Performance and Applications of Cold-Climate Air Source Heat Pumps

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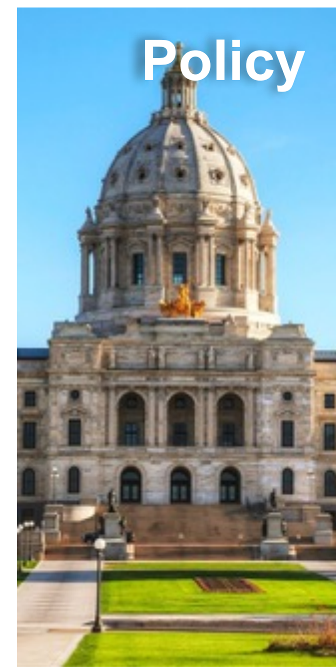

Minnesota Applied Research & Development Fund

- **Purpose to help Minnesota utilities achieve 1.5% energy savings goal by:**
  - ***Identifying new technologies or strategies to maximize energy savings;***
  - ***Improving effectiveness of energy conservation programs;***
  - ***Documenting CO_2 reductions from energy conservation programs.***

Minnesota Statutes §216B.241, Subd. 1e

- ***Additional Support from:***
  - ***Great River Energy***
  - ***Electric Power Research Institute***

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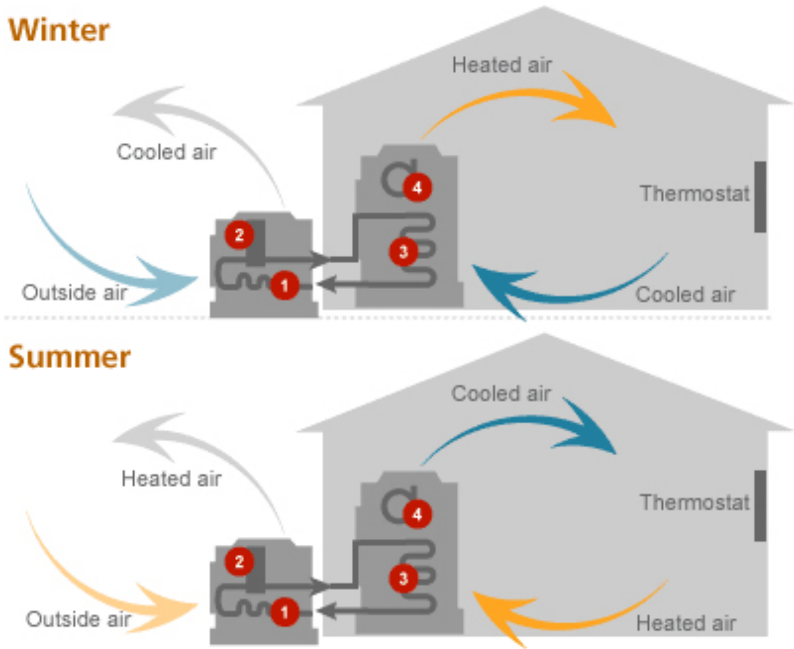
Agenda

- Cold Climate Air Source Heat Pump
  - Technology Advancement
  - Opportunity
  - Installation and operation
  - Results
  - Conclusions

Cold Climate Air-Source Heat Pump?

- An ASHP uses a refrigerant system involving a compressor, condenser, and evaporator to absorb heat at one place and release it at another.
- Delivery of both heating and cooling via forced air distribution
- New generation systems can operate as low as -13 °F
- ASHPs have the potential to deliver energy and peak saving as well as reduce reliance on delivered fuels.



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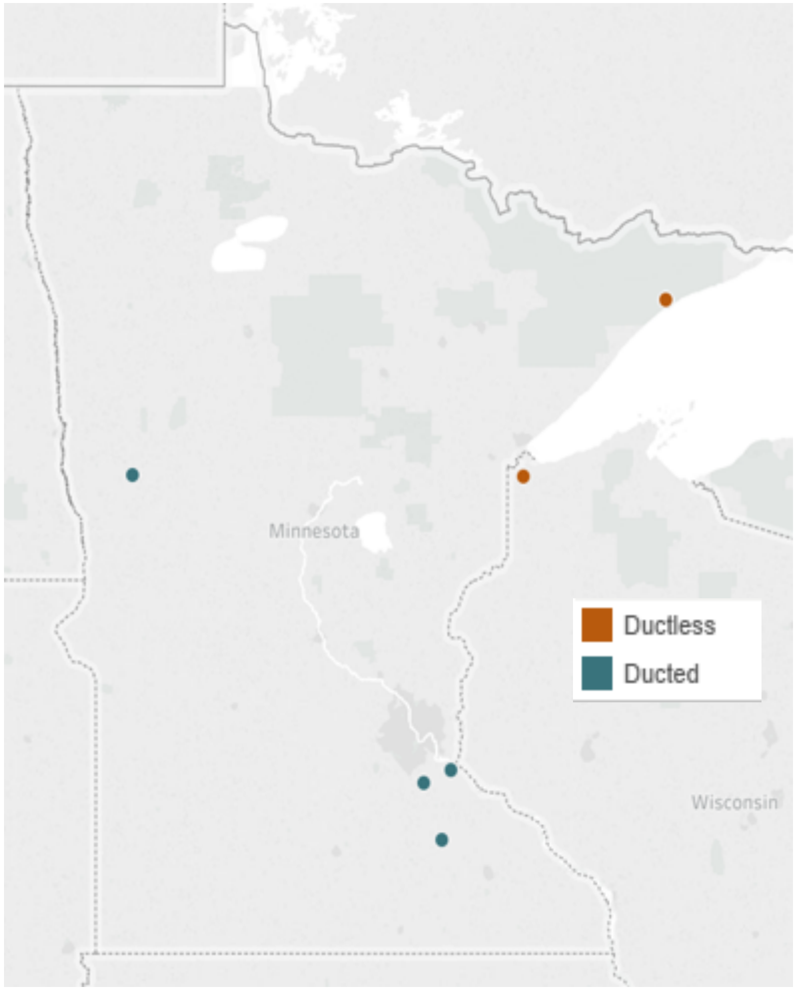
Opportunity

- Winter of 2013/2014 saw delivered fuel shortages in MN
  - Delivered fuel expensive or unavailable
  - Compensation with electric resistance space heaters

- Market:
  - Delivered fuel are the primary space heating fuel for more than 40% of homes in MN, IA, SD, ND (RECS, 2009)
  - Over 25% of Midwest homes rely on fuels other than natural gas for space heating (RECS, 2009)
  - Over 47% of homes in the US rely on fuels other than natural gas for space heating (RECS, 2009)

Study Overview

- Field Study
  - 8 ccASHP in a variety of MN residences
    - 4 ducted whole house system flex fuel
    - 2 ducted whole house all electric
    - 2 ductless mini-split systems
  - Monitor installed field performance of ASHP & backup
- Incorporate into Conservation Improvement Program (CIP)
- Climate zones 6 & 7



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Cold Climate Heat Pump Options

- System type
  - Central whole house ducted
    - Flex Fuel
    - All electric
  - Ductless mini-splits
    - Single Zone
    - Multi Zone
  - Short Duct mini-splits
    - Single Zone
    - Multi Zone

Ducted Whole House Installation

All Electric Heat Pump

Ductless Heat Pumps

Cold Climate Heat Pump Options

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Installation

- Important Issues:
  - Equipment
  - Sizing
  - Operation
  - Integration with back-up systems

Installation Scenarios

- Home has forced air systems → Ducted Whole House System
- Homes with hydronic → Ductless Mini Split System
- Homes with electric resistance → Ductless Mini Split System

- Does the home need cooling?

- What fuel sources are available?

Cold Climate Specification and Product List

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neep Northeast Energy Efficiency Partnerships

COLD CLIMATE AIR SOURCE HEAT PUMP

Download Current ccASHP Specification Listing:

ColdClimateAir-SourceHeatPumpSpecificationListing-Updated 2.24.17.xlsx

Skip to details on listing products

On behalf of energy efficiency stakeholders across the Northeast and Mid-Atlantic, Northeast Energy Efficiency Partnerships (NEEP) is pleased to be housing the new Cold Climate Air-Source Heat Pump (ccASHP) Specification and a list of those products that meet the specification's requirements. Those requirements include both specific performance levels as well as a series of reporting requirements.

Energy efficiency stakeholders from the Northeast lack confidence that the existing heating performance metric (HSPF) for air-source heat pumps provides the necessary information to adequately characterize heating performance at low temperatures. In addition, the supplemental information that is provided by manufacturers to demonstrate cold temperature performance is not standardized or consistent. The current performance metric (HSPF) does not include low temperature testing points below 17°F, assumes the use of electric resistance elements, and tests in steady-state operation (as opposed to allowing modulation). These deficiencies add up to measurements that do not accurately reflect performance of the latest generation of air-source heat pumps, designed and optimized to provide heat during cold conditions.

In order to address these concerns, a group of interested stakeholders, working together as part of the

AIR SOURCE HEAT PUMPS

Cold Climate Air Source Heat Pump

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NEEP's Greatest Heat Pump Hits

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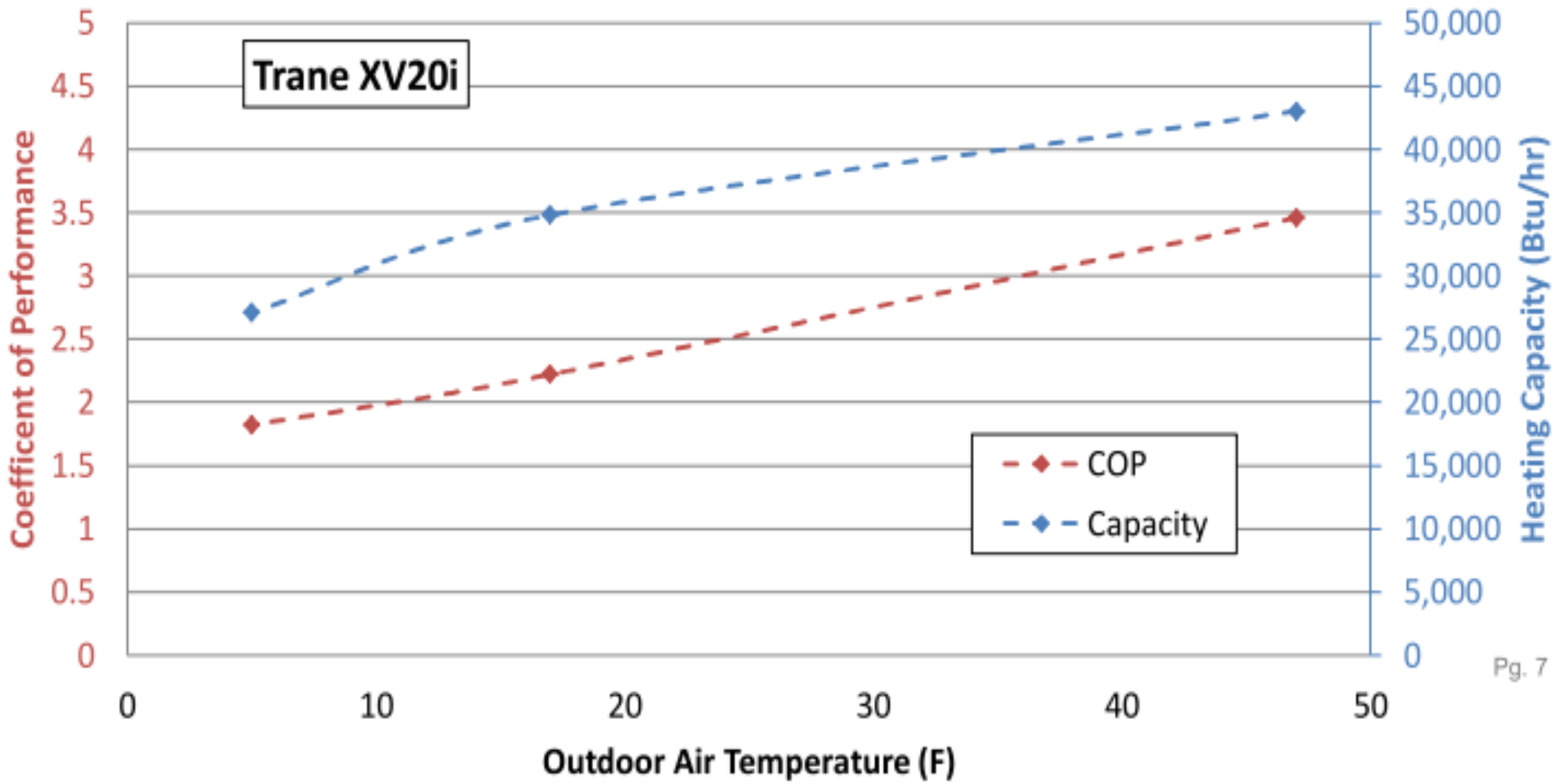
Manufacturer Specified Performance



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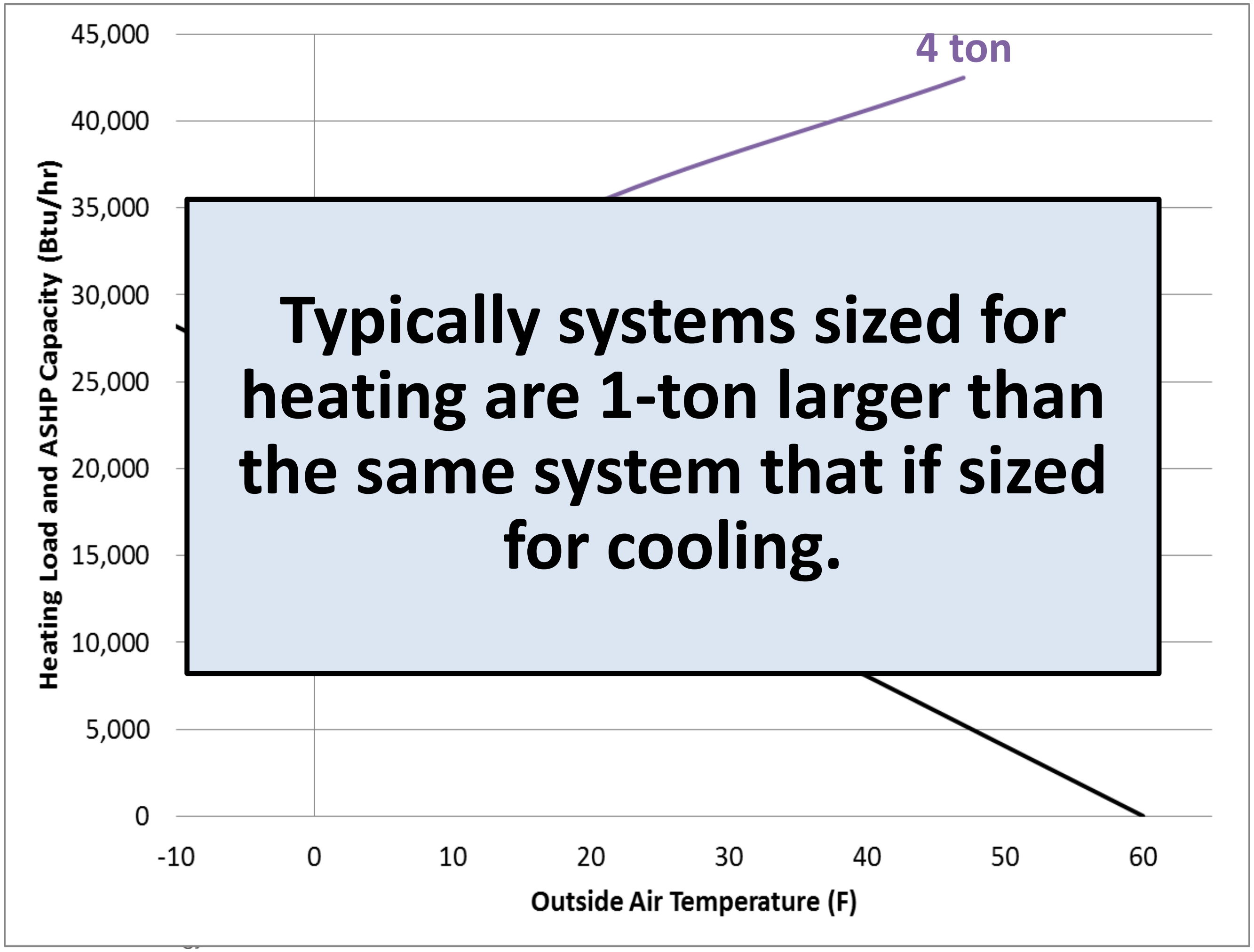
NEEP | Cold Climate Heat Pump Specification

System Design:
Sizing for Ducted Systems



The OAT for the systems to switch to back up:

4 ton ~3 F

3 ton ~10 F

2 ton ~19F

Percentage of heating load meet by ASHP:

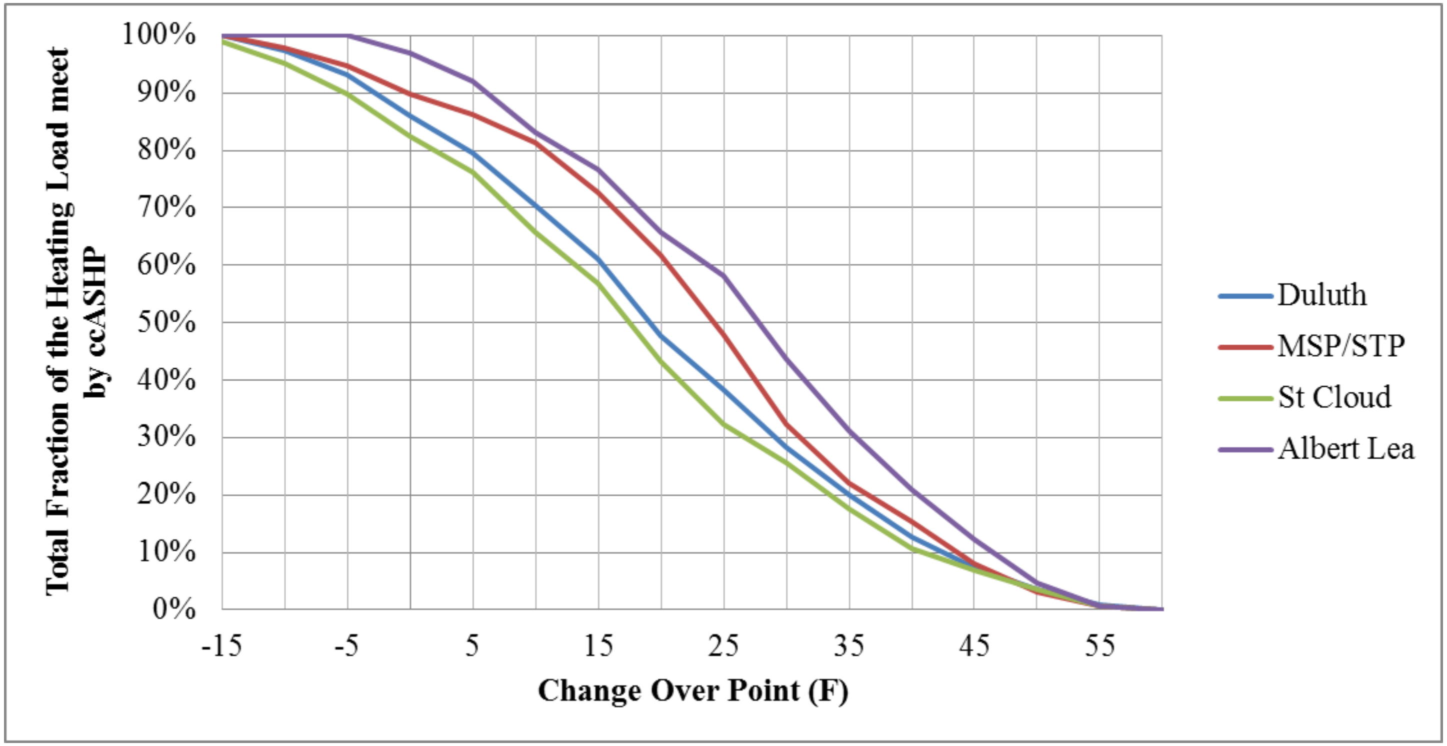
4 ton ~ 86%,

3 ton ~ 77%

2 ton ~ 60%

*Targeted a maximum change-over temp of 10 F

Impact of Change-Over Set Point



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Furnace Integration – Keep or Replace?

- Issues:
  - Air handler requires a multi-stage fan to achieve the full capability of the ccASHPs
  - Furnace and heat pump require integrated controls
- Proposed Solutions:
  - New condensing furnace with control integration
  - New 80% AFUE with multi-stage fan with control integration
  - Retrofit existing system (future?)
  - Plenum electric resistance heater

- Several manufacturers are working on solutions to pair new ASHPs with existing furnaces

Ducted Systems with Booster ER

- New in the last year or so
- Major manufacturers now have options
- Allows full range of ASHP operations
- Electric resistance heater boosts output at very cold temperatures

- All electric

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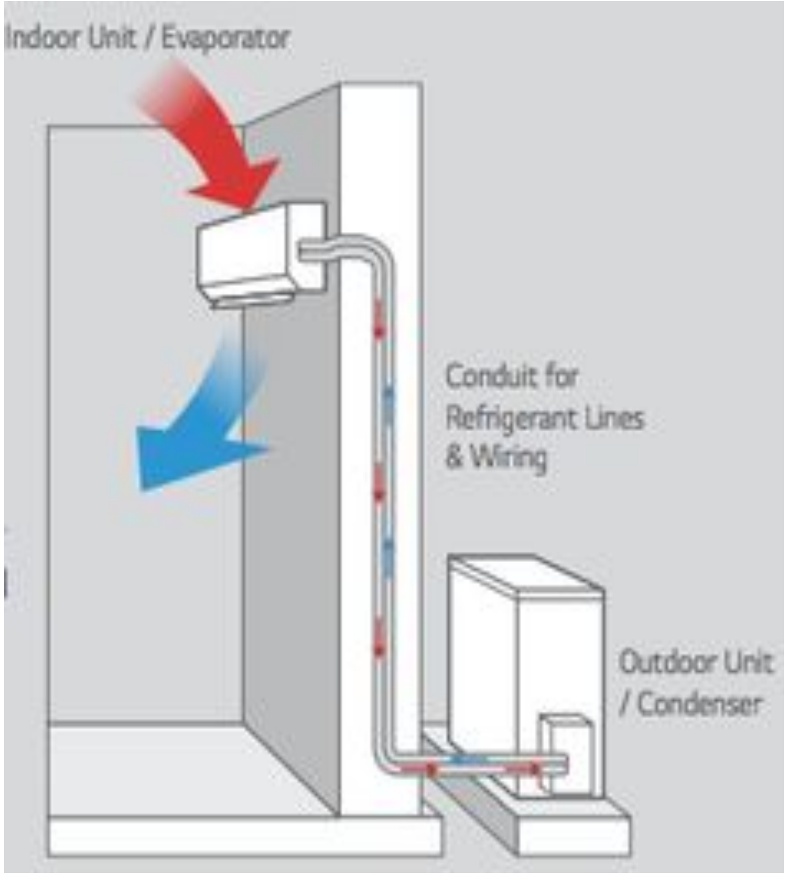
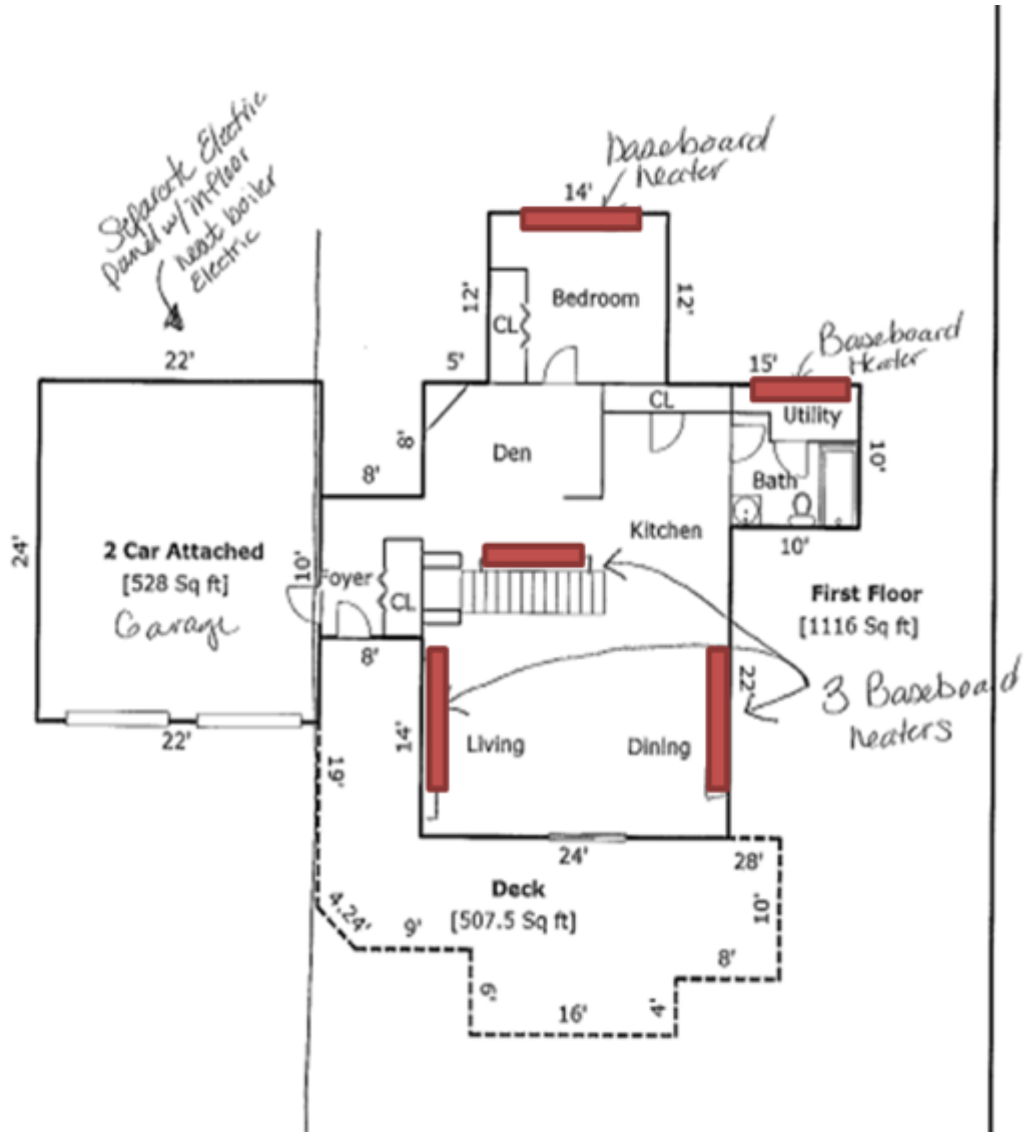
Ductless Heat Pump Installation



Ductless: Install Location



Operation

- Switchover set point:
  - Primary ccASHP meets load at temps greater than switchover
  - Secondary heating system meets load below switchover
- Primary is priority
  - Runs primary system whenever possible
  - Back up as boost or when primary cannot operate
- Dynamic
  - Considers estimates efficiency and energy costs chooses primary/secondary control based on estimated performance
    - Typically based on operating costs

- Controls:
  - Ducted Systems: automated controls to bring up backup
  - Ductless Systems: manual action by homeowner
- Interaction with back-up systems
  - Ducted Systems: Integrated installs with shared controls
  - Ductless Systems: Separate systems

Site Equipment

Site Number	ASHP System	ASHP Size	ASHP Type	Backup
1	Carrier Infinity with Greenspeed [25VNA048A003]	4 ton	Ducted	LP Cond. Furnace
2	Bryant Extreme Heat Pump [280ANV048]	4 ton	Ducted	LP Cond. Furnace
3	Carrier Infinity with Greenspeed [25VNA036A003]	3 ton	Ducted	LP 80% Furnace
4	Trane XV20i [4TWV0036A]	3 ton	Ducted	LP Cond. Furnace
5	Mitsibishi Ductless Hyper Heat [MUZ-FH18NAH]	1.5 ton	Ductless	Electric Resistance
6	Mitsibishi Ductless Hyper Heat [MSZ-FH12NA]	1 ton (2 units)	Ductless	Electric Resistance
7	Mitsubishi Hyper Heat System [PVA-A30AA7]	3 ton	Ducted	Electric Booster
8	Mitsubishi Hyper Heat System [PVA-A30AA7]	3 ton	Ducted	Electric Booster

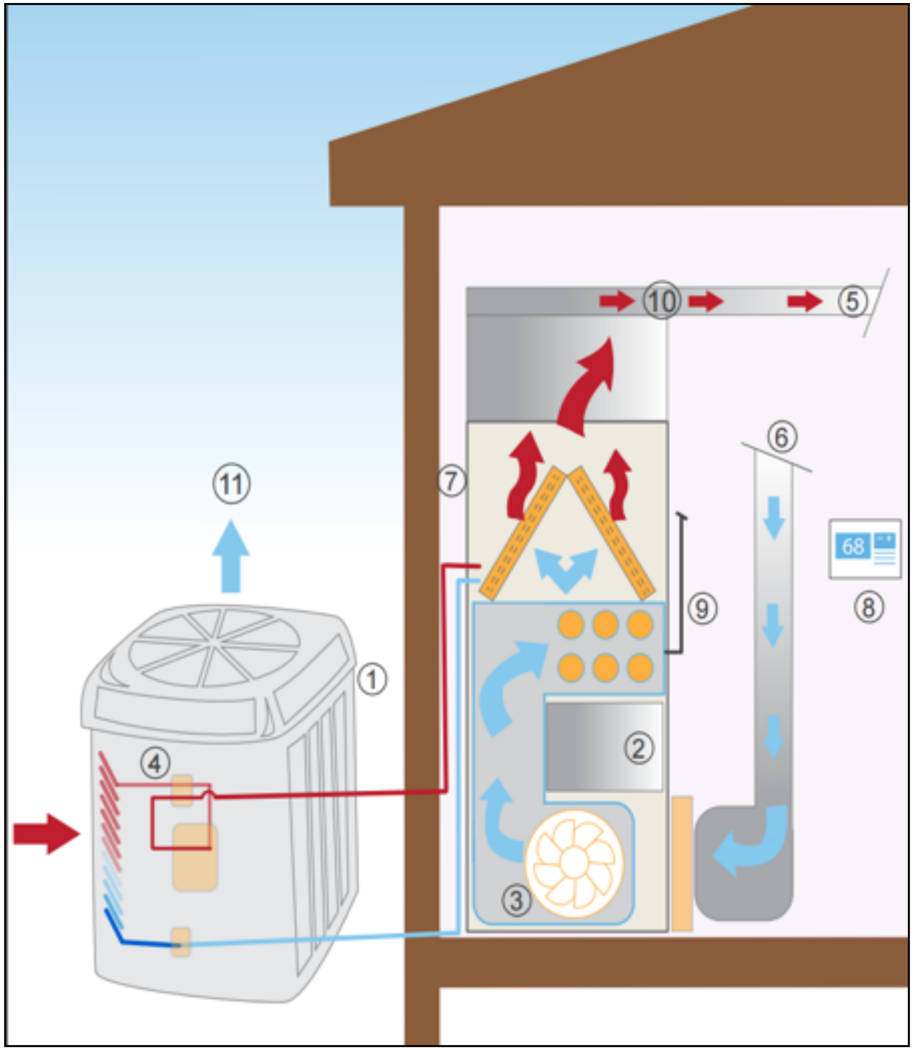
Whole house ducted systems

Instrumentation

Power Measurements:
1) Outdoor unit
2) Indoor unit
3) Indoor fan
4) Reversing valve

Temperatures:
5) Supply Air
6) Return Air
7) Mechanical area ambient
8) Conditioned space

Additional:
9) Back up fuel consumption
10) Delivered air flow
11) NOAA data



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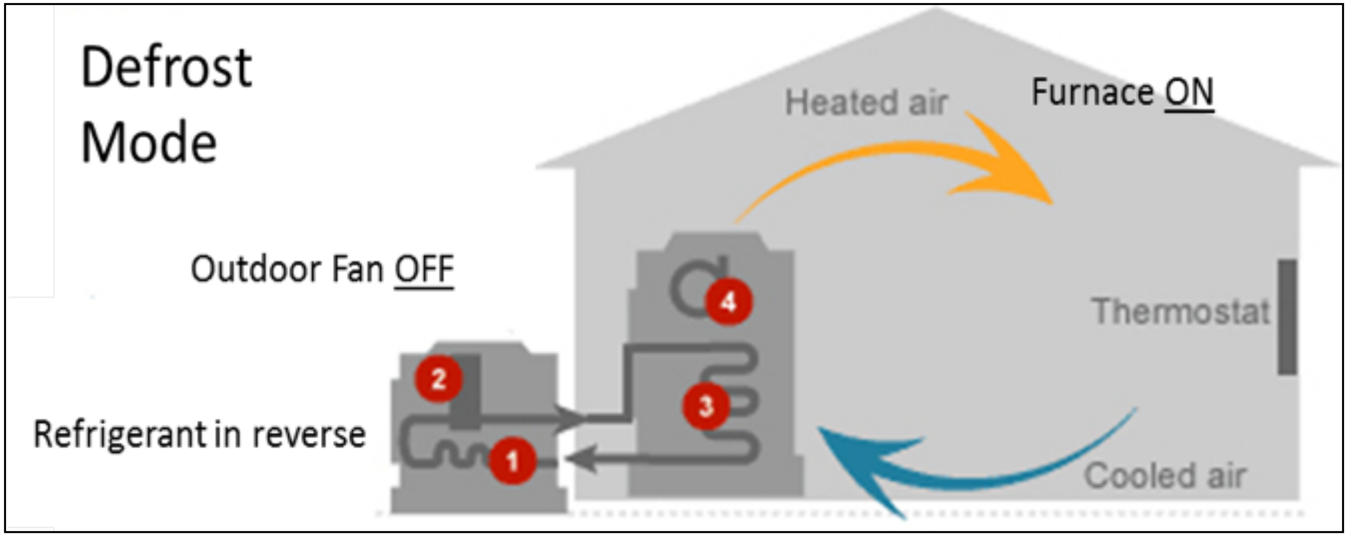
Monitoring

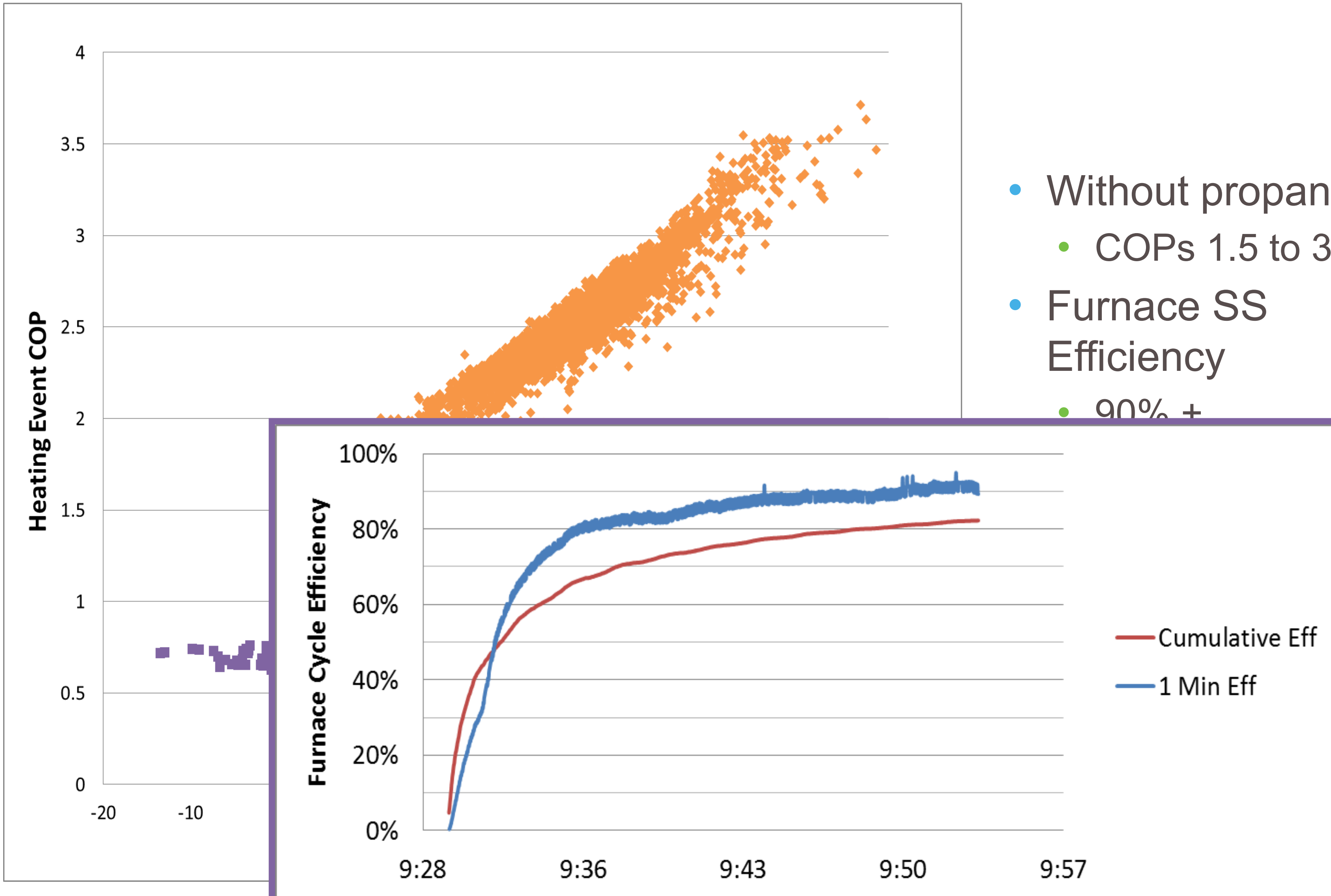
- Measure installed performance data
  - ccASHP with backup mode
  - Baseline mode
- Measure and analyze high time resolution data for at least one full heating season
- Characterize the heating load of the home
- Create equipment performance models

Modes of System Operation

- Heating system has 3 modes of operation
  - ASHP heating
  - Back up heating
  - Defrost



ASHP and Furnace Cycle Efficiency, Site 2

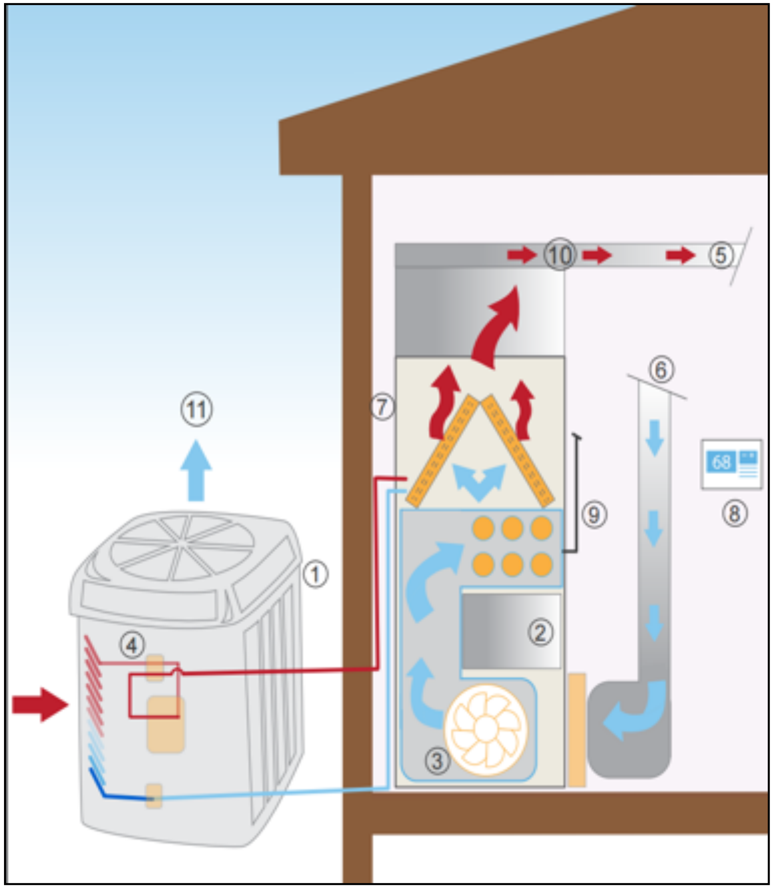


- Without propane:
  - COPs 1.5 to 3.5
- Furnace SS Efficiency
  - 90% +

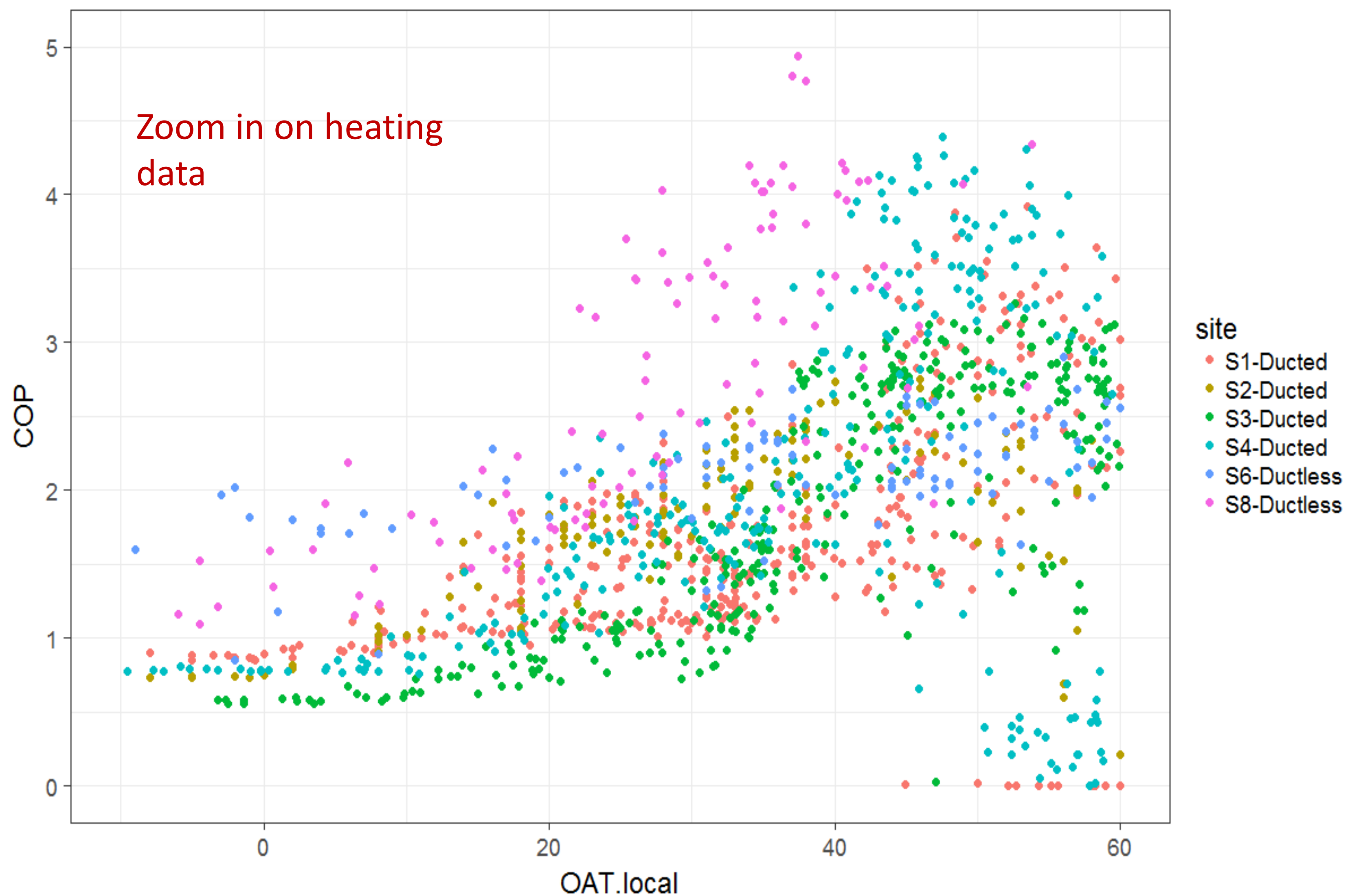
t 10

Defrost Controls

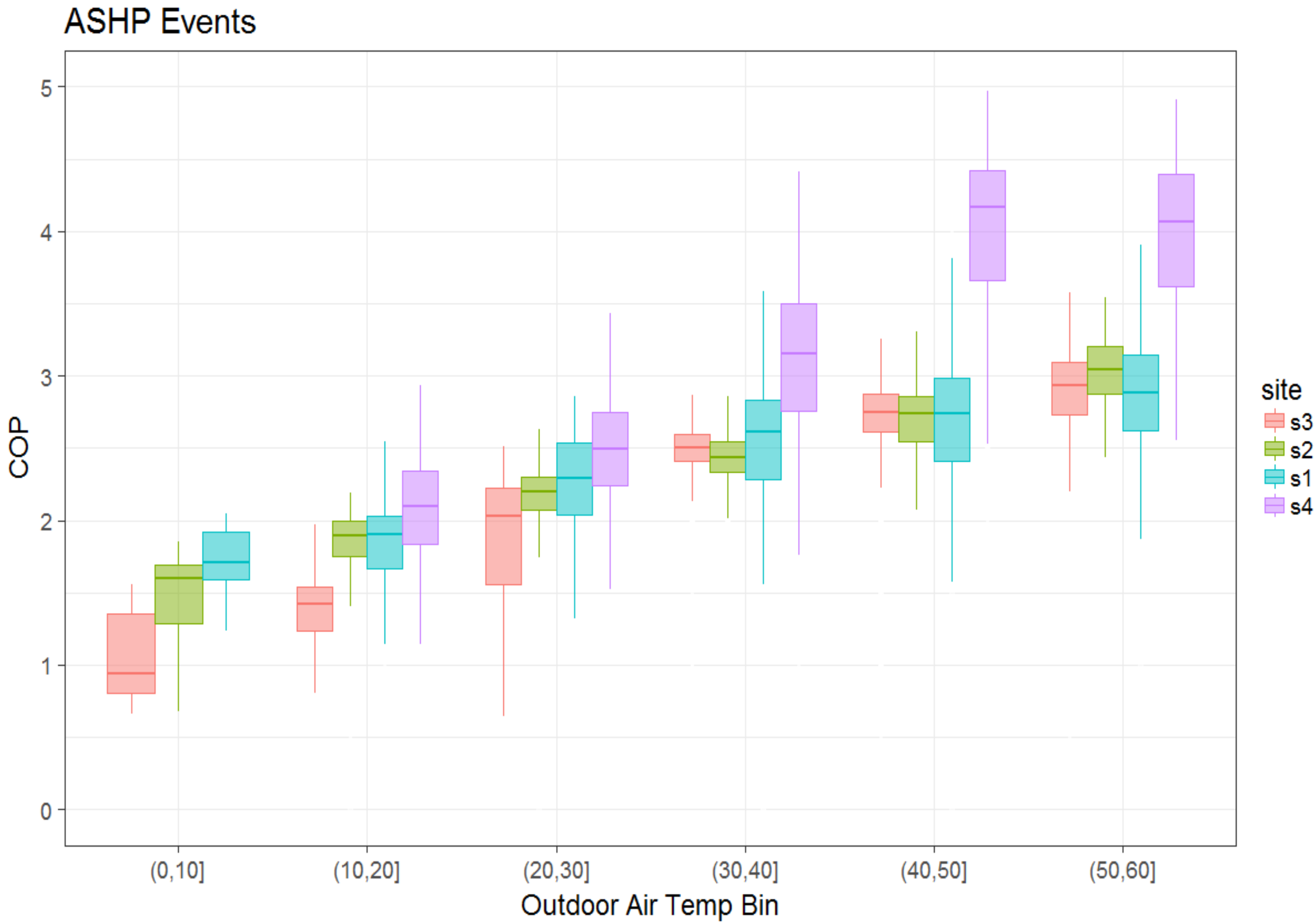
- Temperature near coil
- Lockout time



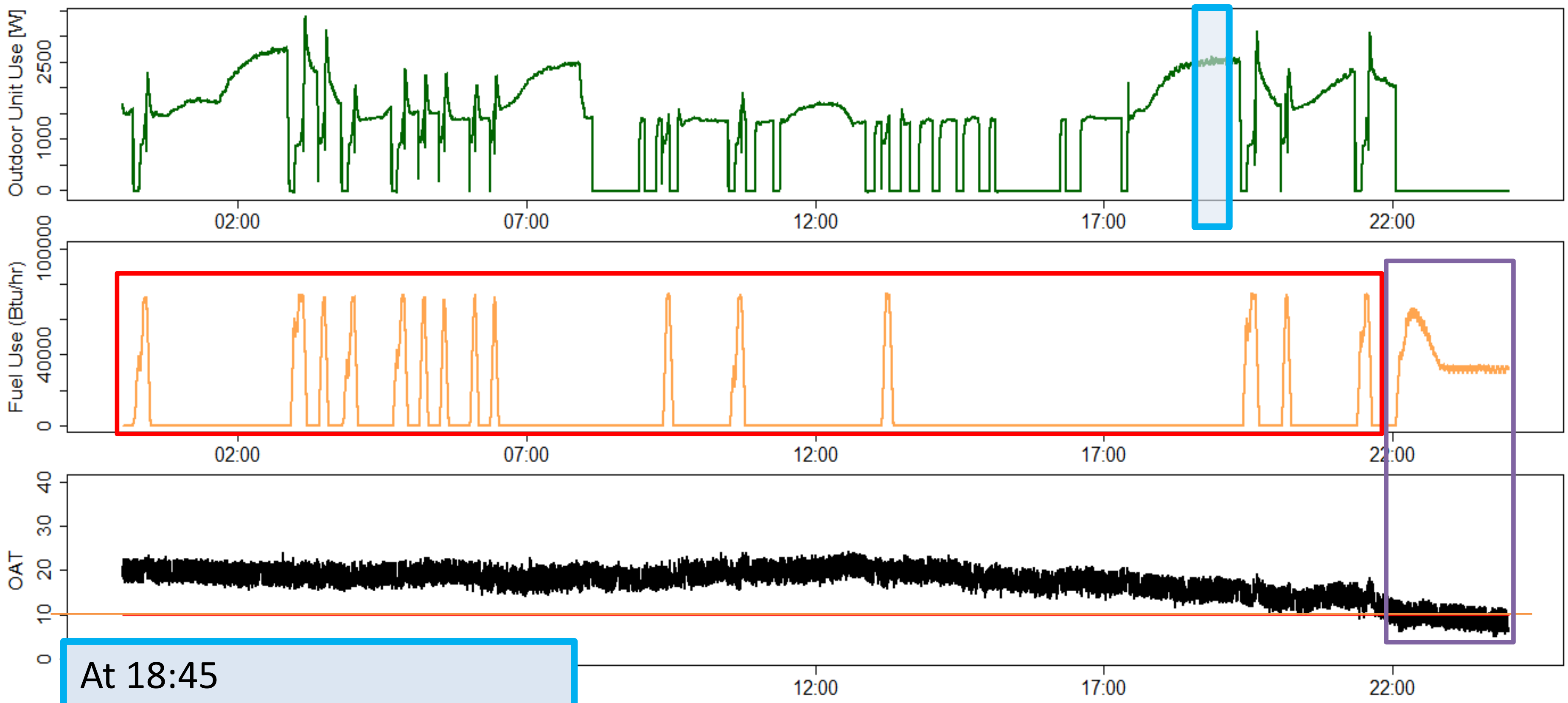
System COP vs OAT



ASHP Performance



Example: Capacity on a 17 ⁰F day

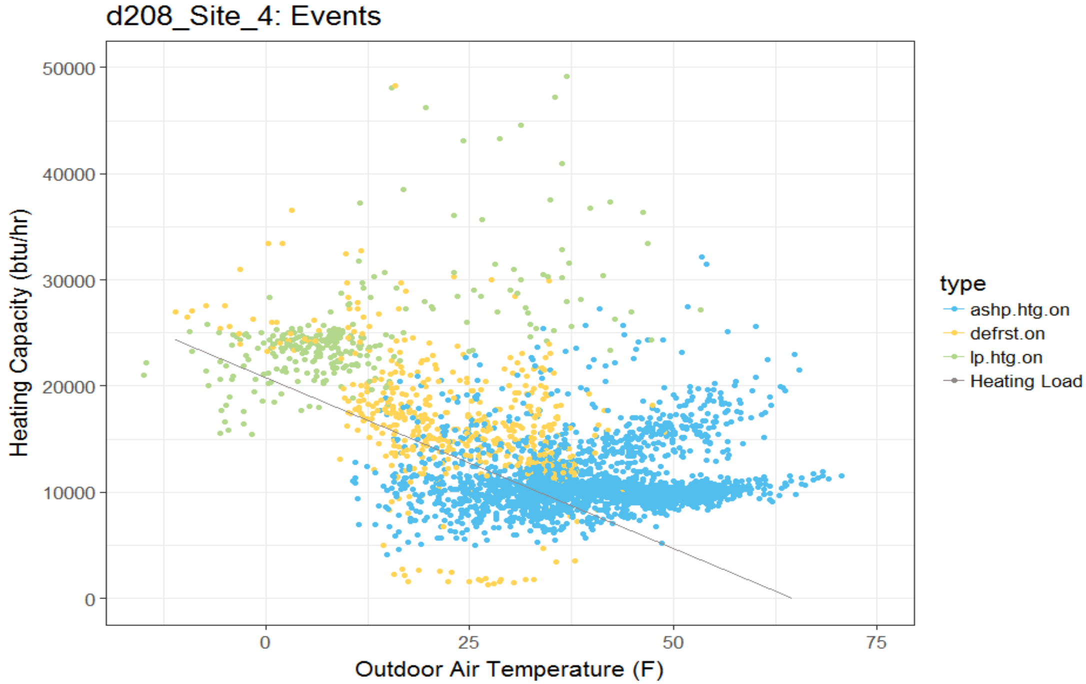


At 18:45
OAT = 15 F
House load = 15,300 Btu/hr
ASHP Output = 16,700 Btu/hr
ASHP Sup Temp = 89 F
Airflow = 734 CFM

Outdoor Temperature Bins	COP of ccASHP only	COP of ccASHP with defrost
10⁰F to 20⁰F	1.86	1.65
20⁰F to 30⁰F	2.17	1.95
30⁰F to 40⁰F	2.44	2.31

Cold Temperature Performance of ASHPs

- Ducted ASHPs were capable of delivering heat at <u>outdoor temps</u> from 5 to 10 F
- Ductless systems operated below -13 F.
  - Homeowner in WI has removed several ER baseboards



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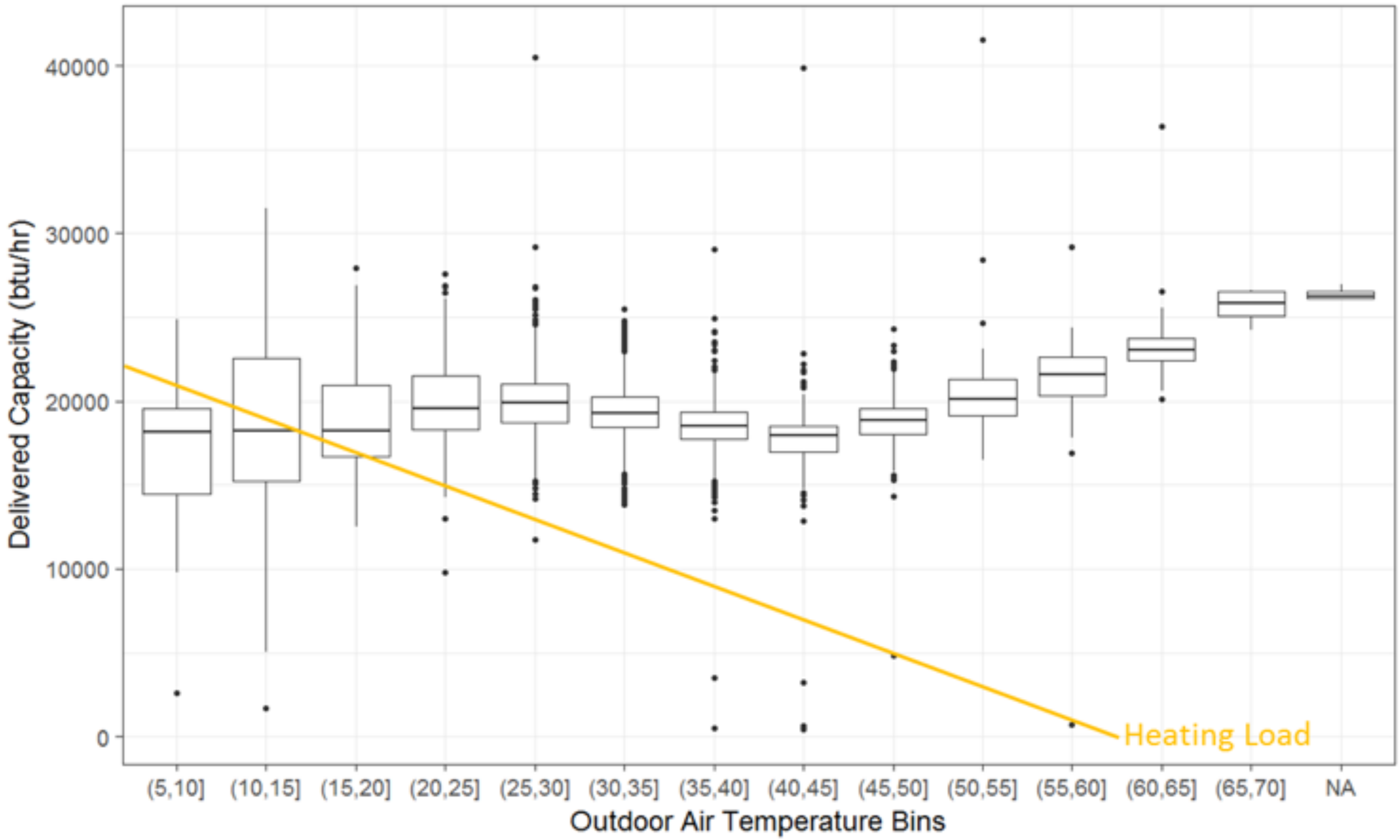
Ducted: Cold Temperature Performance



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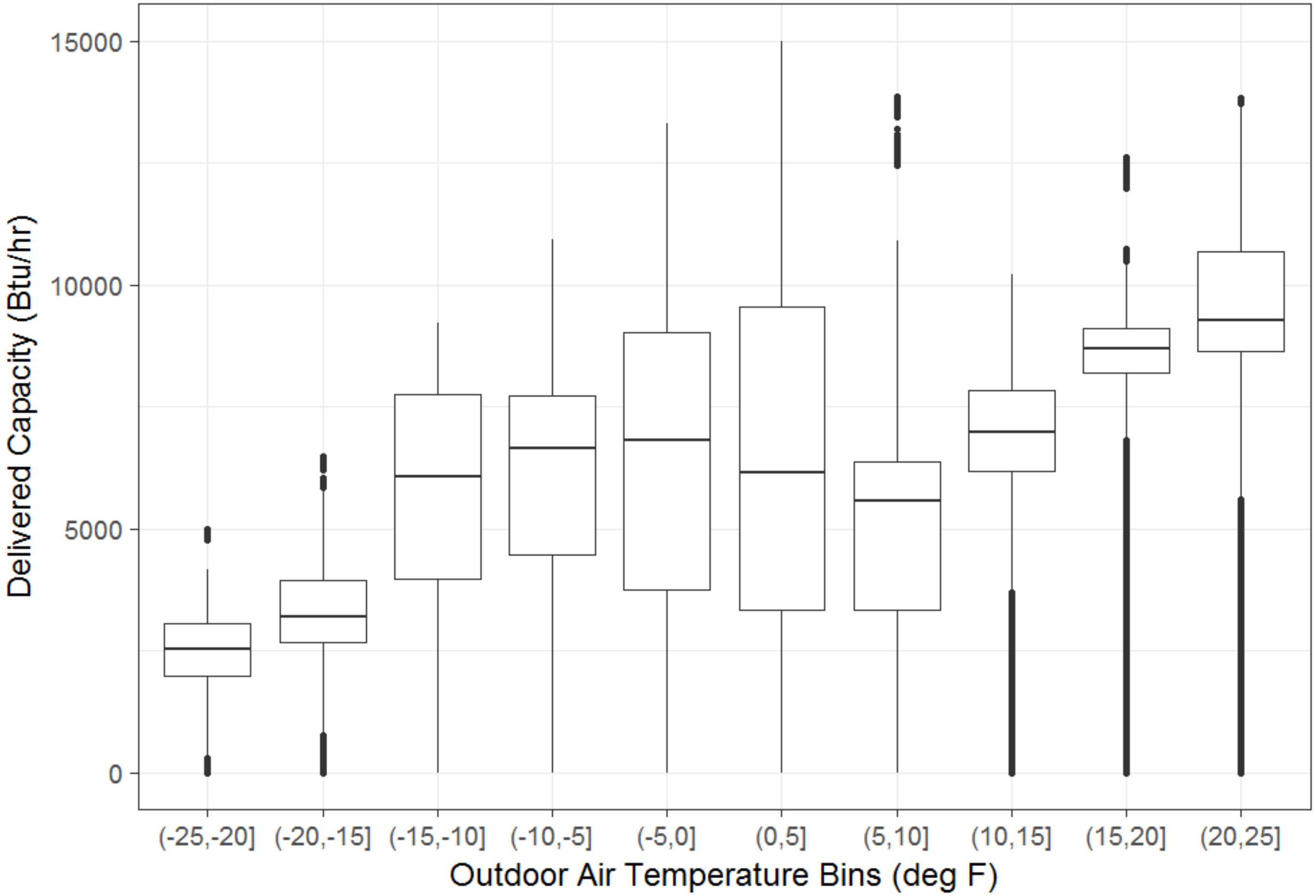
Ductless: Cold Temperature Performance



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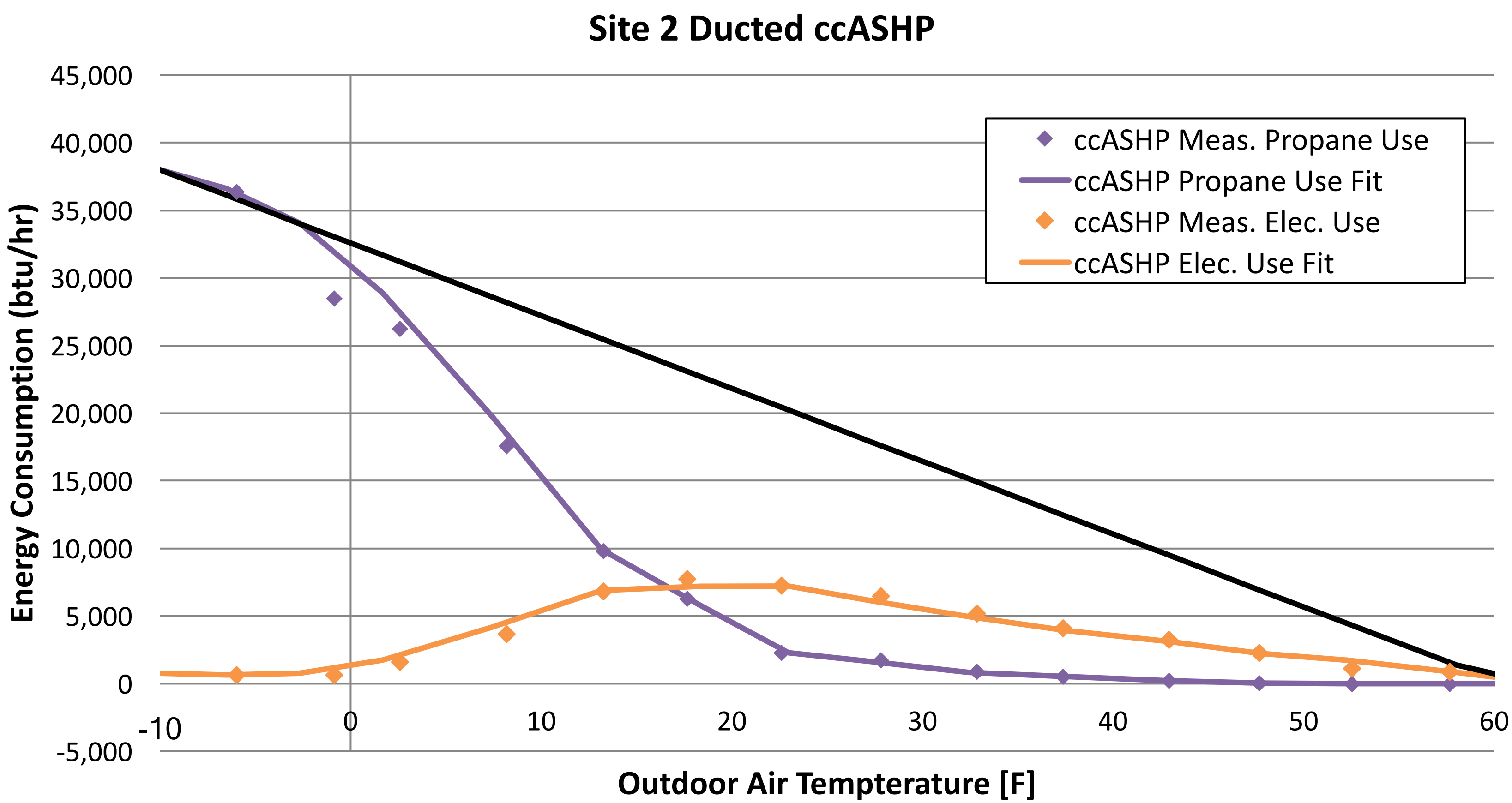
Ducted v Ductless

- Heat pump only events have comparable COPs
- Ducted systems
  - have larger capacities than single head ductless
  - have larger airflows
- Ductless systems
  - provided a smaller fraction of the homes energy (by design)
  - operated at lower outdoor temperatures

Energy Use Analysis

- Measure installed performance data
  - ccASHP with backup mode
  - Baseline mode
- Characterize the heating load of the home
- Create equipment performance models
- Summarize system performance and energy use at each site

Energy Use Vs OAT Models



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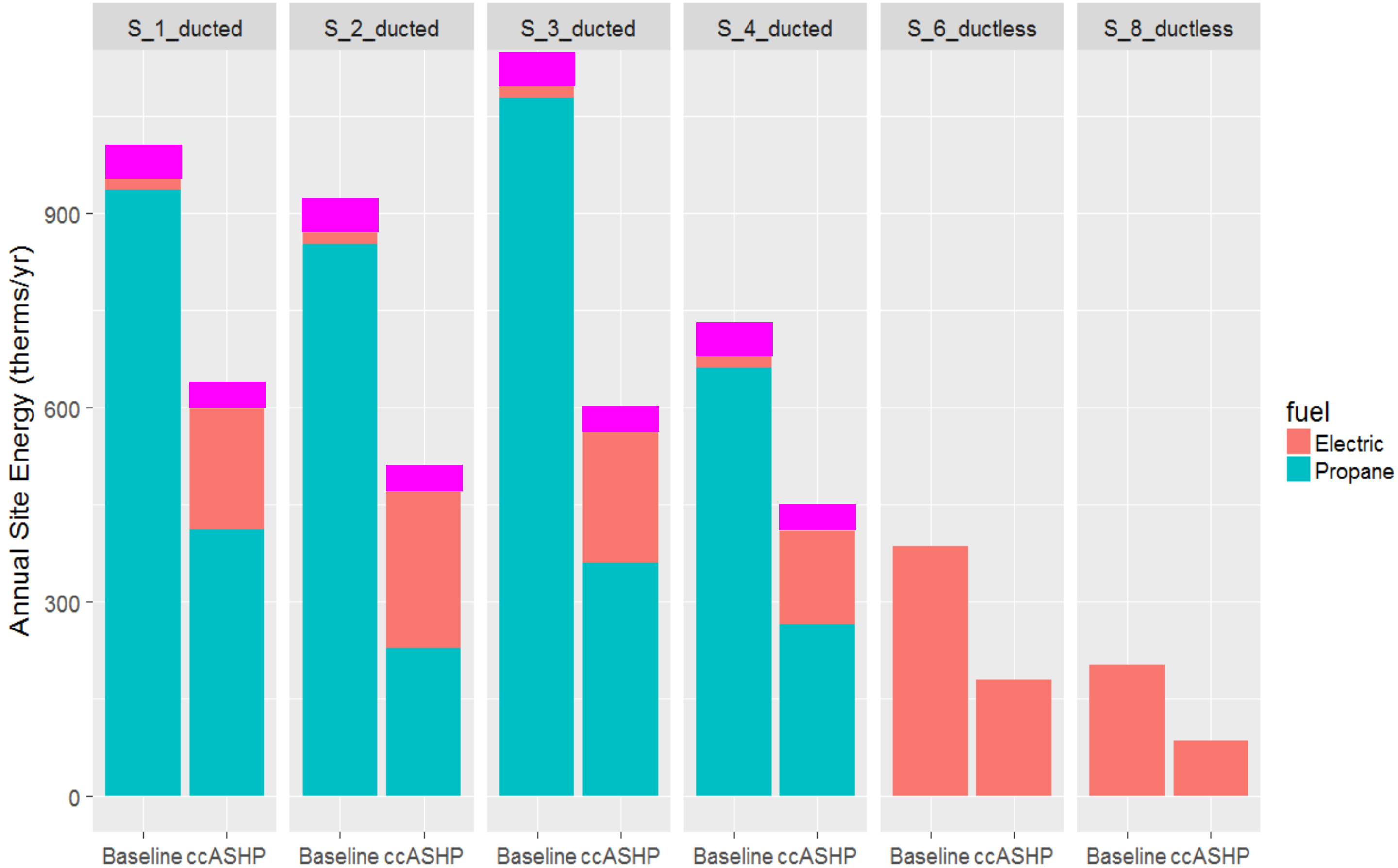
Annual Energy Use (by Test Site)



Cooling Savings with increased SEER (13.0 to 16.5+)
300 to 500 kWh saved per year or ~$50/year

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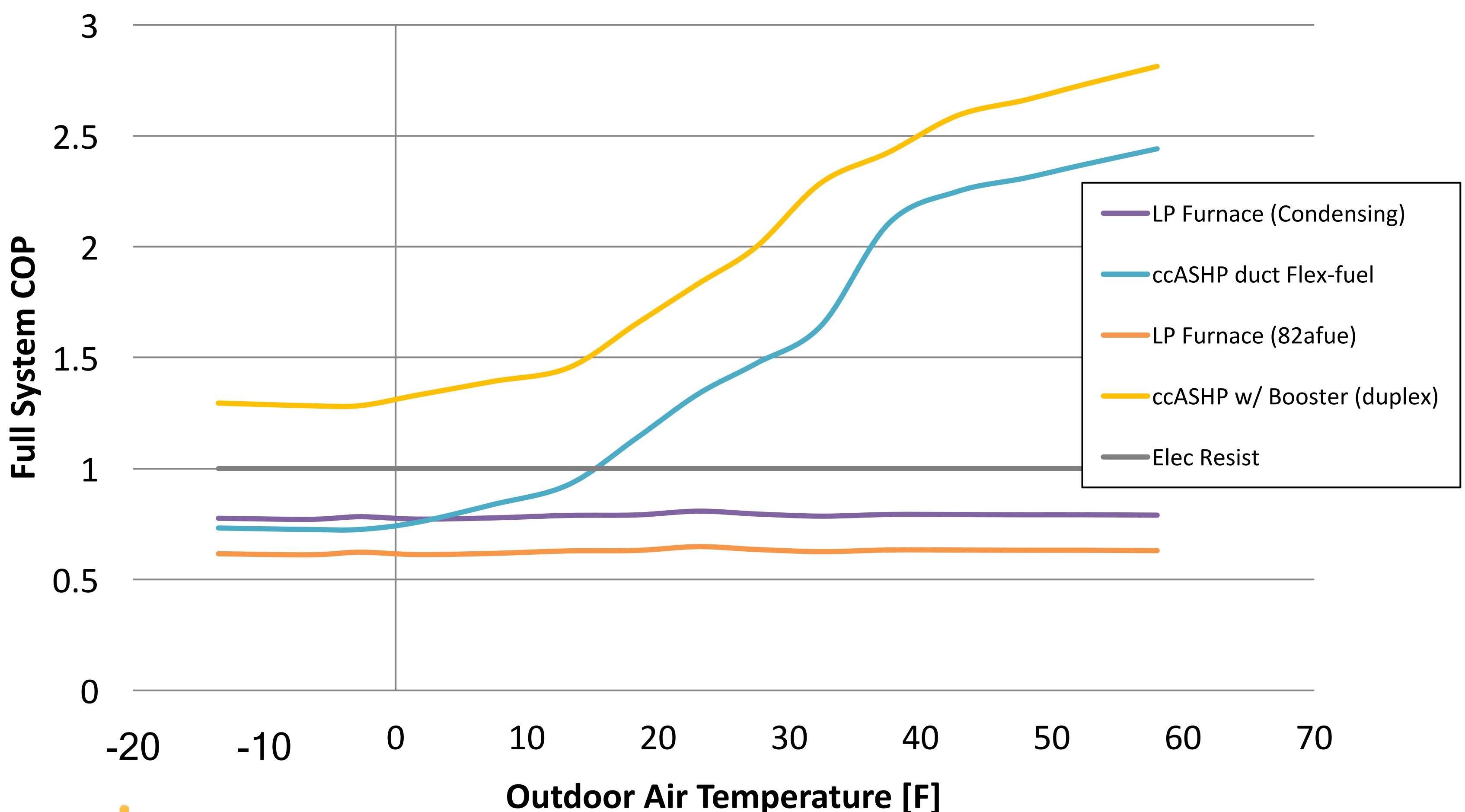
Whole House System Performance



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Annual Characteristics and Savings

	Baseline	Location	Annual System COP	Site Energy Reductio n	Cost Reductio n	Propane reductio n	Savings [$/yr]
Ducted	Condensing LP Furnace	Metro	**1.3**	**41%**	30%	63%	**$450**
Ducted	82% LP Furnace	Metro	**1.1**	**49%**	40%	67%	**$760**
All elec	Elect. Resistance	Metro	**1.9**	**47%**	47%	NA	**$780**
Ductless	Elect. Resistance	Metro	**2.3**	**56%**	56%	NA	**$425** ~50% of load
Ducted	Condensing LP Furnace	Northern MN	**1.2**	**36%**	26%	55%	**$485**
Ducted	82% LP Furnace	Northern MN	**1.0**	**44%**	36%	61%	**$855**
All elec	Elect. Resistance	Northern MN	**1.8**	**44%**	44%	NA	**$900**
Ductless	Elect. Resistance	Northern MN	**2.2**	**53%**	53%	NA	**$480** ~50% of load

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House Load Ducted: ~600 therm/yr
Ductless: ~300 therm/yr

Install Costs

- For the 4 flex fuel ducted systems:
  - Our average cost was ~$14,000*
- NREL Residential equipment install database:
  - $6,340 for ducted 3ton ccASHP
  - $4,000 for a new condensing propane furnace ($3,000 for an 80%).
  - $5,540 for a new comparable SEER A/C

- If furnace or A/C needs replacement
  - Incremental cost ~$3,000 will results in paybacks around 6 years

- Hard to calculate paybacks for ductless systems.
  - Costs have high variance.
  - Systems are often not direct replacements

Summary of Results

- Cold Climate ASHPs:
  - **Energy Reduced:** 37% and 54% of site energy consumption
  - **Cost Reduced:** total heating costs 28% to 54%
  - **Heating Load Served:** on average ducted ccASHP met 84% of the homes heating loads
  - **Propane Reduction:** propane consumption down by 64%
    - Less than 500 gallons per year at each house

  - Percentage of heating load for ductless largely dependent on usage & install location
  - Provided more efficient space heating
    - Ducted ccASHP COP of 1.4 & ductless COP of 2.3.
    - Compared to a COP 1.0 for ER

Policy Analysis – Minnesota context

- Lack of structure for achieving delivered fuel savings from ccASHPs for electric utilities
- The fuel switching concern – should not apply in these scenarios
- Precedents: low income CIP
- New program suggestions
  - Net BTU analysis

- Next Steps
  - Further discussion

Conclusions

- Field monitoring confirmed expected performance of ccASHPs
- Freeze protection and integration with auxiliary heating are important
- Ducted ccASHPs can heat below 5F, ductless below -13F
- Paybacks are attractive when existing heating or cooling system need to be replaced

Future Needs

- There is still room for improvement:
  - Reduce unnecessary back-up heating
    - Defrost?
    - Lower change over point?
  - Reduce upfront installation costs
    - Systems with new furnaces cost $15,000
    - Costs are much higher than incremental equipment costs compared to AC systems

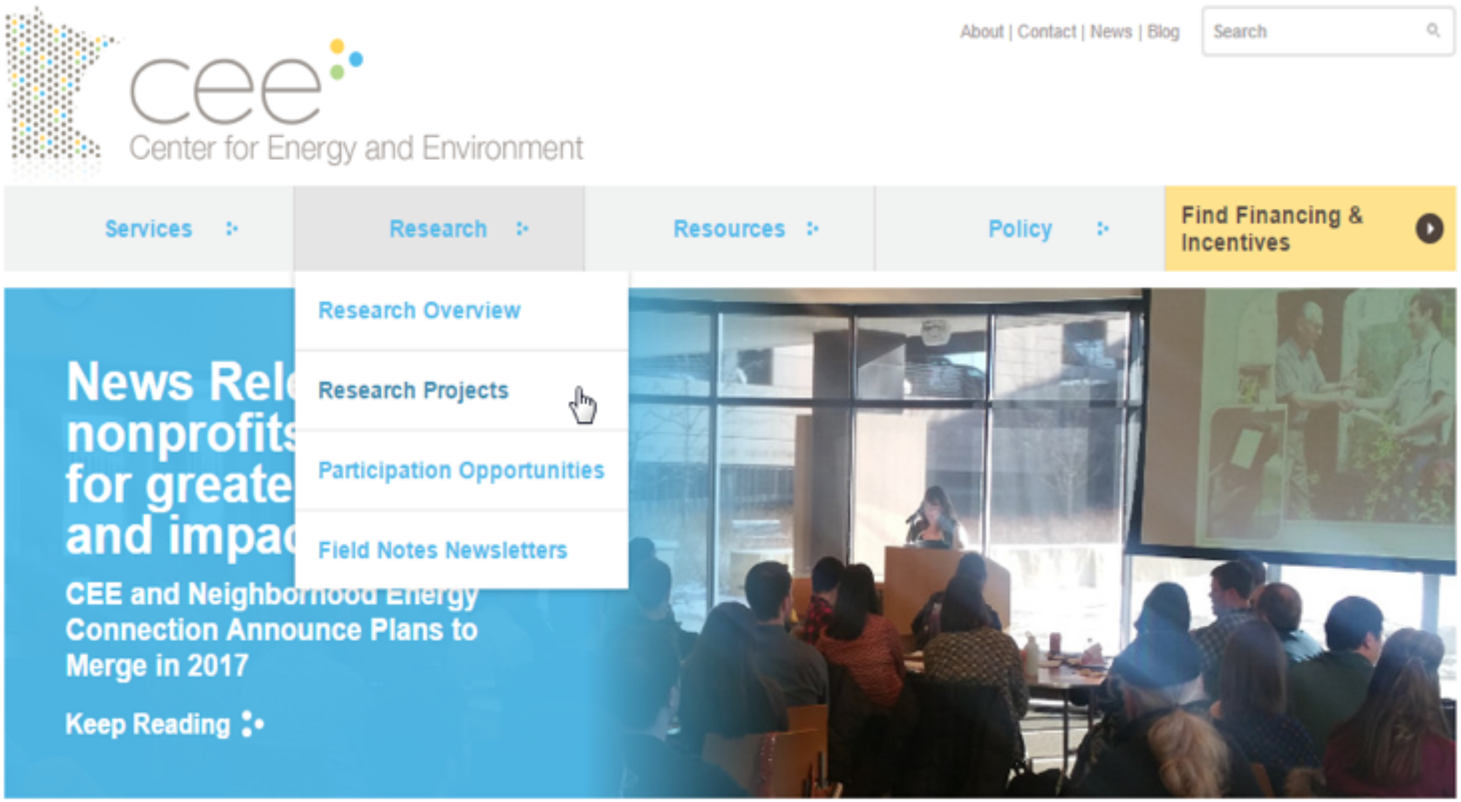
Future Needs – Metrics and Programs

- How should ASHPs be evaluated?
  - Site energy
  - Source energy
  - Carbon reductions
  - Efficiency
  - Homeowner cost

- Impacts of improving equipment
- Impacts of the grid

- Stay tuned for future CEE work

www.mncee.org/heat_pumps



Practical energy solutions for homes, businesses, and communities

THANK *you!*

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THANK *you!*

Specify Ratings (NEEP as example)

- Performance ratings
  - Minimum HSPF rating
    - HSPF ≥ 10 at 47 ºF
- Capacity Ratings
  - Minimum capacity ratings at 47˚F (dry bulb)
    - <65k Btu/hour at 47˚F
  - Require percentage of capacity at colder outdoor air conditions
    - 100% maximum rated capacity at 0 ˚F (not required by NEEP)
- Other performance testing or ratings
  - Metrics: Power draw, capacity, COP
  - At additional temperature levels: 47˚F, 17˚F, 5˚F
- Equipment types
  - Variable Capacity
  - ECM indoor fan