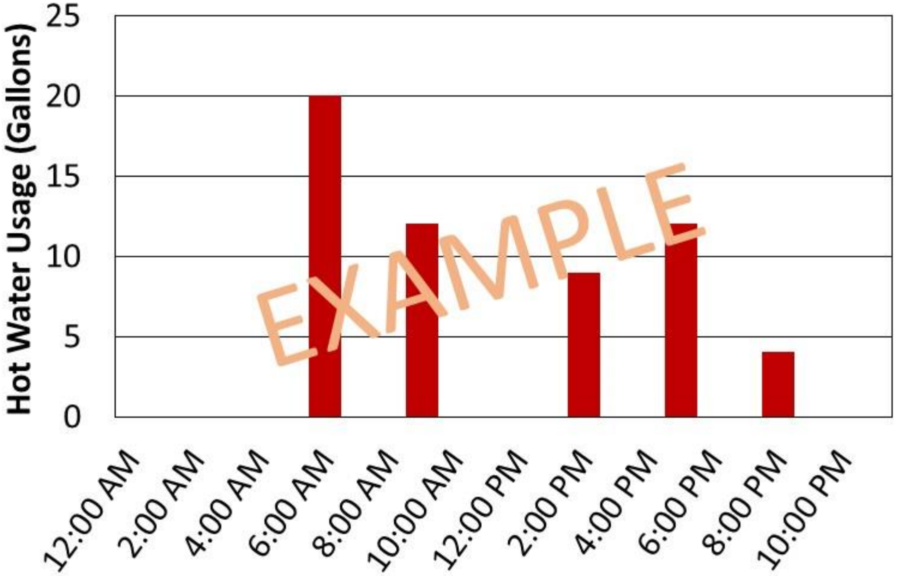
CTA 2045 Dataset (200+ WHs)
- Instantaneous Power (W)
- Present Energy (Wh)

Field Monitoring Subset (60+ WHs)
- Instantaneous Power (W)
- Discharge Hot Water Temperature (°F)

Hot Water Usage Profile

Prevalence

Magnitude



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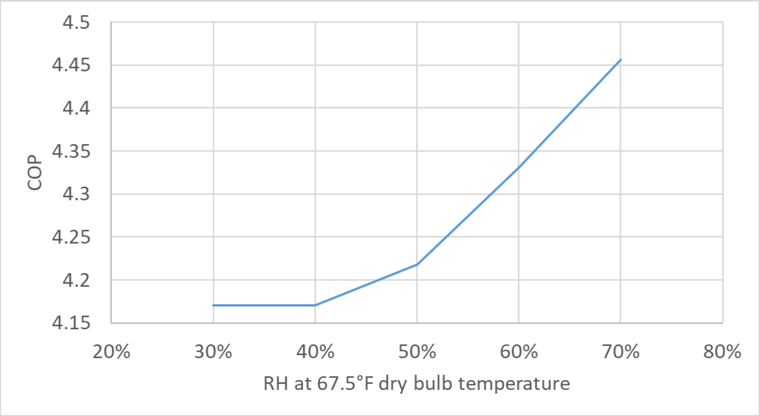
ORNL Approach – Duct Configuration

- **Heat pump water heater performance is dependent on the entering air temperature and humidity**
- **When the evaporator temperature is below the dew point of the air, condensation occurs**
  - Increases heat transfer/capacity
  - Increases efficiency

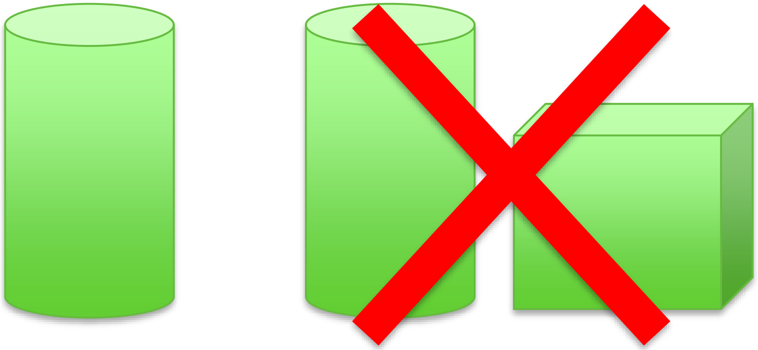


- **Bathroom with a shower is a good source for warm humid air**
  - Added benefit that a shower will typically cause the heat pump water heater to turn on, resulting in automatic ventilation
- **Unconditioned attic is another source for warm air**
  - Only a benefit after sun has heated attic
- **Cool exhaust air can be used to improve refrigerator efficiency**

Impact

- Higher efficiency = Energy savings
  - Targeting an efficiency over 3x greater than that of standard electric water heaters
  - Electricity use for residential water heating is estimated to use 1.3 quads of primary energy = <u>energy savings potential of 0.87 quads</u>
- Lower GWP refrigerant = Reduced global warming impact of refrigerants
  - R-134a GWP = 1430
  - Max Tech HPWH will use refrigerant with GWP between 3 and 7
- Existing low GWP HPWH uses CO2 and is a two-box system with a cost of ~$4,000

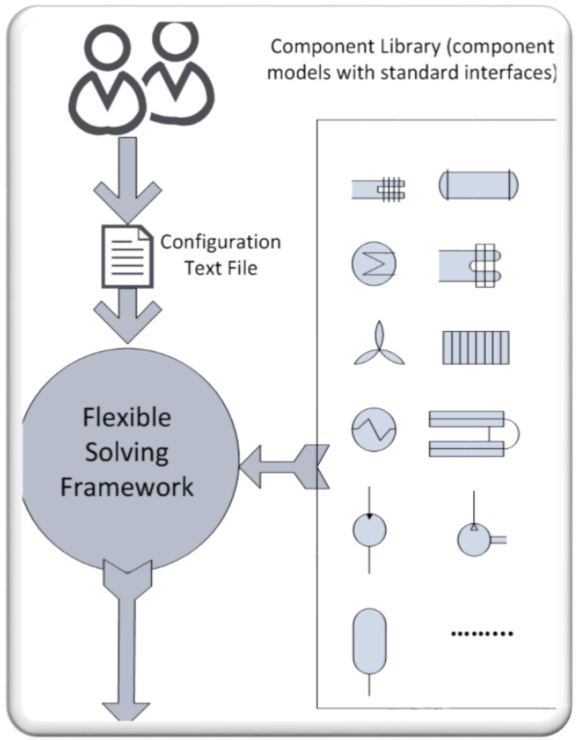
- Max Tech HPWH will be designed based on existing single-box HPWH platform with minimal cost increase over conventional HPWHs

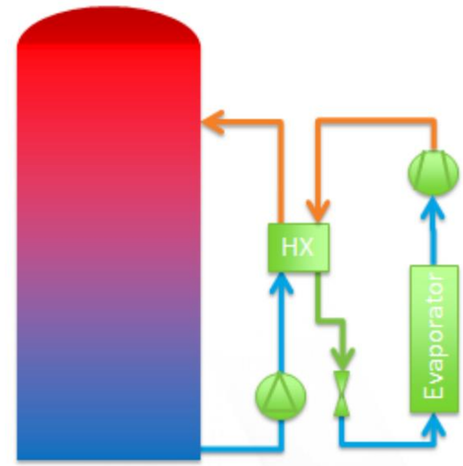


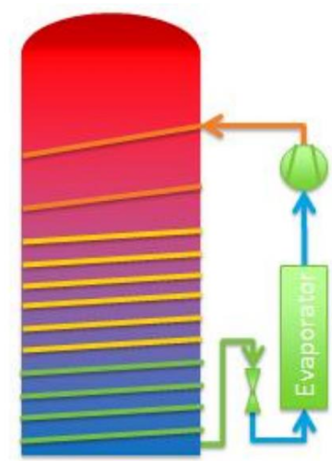
Progress — Development of Model

Component-Based

Component models have standard interfaces to the solving framework, and generic connections to each other.





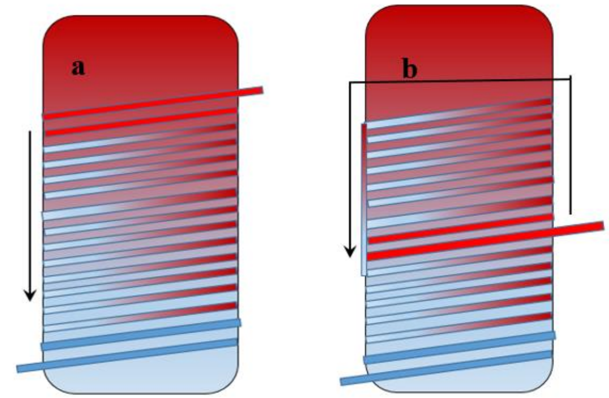


Automatically connect components into required system configuration by user input file.

B. Shen, K. Nawaz, A. Elatar, V. Baxter, "Development and Validation of Quasi-Steady-State Heat Pump Water Heater Model Having Stratified Water Tank and Wrapped-Tank Condenser" International Journal of Refrigeration, 2018, 87,78-90.

Progress — Parametric Analysis

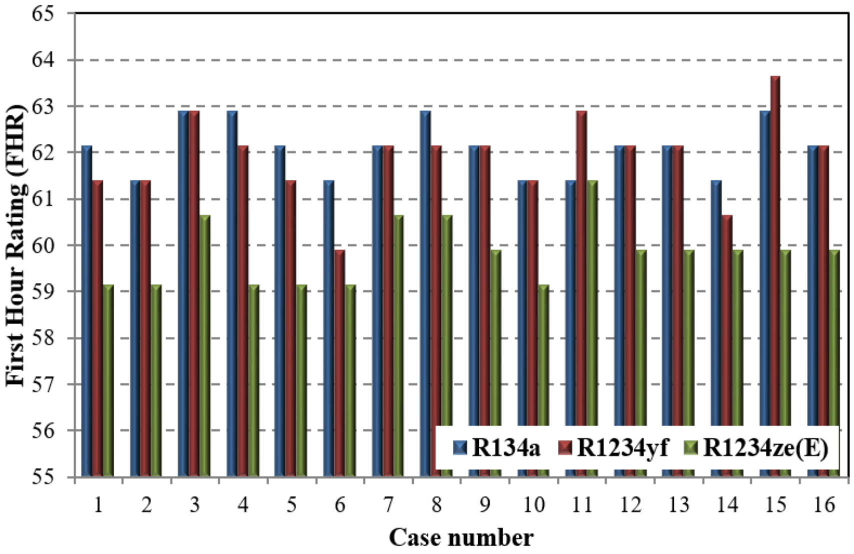
- 46-gallon water tank
- Heat pump T-stat at the top: on at 115°F, off at 125°F.
- Electric element at the top: on at 110°F, off at 125°F.
- Two different evaporator sizes and evaporator flow rate
- Two different heat loss factors from tank
- Two different condenser coil wrap patterns
- Two different condenser tube sizes

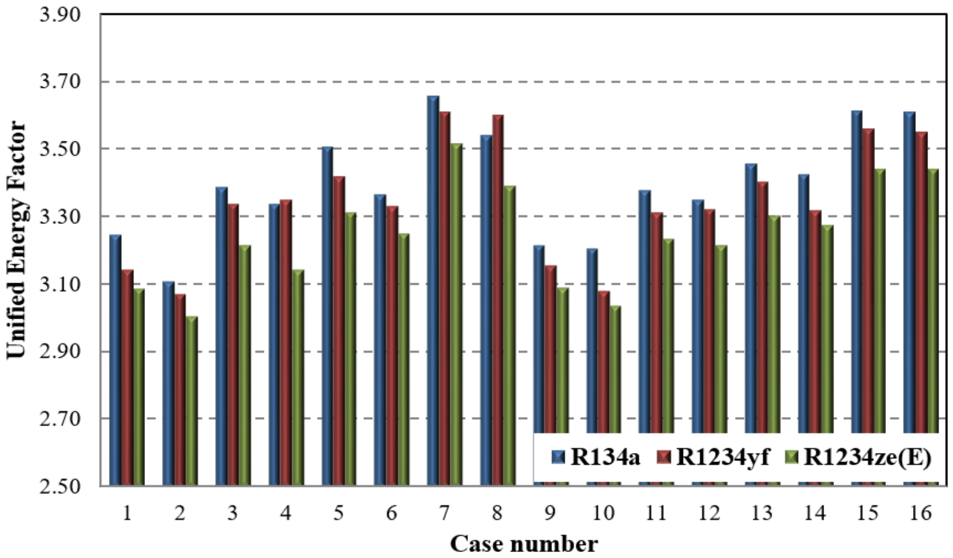


Condenser wrap configurations
(a) counter flow (b) parallel-counter flow

Case number	Wrap pattern	Evaporator size*	Tank insulation effectiveness (%)	Condenser tube size (inches)
1	Parallel-counter	1 Evap	90	0.31
2	Parallel-counter	1 Evap	90	0.50
3	Parallel-counter	2 Evap	90	0.31
4	Parallel-counter	2 Evap	90	0.50
5	Parallel-counter	1 Evap	95	0.31
6	Parallel-counter	1 Evap	95	0.50
7	Parallel-counter	2 Evap	95	0.31
8	Parallel-counter	2 Evap	95	0.50
9	Counter	1 Evap	90	0.31
10	Counter	1 Evap	90	0.50
11	Counter	2 Evap	90	0.31
12	Counter	2 Evap	90	0.50
13	Counter	1 Evap	95	0.31
14	Counter	1 Evap	95	0.50
15	Counter	2 Evap	95	0.31
16	Counter	2 Evap	95	0.50

Progress — Parametric Analysis



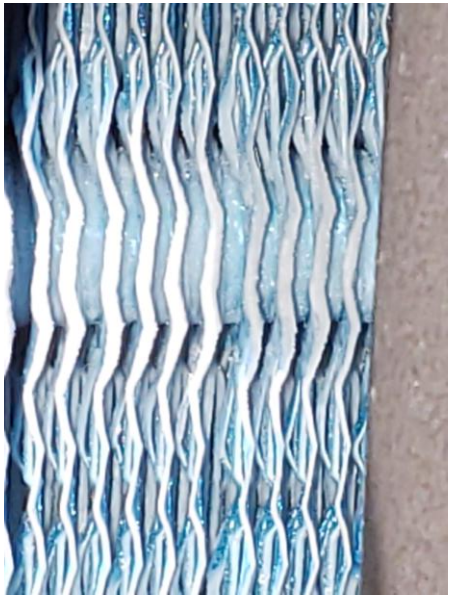


- First hour rating (FHR) for all various cases is comparable- Medium pattern
- R1234ze (E) has reduced FHR due to lower volumetric capacity
- Uniform energy factor (UEF) is more sensitive to tank effectiveness and condenser tube size

Progress — Experimentation

Parameter	R134a	R1234yf	R290
Optimum refrigerant charge	2.3	2.2	1.05
First Hour Rating (FHR)	66	68	67
Uniform Energy Factor	3.44	3.40	3.60

- Low ambient testing is a challenging but required for further technological developments.



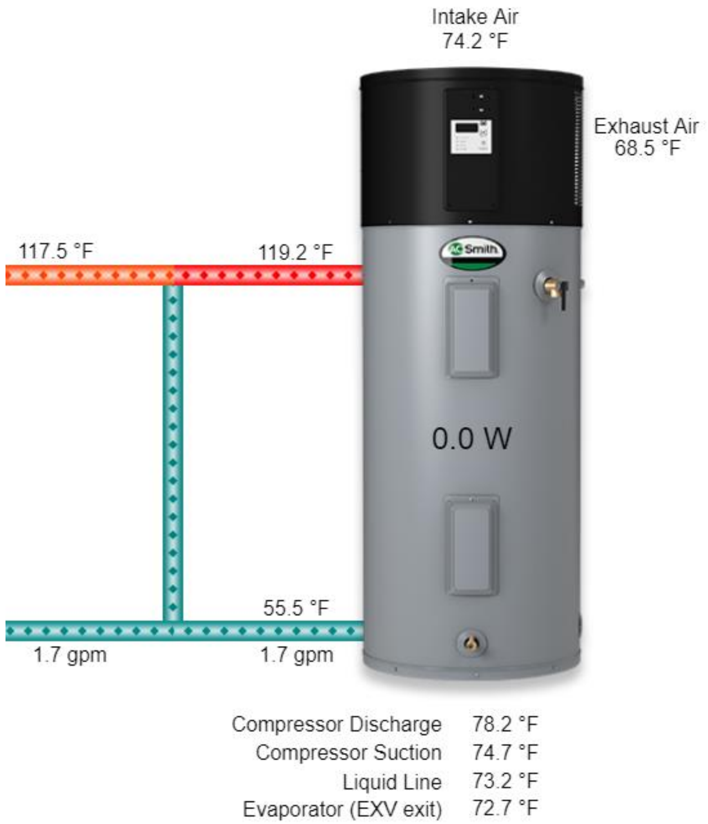
ORNL Progress

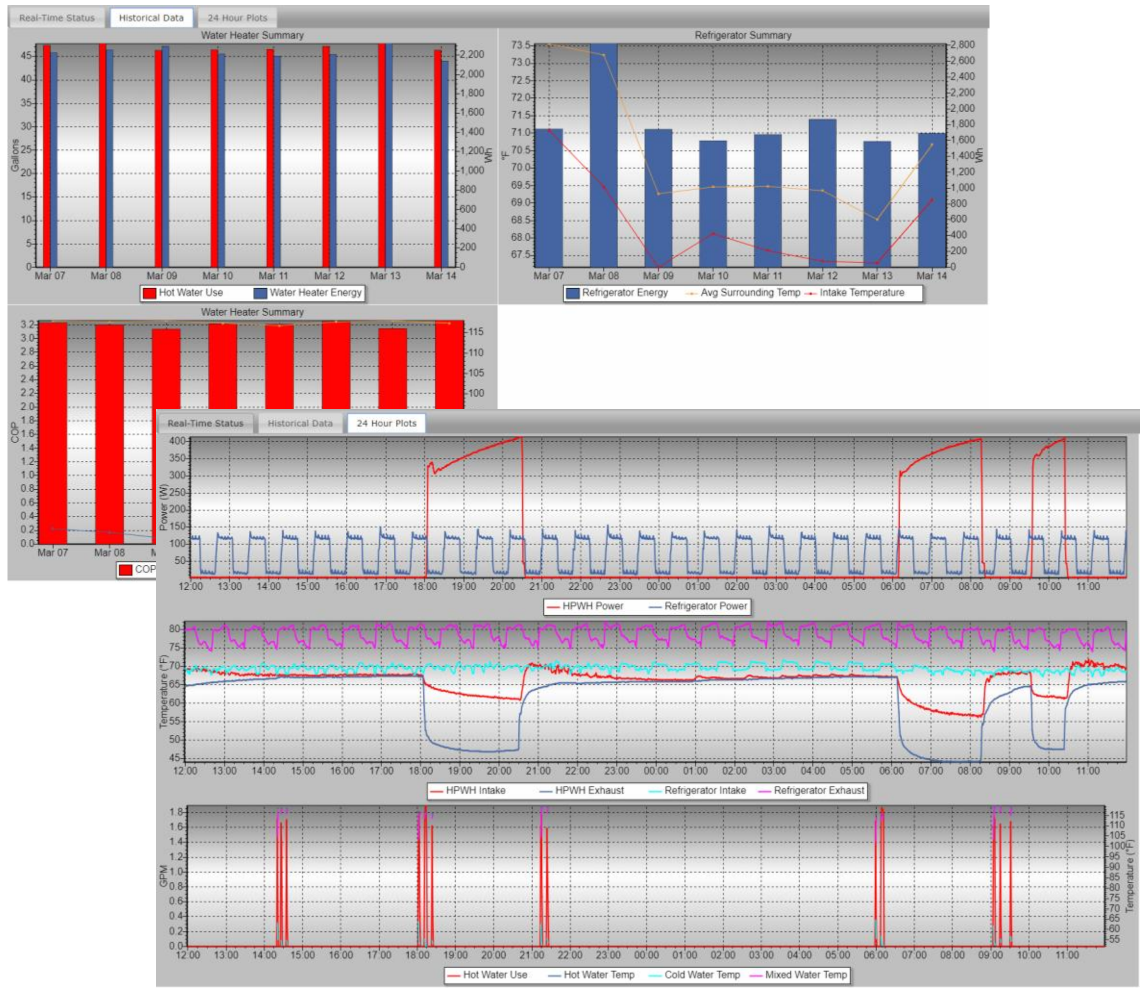
EARLY STAGE PROGRESS

- Baseline HPWH installed in garage and instrumented
- RTDs for cold water inlet, hot water outlet, and mixed temperature
- Flow meters on cold water line to water heater and mixed flow line
- Thermocouples for HPWH intake and exhaust air, compressor suction and discharge, liquid line, evaporator, refrigerator intake and exhaust air, refrigerator ambient
- Power meters on water heater and refrigerator
- Temperature/RH combination sensors for garage ambient, HPWH intake air, and bathroom ambient
- Evaluate performance when varying:
  - Mode: Efficiency, Hybrid, Electric
  - Set point temperature: 120° F, 130° F, 140° F
  - Hot water use: Low, Medium, High

ORNL Progress

- Real-time monitoring webpage displays current data and historical data to quickly identify any issues and determine general trends in data

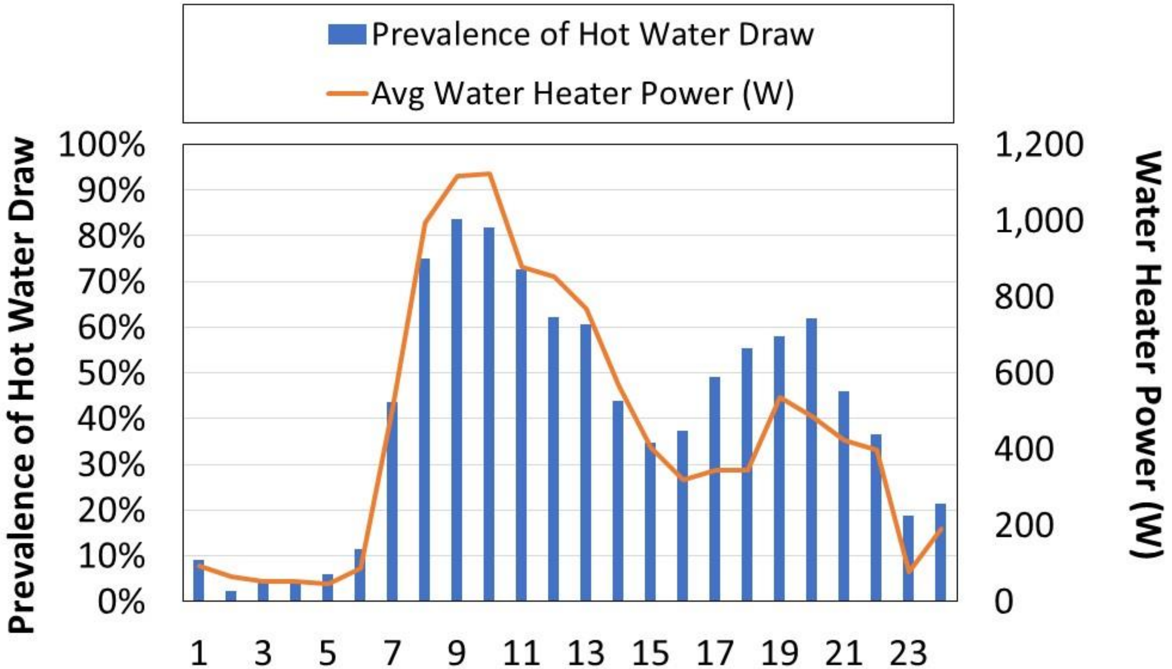




PNNL Progress

Prevalence of Hot Water Usage

Data Sample:
Summer Profile of
ERWH Field Site.



Magnitude of Hot Water Draw

Option A: CTA 2045 Present Energy Data

- Resolution of Data varies with Manufacturer. Limited Accuracy
- Unique Data Characteristics for Each WH Type
- Filter out Stand-by Losses and Noise from Dataset

Option B: Power Demand Data

- Electric Resistance WHs provide simpler path to Determining Magnitude

Stakeholder Engagement

- Direct involvement from HPWH manufacturer
- Feedback from homeowner test sites on noise, air temperature surrounding unit, and hot water quality
- Present project progress at next ACEEE Hot Water Forum and seek feedback from industry

Remaining Project Work

In progress

FY19	FY20
Baseline HPWH testing in unoccupied research house	Max Tech HPWH testing in unoccupied research homes
Develop hot water use profiles from field data	
Evaluation of ducting configurations that may improve installed efficiency of HPWH or other building equipment	Max Tech HPWH testing in up to three occupied homes

Remaining Project Work

- Finalize design of Max Tech HPWH
- Build Max Tech HPWH prototypes
- Identify up to three field test sites
- Install and instrument Max Tech HPWHs at field test sites
- Install and instrument Max Tech HPWHs at research homes
- Comparative testing of performance and demand-side load flexibility

Thank You

ORNL and PNNL

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REFERENCE SLIDES

Project Budget

Project Budget: 400k – ORNL, 400k PNNL
Variances: None
Cost to Date: 38k ORNL, 30k PNNL
Additional Funding: None

Budget History					
FY 2018 (past)		FY 2019 (current)		FY 2020 – 9/30/2020 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
0	0	358k	0	442k	0

Project Plan and Schedule

Describe the project plan including:

- Start date 10/1/2018; End date 9/30/2020;
- Milestones:
  - 6/30/2019 Develop hot water draw profiles from field data
  - 9/30/2019 Slides on duct configuration study results
  - 9/30/2020 Final report on field and lab home study

Project Schedule		
Project Start: 10/1/2018		Completed Work
Projected End: 9/30/2020		Active Task (in progress work)
	◆	Milestone/Deliverable (Originally Planned) use for missed
	◆	Milestone/Deliverable (Actual) use when met on time

	FY2019				FY2020				FY2021			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Current/Future Work												
Evaluate ducting configurations				◆								
Develop hot water draw profiles			◆									
Final report on field study								◆				