2024 PROJECT PEER REVIEW

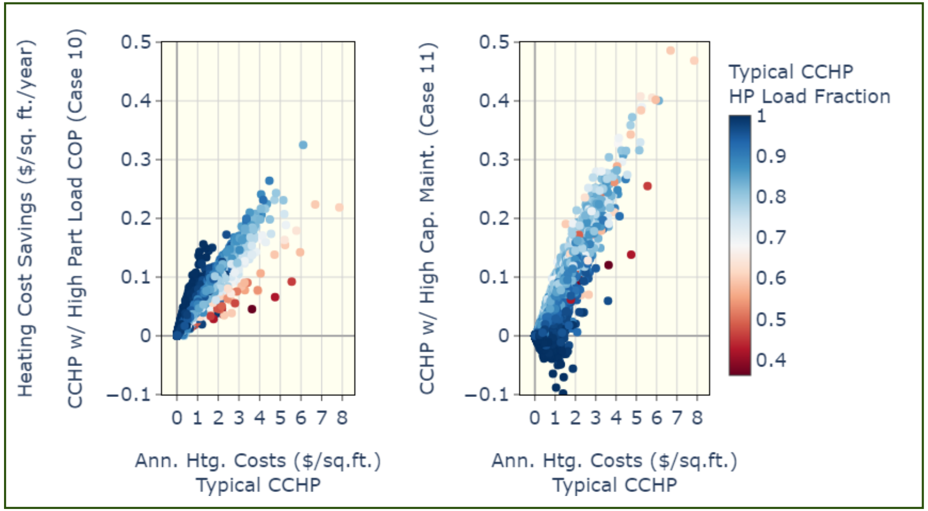
U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

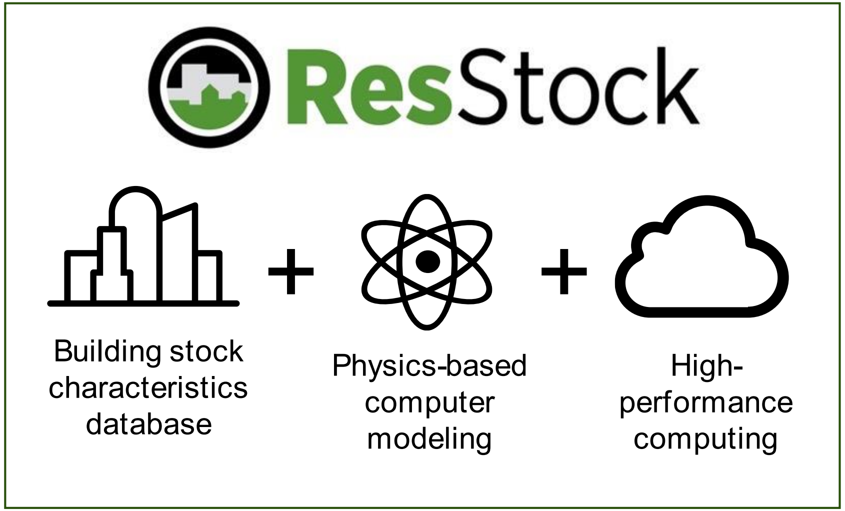
BTO Peer Review

House characteristic-based design guidance on heat pump selection, sizing, and setup for decarbonization

Material in this presentation includes unpublished and/or preliminary data and analysis that is subject to change.

House characteristic-based design guidance on heat pump selection, sizing, and setup for decarbonization





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WBS 1.5.2.30

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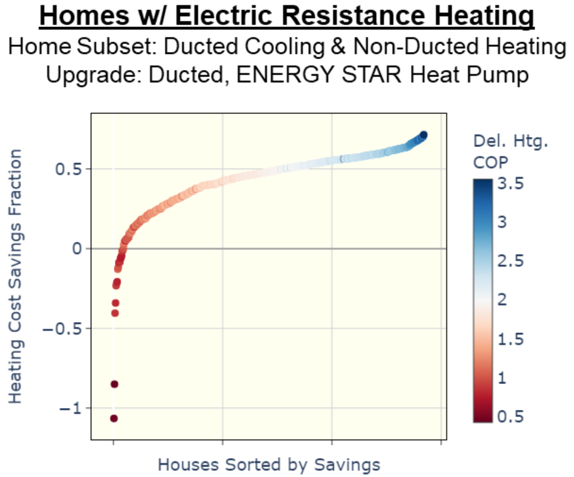
Project Summary

OBJECTIVE, OUTCOME, & IMPACT

The objectives of this project are to (1) develop guidance for installers and consumers to determine heat pump retrofit potential for a given home and develop new rules to support installers and (2) develop a ranked list of heat pump performance metrics that impact operating cost and carbon emissions. The expected output is simplified guidance for contractors on selecting and configuring heat pumps based on readily available house characteristics and climate.



TEAM & PARTNERS

National Renewable Energy Laboratory (NREL)

DOE National Heat Pump Partnership for dissemination of findings

STATS

Performance Period: FY23 – FY25

DOE Budget: $400k, Cost Share: $0k

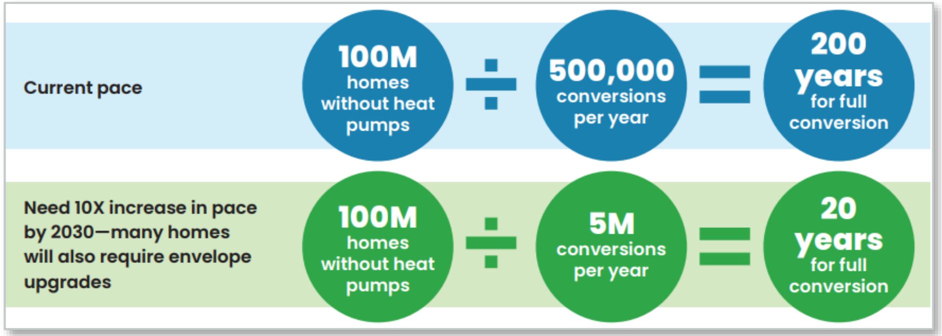
Milestone 1: 6/30/2023 (Go/No-Go) - Simulation plan outlining model inputs and heat pump metrics

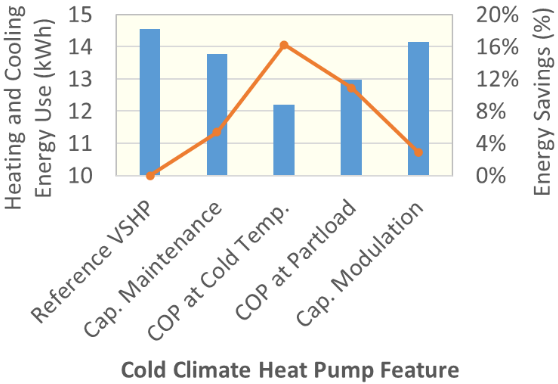
Milestone 2: 9/27/2024 - Technical presentation on impacts of heat pump selection, sizing, and setup

Problem

- Heat pump adoption must accelerate 10x to meet our nation's climate goal.[1]
- Rapid expansion of heat pump use into regions where installers are not as familiar with heat pump selection, sizing, and installation poses significant risks, particularly for low to moderate income households.
- Modeling studies have shown that poorly sized and selected heat pumps can have a significant impact on seasonal efficiency and operating cost.

***Project Focus:* Equitable heat pump deployment strategies to minimize occupant operating expenses while maximizing carbon savings.**





Re-produced from Smith (2022) Variable Speed Heat Pump Product Assessment and Analysis

(Results from Bozeman, MT simulation case.)

[1]*Source: Decarbonizing the U.S. Economy by 2050: A Nat'l Blueprint for the Bldgs Sector*

Alignment and Impact

Project Objective: Conduct building stock simulations to determine the impact of heat pump selection, sizing, and control settings on operating cost and carbon emissions based on house characteristics and climate.

- Avoid heat pump selection, sizing, and setup risks to consumers.
- Ensure residential heat pumps are optimally selected, sized, and setup to achieve operational cost, energy, and carbon savings.

Expected Outputs: An understanding of the heat pump performance parameters and building characteristics necessary for successful deployment.

- Simplified guidance for contractors on selecting, sizing, and configuring heat pumps based on readily available house characteristics and climate.

BTO Decarb Blueprint Cross-Cutting Goal 2: Affordability – Reduce Energy-Related Costs

… reducing the cost of building decarbonization solutions are critical for ensuring that the transition to a low-carbon buildings sector is affordable for all Americans. At the same time, ***building decarbonization solutions must deliver lower energy bills to consumers once installed****.*

Key Barrier – High Soft Costs

Some installers may be unfamiliar with sizing heat pump equipment or rely on sizing rules of thumb as opposed to detailed load calculations, which could lead to ***oversized equipment, unnecessary backup equipment, unnecessary electrical upgrades*** *or uncomfortable occupants.*

Approach

Overall Approach and Timeline

General Approach: Utilize ResStock simulation tool to assess the sensitivity of heat pump performance characteristics and sizing on utility bills and carbon emissions.

Why ResStock? To correlate findings to climate and building characteristics.

FY23: Ideation and Analysis Plan

- Analysis plan completed.
- OS-HPXML model update completed (*separate project*).

FY24: Model Input Definitions and Mid-Scale Runs

- Sizing and defrost model improvements.
- Heat pump model definitions determined.
- Mid-scale ResStock runs.
- Data quality control and analysis prior to production runs.

FY25: Production Runs, Analysis, and Dissemination

- ResStock production runs.
- Data analysis and conclusions.
- Results dissemination through the National Heat Pump Partnership.
- Leverage findings in PNNL's CCHP Decision Tool.

Simulation Cases (Homes w/ Ducts)

<table>
<tr><th colspan="2">Type and Case ID</th><th>Case Description</th><th>Heat Pump Description</th><th>Backup System</th><th>Heat Pump Lockout</th><th>Sizing Approach</th></tr>
<tr><td rowspan="3">Baselines</td><td>1</td><td>ResStock Building Stock</td><td colspan="3">Not applicable.</td><td>ACCA Man. S</td></tr>
<tr><td>2</td><td>E-STAR HP, Existing Sys. Backup</td><td rowspan="2">HSPF2 = 7.8
(Single Stage)</td><td>Existing Sys.</td><td>-10°F</td><td rowspan="10">Heat pumps are sized based on the size of the existing ductwork.

(New Approach)</td></tr>
<tr><td>3</td><td>E-STAR HP, All Electric</td><td>Electric</td><td>-10°F</td></tr>
<tr><td>DF</td><td>4-6</td><td>Dual Fuel Lockout Controls</td><td>HP Cases 3, 8, and 10</td><td>Existing Sys.</td><td>3 increments</td></tr>
<tr><td rowspan="6">HP Selection</td><td>7</td><td>E-STAR Cold Climate (Minimum)</td><td>E-STAR Specification</td><td rowspan="6">Electric</td><td rowspan="6">-15°F</td></tr>
<tr><td>8/8b</td><td>“Typical” Cold Climate, Variable-Speed</td><td rowspan="4">HSPF2 8.75 ± 0.25

Performance based on HP classification.</td></tr>
<tr><td>9</td><td>High COP @ Cold Temperatures</td></tr>
<tr><td>10</td><td>High COP @ Part Load Conditions</td></tr>
<tr><td>11</td><td>High Capacity @ Cold Temperatures</td></tr>
<tr><td>12/13</td><td>Higher Efficiency Heat Pumps</td><td>In development.</td></tr>
<tr><td rowspan="3">HP Sizing</td><td>15a-d</td><td>E-STAR Cold Climate (Minimum)</td><td>Same as Case 3.</td><td rowspan="3">Electric</td><td rowspan="3">-15°F</td><td rowspan="3">Clg. load based through max. load based (4 increments)</td></tr>
<tr><td>14a-d</td><td>“Typical” Cold Climate, Variable-Speed</td><td>Same as Case 8.</td></tr>
<tr><td>16a-d</td><td>High COP @ Part Load Conditions</td><td>Same as Case 10.</td></tr>
</table>

Heat Pump Selection: Determining Performance Characteristics

NEEP ccASHP Product List Data
(~110,000 entries)[1]

↓

Pre-Process Database
(~6,500 central ducted HPs)

- Perform quality control checks
- Collect unique IDU/ODU combos
- Filter on HP type and HSPF2

↓

Determine Performance Inputs

- Select subset based on 90th percentile value for given metric
- Find median performance values vs. temperature

[1] *Downloaded on March 29, 2024*

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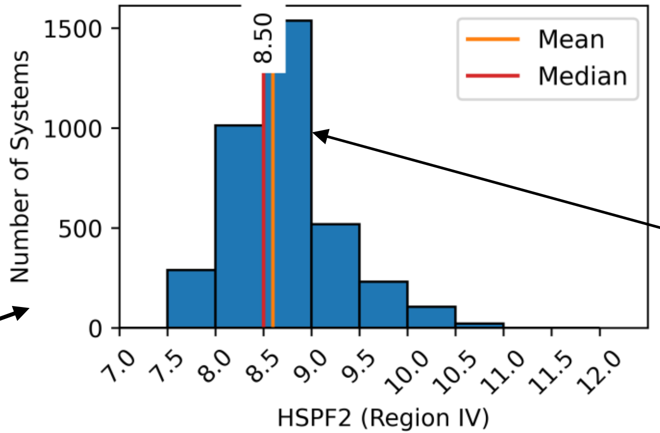
Centrally Ducted ccASHPs
(Unique IDU/ODU Combinations)



Selected HSPF2 bin for this project.

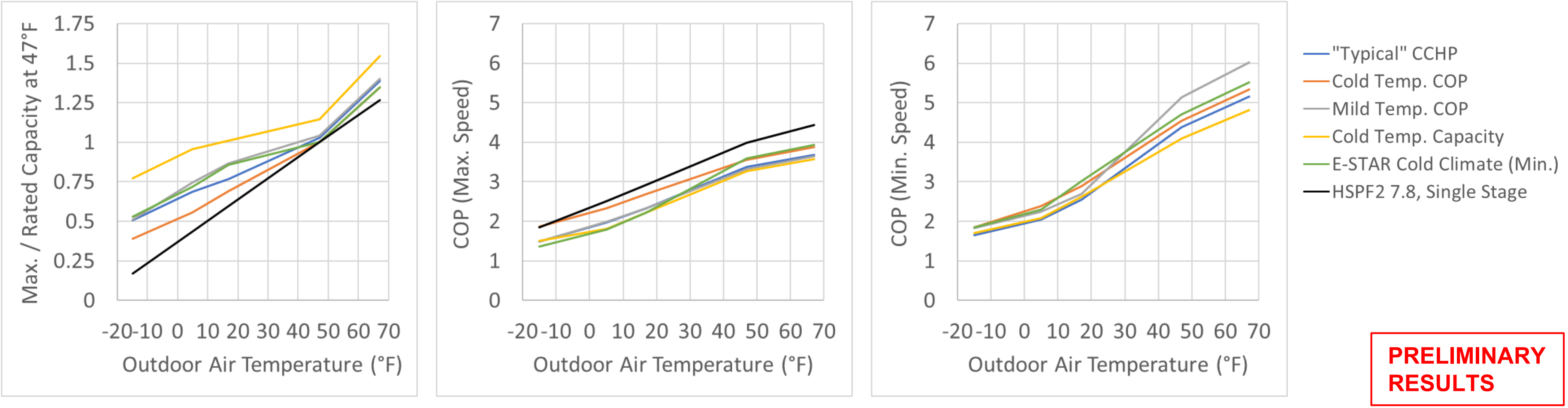
Why filter based on HSPF2?

- With variable-speed HPs, there are many ways to achieve a given HSPF2 rating.
- **Project Goal:** Can we provide guidance to help select the best HP <u>characteristics</u> for a particular home?
- Without HSPF2 filtering, we lose this level of detail.

[1]*Downloaded on March 29, 2024*

Heat Pump Selection: Model Inputs and Approach

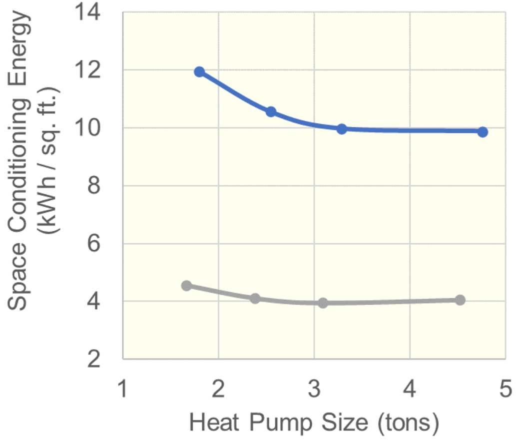
Heat Pump Description		Approach/Metric	HSPF2	SEER2
1-3	ENERGY STAR Minimum Requirement	E-STAR spec. w/ OS-HPXML HP model	7.8	15.2
7	ENERGY STAR Cold Climate (Minimum)	NEEP DB w/ E-STAR CC requirements	8.2	17.2
8	“Typical” Cold Climate, Variable-Speed	Median ccASHP w/in HSPF2 bin	8.5	17.5
9	High COP @ Cold Temperatures	Subset w/ high **maximum capacity COP at 5°F**	8.7	17.3
10	High COP @ Part Load Conditions	Subset w/ high **minimum capacity COP at 47°F**	8.7	15.5
11	High Capacity @ Cold Temperatures	Subset w/ high **max. capacity at 5°F / rated cooling**	8.5	18.5



PRELIMINARY RESULTS

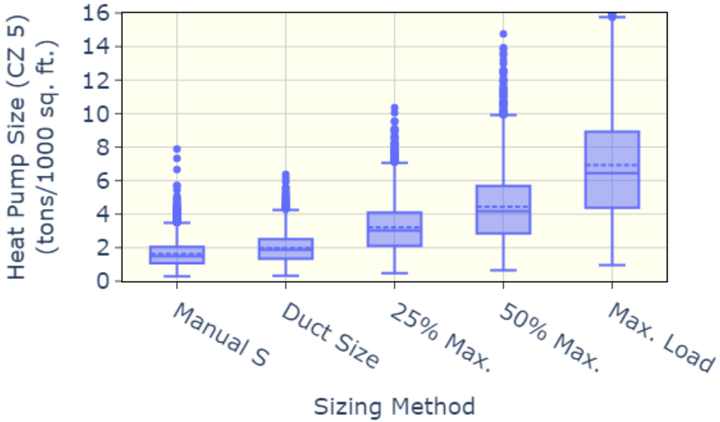
Heat Pump Sizing: Accounting for Duct Size

- Prior this project, ResStock had two heat pump sizing options:
  1. ACCA Manual S (2014) – Applies oversizing factors to the design cooling load.
  2. Maximum Load – Size the heat pump to meet 100% of the design heating or cooling load (whichever is greater).
  - Both approaches neglect the airflow capacity of the existing ductwork.
- **<u>New Approach</u>**: Use the pre-upgrade maximum cooling or heating airflow to determine the heat pump capacity.
- Assess sensitivity by simulating two intermediate heat pump sizes in between the default and maximum load sizing.



Two example homes with different sensitivity to HP size.

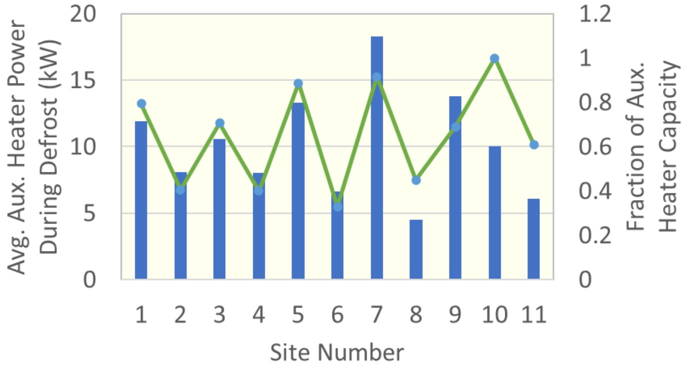
- ~2 kWh/sq. ft. savings could make duct upgrades worthwhile.



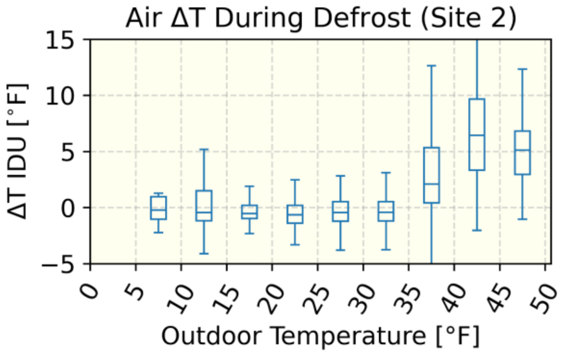
PRELIMINARY RESULTS

Heat Pump Model Improvement: Defrost Energy

- Prior this project, auxiliary heater energy consumed during heat pump defrost mode was neglected.
  - Field data has shown defrost energy consumption is often significant due to the auxiliary heater.
- Addressed two defrost model shortcomings using existing field data:
  - Significant under-prediction of the amount of cooling added to the space.
  - Neglecting the auxiliary heater energy.
- <u>**Updated Assumptions:**</u>
  - Cooling during defrost equals 45% of the rated cooling capacity.
  - Auxiliary heat is used (when available) to supply temperature neutral air.



Defrost mode field data from Winkler and Ramaraj (2023).



Produced using data from Winkler and Ramaraj (2023).

PRELIMINARY RESULTS

Project Risks and Challenges

- **Challenge:** Evolving heat pump product landscape while maintaining a discernable scope.
  - **Mitigation:** Heat pump model definitions are based on a specific version of the NEEP ccASHP Product List and the scope has been developed to includes "today's" heat pump market and expected improvements for high-efficiency products.
- **Challenge:** NEEP ccASHP Product List data quality.
  - **Mitigation:** Performed quality control checks to eliminate obvious errors. Utilized median performance metrics to avoid impact of remaining data issues.
- **Challenge:** Disseminating results into actionable advice to contractors.
  - **Mitigation:** (1) Present findings to DOE's National Heat Pump Partnership and explore opportunities to develop materials for stakeholders. (2) Provide results to PNNL and develop approaches to incorporate findings in the Cold-Climate Heat Pump Decision Tool.

Progress and Future Work

Simulation Status

- Approach to ensure successful ResStock runs:
  - Small Scale → Mid Scale → Full Production runs.
  - Detailed processing and analysis of mid scale runs for quality control.
- Currently analyzing results for mid scale runs.
  - Sample size (30k homes) is sufficient to start investigating trends.
- Following slides offer highlights of several preliminary findings/trends.

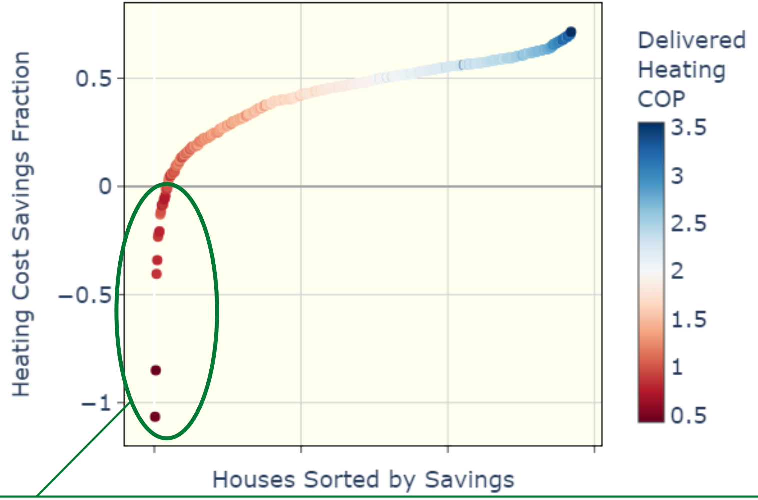
Type and Case ID		Case Description	Run Status	Analysis Started?
Baselines	1	ResStock Building Stock	30k Run	Yes
	2	E-STAR HP, Existing Sys. Backup	30k Run	Yes
	3	E-STAR HP, All Electric	30k Run	Yes
DF	4-6	Dual Fuel Lockout Controls	Development	N/A
HP Selection	7	E-STAR Cold Climate (Minimum)	30k Run	Yes
	8/8b	"Typical" Cold Climate, Variable-Speed	30k Run	Yes
	9	High COP @ Cold Temperatures	30k Run	No
	10	High COP @ Part Load Conditions	30k Run	Yes
	11	High Capacity @ Cold Temperatures	30k Run	Yes
	12/13	Higher Efficiency Heat Pumps	Development	N/A
HP Sizing	15a-d	E-STAR Cold Climate (Minimum)	30k Run	Yes
	14a-d	"Typical" Cold Climate, Variable-Speed	30k Run	Yes
	16a-d	High COP @ Part Load Conditions	Development	N/A

Highlight of Preliminary Findings: Non-Ducted Heating Systems

Homes w/ Electric Resistance Heating

Home Subset: Ducted Cooling & Non-Ducted Heating

Upgrade: Ducted, ENERGY STAR Heat Pump



Delivered heating seasonal COP < 1 due to inefficient duct work will increase heating bills.

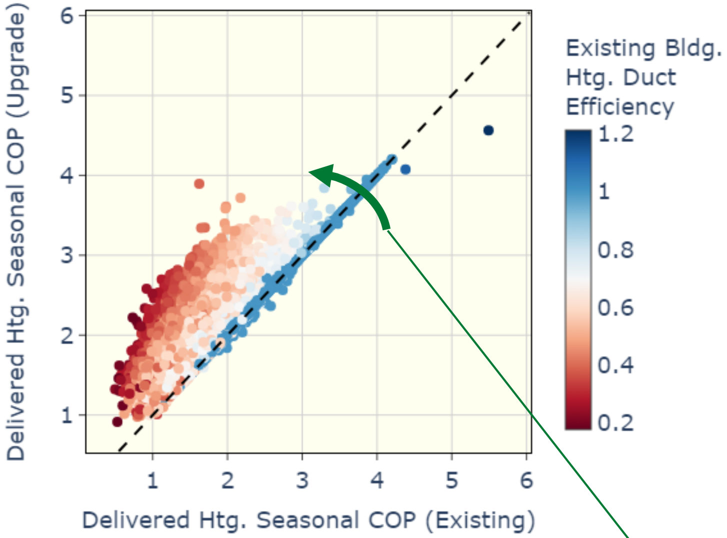
- Homes heated with electric resistance heaters are often considered prime candidates for heat pump upgrades.
- ~10% of homes heated with electric resistance have non-ducted baseboards with ducted central air conditioning.
  - Should these homes receive a ducted or non-ducted heat pump?
  - Ducts in these homes are sized for the air conditioner and may be inefficient.
- Poor ducts can result in delivered heating seasonal COP less than 1 leading to increased heating utility bills.
  - Similar issues for homes with fuel oil heating and propane.

PRELIMINARY RESULTS

Highlight of Preliminary Findings: Ducts and Variable-Speed Heat Pumps

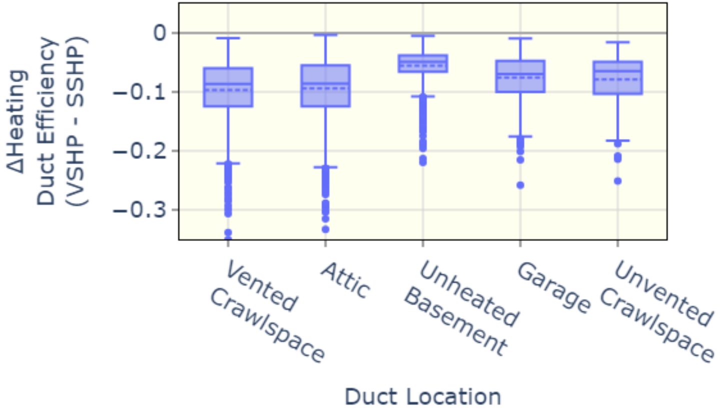
Homes w/ "Typical" Ducted Cold-Climate HP

Existing Home: Duct conduction and leakage using ResStock DB
Upgrade: Ducts w/ R-8, 10% Air Leakage



Delivered heating COP improvement due to duct retrofit.

- Duct losses have been shown experimentally and analytically to increase for variable-speed equipment compared to fixed speed equipment.
- Higher duct losses can eliminate the benefit of a variable-speed cold climate heat pump compared to a single-stage ENERGY STAR heat pump.

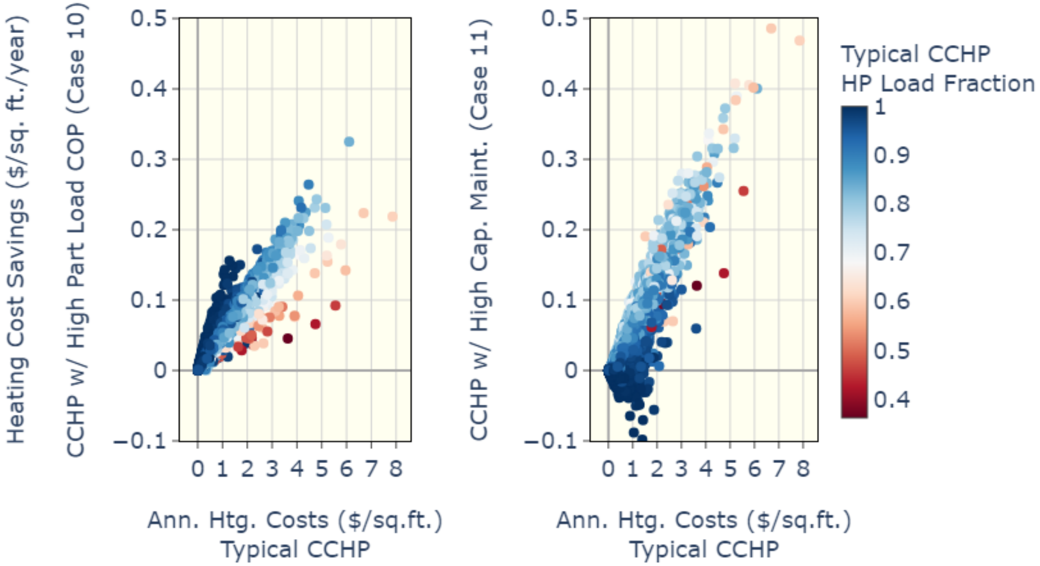


PRELIMINARY RESULTS

Highlight of Preliminary Findings: Heat Pump Selection Impact on Annual Heating Bills

Homes w/ "Typical" Ducted Cold-Climate HP

Comparison Cases: (Left) CCHP with High Part Load COP (Case 10)
(Right) CCHP with High Capacity Maintenance (Case 11)



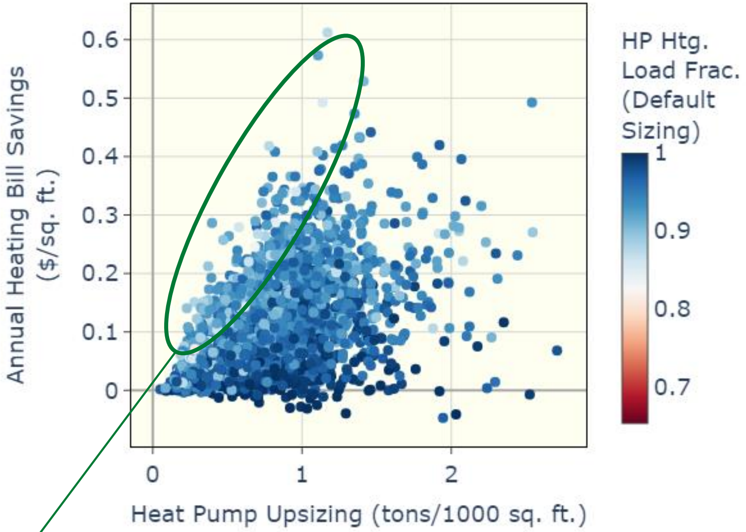
- In general, CCHPs with high part load COP (left plot) reduce heating costs compared to a "typical" CCHP.
  - Homes will benefit more when the heat pump can meet most of the heating load.
  - Savings can add up to be a significant fraction of the total installed cost over the life of the equipment.
- CCHPs with high capacity maintenance (right plot) are better suited for homes where a typical CCHP meets less of the annual heating load.

PRELIMINARY RESULTS

Highlight of Preliminary Findings: Heat Pump Sizing Impact on Annual Heating Bills

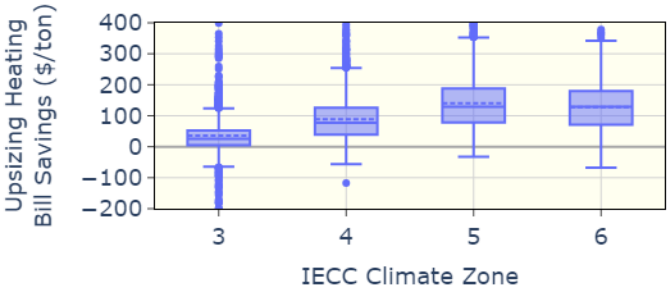
Climate Zone 5 Homes w/ "Typical CCHP" Upgrade

Comparison: Impact of upsizing the heat pump from the default sizing approach to 25% of Max. Load sizing.



These homes benefit the most from upsizing.

- In general, homes will benefit less from upsizing when the heat pump already meets most of the heating load.
  - Some homes have small differences between the default sizing and Max. Load sizing approaches (points close to x=0).
- However, there are many homes with high HP utilization (>90%) that benefit from upsizing.
- Homes in colder climates tend to benefit more from upsizing due to increased HP utilization.



PRELIMINARY RESULTS

Future Work and Timeline

- Q4FY24: Continue analyzing mid-scale runs
- Q1 FY25: Finalize development of remaining simulation cases.
- Q1 FY25: ResStock production runs.
- Q1-2 FY25: Process and analyze product run results.
- Q1-2 FY25: Develop communication materials (one-pagers and journal paper).
- Q2 FY25: Disseminate results with DOE's Heat Pump Partnership stakeholders.
- Q2 FY25: Coordinate with PNNL to ensure the CCHP Decision Tool aligns with findings.

Thank you

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WBS #: 1.5.2.30

Reference Slides

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	$275k				$125k				$0k			
Spent budget	$68.5k				$228.2k				$103.3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
FY23 Milestone: Go/No-Go – Simulation plan approved.												
FY24 Milestone: Technical update presentation on status.												
Current/Future Work												
FY25 Milestone Q2: Draft publications on study results.												
FY25 Milestone Q4: Results disseminated to HP partnership.												

Team

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