Cold-Climate Air-Source Heat Pumps

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Discover + Deploy

the most effective solutions for a healthy, low-carbon economy

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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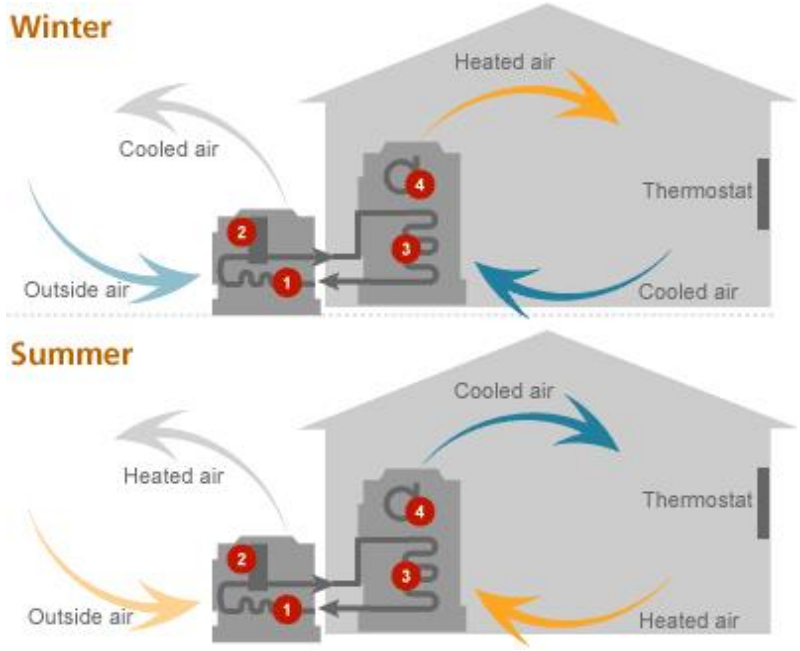
Agenda

- 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)

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

Cold Climate Heat Pump Options

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Ducted Whole House Installation

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All Electric Heat Pump

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Ductless Heat Pumps

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    - Single Zone
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Ducted Mini Splits

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Installation

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

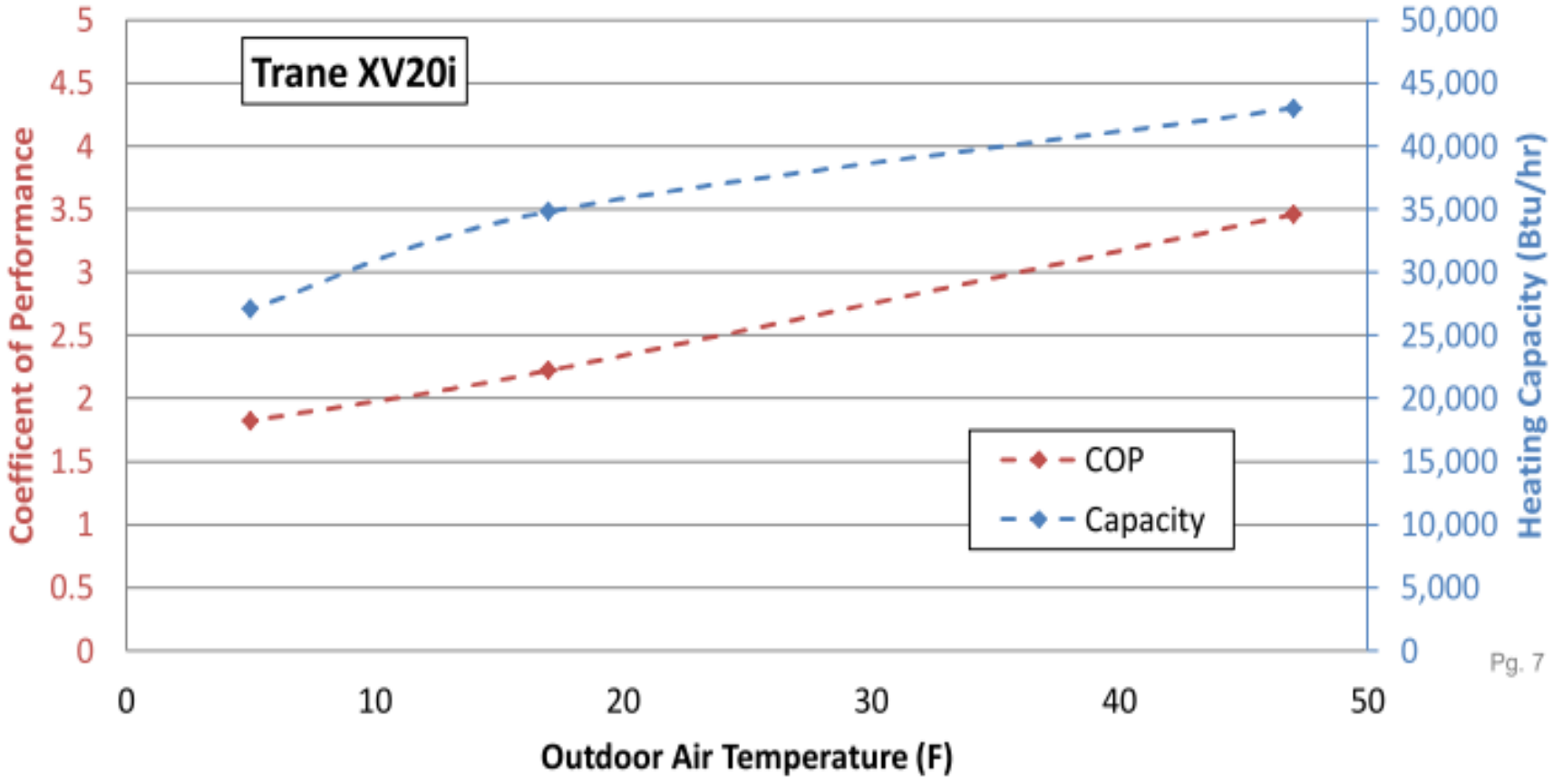
Installation Scenarios

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

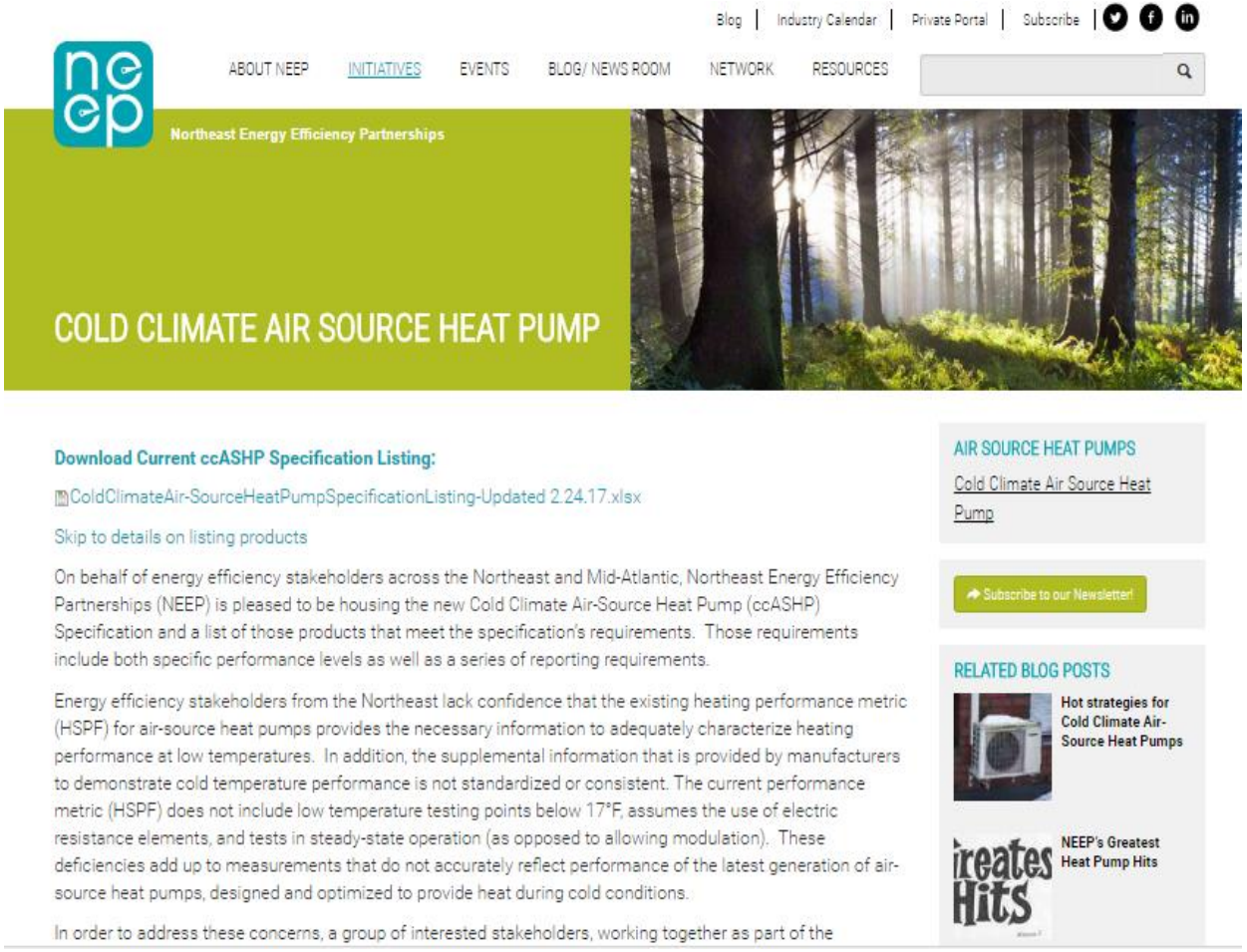
- Does the home need cooling?

- What fuel sources are available?

Manufacturer Specified Performance



Cold Climate Specification and Product List



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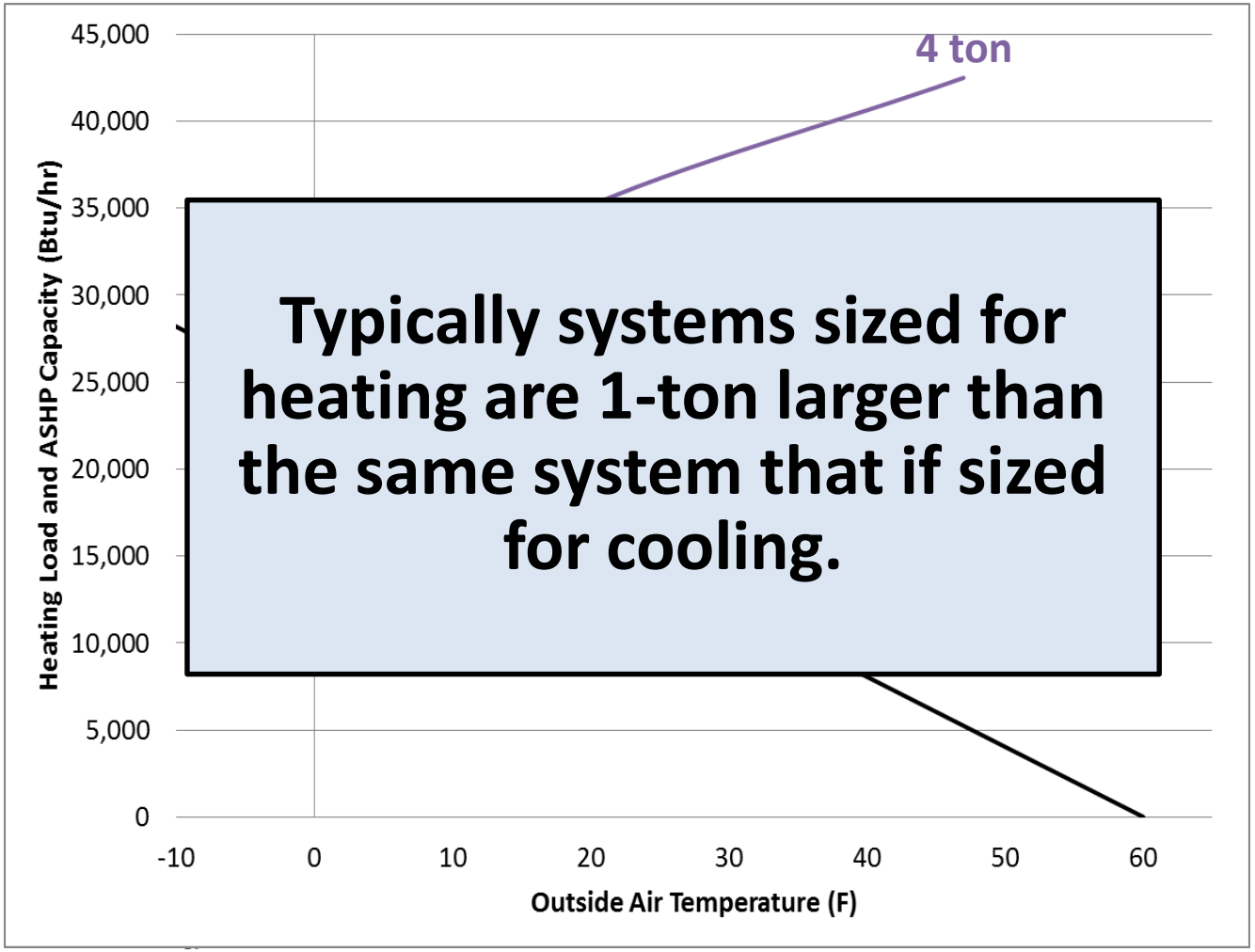
Specify Ratings (NEEP as example)

- 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

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

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:

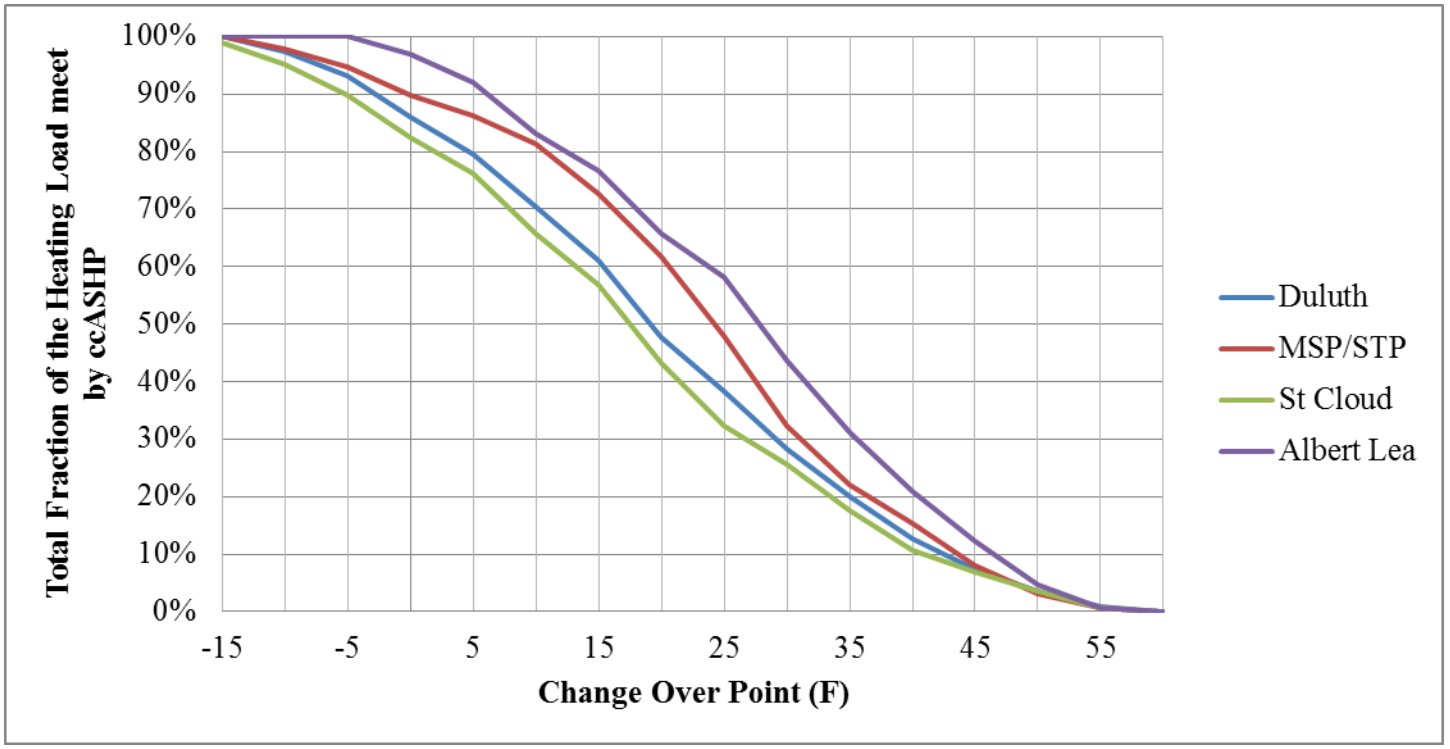
4 ton ~ 86%,

3 ton ~ 77%

2 ton ~ 60%

*Targeted a maximum change-over temp of 10 F

Impact of Change-Over Set Point

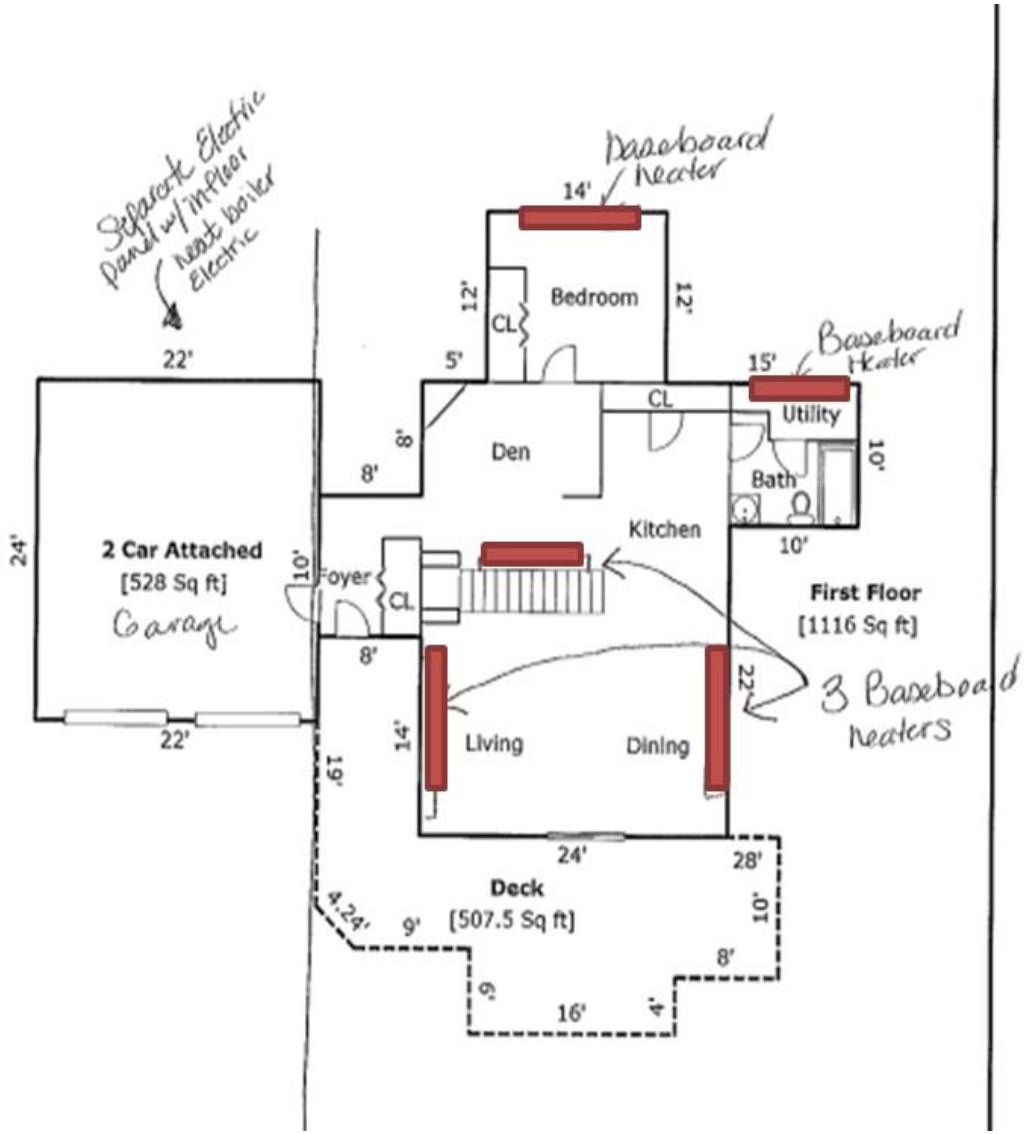


Furnace Integration – Keep or Replace?

- 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

Ductless Heat Pumps

Ductless: Install Location



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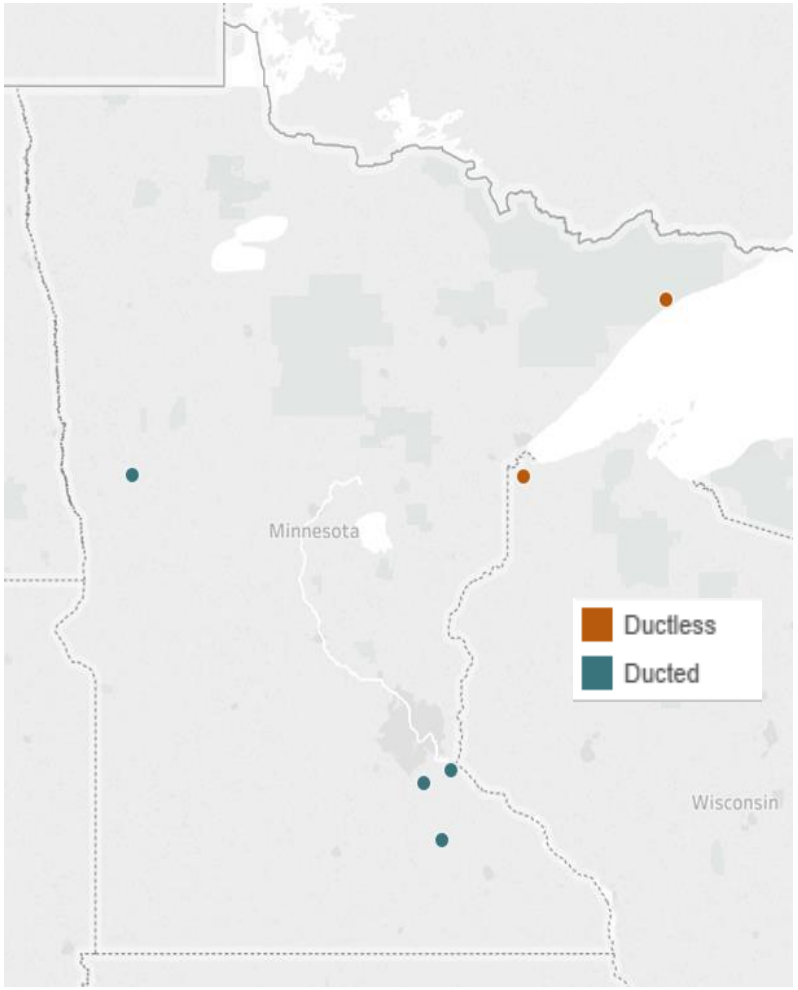
Other Installation Considerations

- Refrigerant
  - R-410A
  - What's next?
- Integration with other systems
  - Ventilation
  - Energy recovery
- Control options
  - Cost
  - Environment
  - Minimizing back-up use

Study Overview

- Field Study
  - 8 ccASHP in a variety of MN residences
    - 6 ducted whole house system
      - 4 flex fuel
      - 2 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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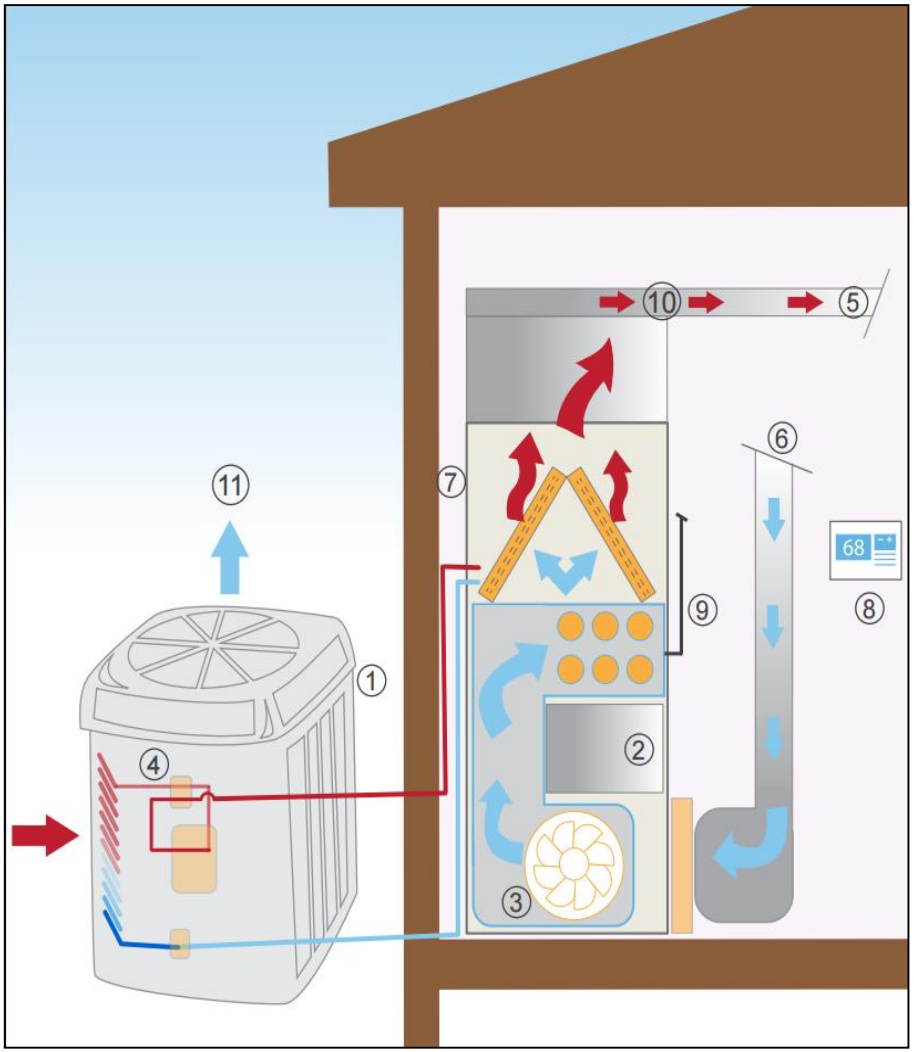
Instrumentation

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



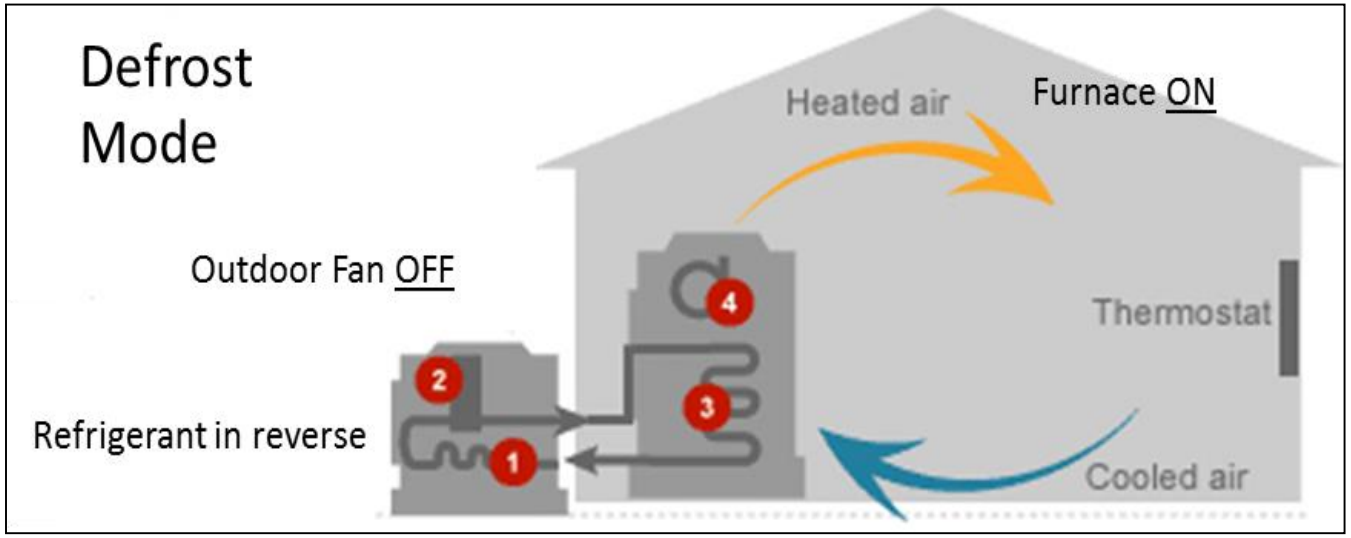
Site Equipment

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

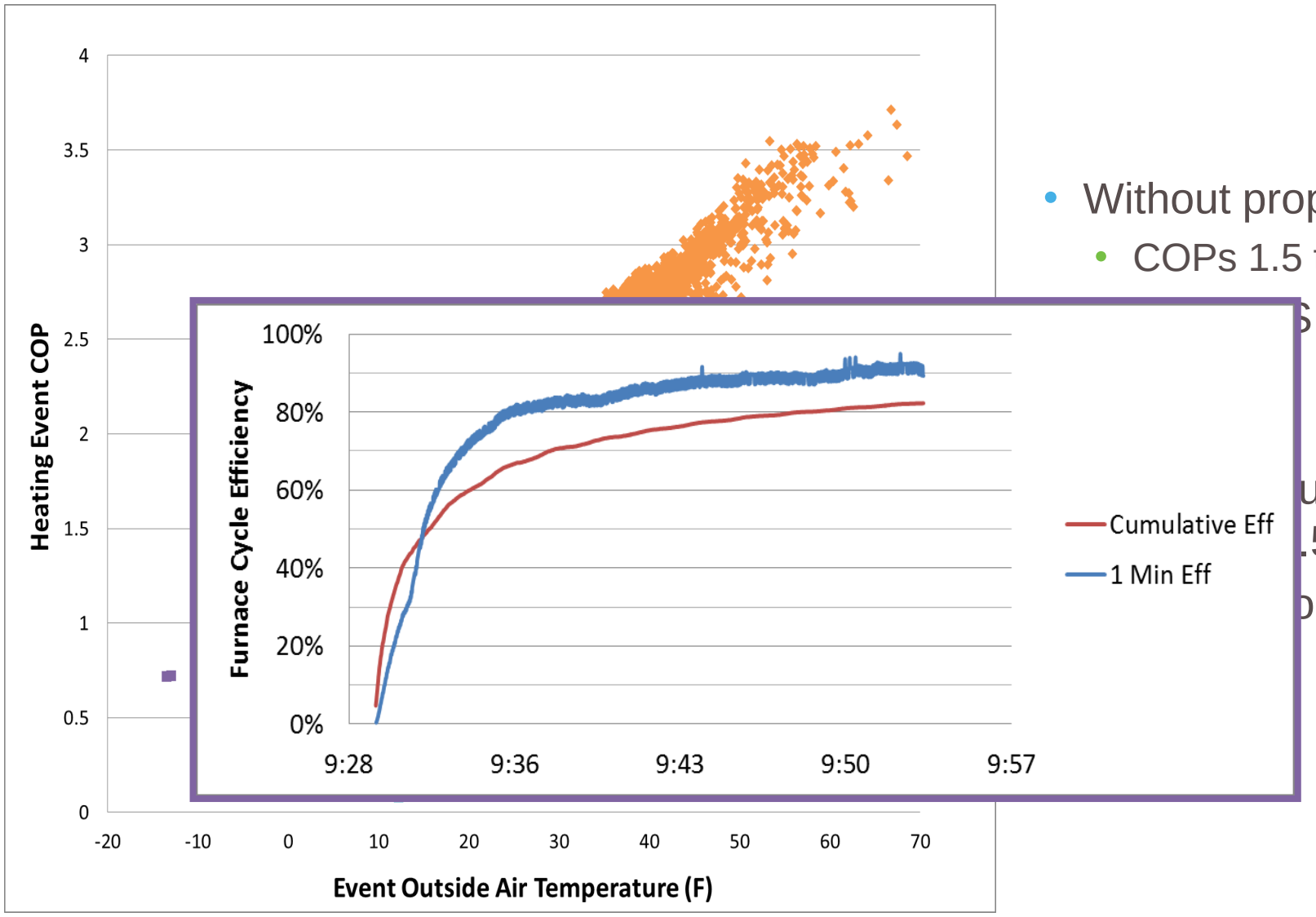
Whole house ducted systems

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

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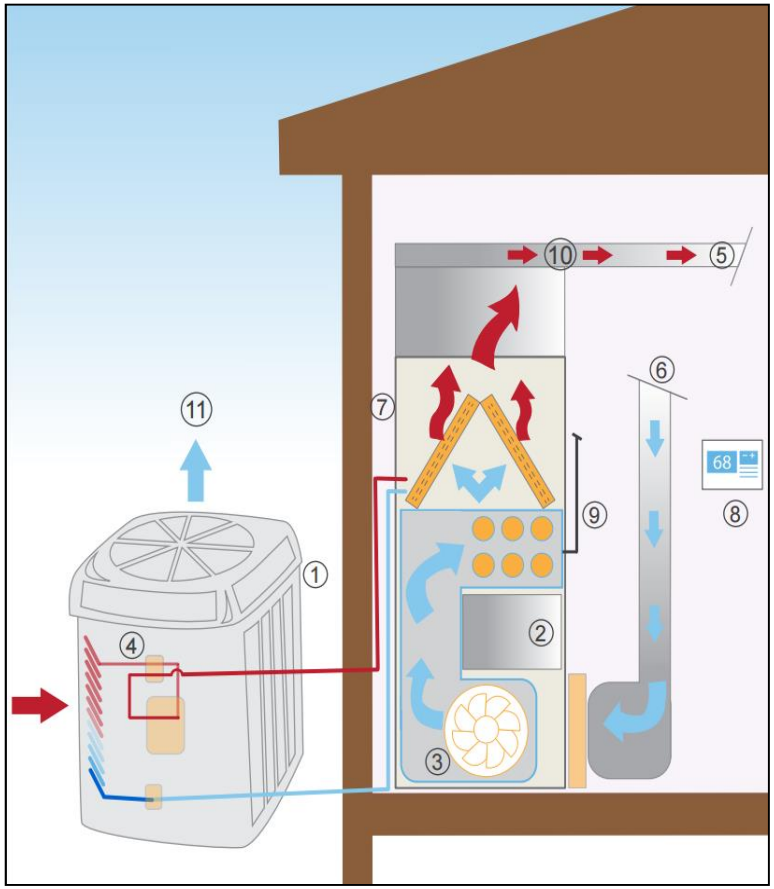
Defrost Controls

- Temperature near coil
- Lockout time



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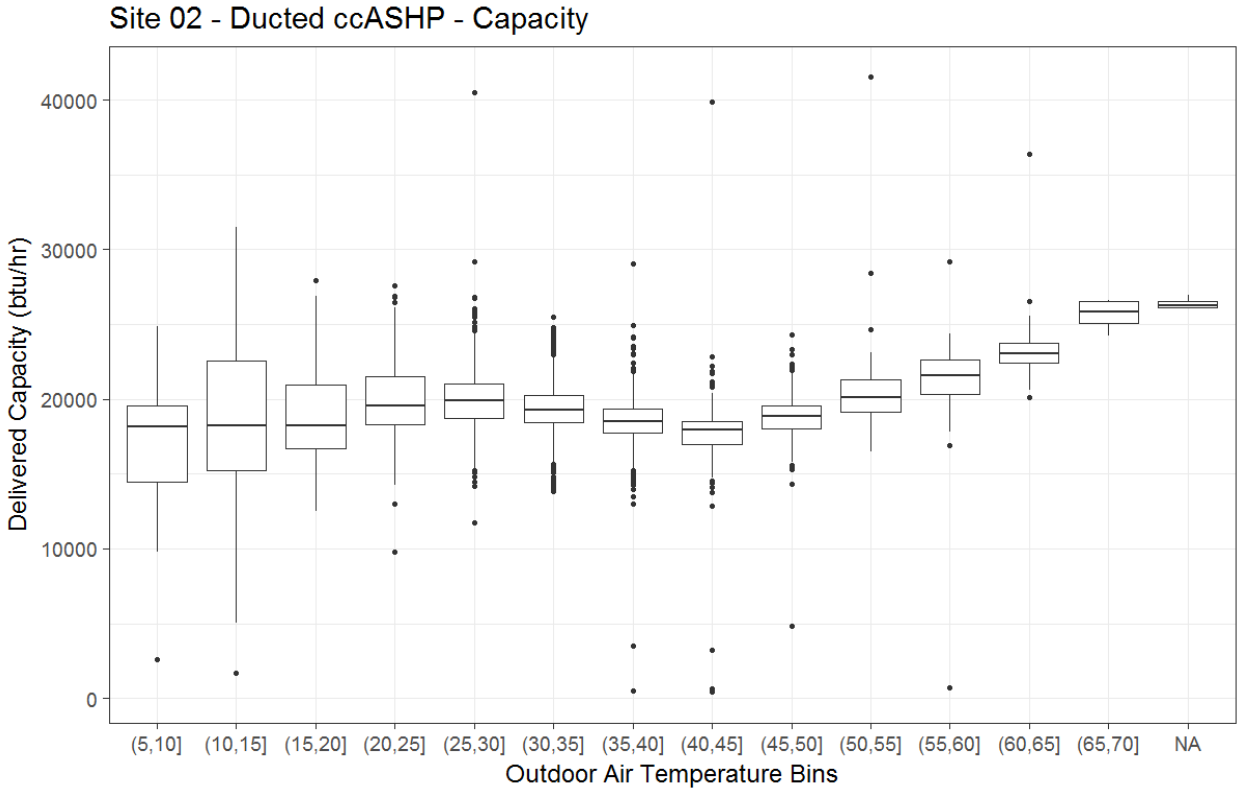
Example: Capacity on a 17 ºF day

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

mode	Active time (seconds)	% of Day
Heating	72248	83.6%
Heating: ASHP only	65991	66.0%
Heating: LP Only	6549	7.6%
Defrost:	8708	10.1%

Cold Temperature Performance of ASHPs

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



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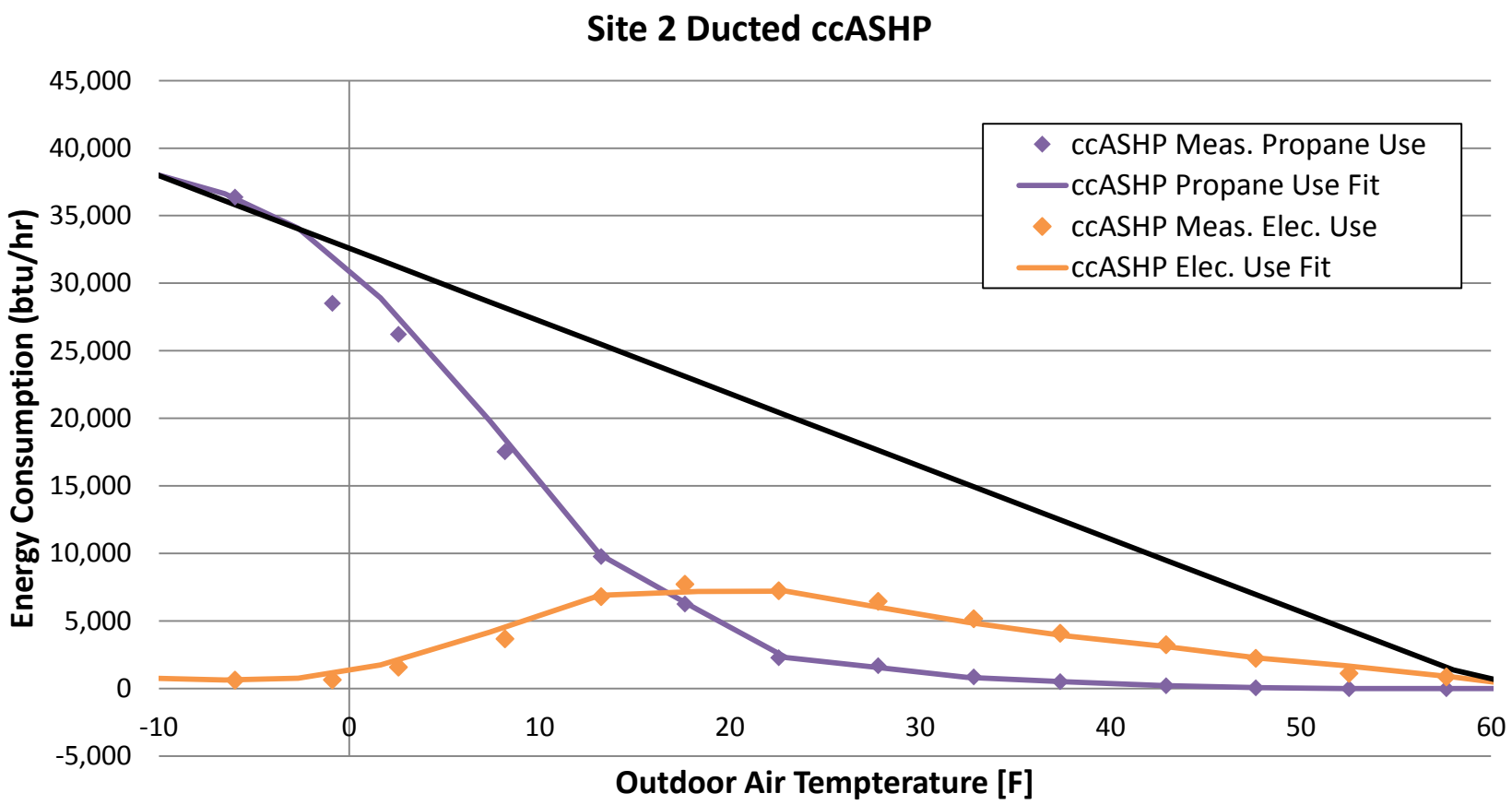
Energy Use Analysis

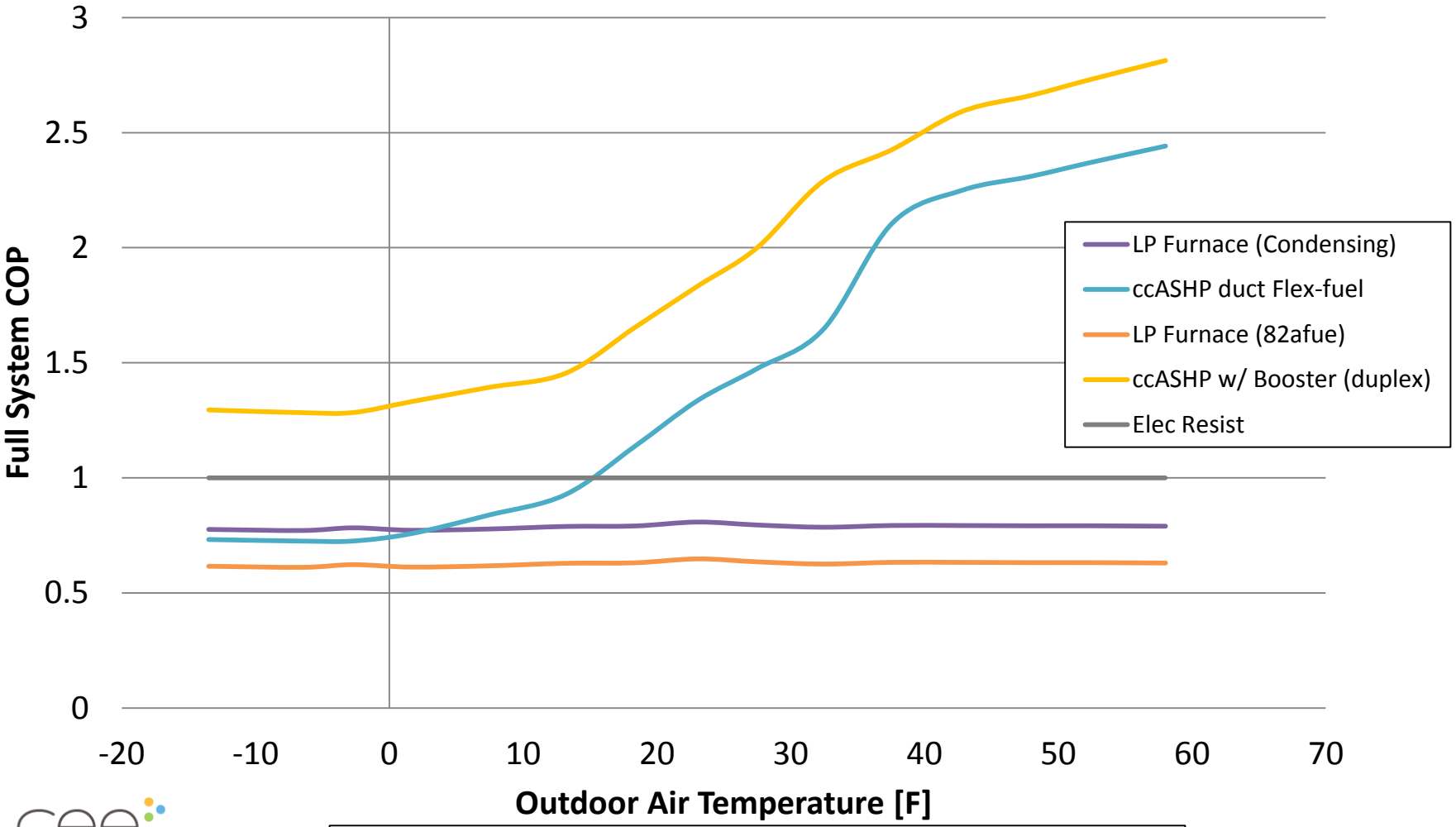
- Measure installed performance data
  - ccASHP with backup mode
  - Baseline mode
- Characterize the heating load of the home
- Create equipment performance models

- Summarize system performance and energy use at each site

Energy Use Vs OAT Models – Flex Fuel



System Performance



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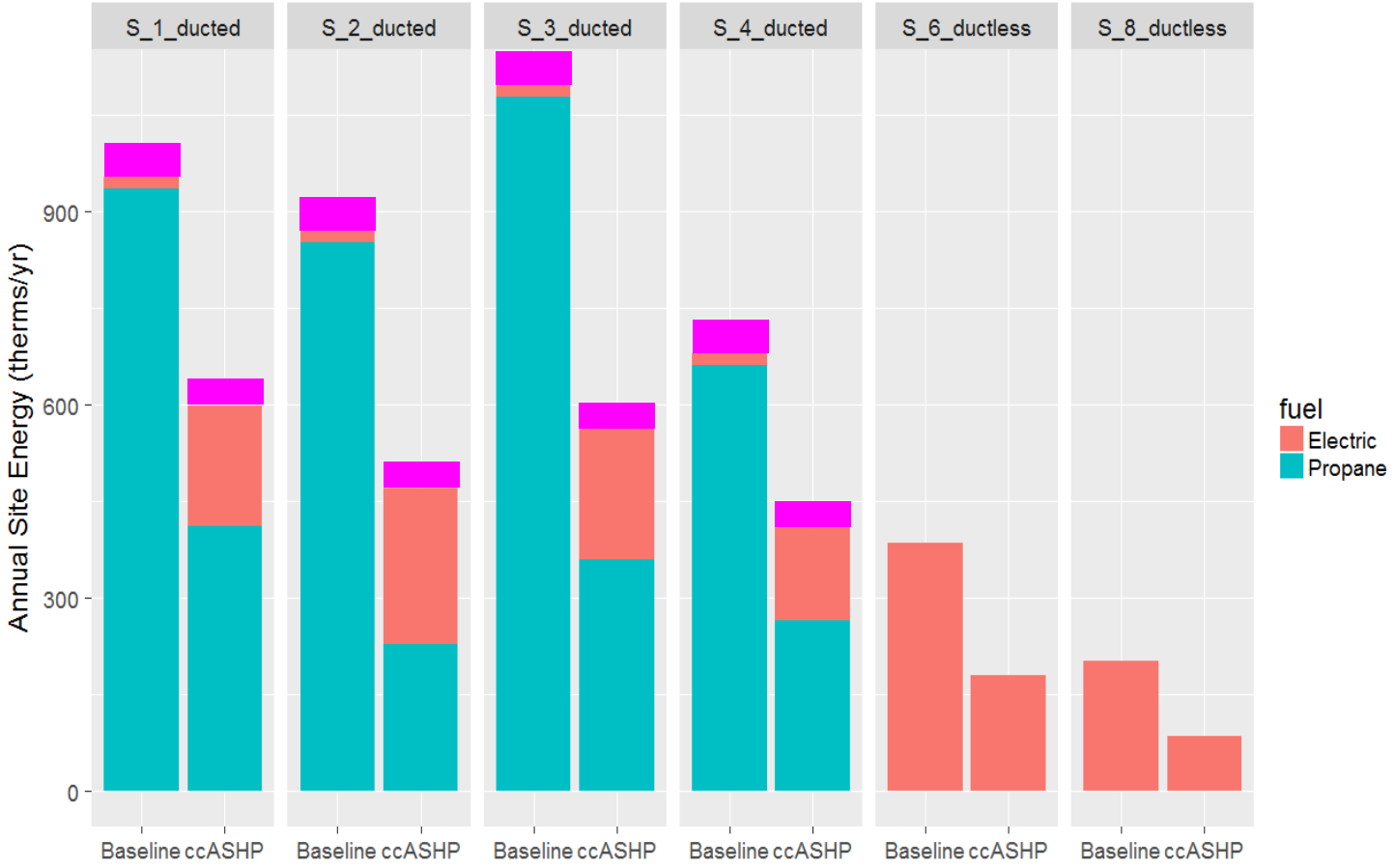
Annual COP: All-elect and ductless ~1.9 to 2.1
Flex Fuel ~1.2 to 1.3

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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Annual Characteristics and Savings

Site	Heating balance Point [F]	Heating Design Load [Btu/hr]	Site Energy Reduction	Cost Reduction	Propane reduction	Savings [$/yr]
S_1_ducted	62.6	35,468	**37%**	28%	56%	**$469**
S_2_ducted	60.9	30,046	**46%**	32%	73%	**$497**
S_3_ducted	66.1	24,923	**49%**	40%	67%	**$767**
S_4_ducted	64.5	22,778	**40%**	30%	60%	**$358**
S_6_ductless	70.1	14,200*	**52%**	52%	NA	**$610**
S_8_ductless	59.1	9,400*	**54%**	54%	NA	**$349**
S_10_elec	70	15,150	**47%**	47%	NA	**$496**
S_12_elec	68	26,446	**48%**	48%	NA	**$833**

** Design loads for ductless systems are estimated and intended as metric to gauge magnitude of heating load.*

Install Costs

- For the 4 ducted flex fuel 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

Further discussion of costs

- Incremental equipment costs
  - Vs split system A/C
  - Vs other ASHPs
- Incremental labor costs
  - Vs split system A/C
  - Vs other ASHPs
- Risks
  - Impact of pushing to low temperature performance
- Thermostats and other controls

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

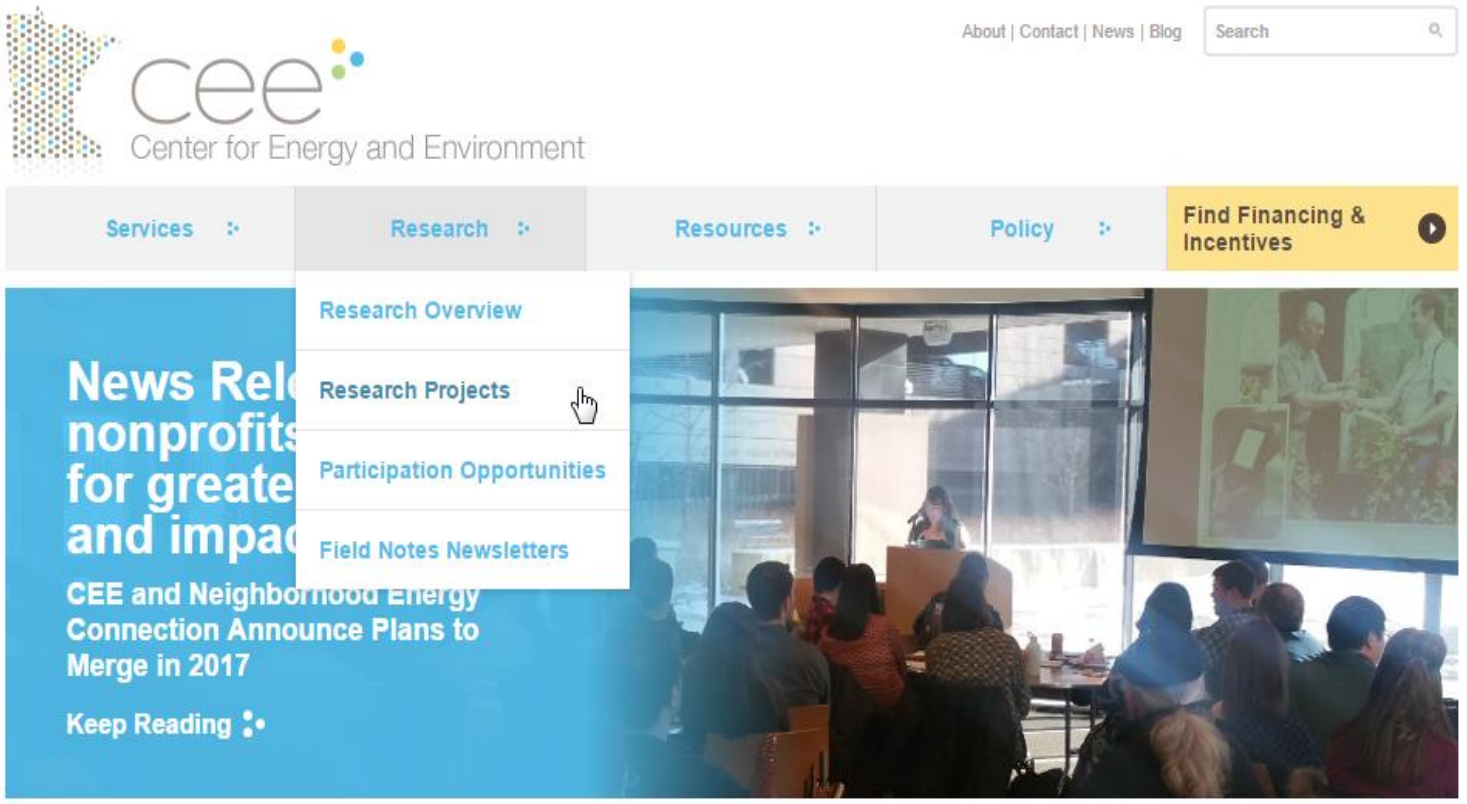
Conclusions

- 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 – 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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