Better Buildings®
U.S. DEPARTMENT OF ENERGY

Better Buildings Residential Network
Peer Exchange Call Series

Heat Pumps at Scale, the Game Changer – Where Are We Now, and What Will It Take?

December 9, 2021

Agenda and Ground Rules

- Agenda Review and Ground Rules
- Opening Poll
- Residential Network Overview and Upcoming Call Schedule
- Featured Speakers
  - **Christopher Dymond,** *Northwest Energy Efficiency Alliance (NEEA)*
  - **Kyle Glusenkamp,** Oak Ridge National Laboratory *(ORNL)*
  - **Xudong Wang,** *Air Conditioning, Heating, and Refrigeration Institute (AHRI)*
- Open Discussion
- Closing Poll and Announcements

Ground Rules:

1. **Sales of services and commercial messages are not appropriate** during Peer Exchange Calls.
2. Calls are a safe place for discussion; **please do not attribute information to individuals** on the call.

The views expressed by speakers are their own, and do not reflect those of the Dept. of Energy.

Join the Network

Member Benefits:

- Recognition in media and publications
- Speaking opportunities
- Updates on latest trends
- Voluntary member initiatives
- One-on-One brainstorming conversations

Commitment:

- Members only need to provide *one number*: their organization's number of residential energy upgrades per year, or equivalent.

Upcoming Calls (2nd & 4th Thursdays):

- *1/13: Known Unknowns: Key Energy-Efficiency Trends in the New Year*
- *2/10: Secrets from the Most Successful Residential Efficiency Programs*
- *2/24: It's Not About Energy, It's About Comfort – Addressing the Reality*

Peer Exchange Call summaries are posted on the Better Buildings website a few weeks after the call

For more information or to join, for no cost, email bbresidentialnetwork@ee.doe.gov, or go to energy.gov/eere/bbrn & click Join

Christopher Dymond

Northwest Energy Efficiency Alliance (NEEA)

Advanced Heat Pumps Sources of Savings

Better Buildings Residential Network
December 9, 2021

Christopher Dymond
Sr. Product Manager
Northwest Energy Efficiency Alliance

Outline

- HP Basics
- Whole Savings
- Known Unknowns

"The utility's favorite chew toy"

- Tom Eckman, NW Power Council

Presentation Goal

- Understand the potential of advanced heat pumps and Two of the challenges to maximizing their potential

Basics

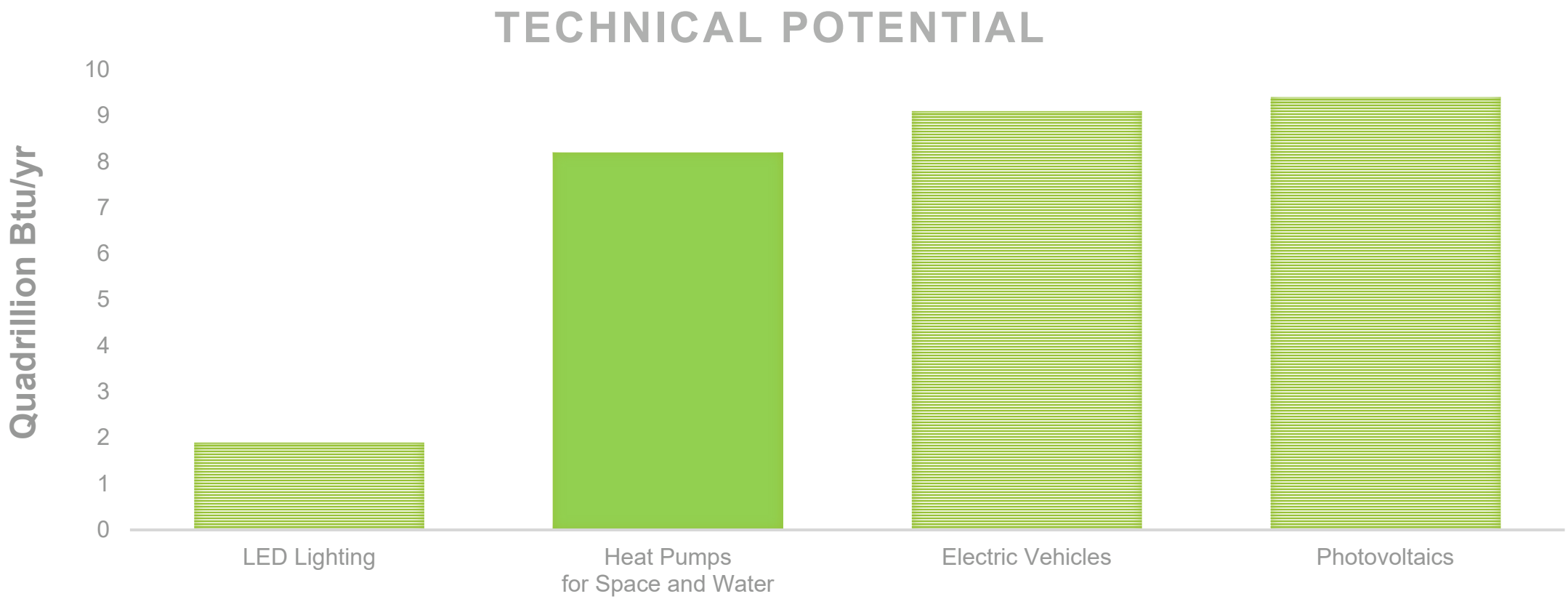
Heat Pumps Move Heat

(they don’t create it)

8

The 3rd Largest Potential

Customer side contribution to meeting our future energy needs



Market Transformation Potential of the ASHP - 2018 ACEEE Paper Excerpt

ASHP systems are based on a seasonal COP of 2.2 for water heating and 3.3 for space heating sourced by a 50% efficient electrical grid (generation, transmission and distribution losses). 50% efficient is high, but chosen as a proxy for a gas turbine + renewable energy dominated utility grid likely by 2050. The iASHP systems could also powered on-site by gas. Such systems would need COP values not much higher than 1.1 for water heating and 1.65 for space heating to provide the equivalent source energy reduction. The lighting baseline estimate is adjusted to pre LED conditions NEEA's building stock assessment (NEEA) values, with end state efficacy estimates of 100 lm/W for residential lighting and 150lm/W for commercial. The photovoltaic "savings" are based on a projected 1000 GWp of installed capacity under a solar resource of 1400 kWh/Wp.

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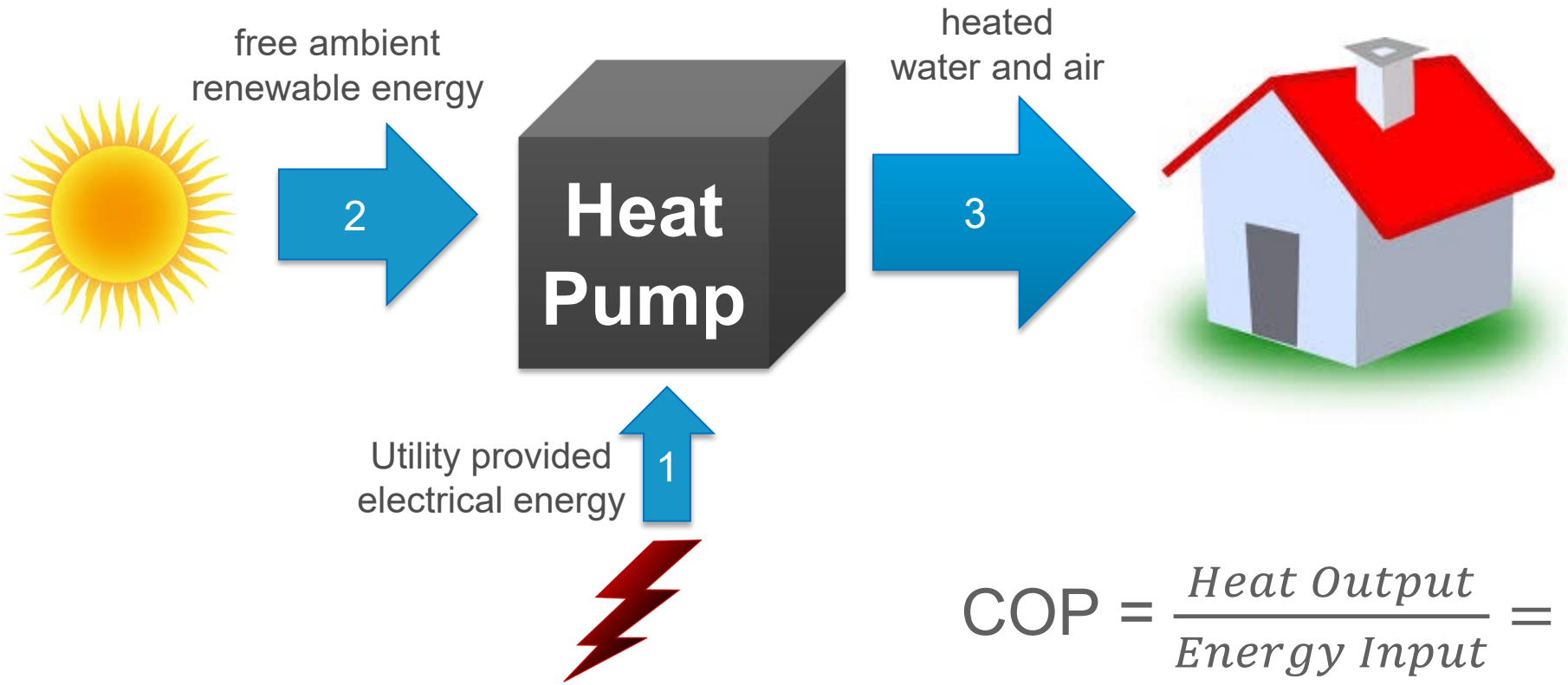
Air Source Heat Pump

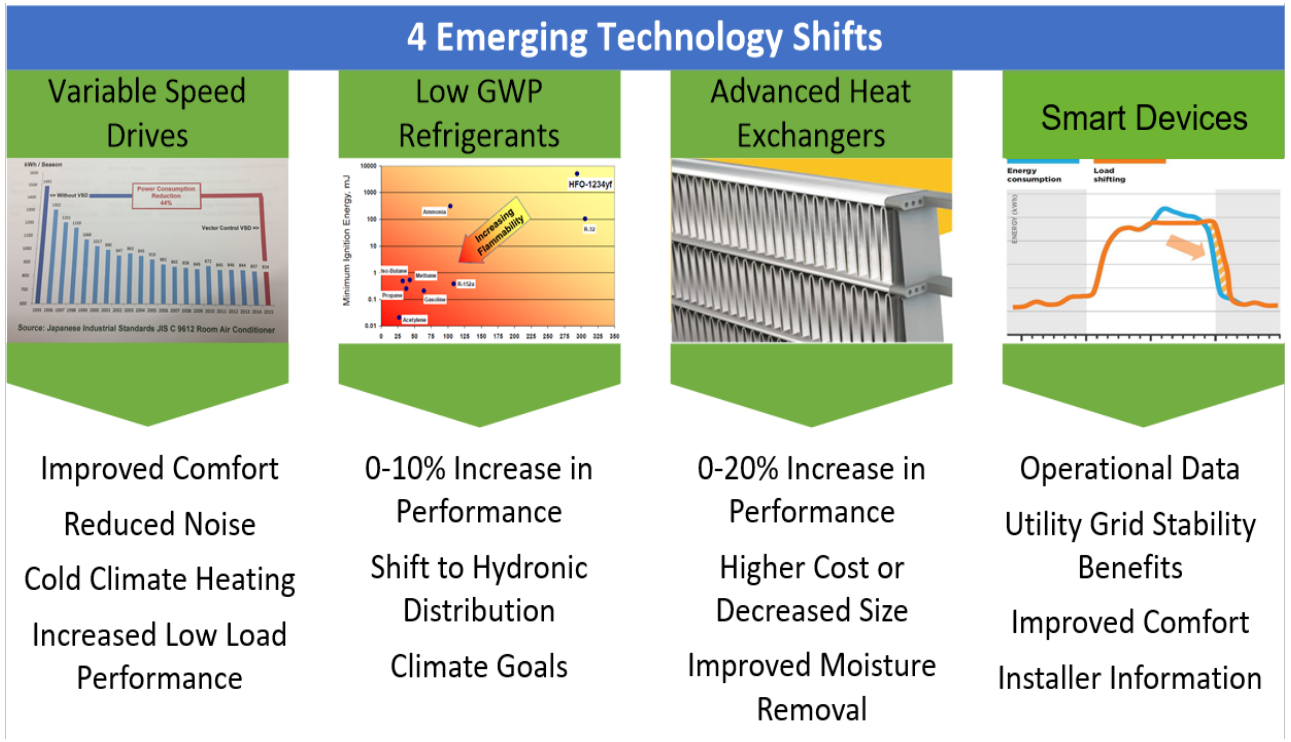
(in heating mode)



$$\text{COP} = \frac{Heat\ Output}{Energy\ Input} = \frac{3}{1} = 3.0$$

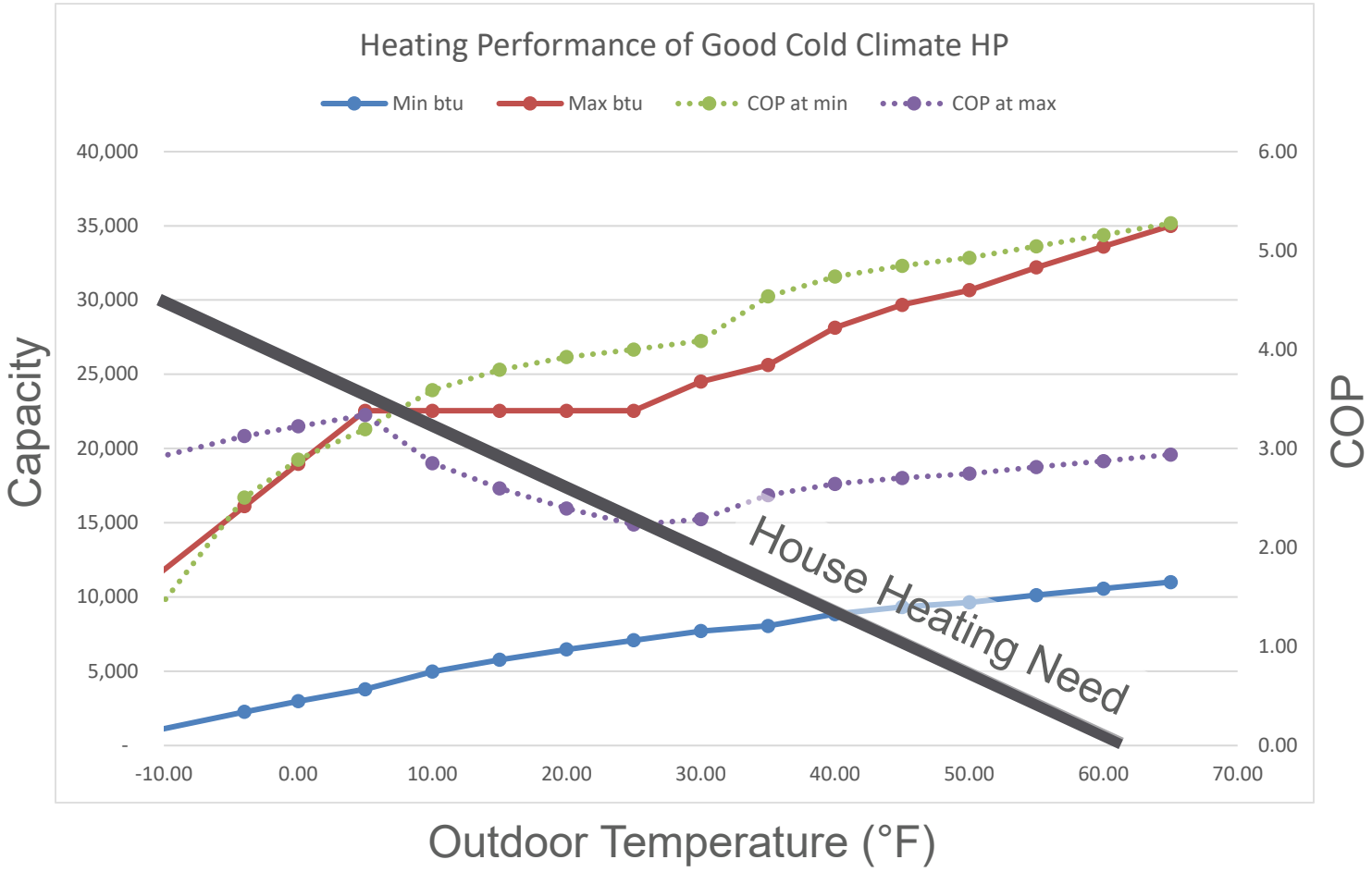
Advanced Heat Pump Technology Shift

- Variable Speed Motors
- Refrigerants
- Heat Exchangers
- Connected Diagnostics



HP Performance is Temperature Dependent

- When it is cold outside the heat pump has to work harder to heat the house
- When it is hot outside heat pump has to work harder to cool the house



Residential Space Conditioning Savings

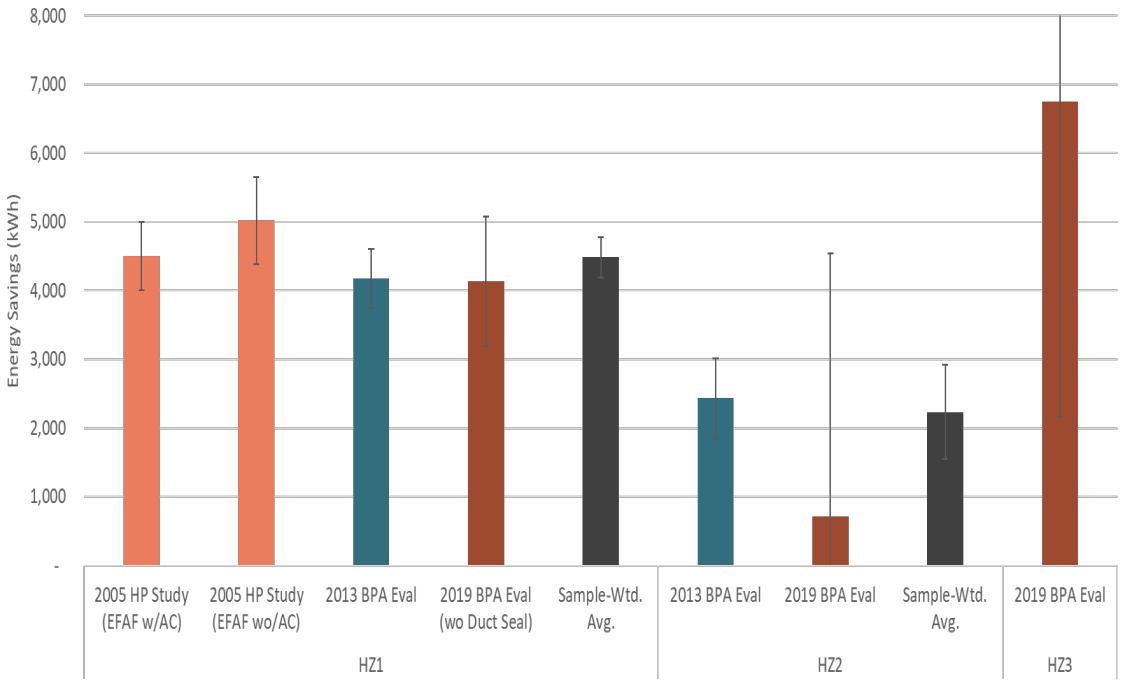
Program Energy Savings Evaluations

Savings were

30-50%

LOWER

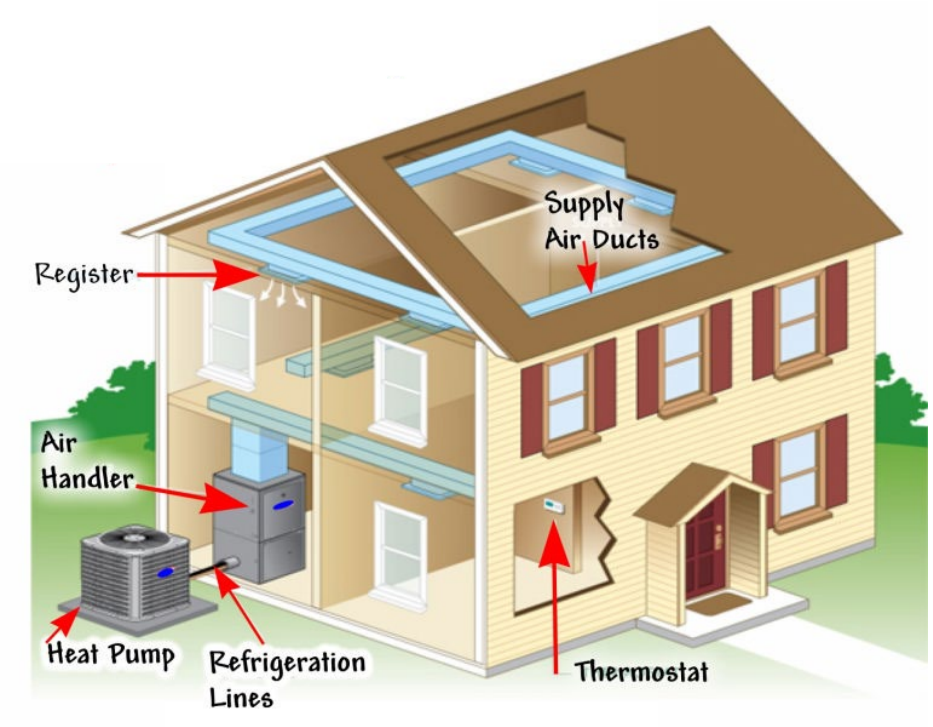
than rated performance*



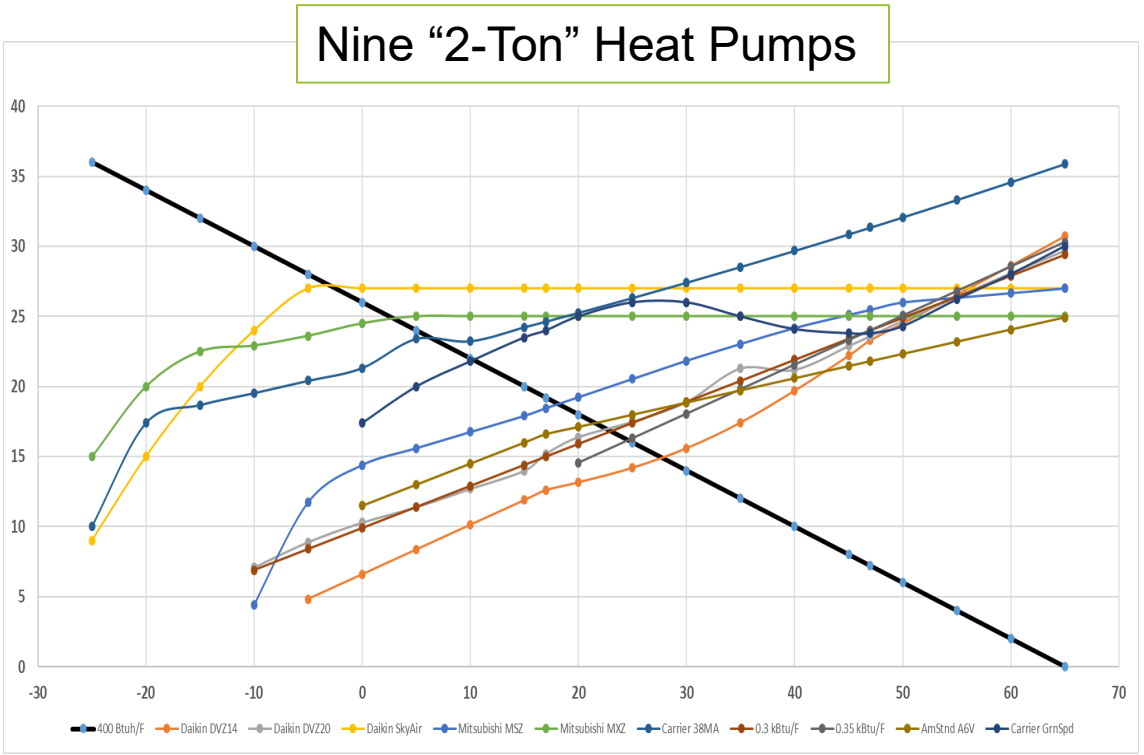
RTF – Dec 10, 2019 ASHP Workgroup PPT

* As indicated by numerous evaluation studies over the past 40 years FSEC-PF-413-04 (ucf.edu)

Heat Pumps are Systems, Not Widgets

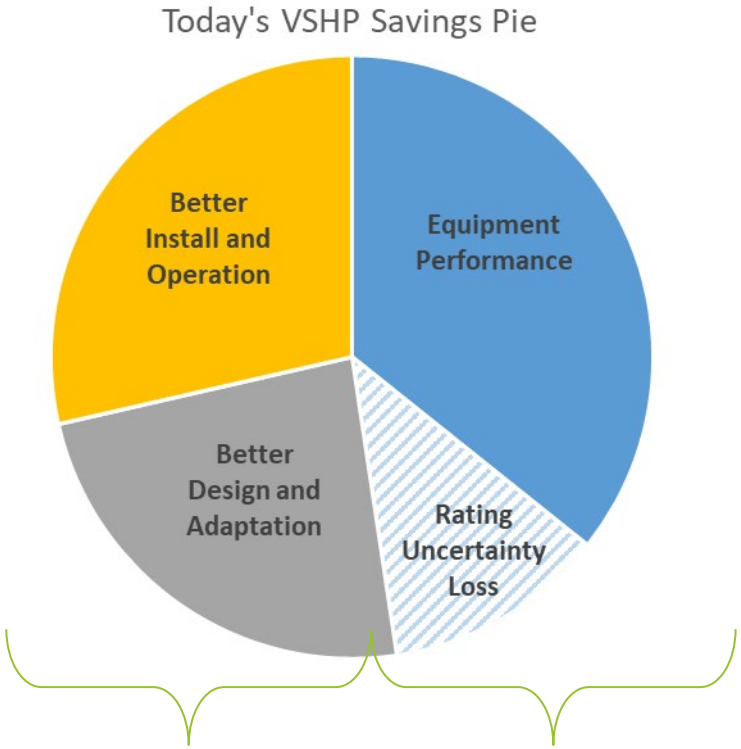


Graphic - Goodman manufacturing

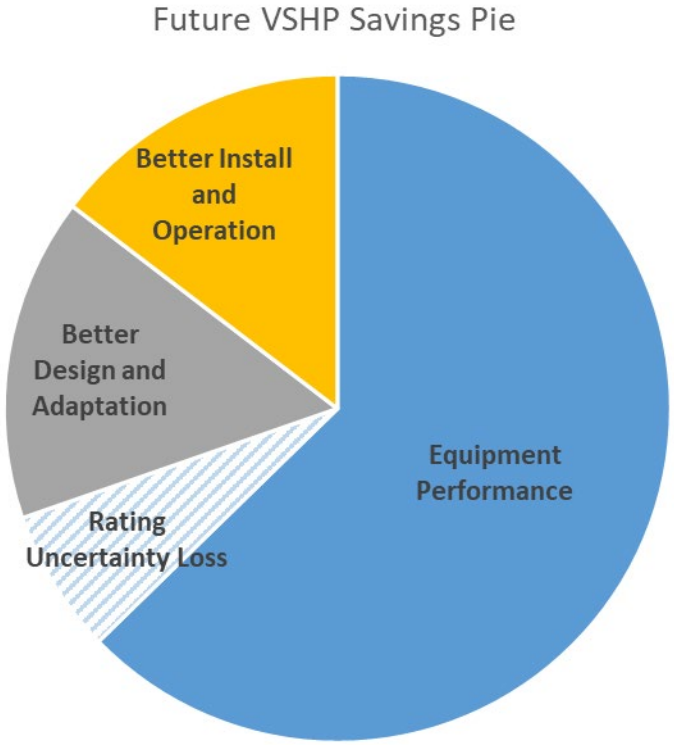


Many things affect system performance: House characteristics, climate, HP capacity curves, HP efficiency curves, distribution system, air flow, homeowner preferences, thermostat settings, etc.

The Whole Savings Pie . . .



Future Improvements



Standards of Practice
(hard to change, hard to measure)

Equipment Performance
(easy, but sometimes $$$)

Hypothesis: Future HPs will . . .

1. have 10% better performance
2. be easier to design & install right

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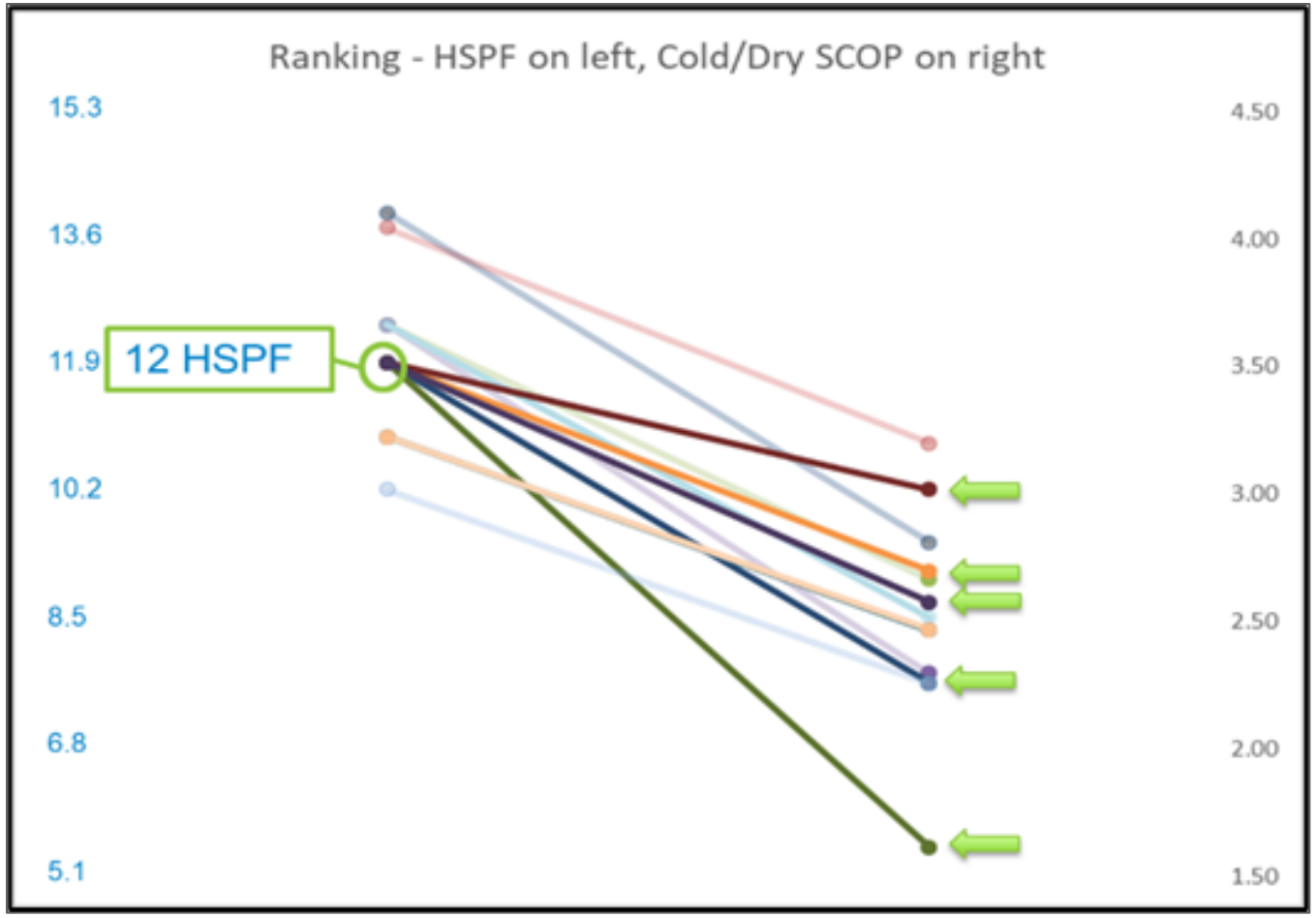
Two Known Unknowns

#1 - What is a Good Rating?



Five units with the same rated performance (HSPF of 12)

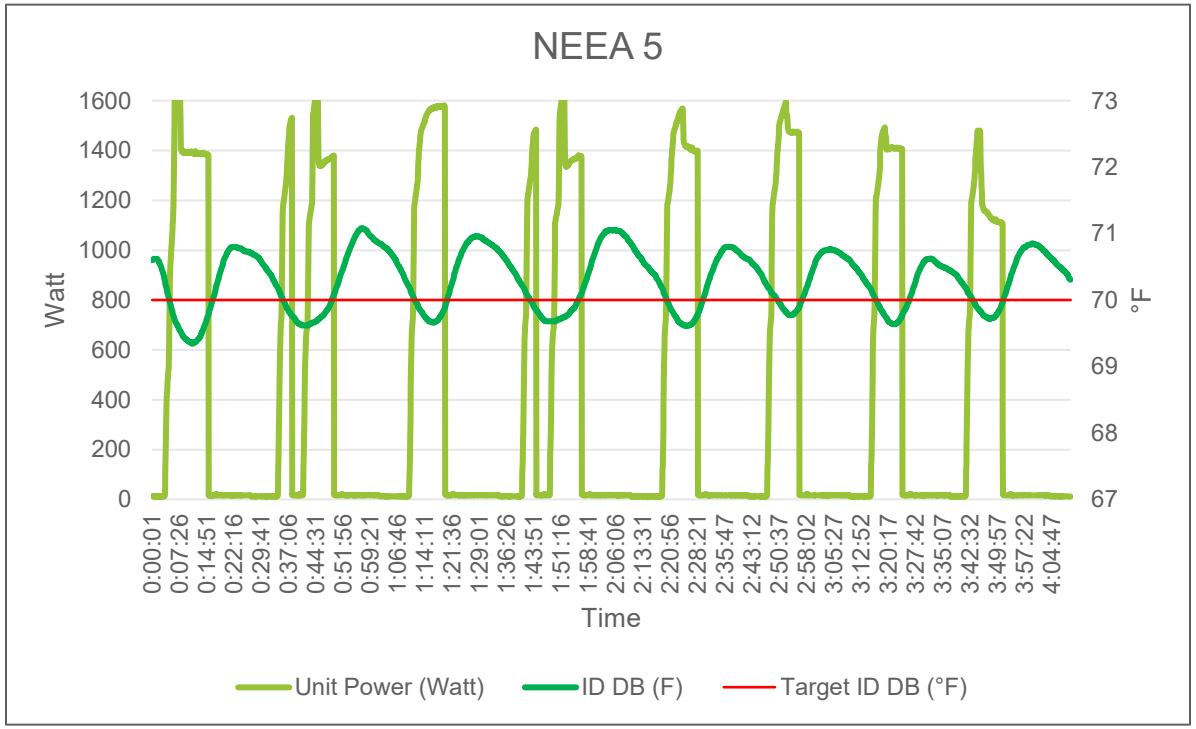
Had much different performance when tested under their own controls, and under residential load conditions

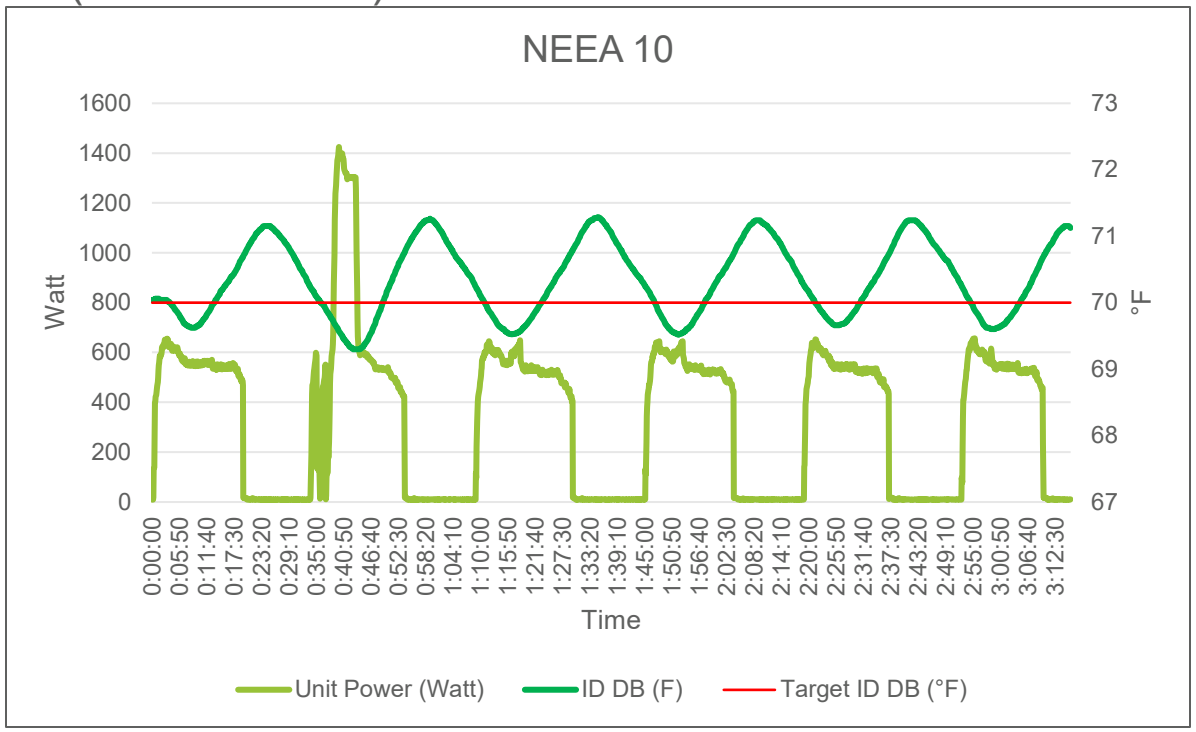
Better Control Algorithm Example

(same make, same size, same model, different year)

	NEEA 5	NEEA 10
Cooling Cap (95F, Btu/h)	12,000	12,000
EER (95F)	13.00	15.00
SEER	25.00	27.00
High Heat (47 F, Btu/h))	16,500	14,500
Low Heat (17 F, Btu/h)	10,000	9,300
HSPF	12.00	13.00
Test Date	March 2019	August 2020

Test Condition HC (Tamb = 17°F)





COP = 2.03

66% better

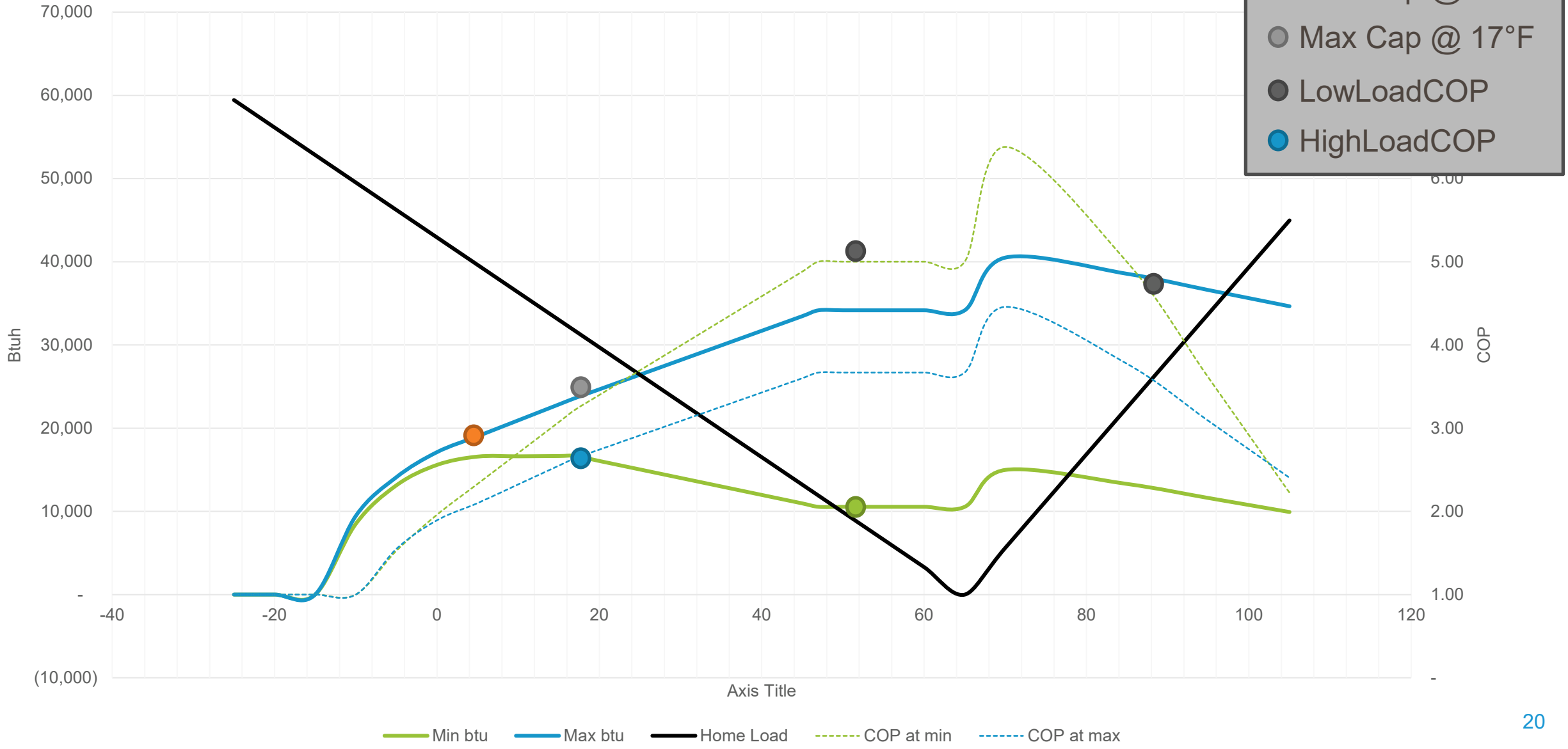
COP = 3.37

Rated HSPF = 12

8% better

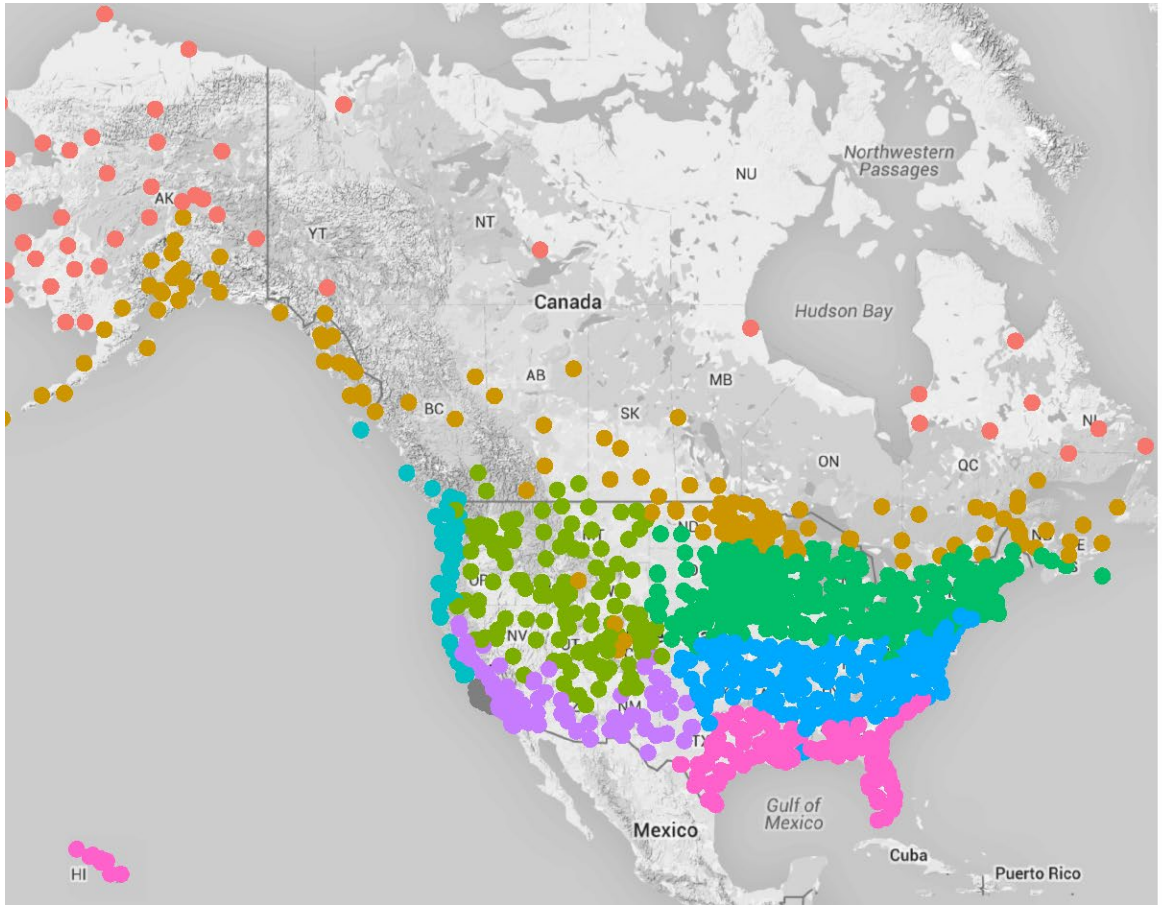
Rated HSPF = 13

NEEP Cold Climate HP Database

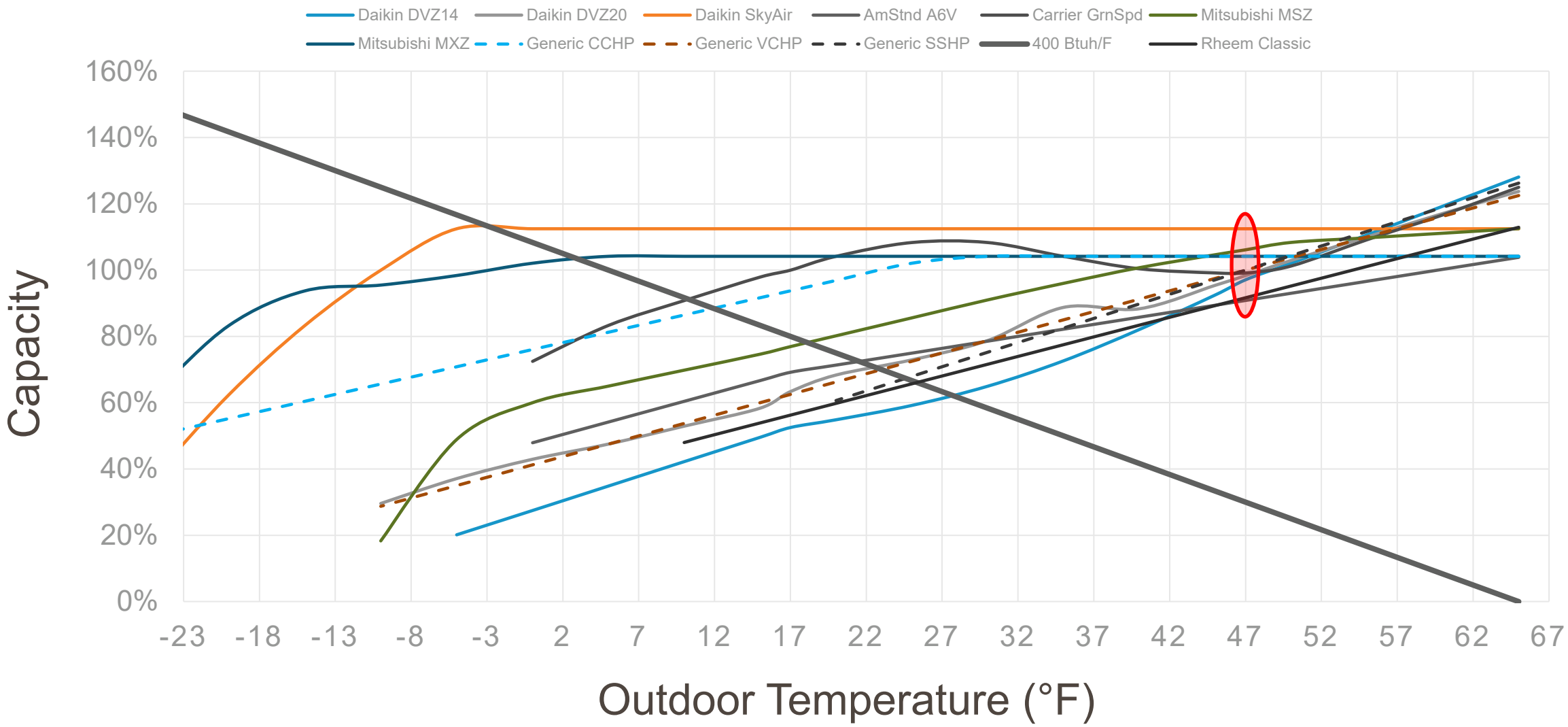


#2 What is the Right Heat Pump?

Different Climates



Not all 2 Ton Heat Pumps are the same



Different Types Heat Pumps

Mini-Split

Micro/Portable

Packaged

Unitary

Hybrid

Combo

Dual Fuel

Gas Heat Pumps

Different Types of Houses

Modern

Contemporary

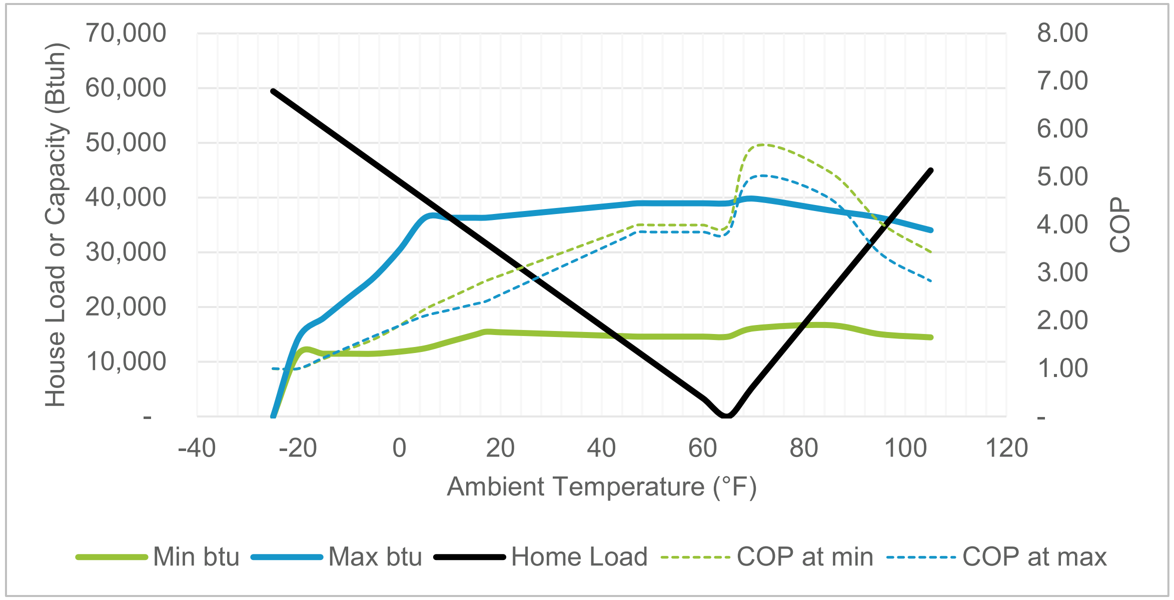
Prairie

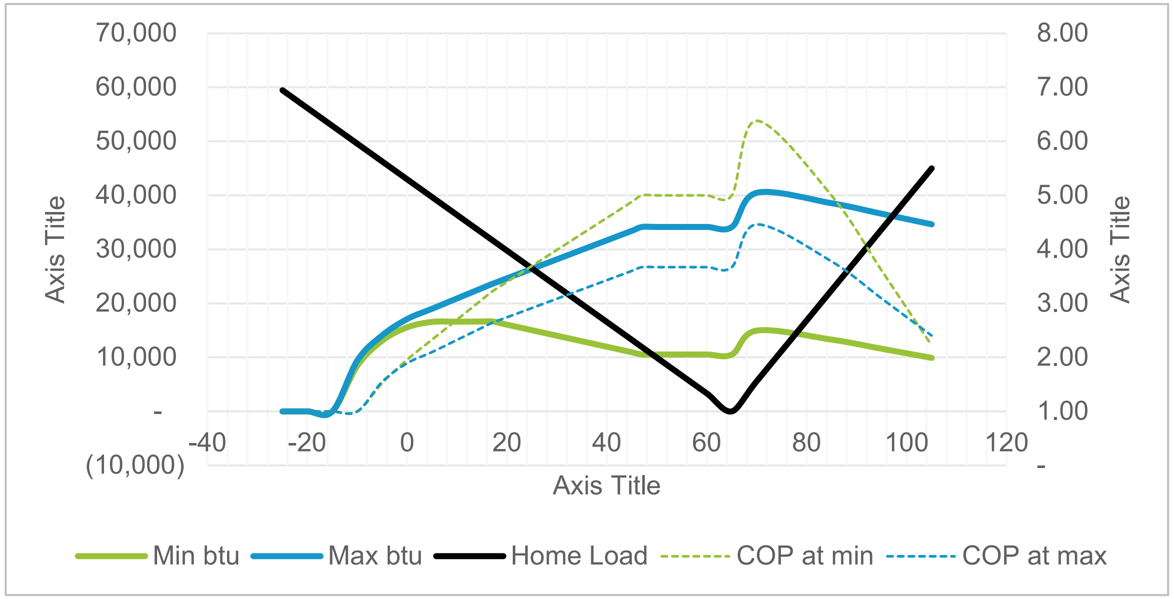
Ranch

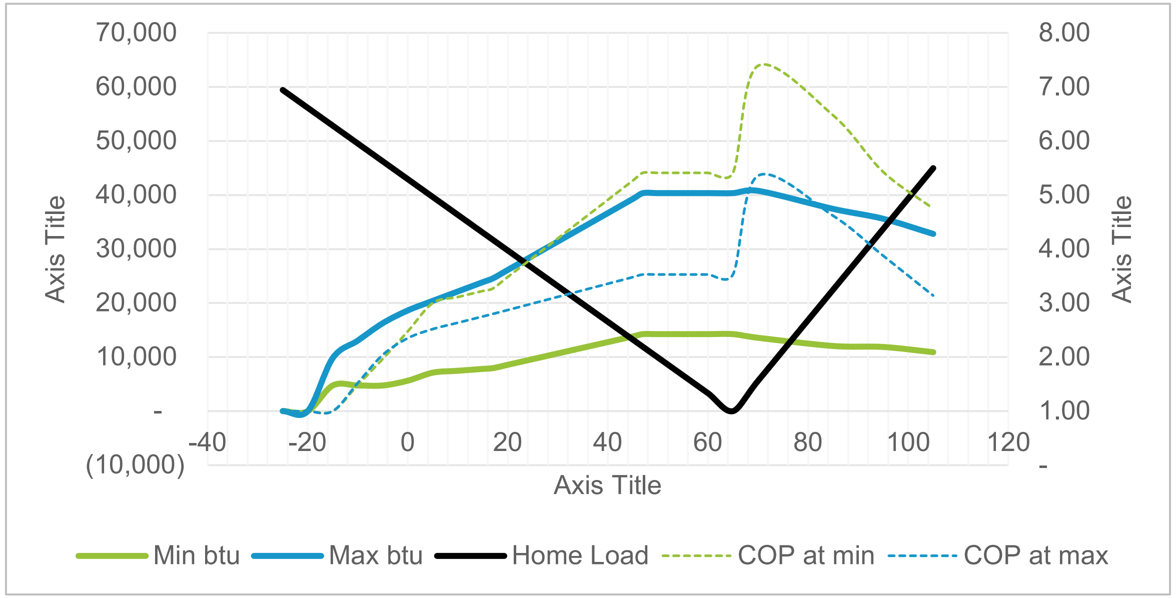
Tudor

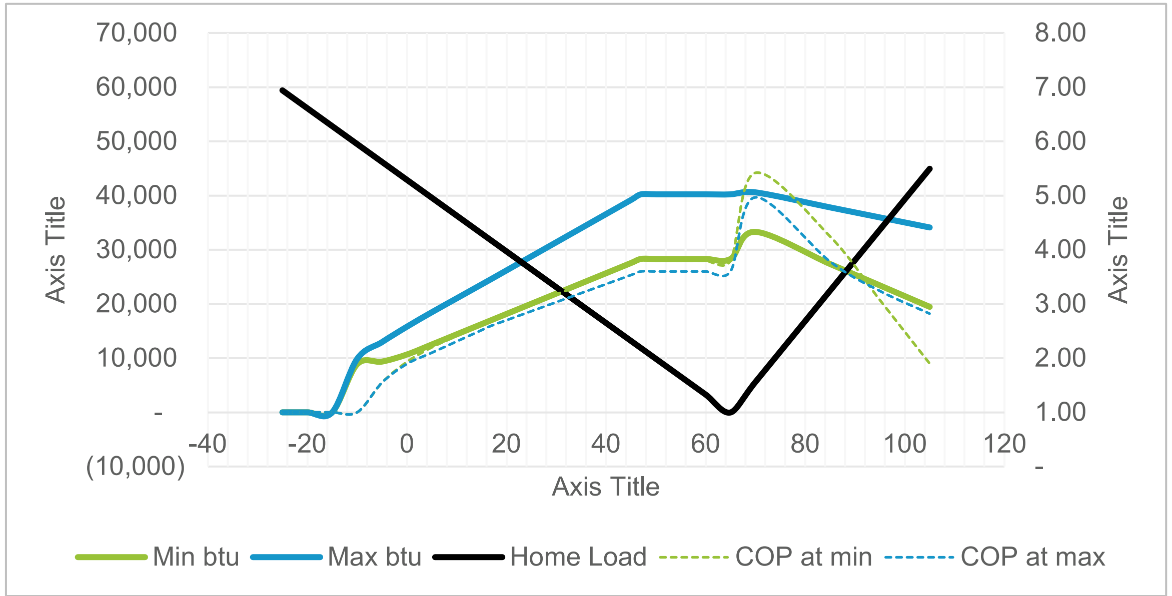
Victorian

Different Performance Curves





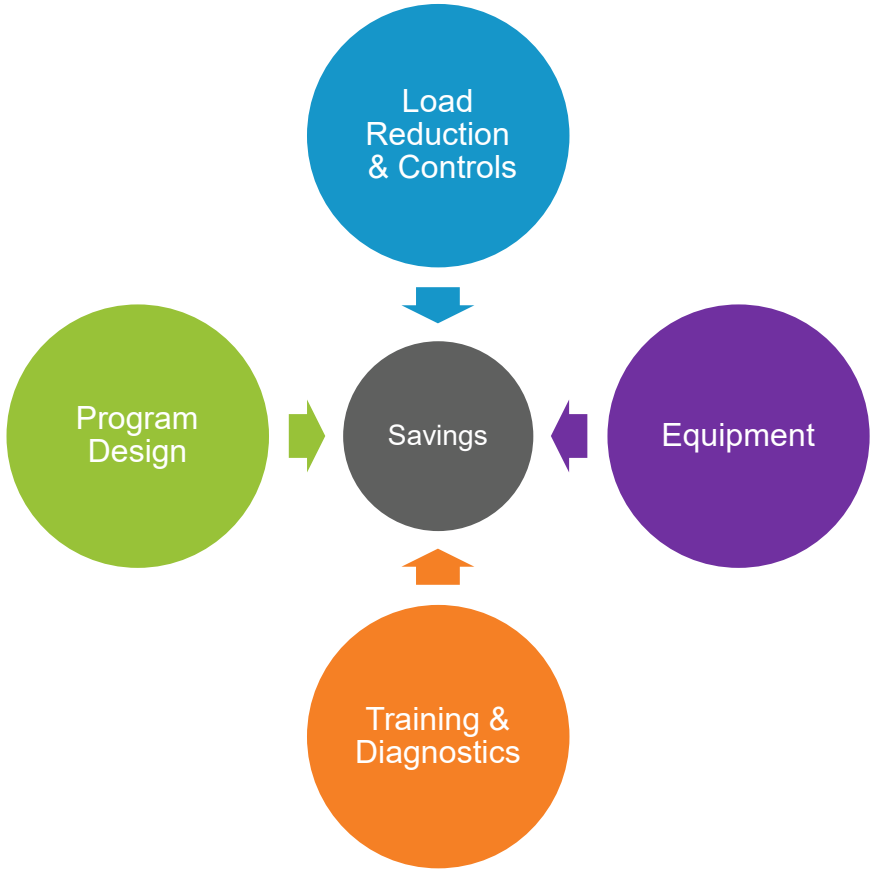




Conclusion

Four Sources of Savings

1. Reduce Unnecessary Heating/Cooling
   - Weatherization, duct sealing,
   - Backup heat control
2. Improve System Performance
   - Better HSPF, SEER, cold climate
3. Improve System Design and Application
   - Choose the right system for situation
4. Target Biggest Opportunities
   - Use program design to go after top priorities and biggest savers first



The Advanced Heat Pump Coalition

"A Coalition of the Willing"

- Goal

  To increase research collaboration among energy efficiency organizations that are working to accelerate market adoption of advanced heat pumps.

- Membership
  - ACTIVE = Fund and Guide collaborative activities
  - PASSIVE = attend webinars, provide feedback
- Committees
  - Steering Committee (NEEA, NEEP, MEEA, CEC, NRCan, EPA)
  - WG #1 – Improved Test Procedure and QPL
  - WG #2 – Roadmap and Manufacturer Engagement
  - WG #3 – Best Practices (Design, Adaptation, Installation and Operation)

Bright Minds From These Organizations:

Website: The Advanced Heat Pump Coalition (mwalliance.org)
To Join, email Morganne Morganne.Blaylock@icf.com

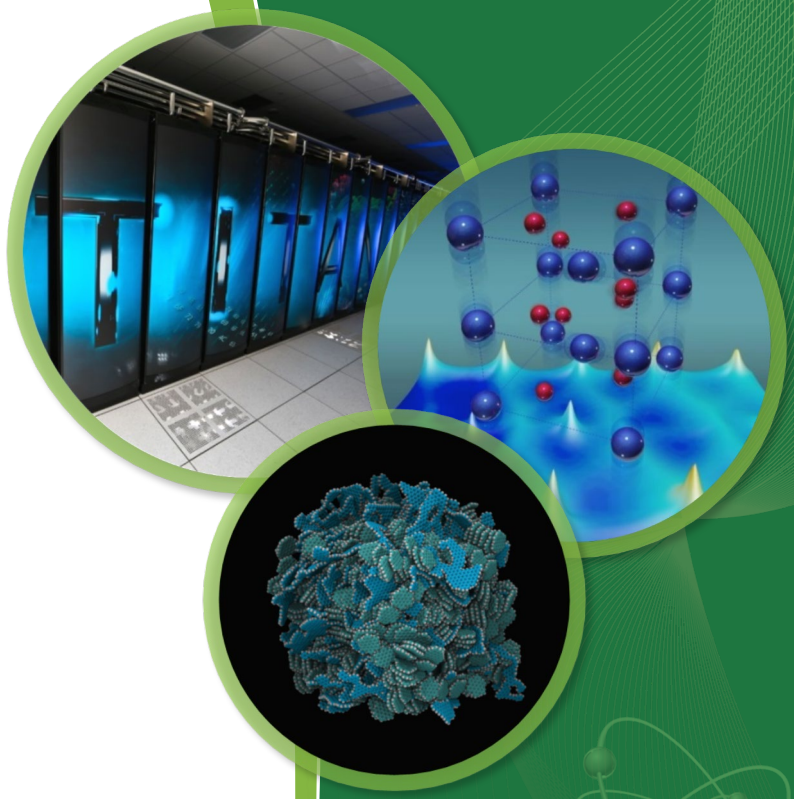
THANK YOU

Christopher Dymond
Sr. Product Manager
Northwest Energy Efficiency Alliance

Kyle Glusenkamp

Oak Ridge National Laboratory (ORNL)

The Future of Efficient Equipment for Buildings



Kyle Gluesenkamp

Senior R&D Scientist

Subprogram Manager for HVAC&R, Water Heating, and Appliances

Oak Ridge National Laboratory

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Contents

- ORNL's Buildings program
- Example projects
- How ORNL can work with industry
- Conclusions

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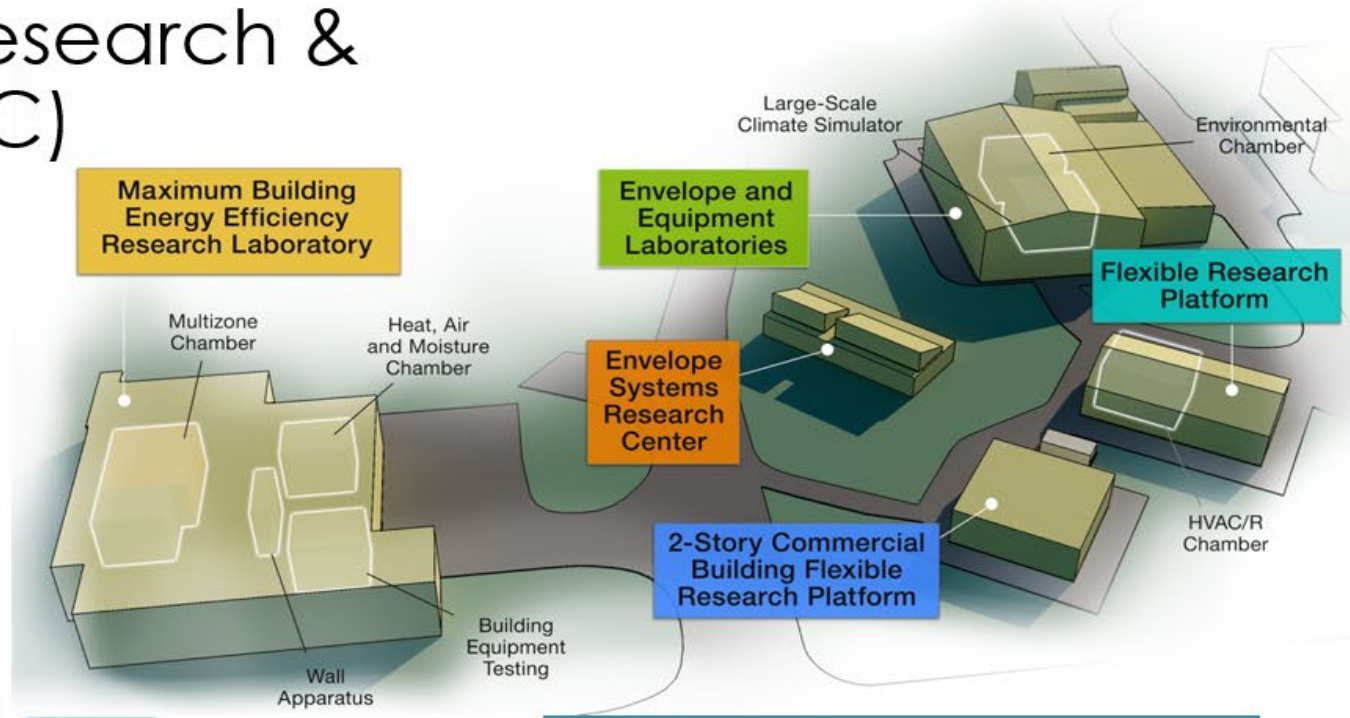
Acknowledgements

This material is based upon work supported by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Office, under Contract No. DE-AC05-00OR22725 with UT-Battelle, LLC. This research used resources at the Building Technologies Research and Integration Center, a DOE Office of Science User Facility operated by the Oak Ridge National Laboratory.

ORNL's Buildings Research

Building Technologies Research & Integration Center (BTRIC)

- Established in 1993
- DOE's only user facility focused on building technologies
- Over 50,000 ft^2 research space



Breaking New Ground in Energy Efficiency
FY20 Statistics

- **2,900+** Visitors Since 2012
- **10** R&D 100 Awards to Date
- **27** University Partners
- **6** User Agree-ments active
- **42** CRADAs active
- **239** Publications in FY 2020
- **157** R&D Partners
- **45** Strategic Partner-ships

Facility Capabilities

- Buildings-to-Grid
- Building Equipment
- Building Envelope
- Building Energy Modeling
- Commercial Building Integration
- Residential Building Integration

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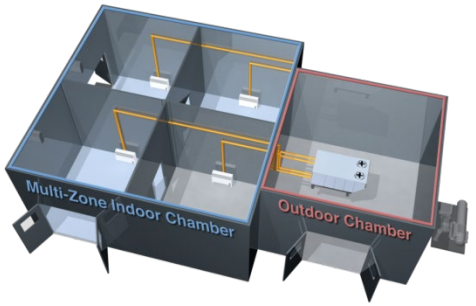
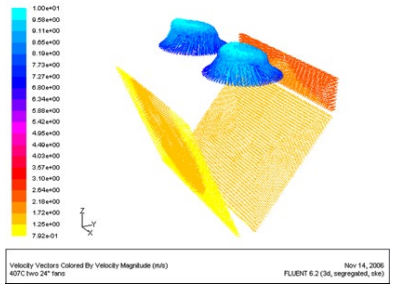
Building Equipment: Infrastructure and Expertise

- Four sets of environmental chambers, one appliance chamber
- Three wind tunnels of varying capacities
- Two compressor calorimeters
- Advanced modeling capabilities
- Controlled field test sites (Yarnell Station house, Flexible Research Platforms)
- Access to ORNL's other core capabilities:
  - Additive manufacturing
  - Neutron imaging
  - Materials expertise
- 40+ years of experience in building equipment research
  - 15 PhD, 3 MSc, 3 technical
  - 7 R&D100 Awards
  - 25 patents
  - DOE Energy 23 Award – 2nd place among all DOE programs
  - Peter Ritter von Rittinger International Heat Pump Award, 2017





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What We Do

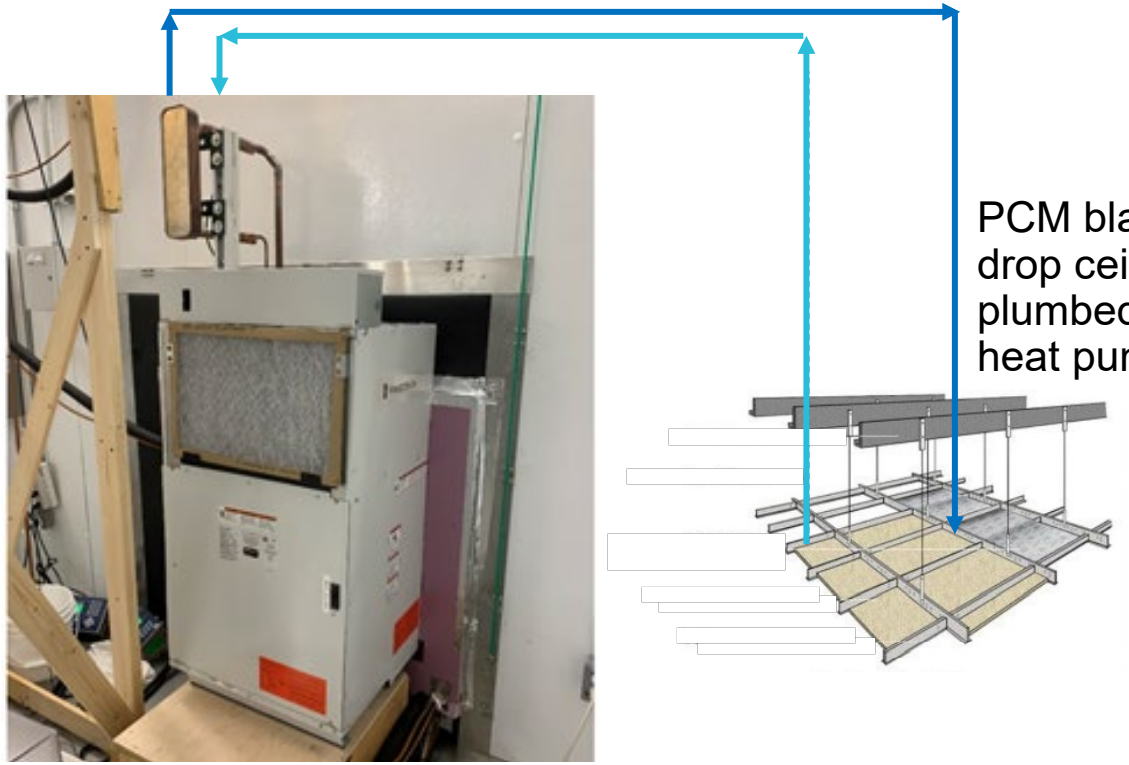
- ORNL is increasing the cost-effectiveness and energy efficiency of current building technologies to increase deployment and reduce greenhouse gas emissions as well as pushing the boundaries of next-generation technologies
  - In FY21: 81 journal publications, 48 conference paper publications, and 28 ORNL reports
- ORNL's strong relationships with manufacturers enable high quality, cost-effective, impactful solutions
  - 42 active CRADAs in FY21
  - 31 active Strategic Partnership Projects (SPPs)
  - More than 100 projects
  - 25 invention disclosures, 11 patent applications, 2 patents issued, 1 patent license executed

ORNL Priorities

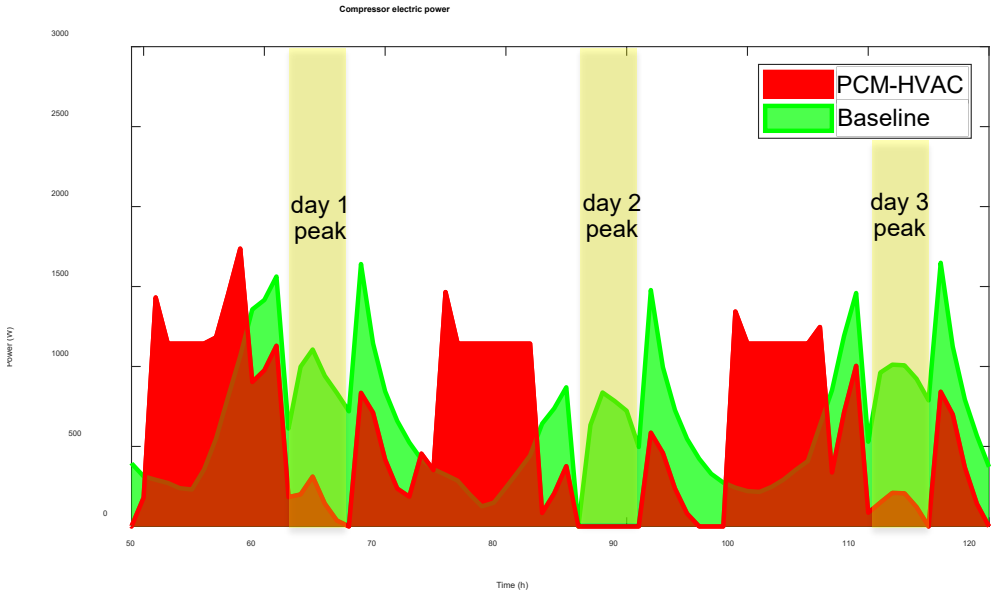
- ✓ Advanced Building Construction: Enabling affordable, low-carbon buildings that tackle the housing crisis
- ✓ (Cold Climate) Heat Pumping Technologies: Lowering cost and developing low-global warming potential (GWP) refrigerant solutions through RD&D with industry partners
- ✓ Grid Flexible: Leveraging expertise and capabilities to provide grid integration of building technologies, enabling grid-interactive efficient buildings
- ✓ Thermal Energy Storage: Enabling advanced energy storage technologies through development of new thermal energy storage materials, integration strategies, and controls
- ✓ Transactive Controls: Developing and integrating cost effective wireless sensor technologies and controls to enable building flexible demand and integration of distributed energy resources
- ✓ Modeling: Modeling and data analytics serving to define empirical test cases and validation of building energy modeling software
- ✓ STEM: Developing unique educational platforms to engage the next generation of building scientists and support workforce development

PCM Integrated with Multi-Functional Heat Pump

The PCM in the envelope is integrated with an air-source multi-functional heat pump.
The system delivers 90% peak demand reduction and 40% utility cost reduction (Georgia Power TOU pricing)



PCM blanket in drop ceiling, plumbed to heat pump



The multi-functional heat pump charges the PCM off-peak, and reduces load during peak hours.

90% peak power reduction while maintaining comfort

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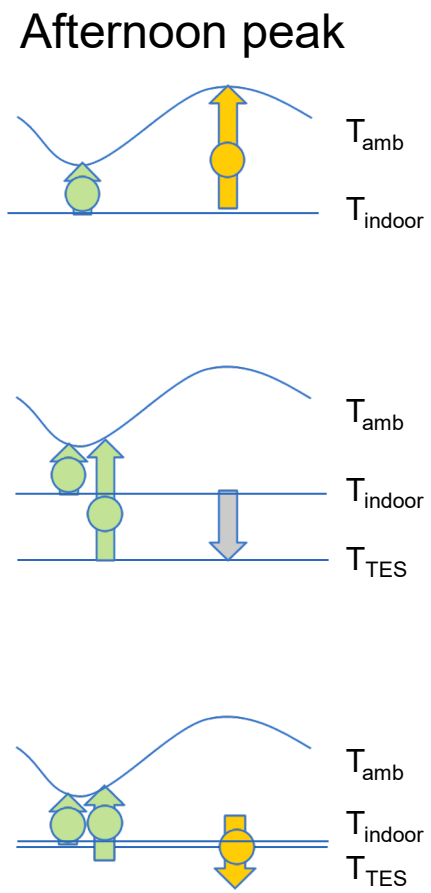
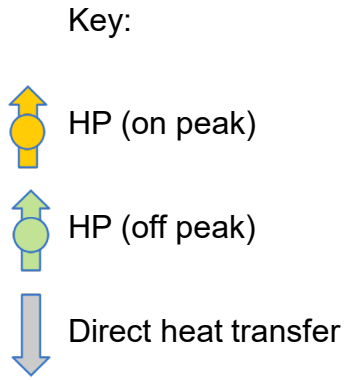
Thermal Energy Storage Can Lower CO_2 (Unlike Batteries)

Conventional HVAC

Direct use of TES

Indirect use of TES
(near room temp. TES)





Based on a Carnot analysis for direct case,

$$\frac{COP_{TES}}{COP_{conv}} = 1 + \frac{\Delta T_{storage} - \Delta T_{diurnal}}{\Delta T_{lift,peak}}$$

TES is more efficient for:

- **Large daily temperature swing**
- **TES close to indoor temperature**
- **Less extreme climate**

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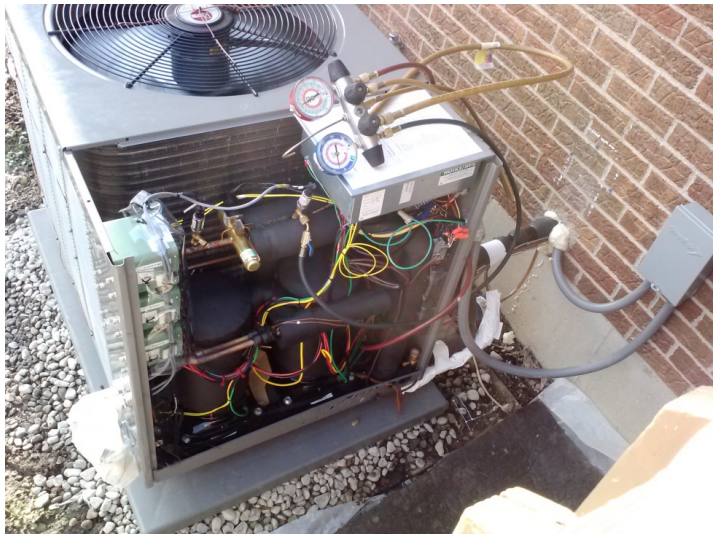
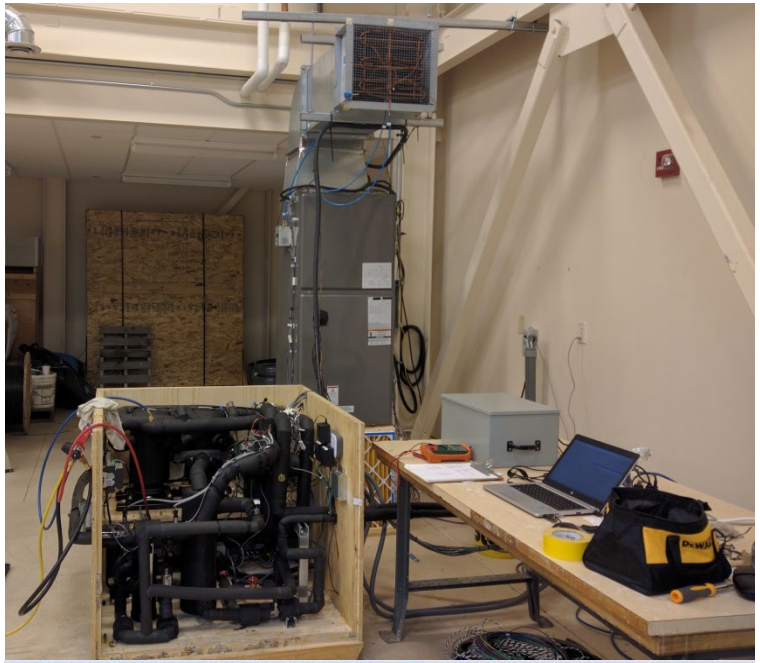
Cold Climate and Integrated Heat Pumps

CCHP



Field testing in Ohio using a pair of single-speed compressors;
achieved 75% rated capacity down to −13°F;
40% energy bill reduction in a peak heating month



Field testing in Alaska, using a pair of vapor-injection compressors

- Work in most extensive and extreme ambient range down from −30°F to 60°F
- >1.6 COP at −30°F.

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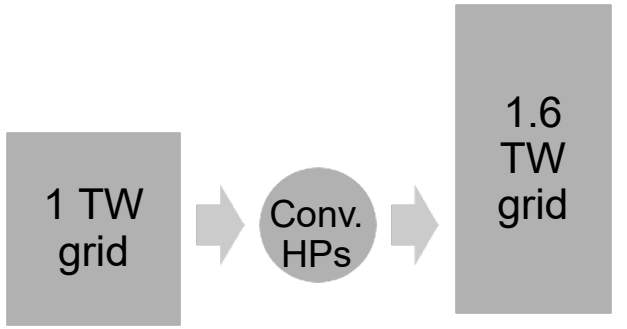
TES to enable residential heating electrification

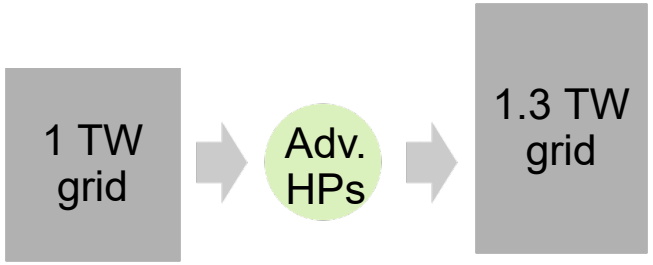
If all 57 million furnaces were replaced with conventional or cold-climate heat pumps…

Electrification with conventional HP



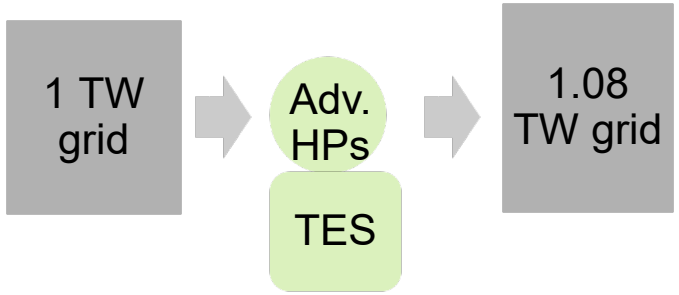
Electric resistance backups 10 kW on cold days increases demand significantly

Electrification with cold-climate HP (CCHP)



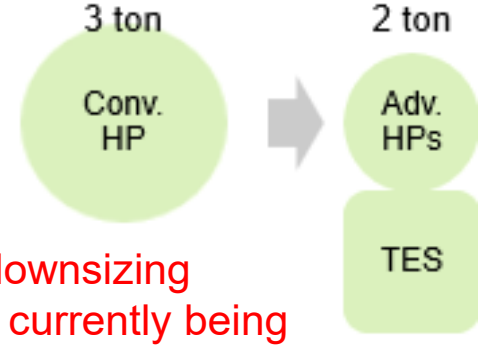
Maintain COP >2 on coldest days

Peak load management with CCHP and TES



TES to enable shifting of 75% of peak loads to off-peak hours

TES can boost HP capacity and reduce HP size



(Actual downsizing potential currently being modeled)

$1000 savings: Downsizing residential HP from 3-ton to 2-ton

$700 cost: Installing 4 hours of TES at $25/kWh

$300: net first cost savings to homeowner, while delivering additional peak-reduction benefits to the grid

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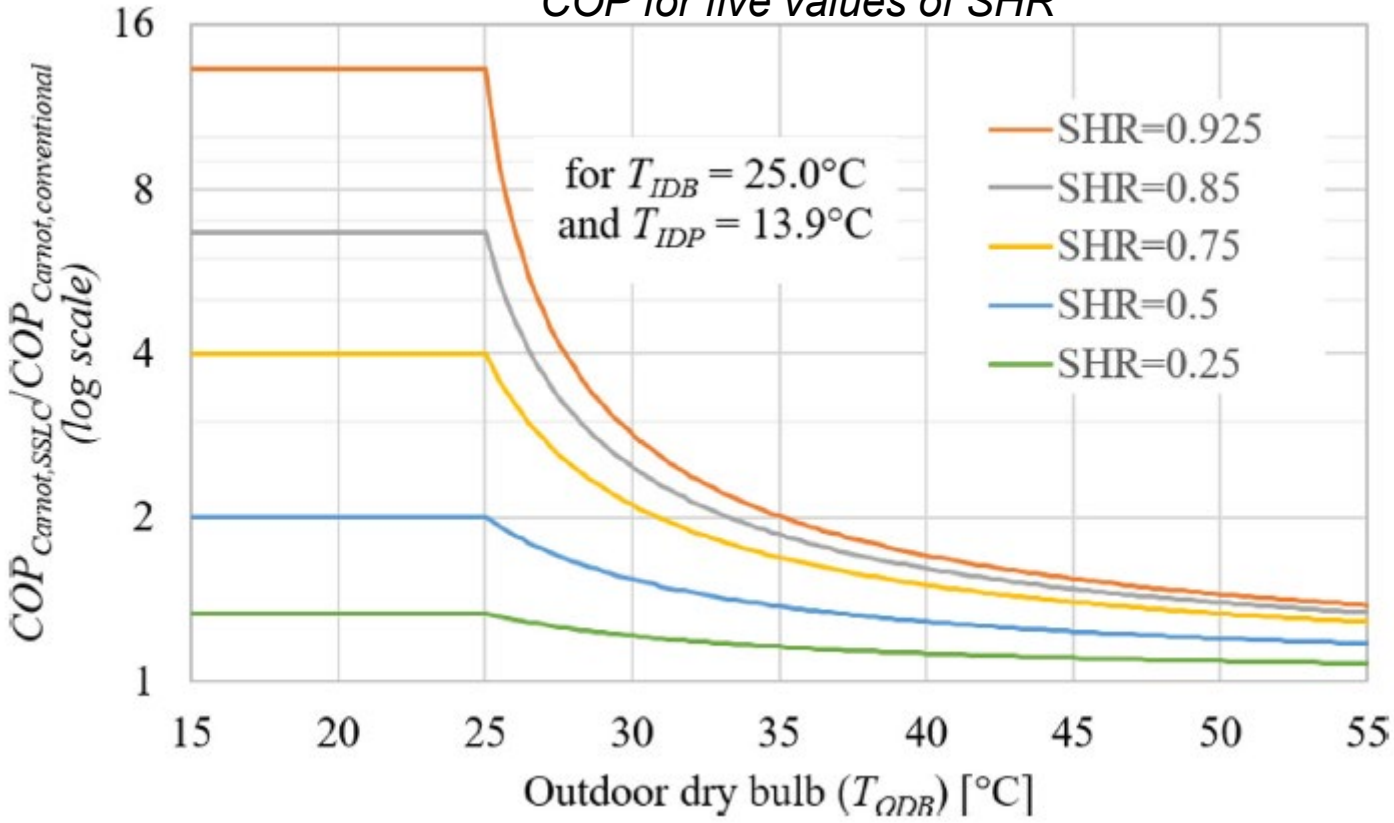
Separate Sensible and Latent Cooling (SSLC)

- Buildings today rate poorly on comfort
- Conventional AC:
  - only dry bulb temperature is measured
  - Humidity control is addressed (often poorly) through system sizing practices
- SSLC can improve comfort AND efficiency.

Figure: Ratio of SSLC Carnot COP to conventional Carnot COP for five values of SHR



The laws of thermodynamics impose a fundamental limit on air conditioning efficiency (the Carnot limit). SSLC operates with a different Carnot limit than conventional methods.

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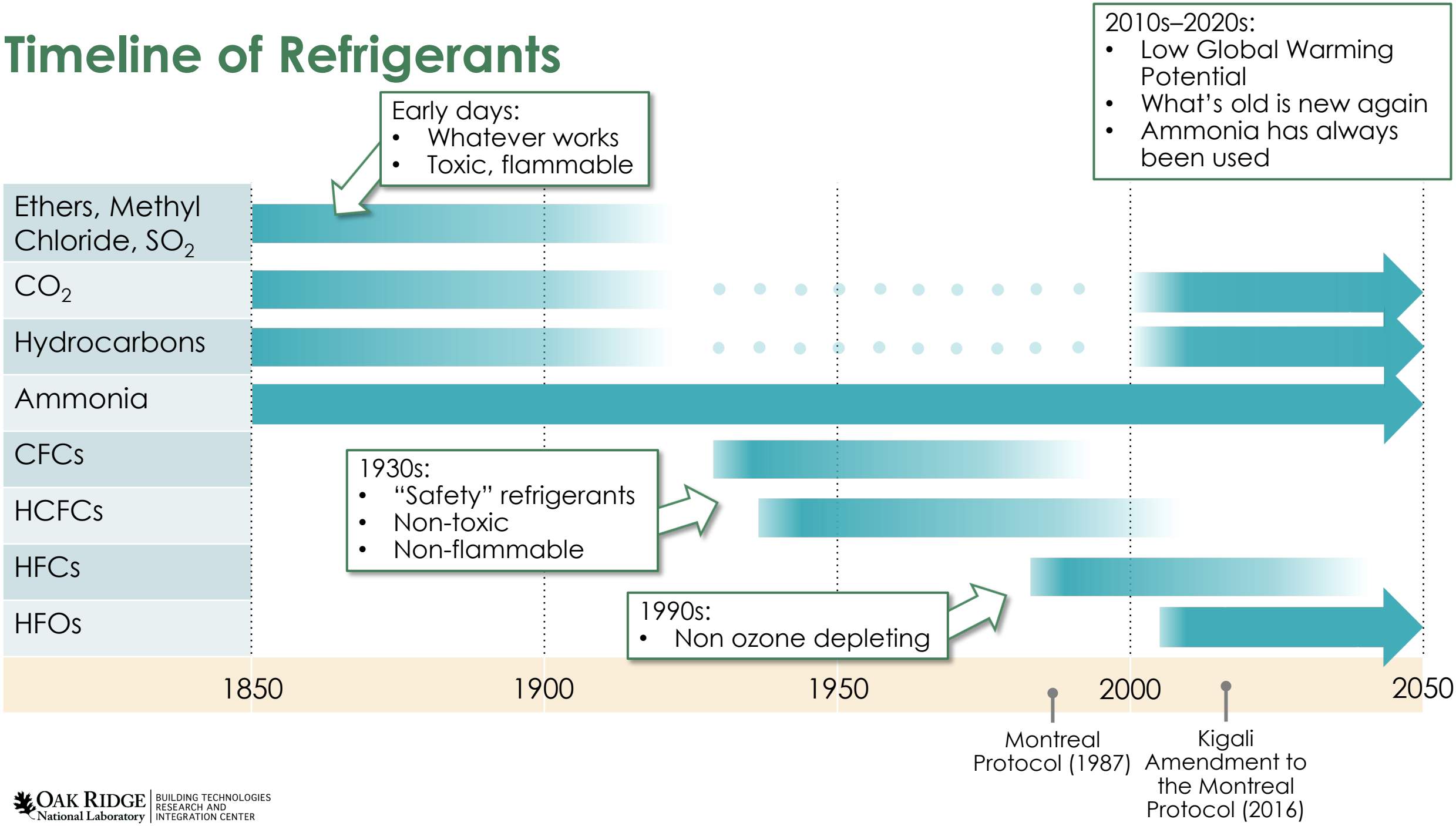
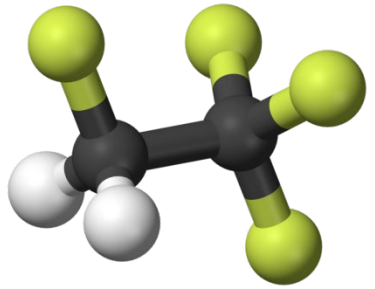
Timeline of Refrigerants

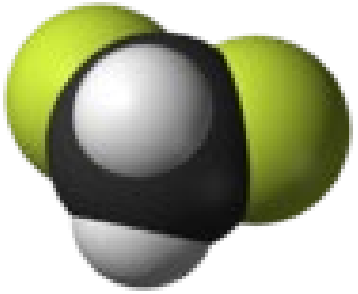


Current and Next Generation Refrigerants

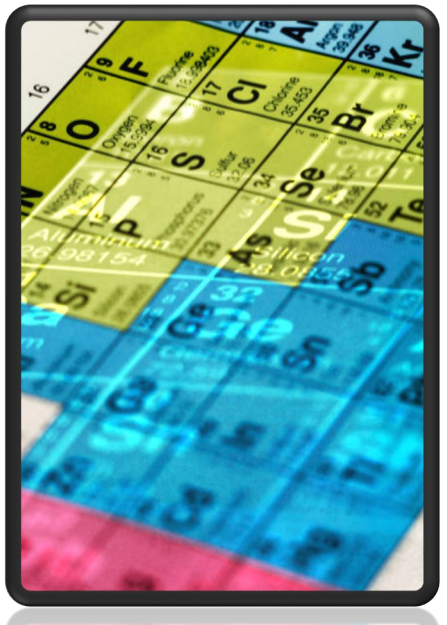
- Hydrofluorocarbons (HFCs)
  - Contains no chlorine
    - No threat to ozone
  - Potent greenhouse gasses
    - Several thousand times more potent than CO_2
- Hydrofluoro-olefins (HFOs)
  - Fluorinated propene isomers
  - Low Global Warming Potential
- "Natural" Refrigerants
  - What's old is new again?
  - Ammonia, CO_2, hydrocarbons
  - Very low global warming potential

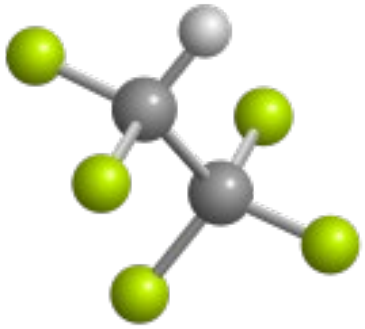


R-134a



R-32





R-125

Sample project list

- High-Efficiency Air-Source Multi-Stage Cold-Climate Integrated Heat Pump
- Next Generation Low Cost Direct-Expansion Heat Pumps Using Refrigerant Mixtures with GWP <150
- International HVAC&R Research Collaboration through IEA and IIR
- Novel Heat Exchanger Design Based on Porous Materials (CRADA Baltimore Air Coil (BAC))
- Refrigerated Vending Machines with A3 Refrigerants (CRADA with National Appliance Manufacturers Association, NAMA)
- Flexible HP WH with embedded energy storage (CRADA AOS)
- Seamlessly Fuel-Flexible Heat Pump (SSFHP)
- NG blend with Hydrogen fuel cooking appliances/CRADA with SoCalGAS
- Fast Drying Hybrid Thermoelectric Dryer
- Low-charge Ammonia/CO2 System for Integrated Refrigeration, Air-Conditioning & Heating in Commercial Application
- Real-world Leak Assessments of Alternative Flammable Refrigerants
- Max Tech Efficiency Electric HPWH with low-GWP Halogenated Refrigerant
- Advanced Adsorption technology for new high-efficiency natural-gas furnace at low cost.
- Low cost, high performance polymer composite heat exchangers manufactured by additive manufacturing
- Cast Heat Exchanger Using the Novel Ce-Al Alloy

Industry-ORNL: Common Collaboration Mechanisms

Table is non-comprehensive and for illustrative purposes only

Collaboration mechanism	Industry contribution		*Typical* treatment of generated IP	Publications and reporting requirements
	Quantity	*Type*		
FOA: funding opportunity announcement	10-20% cost share	In kind	Background: unchanged By industry: industry owns By ORNL: ORNL owns Joint: right of first refusal	Annual peer review. Journal, conference pubs. Regular reporting to DOE.
CRADA: cooperative research and development agreement	50% typical	In kind[3]	Background: unchanged[1] By industry: industry owns By ORNL: ind. has ROFR[2] Joint: ind. file; has ROFR	Journal, conference pubs. Regular reporting to DOE. Final report (optional embargo for some years).
SPP: strategic partnership project	100%	Direct funds	Industry sponsor may own or take title to generated IP	Report to DOE.

Footnotes cover some additional details:
1. Can become CRADA subject inv. if first reduced to practice under CRADA
2. Commercial license is another option
3. Can also be combination of in-kind plus funds-in

More details: https://www.ornl.gov/sites/default/files/MechanismsMatrix.pdf

Conclusion

- We are in the midst of an unprecedented energy transition
  - Next generation low-GWP refrigerants
  - Decarbonization and electrification
- ORNL is a federally funded R&D center equipped to support industry and utilities in the nation's transition to a next generation HVAC and energy conversion world
- We welcome opportunities to support you!

Thank You

OAK RIDGE National Laboratory

Xudong Wang

Air Conditioning, Heating, and Refrigeration Institute (AHRI)

Heat Pumps at Scale, the Game Changer – Where Are We Now, and What Will It Take?
Better Buildings Residential Network
Energy Efficiency and Renewable Energy
U.S. Department of Energy

Food for Thought: Heat Pumps for Space Heating at Scale

December 9, 2021

Xudong Wang

Air-Conditioning, Heating, and Refrigeration Institute

2311 Wilson Blvd., Suite 400, Arlington, VA 22201

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Overview

Heat pump market trend

Technology challenges

Key factors to consider

Needed technologies/tools moving forward

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commercial & industrial refrigeration equipment

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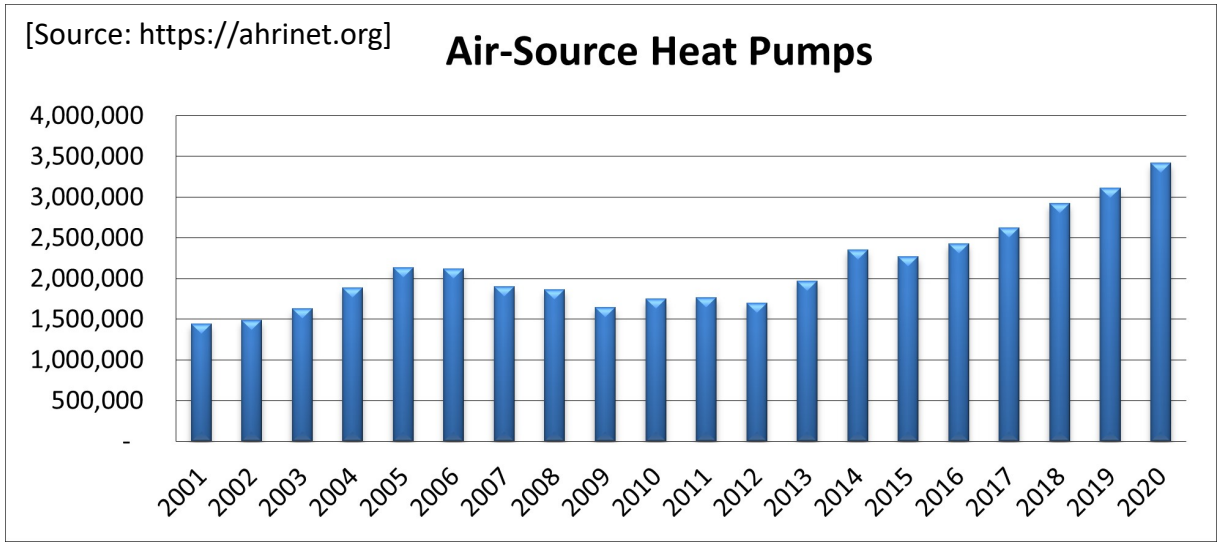
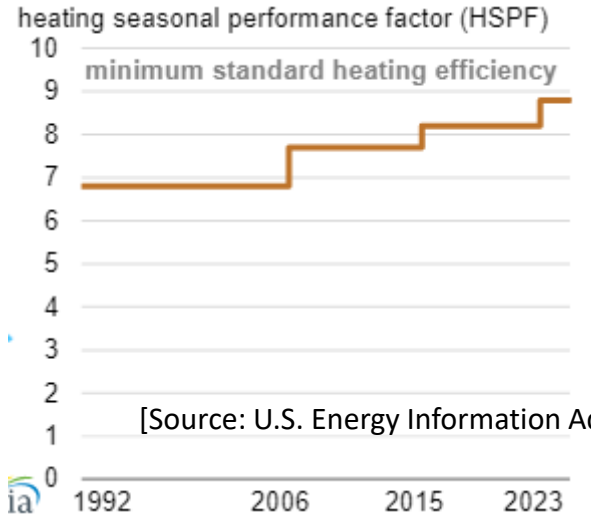
Heat Pump Market Trend

- Market has been growing, and products get more and more efficient

[Source: https://ahrinet.org]





[Source: U.S. Energy Information Administration]

- Shipments are much larger to southern states than to the north

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Heat Pump Market Trend

- There is more space to grow
  - 76 million primary occupied U.S. homes (64% of the total) use central air-conditioning equipment source: 2015 Residential Energy Consumption Survey by EIA
  - Only about 13 million homes (11% of the total) use heat pumps for heating or cooling source: 2015 Residential Energy Consumption Survey by EIA
- Increasing regulatory trend to convert heating from gas to electric heat pumps
  - Heat pumps generate heating capacity greater than energy they consume.
  - Heat pump technology is considered by policy makers and regulators as a major means of decarbonization to meet their emission reduction goals.

Heat Pump Challenge

- In some areas, heat pump use may result in more carbon emissions than gas heating

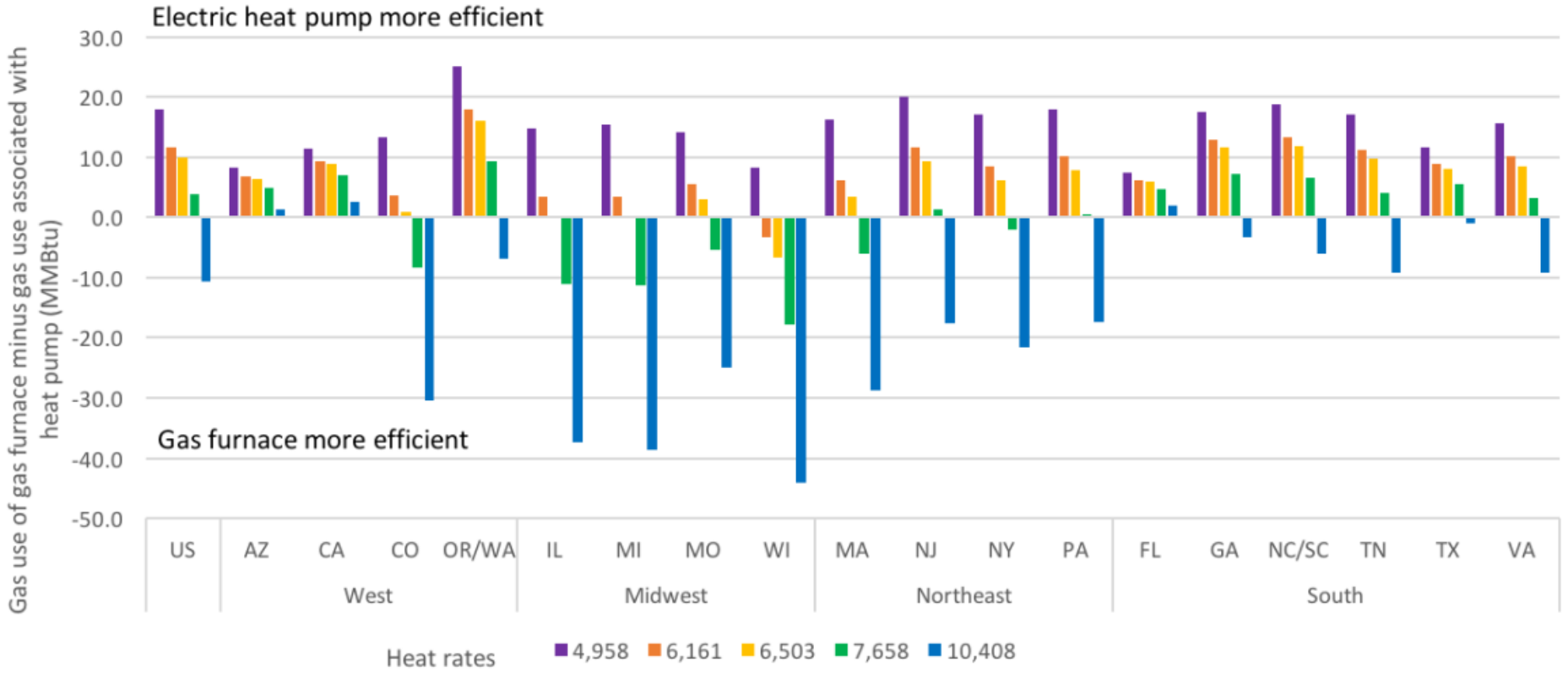

Figure 3. Comparison of a 95% AFUE furnace with a 10.3 HSPF electric heat pump

Source: 2016, Comparative Energy Use of Residential Gas Furnaces and Electric Heat Pumps, ACEEE

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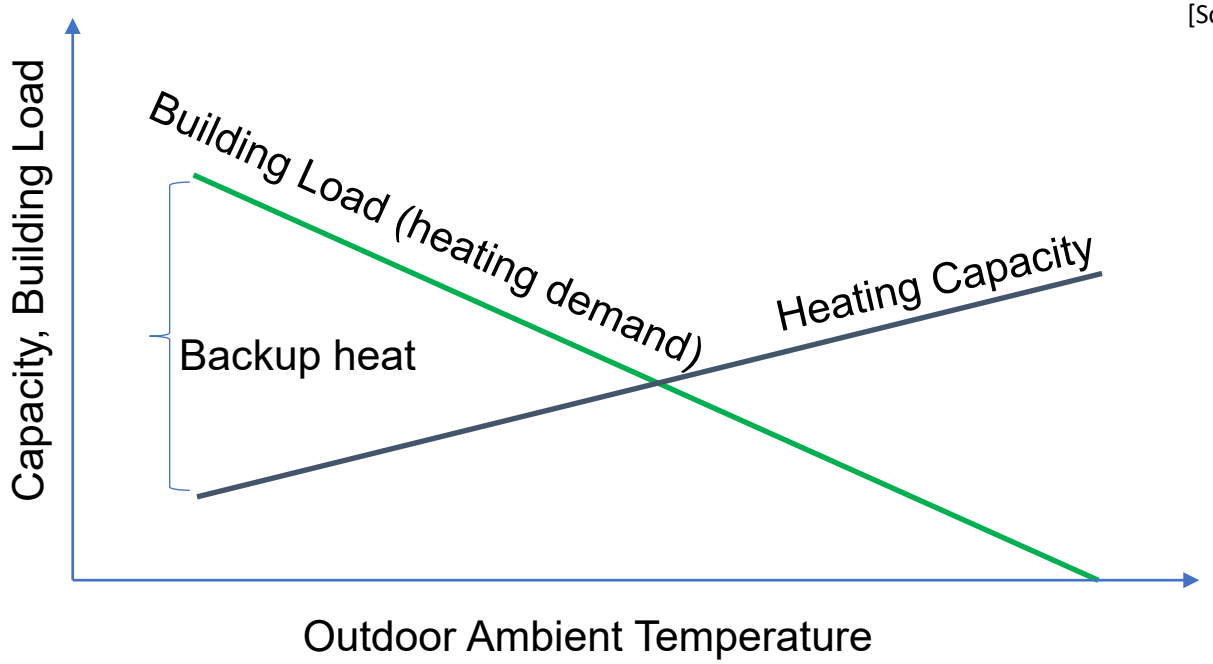
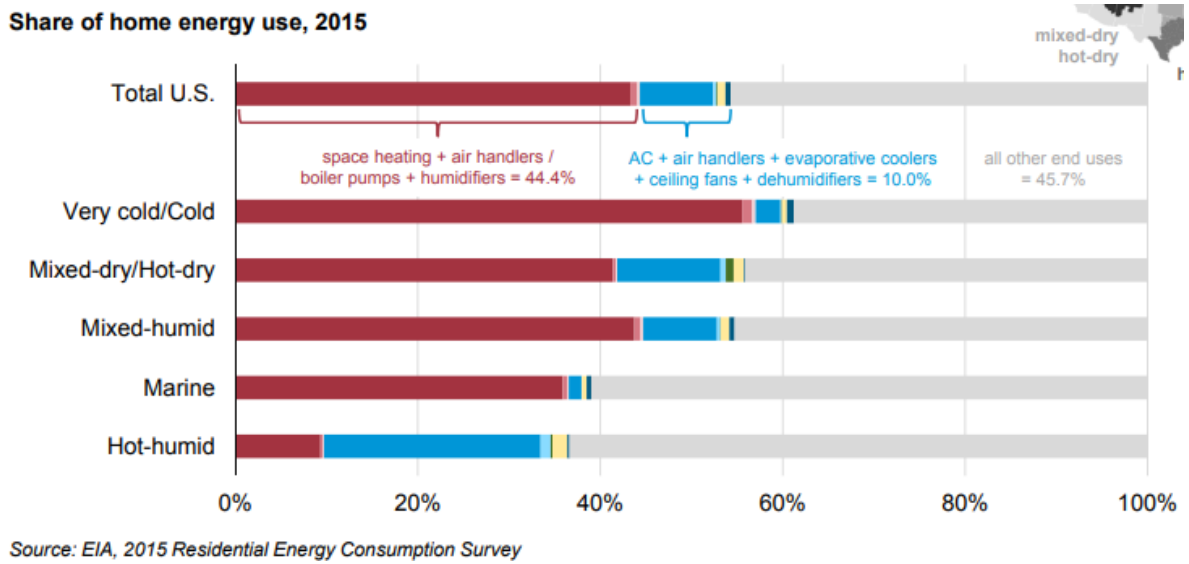
Typical Performance and Load Profile



[Source: https://www.eia.gov/consumption/residential/webinar_slides/highlights_from_the_2015_RECS.pdf]



- The heat pump capacity and efficiency inevitably decrease as the outdoor ambient temperature drops (provide the least heating when it is the most needed.)
- It requires additional energy to provide the backup heat.
- Winter heating demand is much larger than summer cooling demand in most regions.

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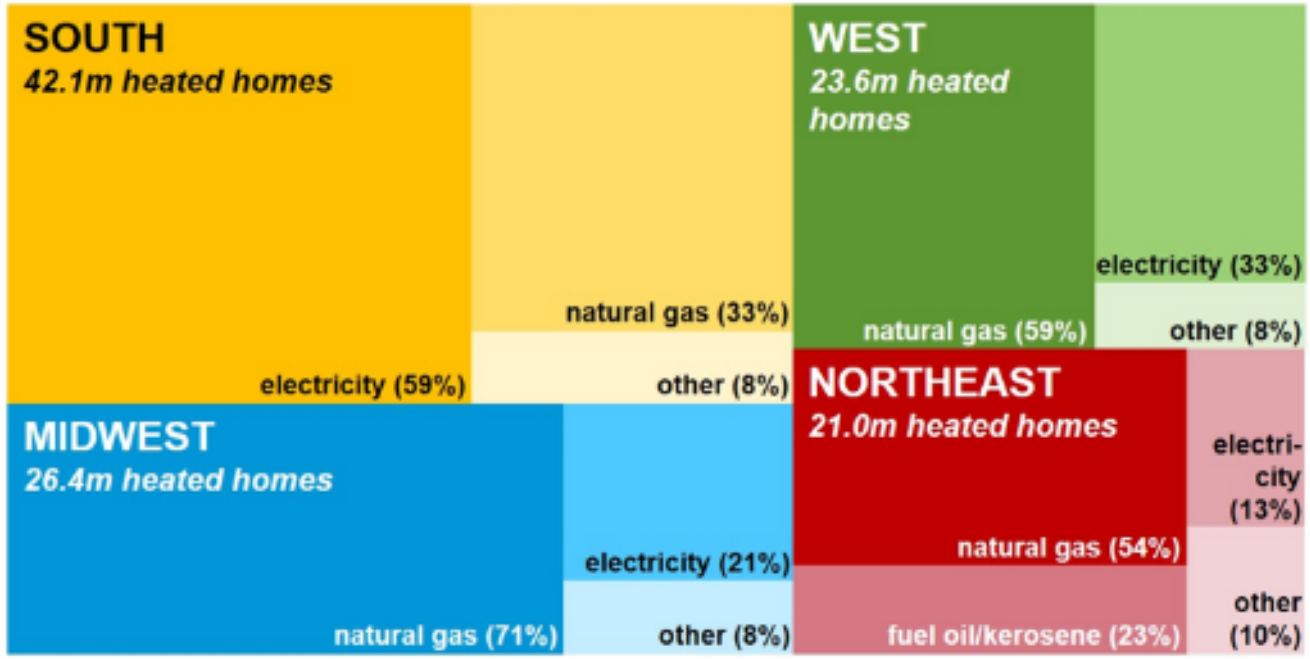
Energy Sources for Heating

- Natural gas is the primary home heating fuel in most regions
- Switching to heat pumps at scale requires grids to handle a significantly larger winter peak demand

Figure 4. Natural gas is the most-used heating fuel in heated homes in three of four Census regions

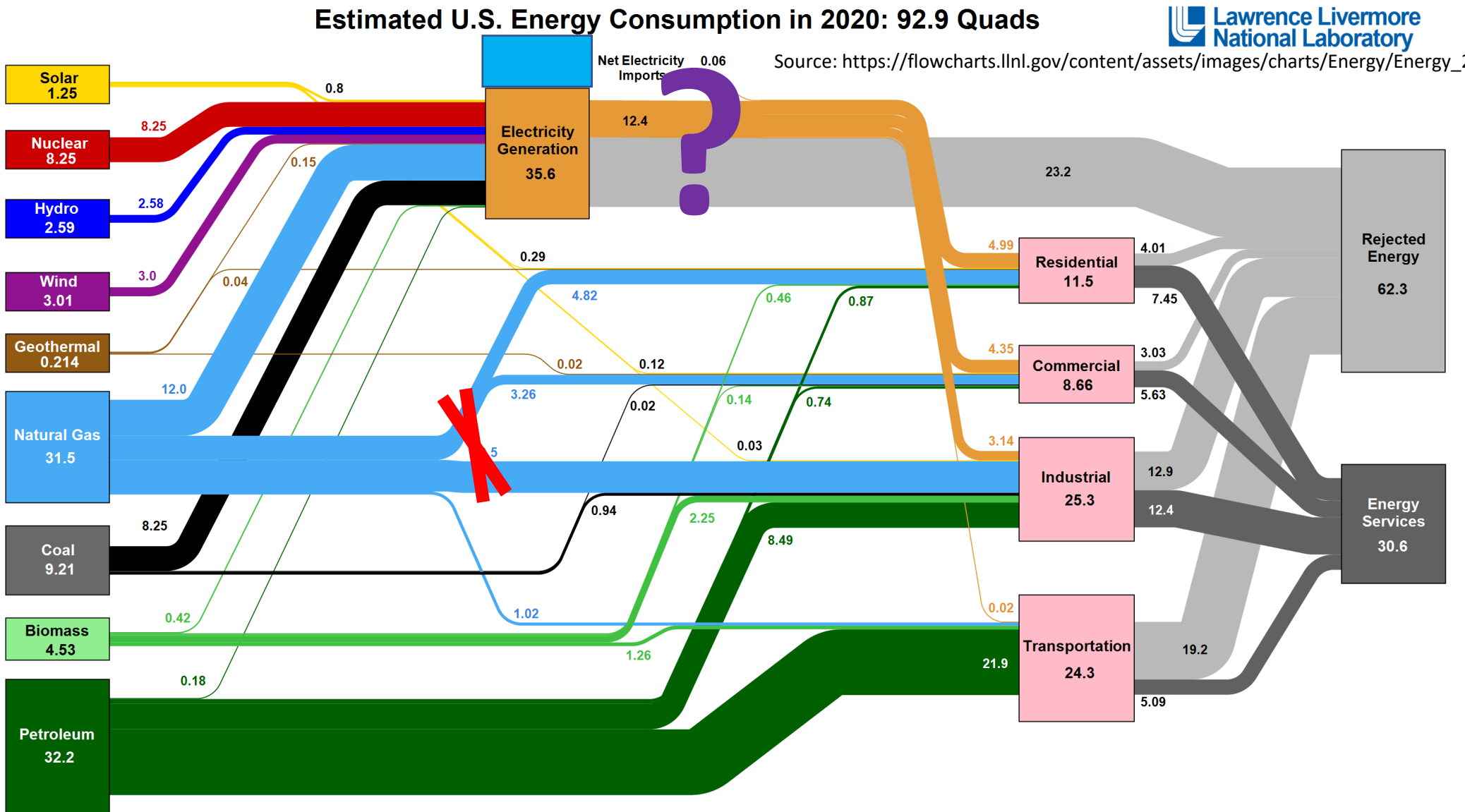
main space heating fuel by Census region



Note: Fuel oil includes homes that used kerosene.

Source: U.S. Energy Information Administration, 2015 Residential Energy Consumption Survey.
[Source: https://www.eia.gov/consumption/residential/reports/2015/overview/]

- Could the current local power plants and renewable energy keep up the increased demand?
- If not, where is the make-up electricity coming from, and what are its energy sources and their emission factors (natural gas, renewable, coal etc)?



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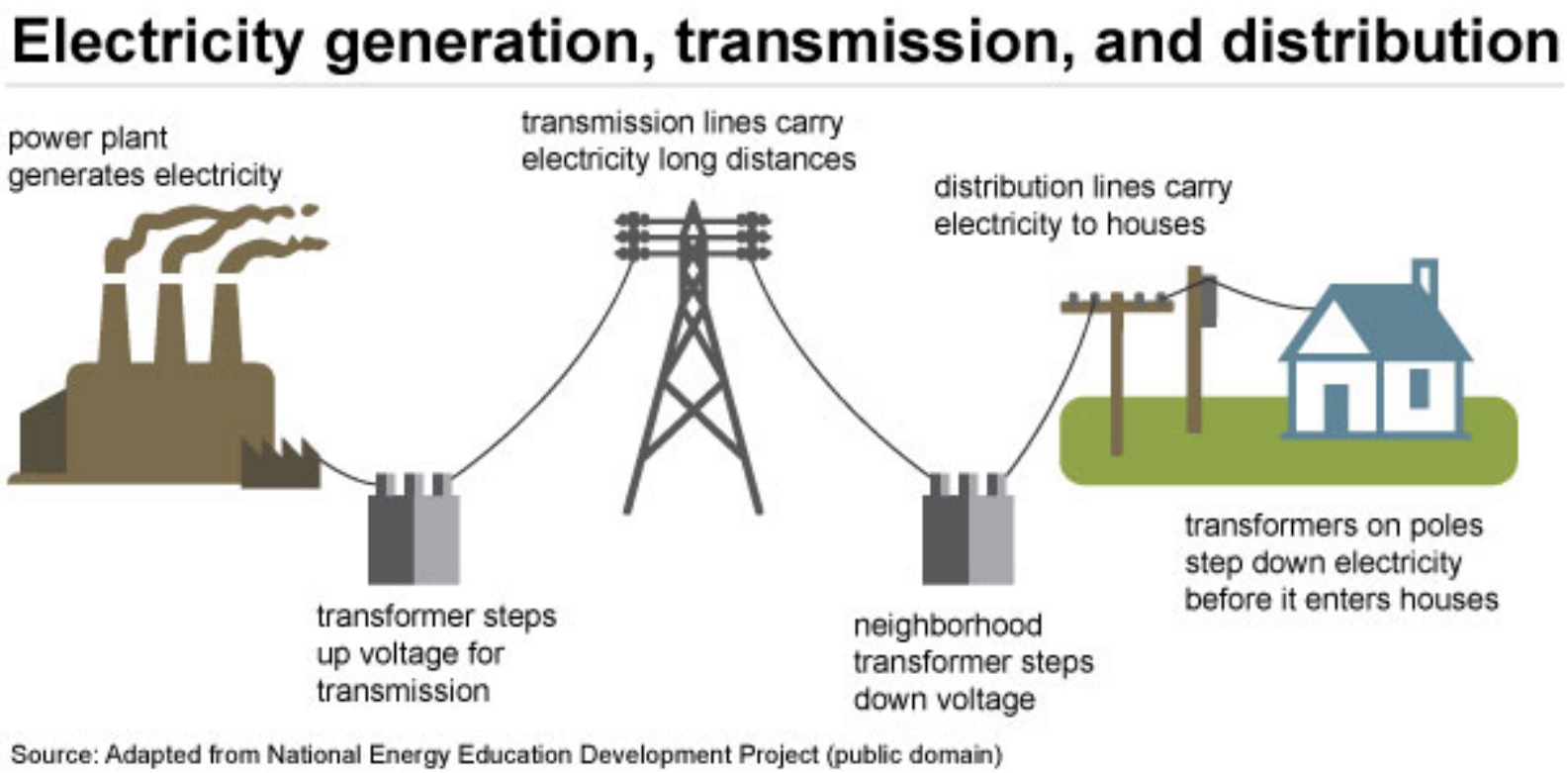
Electricity at meter is not the whole picture



[Source: https://www.eia.gov/energyexplained/electricity/delivery-to-consumers.php]

- In 2020, the energy consumed to generate electricity was 36.47 quad btu, and only 12.97 quad btu electricity (~36%) was delivered to end use
- The rest were losses from conversion, transmission and distribution

[Source: https://www.eia.gov/totalenergy/data/flow-graphs/electricity.php]

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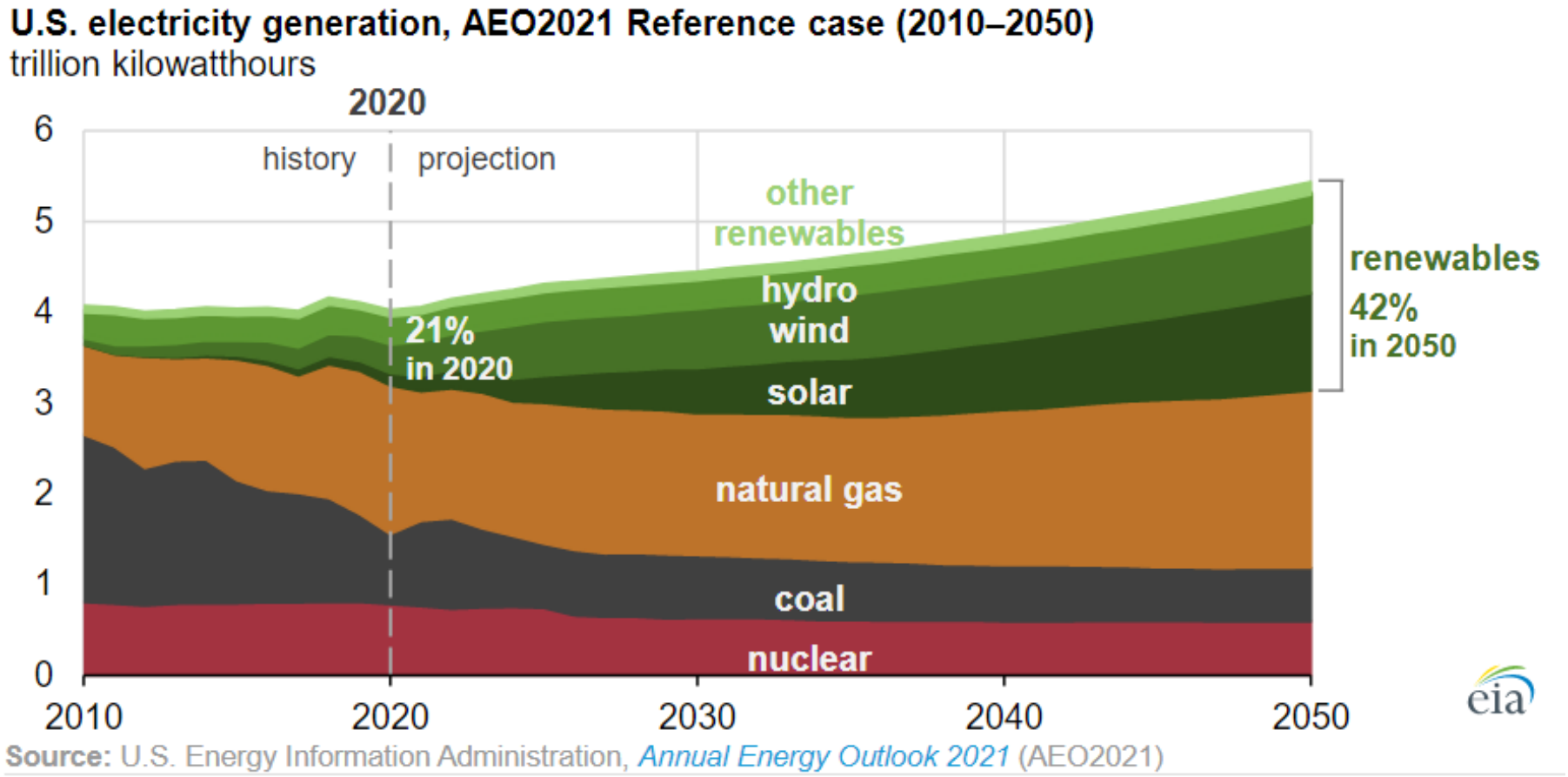
Power Mix Impact



- Renewable energy has increased, but there are still a number of coal burning power plants
- Regions using electricity primarily generated from coal should use gas heating instead of heat pumps

[Source: https://www.eia.gov/todayinenergy/detail.php?id=46676]

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Technologies for Emission Reductions

Heat pump technology advancement on:

- Cold climate heat pumps
- Heat pumps coupled with thermal energy storage

Alternatives:

- High efficiency gas systems
- Gas products using hydrogen or renewable gas
- Gas absorption heat pumps
- Dual fuel heat pumps

A Needed Tool For Measuring Climate Impact

- To provide an easy way for policy makers to determine the carbon impact of proposed energy policies
- National map of states' ability to electrify
- State status report on electrification readiness:
  - Percent capacity and carbon output for each energy source
  - Carbon impact of appliance changes (new electric, upgraded gas, etc.)
- Local carbon footprint home calculator

Summary

- Heat pumps are getting more and more popular and play an important role in decarbonization
- It is not a one-size-fits-all technology, and mass deployment requires careful emission and cost savings analyses
- Grid cleanliness, capacity and reliability are keys to the success
- Gas heating technologies do exist and are emerging as alternatives to achieve the same emission reduction goals

Questions?

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