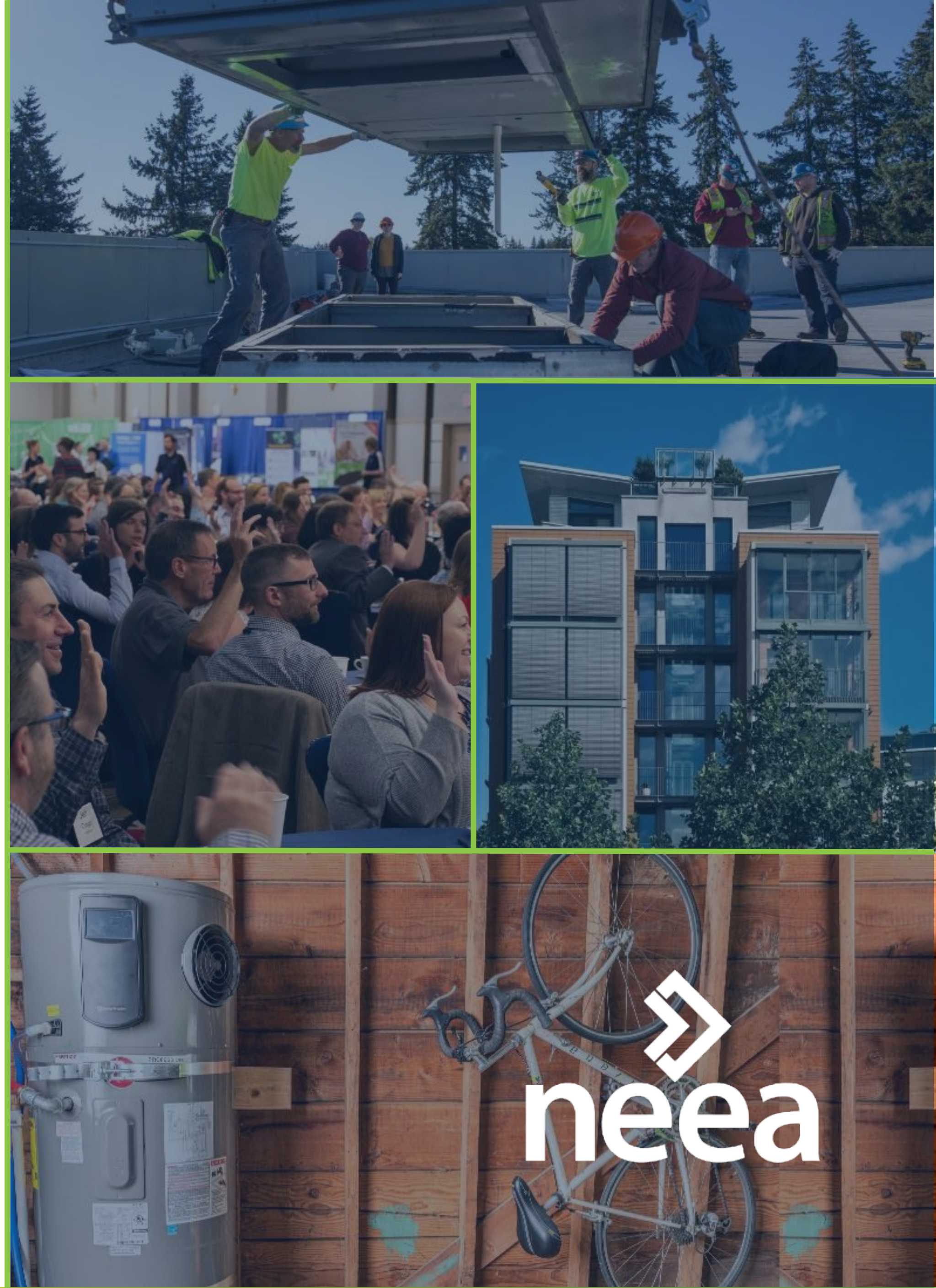
Regional Emerging Technology Advisory Committee (RETAC)

Northwest Energy Efficiency Alliance

Q1 2024 Meeting

March 28, 2024

8:30 a.m. – 12:15 p.m.

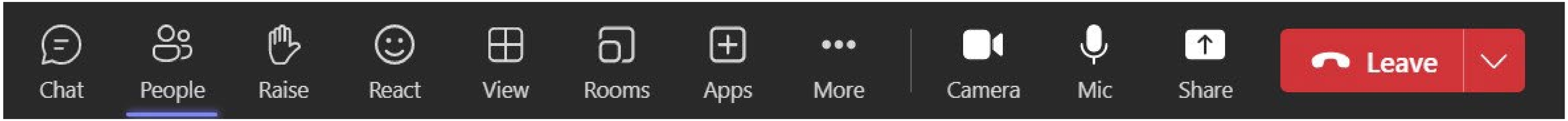


CLASSIFICATION LEVEL: PUBLIC

Navigating MS Teams Layout

Raise Hand

Camera &
Microphone



Chat

Exit Call

Note: These options may vary, depending on which version you're using.

Name,

Title,

Organization

and …

What is your favorite new (to you) technology that you use, or are interested in?

Waterdrop system installation in CA

Agenda

8:30 am	Welcome and Announcements
9:00 am	*New!* ORNL Emerging Technology Update
10:15 am	*Break*
10:30 am	*New!* ACEEE Hot Air/Hot Water Forum Round Table
11:00 am	*New!* NEEA Emerging Technology Update
12:00 pm	Wrap-Up

Q4 2023 Emerging Tech Newsletter

2024 Q1 *Emerging Technology Quarterly Newsletter*

WHAT'S NEW:

2024 is off to a strong start for the Emerging Technology team. In addition to the progress on existing efforts, several new projects got underway including testing of commercial heat pump dryers, a commercial secondary window field study in collaboration with the California Energy Commission, participation in the development of vacuum insulated panels for easy exterior building retrofits, and the site selection of luminaire level lighting controls with integrated HVAC field test. Additionally, ENERGY STAR® and the U.S. Department of Energy (U.S. DOE) released a draft test procedure for micro heat pumps as an addition to the room air conditioner specification, which is expected to be adopted the first half of 2024. Lastly, the U.S. DOE launched a $2 million prize to advance American-made secondary glazing systems.

Recently Published Emerging Technology Reports:

- Commercial Secondary Window Field Test
- Heat Pump Water Heaters In Multifamily New Construction: Design Charette Findings

Recent Product Councils:

- Montana State University Integrated Design Lab – Ventilation Requirements for Residential Buildings in Cold Climates
- Existing Building Audits with QBAT
- Integrated Design Lab Series – University of Idaho – Bio-Based Building Materials and Rural Energy Audits

Information on upcoming Product Councils is always available at https://neea.org/get-involved/product-council.

Please reach out to Eric Olson or one of NEEA's product managers with questions or suggestions on NEEA's emerging technology work. NEEA staff would love to hear from you.

~ **Eric Olson**, Manager, Emerging Technology & Product Management ~

TABLE OF CONTENTS

Questions about this report may be addressed to:
Eric Olson
Manager, Emerging Technology & Product Management
eolson@neea.org

PUBLISH DATE: MARCH 15, 2024

https://neea.org/resources-reports

- Selected Q1 Highlights
  - Recent Product Councils
    - Montana State University Integrated Design Lab
    - Existing Building Audits with QBAT
    - University of Idaho Integrated Design Lab
  - Recently Published Emerging Technology Reports
    - Commercial Secondary Window Field Test
    - Heat Pump Water Heaters In Multifamily New Construction: Design Charette Findings

Q1 2024 Emerging Tech Newsletter

Product Summary & Readiness Levels

	PRODUCT OR PROJECT	PROGRAM*	FUEL TYPE	SECTOR	ELECTRIC SAVINGS POTENTIAL[1]	GAS SAVINGS POTENTIAL[2]	PRODUCT PERFORMANCE[3]	MARKET/ COMMERCIAL[3]	PROGRAM READINESS[3]
Products	Ultra-High Definition TVs	RPP			57	N/A	4	5	5
	Residential Laundry Field Study	RPP			N/A	N/A	5	5	5
	Monitors and Commercial Displays	TBD			TBD	N/A	3	5	1
	Laundry Centers & All-in-One Washer-Dryers	RPP			TBD	TBD	3	5	2
	Commercial Heat Pump Dryers	TBD			TBD	TBD	1	3	1
HVAC	Very High Efficiency Dedicated Outside Air Systems	VHE DOAS			85	20†	4	5	5
	Efficient Rooftop Units	ERTU			N/A	9	4	3	4
	Heat Pump Rating Representativeness	AHP			TBD	N/A	3	5	4
	Heat Pump Advanced Features and Capabilities	AHP			35†	N/A	3	5	4
	Micro Variable Speed Heat Pump Field Study	TBD			TBD	N/A	1	3	1
	Heat Pump Ready ENERGY STAR® Manufactured Homes	AHP			TBD	N/A	4	5	3
	Dual Fuel Gas-Electric Heat Pump	DFHP			TBD	TBD	5	3	1
Building	High-Performance Windows	HPW			60	30	4	3	4
	Secondary Windows	Window Attachments			35	23†	1	5	4
	Skinny Wall Retrofit Panels	TBD			TBD	TBD	2	1	1
Lighting	Luminaire Level Lighting Controls	LLLC			75	N/A	4	4	3
	LLLC with HVAC Control	LLLC			358	TBD	3	2	3
	Parking Lot Lighting with LLLC	TBD			TBD	N/A	3	3	1
Water Heating	Combination Hot Water and Space Heat	N/A			130	N/A	1-4	1-3	2
	Heat Pump Water Heaters in Confined Spaces	HPWH			TBD	N/A	2-5		
	Integrated Residential GHPWH	GHPWH			N/A				
	Central Commercial Heat Pump Water Heater	HPWH							
	Central Commercial Thermally Driven Heat Pump	TBD							
	Split System Heat Pump Water Heater	HPWH							

https://neea.org/resources-reports

Other stuff we're doing…

- Continue monitoring additional sites with Very High Efficiency DOAS
- Continue monitoring Efficient Rooftop Units installation, final report anticipated at Q3 2024
- Working with other organizations on a GTI ENERGY-led California Energy Commission secondary window field study
- Participating in a co-funded project to develop customizable vacuum insulated panels for external building installations

2024 RETAC Meeting Dates

Q1	Thursday, March 28
Q2	Thursday, June 27
Q3	Wednesday, September 25
Q4	Thursday, December 12

Conferences
Product Councils

Conferences

Past Conferences

- IEEE Rising Stars Conference – January 2024
- Consumer Electronics Show – January 2024
- CEE Winter Program Meeting – January 2024
- AHR Expo and ASHRAE Winter Conference – January 2024
- Midwest Energy Efficiency Alliance Conference – January 2024
- AESP Annual Conference – February 2024
- National Association of State Energy Officials Policy Outlook – February 2024
- IEEE Integrated Smart Grid Technologies Conference – February 2024
- Building Science Symposium – February 2024
- International Builders Show – February 2024
- Hydraulic Institute – February 2024
- AESP 2024 Conference – February 2024
- EPRI 2024 Conference – March 2024
- ACEEE Hot Water & Hot Air Forum – March 2024
- 2024 HVACR Education Conference – March 2024
- LEDucation – March 2024
- Dry Climate Forum – March 2024

Conferences

Upcoming Conferences

- GTI Emerging Technology Program – April 2024
- Better Building, Better Plants Summit – April 2024
- Int’l Facility Management Assoc. OR and SW WA Symposium – April 2024
- Energy Solution Center Tech & Market Forum – April 2024
- LightSpec West – April 2024
- Utility Energy Forum – April 2024
- AEE West – May 2024
- Peak Load Management Conference – May 2024
- AIA Oregon Design Conference – May 2024
- Efficiency Exchange 2024 – May 2024
- Emerging Water Technology Symposium – May 2024
- IES DOE Research Symposium – May 2024
- Getting to Zero Forum – May 2024
- Association Society of Gas Engineers – June 2024
- CEE Summer Meeting – June 2024
- ASHRAE Summer Conference – June 2024
- Window and Door Manufacturers Association – June 2024

Q1 2024 Product Council Presentations

Presenter	Topic	Date Scheduled	Webinar Recording
Pacific Northwest National Laboratory (PNNL)	Existing Building Audits with QBAT	2/27/2024	Northwest Energy Efficiency Alliance (NEEA) | Existing Building… (presentation slides only)
Integrated Design Lab Series: University of Idaho	Bio-based Building Materials and Rural Energy Audits	3/5/2024	Northwest Energy Efficiency Alliance (NEEA) | IDL Series - University…
Integrated Design Lab Series: Washington State University	Understanding the Workforce Landscape for Industrialized Construction Products and Practices	3/19/2024	Northwest Energy Efficiency Alliance (NEEA) | IDL Series - Washington…
Integrated Design Lab Series: Washington State University	Market Engagement in Whole Building Energy Efficiency and Integrated Design	3/26/2024	Available Soon!

Upcoming Product Council Presentations

Presenter	Topic	Date Scheduled	Registration Link
Christopher Dymond with Cadeo Group	Low Load Efficient Heat Pump Research	4/2/2024	Registration Link
PlentifulAI	AI Targeting of Energy Efficiency & Decarbonization Opportunities	5/21/2024	Available Soon!

https://neea.org/get-involved/product-council

 |

ORNL Emerging Technology Update

ORNL overview, and selected projects in thermal storage and dual fuel heat pumps

Kyle Gluesenkamp
Oak Ridge National Laboratory

March 28, 2024

NEEA Q1 Regional Emerging Technology Advisory Committee Meeting

Agenda

- ORNL history; current Buildings research at ORNL
- Specific projects
  - Thermal storage integrated with heat pump
  - Dual fuel heat pump
- Collaboration mechanisms and brainstorming on joint opportunities

I'll pause for discussion after each main agenda item

- For next time:
  - Refrigerants
  - Envelope technologies
  - You name it!

National Laboratory System

- Character and Mission vary by Laboratory
- Long-term S&T challenges of importance to Nation and that require multi-disciplinary expertise and unique tools
- Unique user-facilities that are accessible to scientists throughout the world
- National response to urgent needs and disasters
- Development of the next-generation workforce
- Regional footprint of labs, important to translate science to solutions

17 Labs	70,000 employees	$388B economic returns	118 Nobel Prizes

Visit the nationallabs.org for more information

Oak Ridge National Laboratory evolved from the Manhattan Project

ORNL in 1943

The Clinton Pile was the world's first continuously operated nuclear reactor

ORNL facts and figures

$2.7B
annual expenditures

~6,040
employees

$750M
modernization investment

Nation's most diverse energy portfolio

3,200
research guests annually

Nation's largest materials research portfolio

Forefront scientific computing facilities

World's most intense neutron source

World-class research reactor

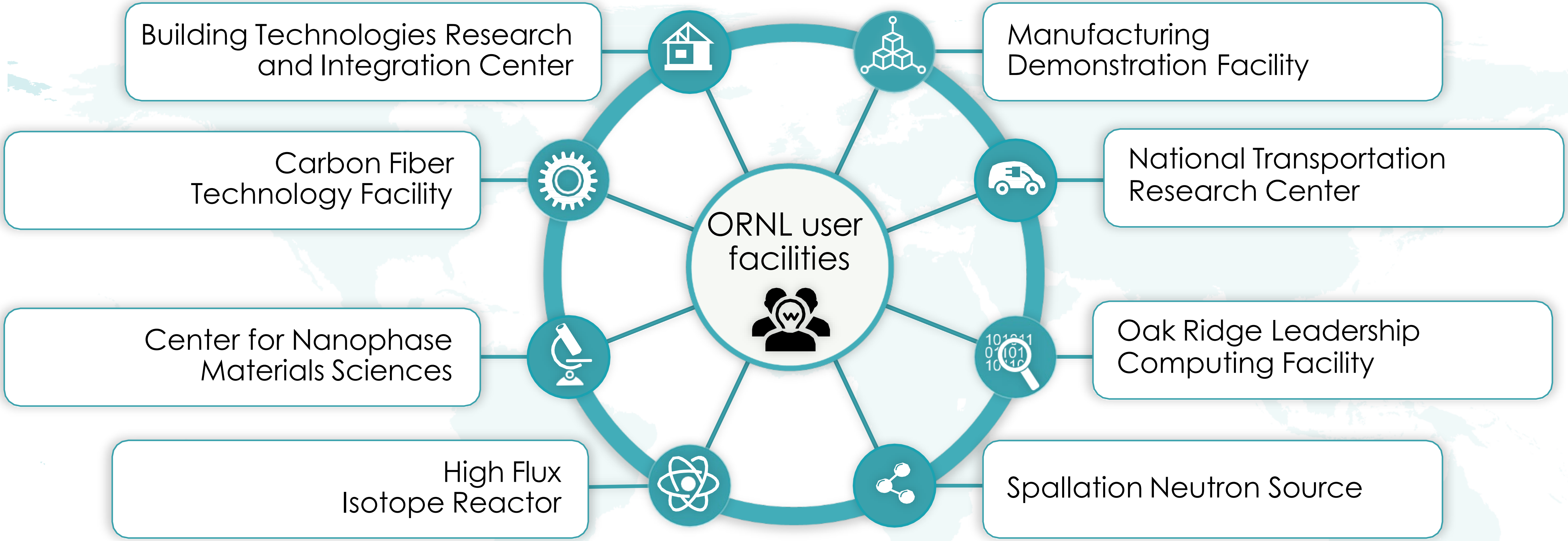
2,511
journal articles published in FY21

Managing major DOE projects: US ITER, exascale computing

241
invention disclosures in FY21

52
patents issued in FY21

ORNL’s distinctive facilities bring thousands of R&D partners to Tennessee each year



Building Technologies Research and Integration Center (BTRIC)

- Equipment technologies
- Building envelopes
- Building systems integration
- Buildings-to-grid

Deliver scientific discoveries and technical breakthroughs to accelerate building energy efficiency solutions

BUILDINGS-TO-GRID

- Low-cost wireless sensor technologies
- Transactive controls
- Power electronics
- Building energy models

HVAC&R AND APPLIANCES

- Develop affordable component and system technologies
- HVAC
- Water heating
- Refrigeration
- Appliances
- Energy storage

ENVELOPES

- Develop affordable technologies to address heat, air, and moisture flow
- Low-cost high R-value insulation
- Dynamic insulation
- Thermal energy storage
- Walls, roofs, attics, foundations, sheathings, membranes, coatings, and materials

INTEGRATION

- Performance characterization at the materials, component, system and whole-building levels
- Evaluate prototypes under realistic conditions
- Evaluate impacts of retrofit technologies

Grid-Interactive Efficient Buildings

Building Technologies Research & Integration Center (BTRIC)

Demonstrating building energy efficiencies **since 1993**

60,000+ ft² of research space

Only DOE-designated user facility for building technologies

13
R&D100 AWARDS

125+
R&D PARTNERS

52
ACTIVE CRADAS

31
ASHRAE AWARDS

236
PUBLICATIONS

3,650+
VISITORS SINCE 2012

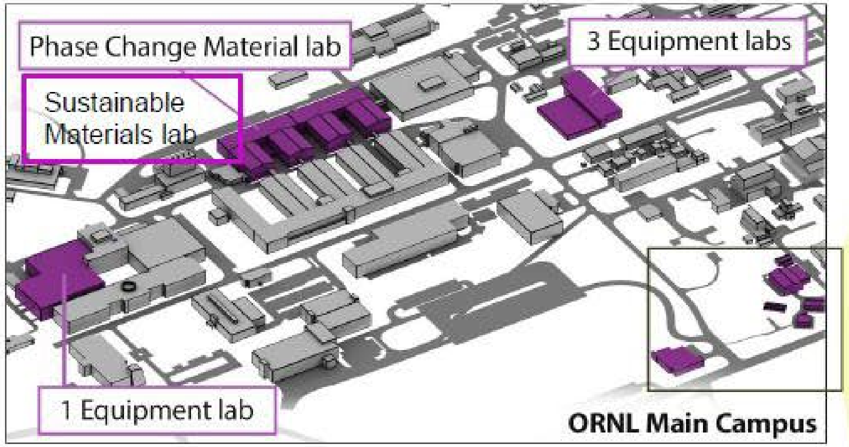
32
STRATEGIC PARTNERSHIPS

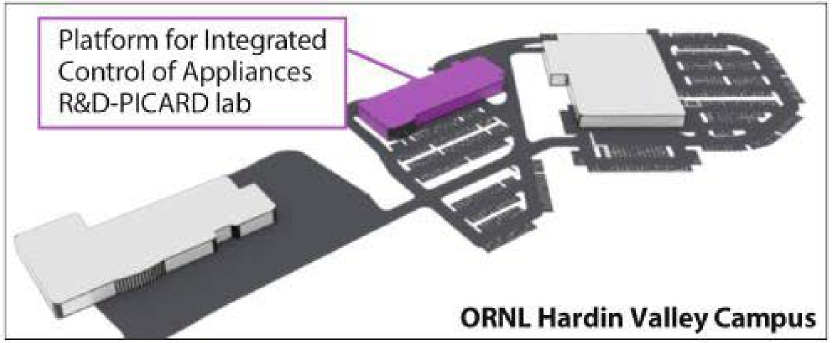
54
UNIVERSITY PARTNERS

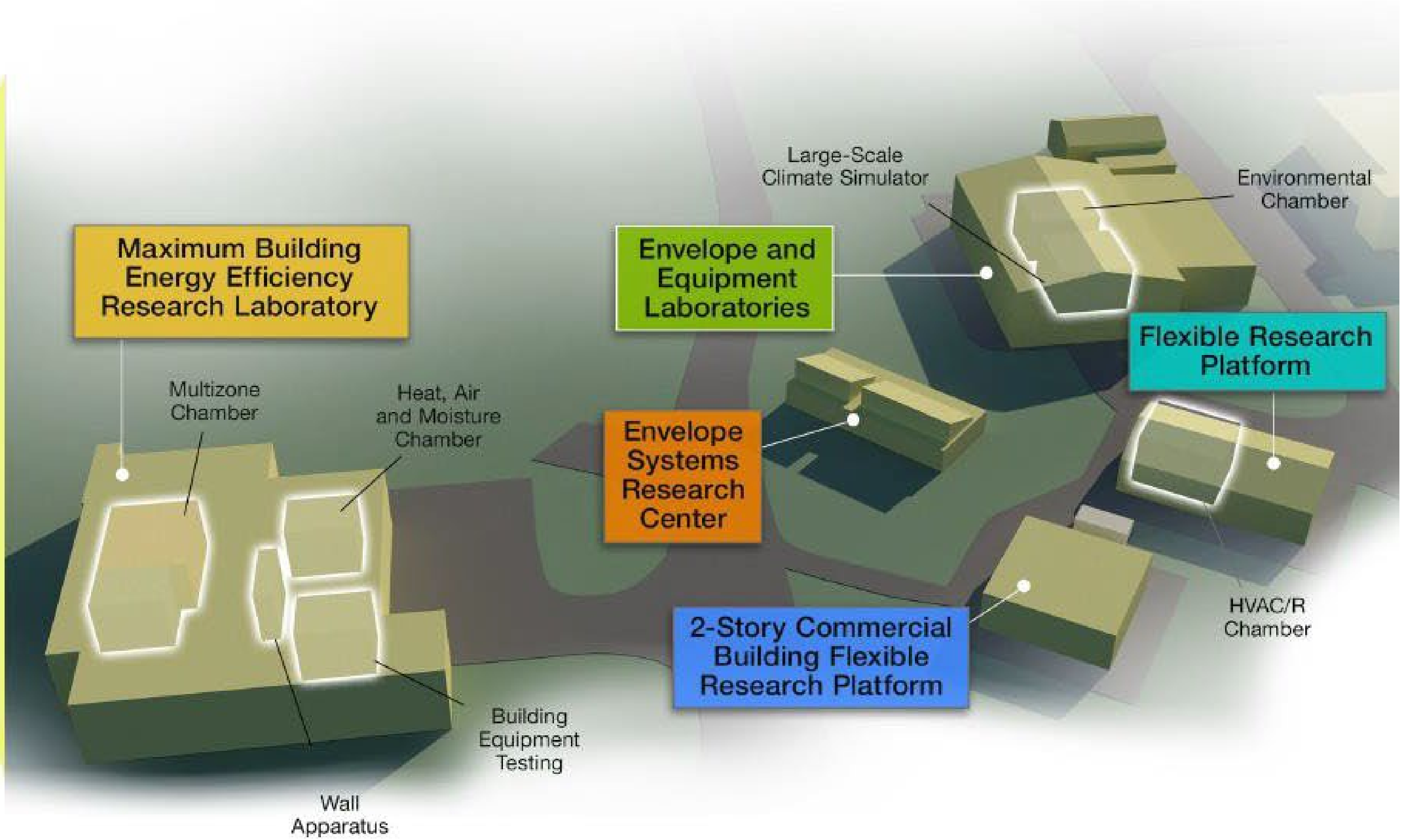
BTRIC's 13 R&D 100 awards since 1992

13 R&D 100 Awards	2022 Ultraclean Condensing Gas Furnace Zhiming Gao, Kyle Gluesenkamp, Kashif Nawaz, Anthony Gehl, Josh Pihl, Dino Sulejmanovic, Tim Laclair, Mingkan Zhang, Lingshi Wang, Van Baxter, Bo Shen, Xiaobing Liu, Jeff Munk, Jim Parks	2021 Autonomous Self-Healing Sealant Diana Hun, Pengfei Cao, Tomonori Saito, Zhen Zhang, Bingrui Li, Natasha Ghezawi, Zoriana Demchuk	2021 BIG-NET: Bis-iminoguanidine Negative Emission Technology Kashif Nawaz, Charles Seipp, Neil Williams, Costas Tsouris	2016 Roof Saving Calculator Joshua New, William Miller, Aaron Garrett, Yu Huang	2013 ClimateMaster Trilogy 40 Q-Mode Geothermal Heat Pump Shawn Hern, Van Baxter, Daniel Ellis, Dennis Harris, Ed Vineyard, Moonis Ally, Jeffrey Munk, Bo Shen, Keith Rice, Anthony Gehl	2011 NextAire Packaged Gas Heat Pump (PGHP) Ed Vineyard, Abdolreza Zaltash, Randall Linkous. Isaac Mahderekal, Randall Wetherington, Patrick Geoghegan, Tommis Young, Robert Gaylord, Anthony Hills
2009 Fire-Resistive Phase Change Material Jan Kosny, David Yarbrough, Marc LaFrance, Tim Riazzi, Dan Davis, Dale Work, Doug Leuthold	2006 Hybrid Solar Lighting Systems Jeffrey D. Muhs, David L. Beshears, Art Clemons, Dennis D. Earl, John K. Jordan, Melissa Voss Lapsa, Randall F. Lind, L. Curt Maxey, Christina D. Ward, R. Wes Wysor	2006 Trane CDQ Jim Sand and Art Hallstrom	2005 SEMCO Revolution: Integrated, Active-Desiccant Rooftop Air Conditioner James R. Sand and John C. Fischer	2001 Drop-In Residential Heat Pump Water Heater J.J. Tomlinson, V.D. Baxter, R.L. Linkous, R.W. Murphy, J. Hoyt, R. Williams, R. Zogg	1999 Frostless Heat Pump Vince C. Mei, Fang C. Chen, Richard W. Murphy, Ron E. Domitrovic	1992 CRC HFC Ratiometer F.C Chen, S.L. Allman, C.H. Chen

BTRIC Footprint at ORNL





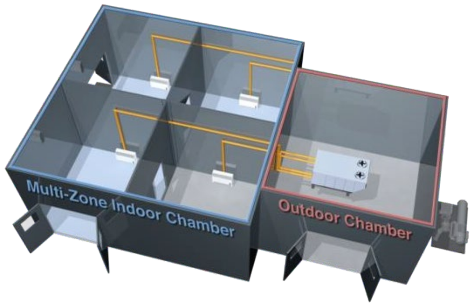


BTRIC Facilities on ORNL Main Campus

Oak Ridge National Laboratory

Building Equipment Infrastructure

- 60,000 sq. ft. research footprint
- Multiple **environmental chambers**, capable of limited A2L and A3 quantities
  - Bldg 3170A: 8-ton, 20x40x18 ft, 2-room
  - Bldg 4020: 10-ton, 14x34x11 ft, 5-room
  - Bldg 5800: 20-ton, 40x20x14 ft, 2-room
  - Bldg 3144: 15-ton, 24x24x18 ft, 2-room (under construction)
  - Bldg 2500: 5-ton, 22x12x10 ft, 2-room (under construction)
  - Appliance: 3-ton, 7x7x8 ft, 1-room (under construction)
- Controlled field test sites (Yarnell Station house, two Flexible Research Platforms)
- Psychrometric sampling stations (ASHRAE 37-compliant)
- Air-side code testers (ASHRAE 37-compliant)
- Water conditioning systems (CFR UEF-compliant)
- Controlled refrigerant test loops
- Two compressor calorimeters



Equipment-related programs

- Equipment Research
  - Heating, Ventilation, and Air Conditioning (HVAC)
  - Water Heating
  - Refrigerants and Refrigeration
  - Hybrid Technologies
  - Modeling

- BEADS Research (Building Electric Appliances, Devices, and Systems)
  - Major electric appliances
  - Plug loads and miscellaneous electric loads

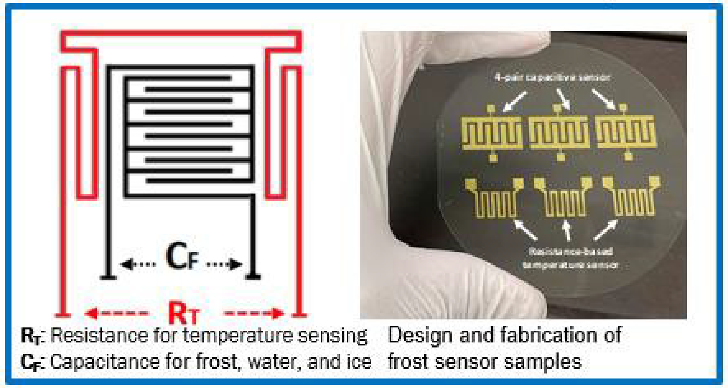
- TES Research (Thermal Energy Storage)
  - HVAC-integrated and envelope-integrated TES
  - PCM materials

Collaborators

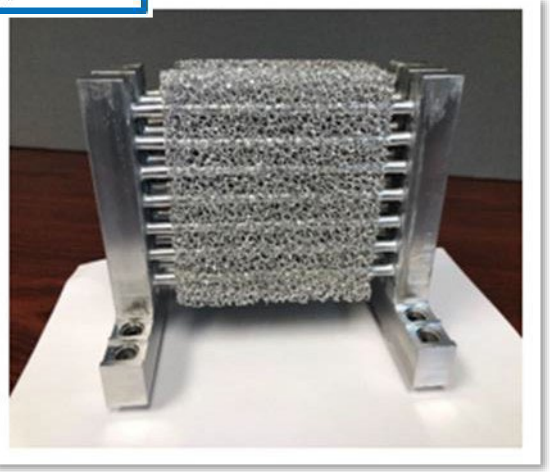
AeroShield
AHRI AIR-CONDITIONING, HEATING, & REFRIGERATION INSTITUTE we make life better®
ARKEMA INNOVATIVE CHEMISTRY
Heraeus
AWHi ADVANCED WATER HEATING INITIATIVE™
Carrier
THE UNIVERSITY OF TENNESSEE KNOXVILLE
Koura
HUSSMANN®
Hillphoenix
effecterra
ECOTOPE
COPELAND
EMERSON.
Honeywell
AO Smith. Innovation has a name.
WaterFurnace
DANDELION
NORTEK
Whirlpool CORPORATION
Johnson Controls
Syracuse University
Optimized Thermal SYSTEMS
ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
NEOGRAF SOLUTIONS
Lync® by WATTS
NevadaNano
TAYLOR®
UNIVERSITY OF MARYLAND
CLIMATEMASTER®
STEFFES
nbi new buildings institute
PURDUE UNIVERSITY
TVA
NEW YORK STATE OF OPPORTUNITY. NYSERDA
Oregon State University
Melink
Dalrada Corporation
GTI ENERGY solutions that transform
Senseair
EPRI
Georgia Tech
Rheem
Southern Company
Electrification Strategies, LLC
KCDC Knoxville's Community Development Corporation
SAMSUNG
OSU
LENNOX
PRINCETON UNIVERSITY
TRANE
SoCalGas
OAK RIDGE National Laboratory
DAIKIN
SUPER RADIATOR COILS
Danfoss
ISOTHERM, INC. ENHANCED HEAT TRANSFER
Rinnai
Chemours™

HVAC Research

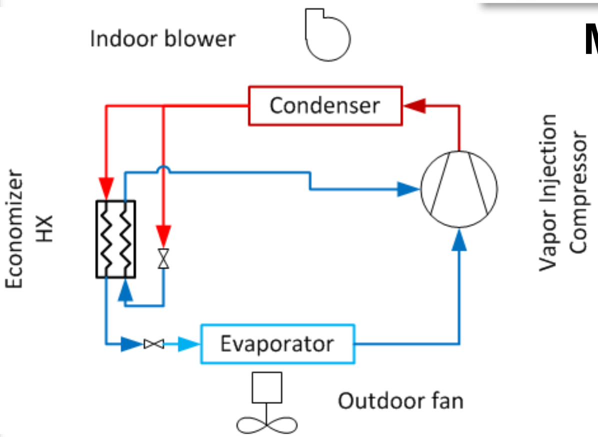
- Heat pumps
  - Cold climate, non vapor compression
- Separate sensible and latent cooling (SSLC)
- Humidity control
- Direct air CO_2 capture
- Indoor air quality
- Frost sensing



Frost Sensor Design



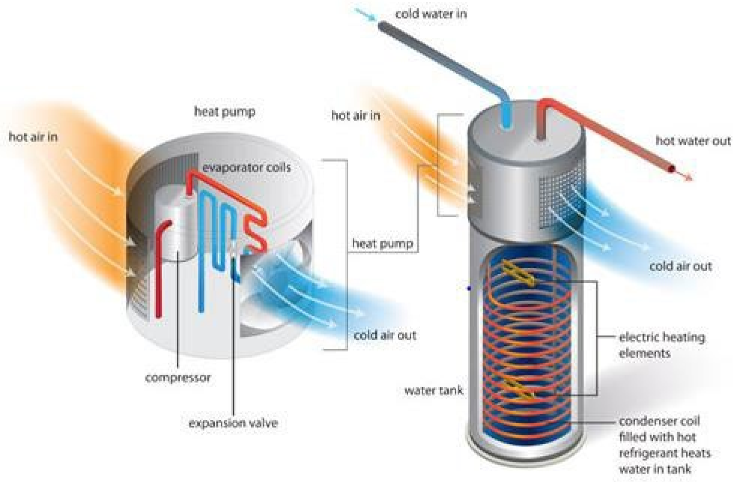
Metal Foam Heat Exchangers



Cold Climate Heat Pump

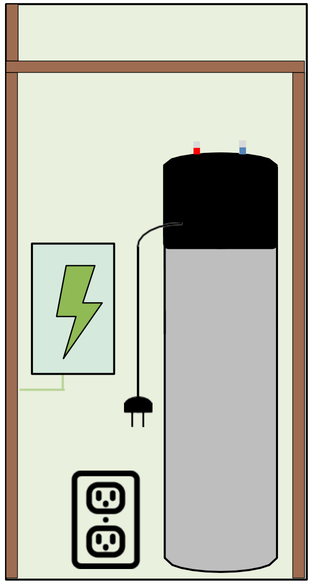
Water Heating Research

- Signature expertise in the development of electric heat pump water heaters (HPWH)
- Low-GWP refrigerant HPWHs
- 120 V HPWHs
- High-temperature heat pumps



Alternative Refrigerants for HPWHs

High Temperature Heat Pumps

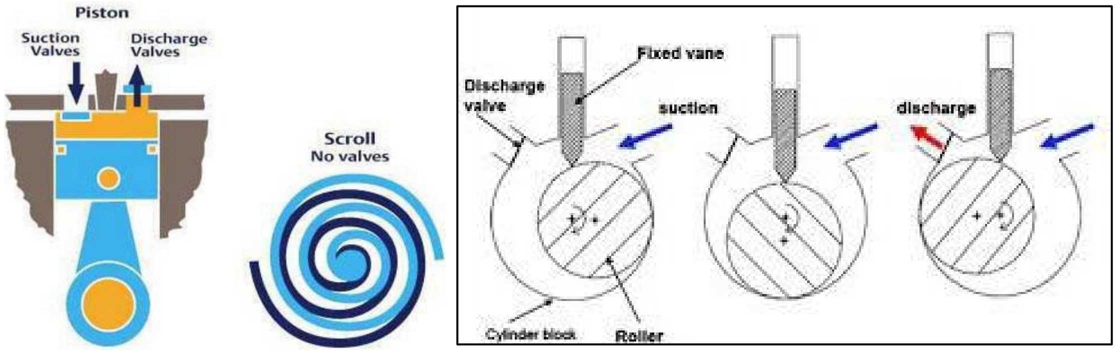


120 V HPWHs

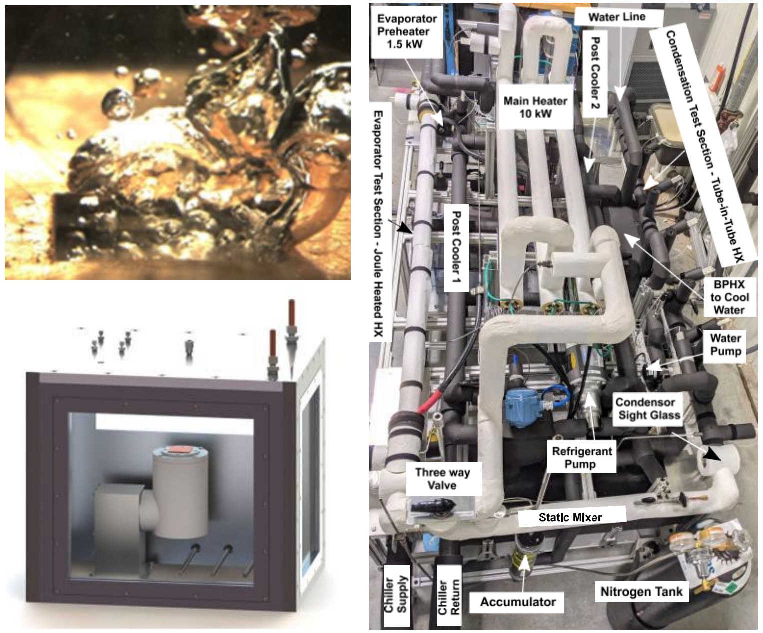
Refrigerants and Refrigeration Research

- Refrigerant heat transfer characterization
- Refrigerant charge minimization
- Low GWP refrigeration system development
- Life Cycle Climate Performance (LCCP) evaluation

Transcritical CO_2 Refrigeration



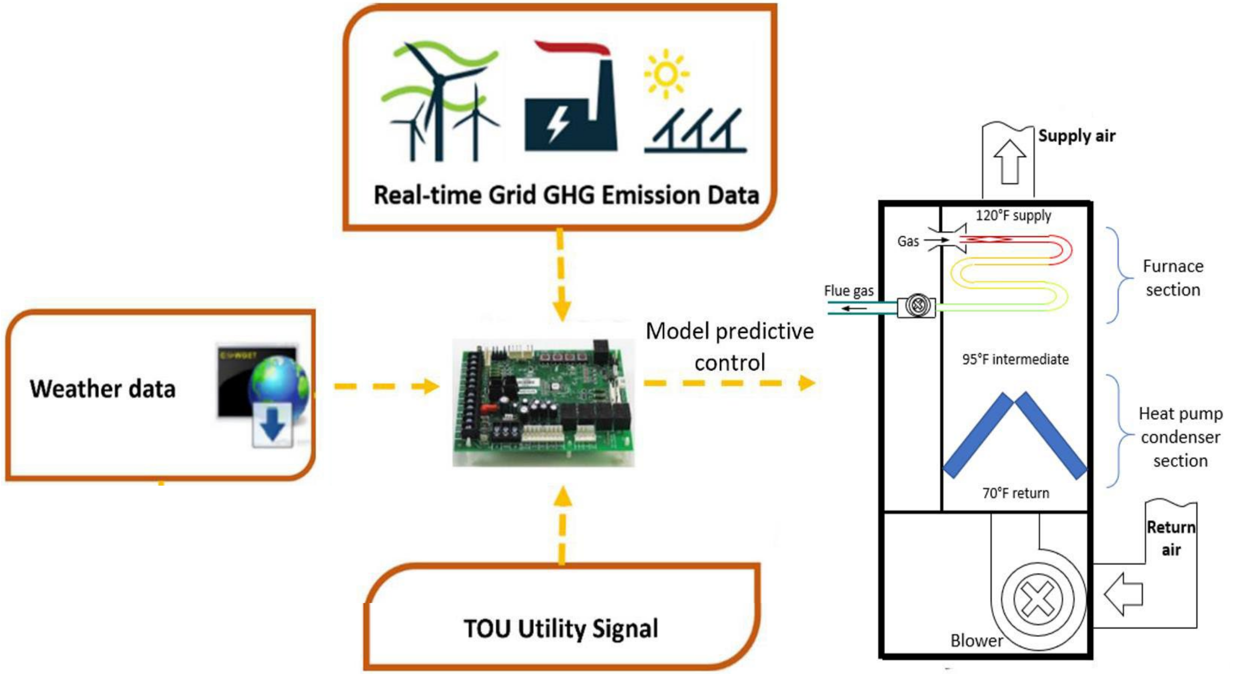
Compressor Development



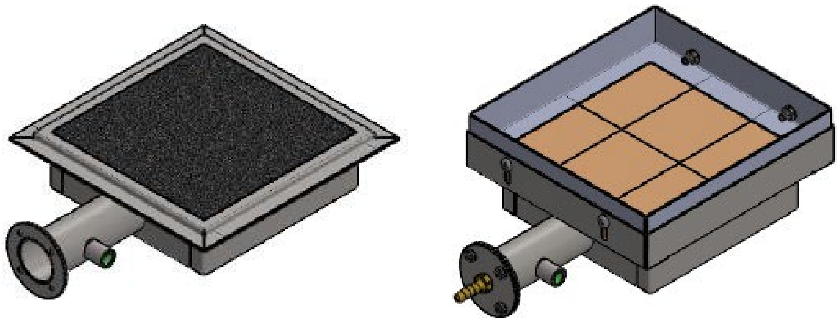
Refrigerant Heat Transfer Characterization

Hybrid Technologies

- Dual fuel heat pumps
- Flue gas treatment
- Cooking appliances

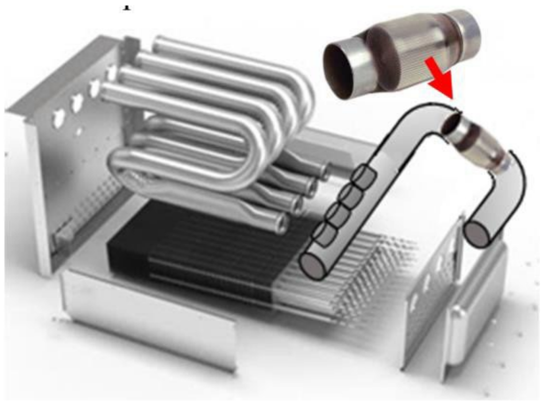


Simultaneous Hybrid Heat Pump with Grid-responsive Controls



Low emission cooking (burner design)

Natural gas furnace utilizing innovative nano-array acidic gas trap



Thermal Energy Storage

- HP-integrated TES
  - Residential split
  - RTU
- Low-cost PCM development
- Grid-integrated controls development
- Simple sizing and valuation tool

BEADS

- Induction cooking
- Thermoelectric HP dishwasher
- 120 V desiccant clothes dryer
- Combined washer/dryer

Modeling

- Heat Pump Design Model (HPDM):
  - High-fidelity design tool for vapor compression systems
  - HPDM: http://web.ornl.gov/~wlj/hpdm/MarkVI.shtml
  - Flexible HPDM: http://hpdmflex.ornl.gov/hpdm/wizard/welcome.php
- SorpSim: Built upon the ORNL legacy sorption modeling tool ABSIM
  - Design and evaluate thermally activated cooling and heating technologies
- Life Cycle Climate Performance (LCCP)
  - Evaluate lifetime carbon emissions from HVAC&R equipment
  - http://lccp.umd.edu/ornllccp/

Pause for discussion

For more information, contact:
Kyle Gluesenkamp
gluesenkampk@ornl.gov

OAK RIDGE
National Laboratory

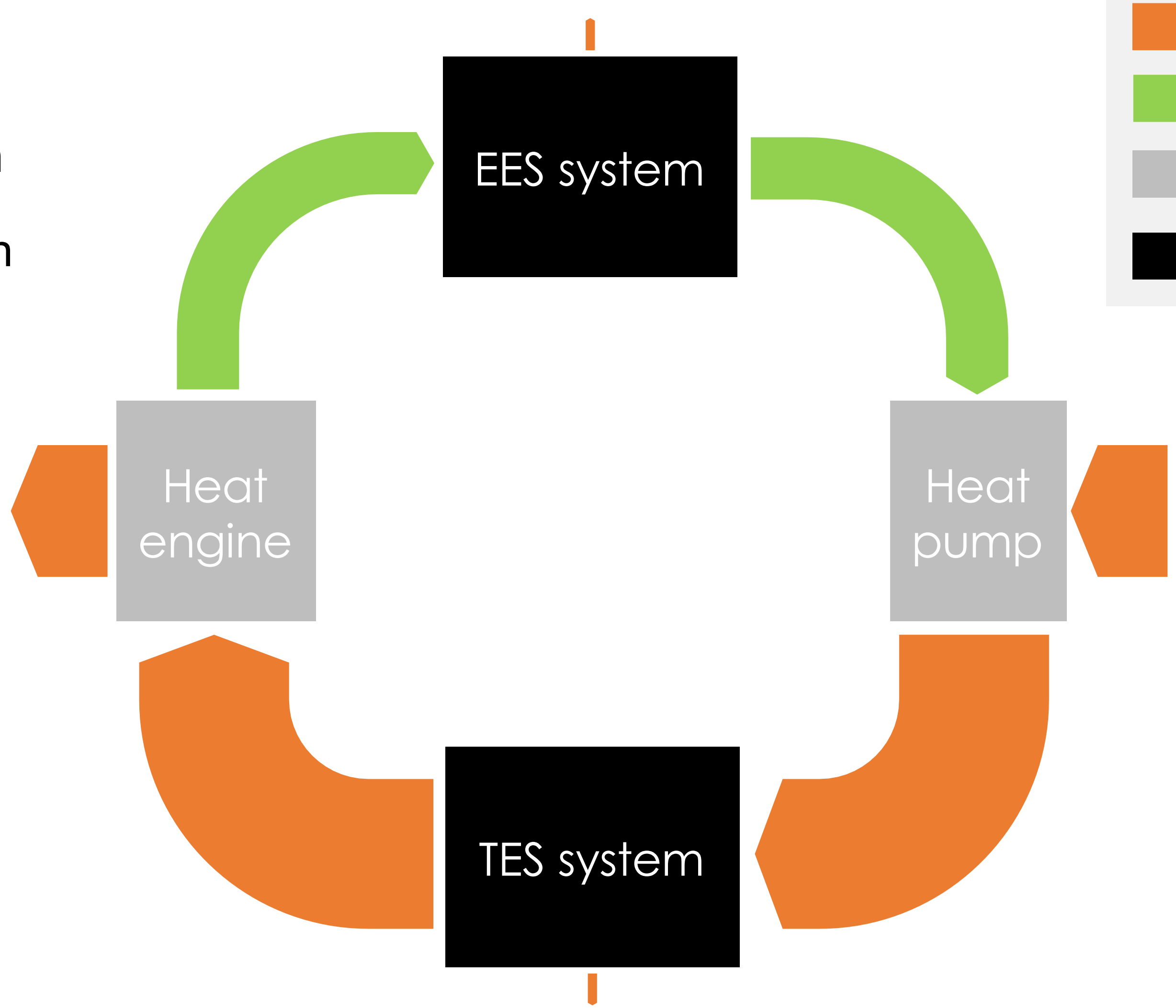
Thermal Energy Storage

Things people can mean by TES:

A Generic View of Energy Conversion and Storage

Thermodynamics dictates:

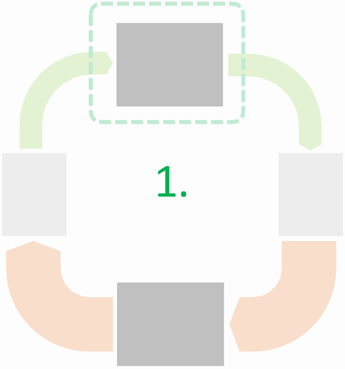
1. Energy balance on each device (1st Law)
2. Entropy increase in each device (2nd Law)

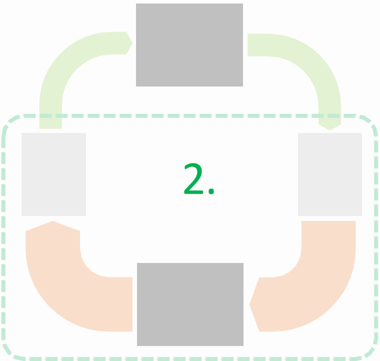


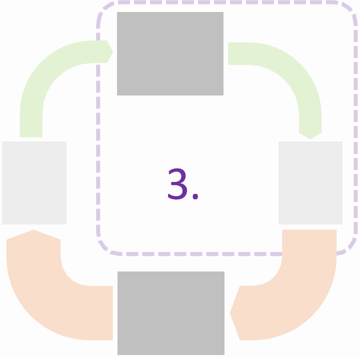
Flow of thermal energy
Flow of electrical energy
Steady state device
Storage device

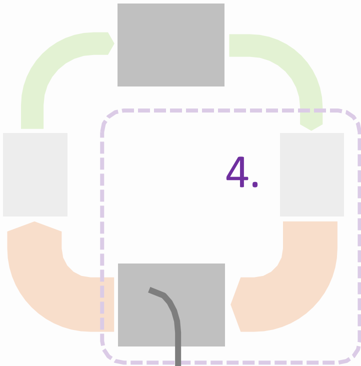
Abbreviations:
EES: electrical energy storage
TES: thermal energy storage

Types of Storage





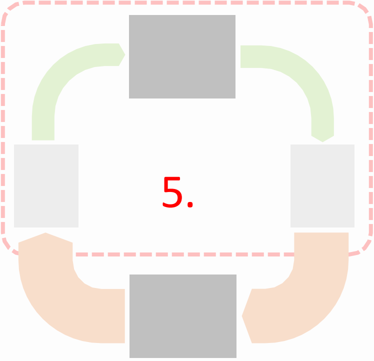


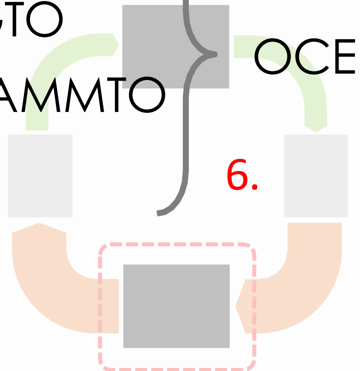


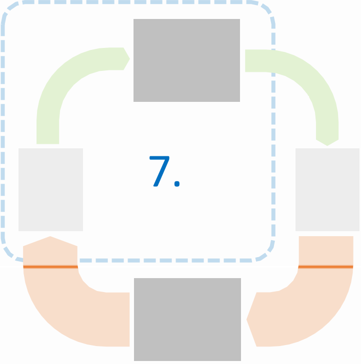
		Storage type	
		EES	**TES**
Overall conversion type	**E-to-E**	1. primary EES use case	2. Carnot battery
	E-to-T	3. battery-powered HP	4. buildings: TES with HP
	T-to-T	5. generation with HP	6. building envelopes
	T-to-E	7. unusual	8. CSP with molten salt

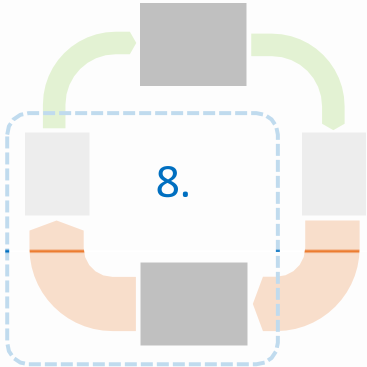
OE
BTO, GTO
IEDO/AMMTO
SETO

OCED









Stor4Build

Stor4Build is a multi-lab Building Energy Storage consortium co-led by **LBNL, NREL and ORNL**. It includes active participants from industry, utilities, nonprofit organizations, communities, building owners, minority serving institution, universities, government, and other research institutions.

Bottom line up front

For a future carbon-free grid,

- Thermal storage in buildings can make **decarbonization more equitable** by being the **lowest-cost storage per kWh$_{\text{electric}}$**
  - Electrical storage also needed; maximizing TES minimizes total cost
- Key market needs:
  - Market incentives for storage in buildings (especially residential) Utilities
  - Awareness of the existence and the performance of TES
  - Availability of TES products Researchers and manufacturers
- Key technology needs:
  - Low-cost TES materials
  - Low-cost integration of TES with buildings
  - Low-cost installation

This presentation concludes with one solution ORNL has developed

OAK RIDGE National Laboratory

National scale of storage

- The US electric grid: about 1 TW electrical power
- Example 1: storage for 30% of 1 TW for four hours: 1.2 TWh energy
- This equates to an average of: (address duck curve)
  - 4.4 kWh per residential building and
  - 108 kWh per commercial building
  - (assuming each sector has half the nation's storage).
- At rate of $11.5k installed per 13.5 kWh Li-ion battery, this implies:
  - $3,750 per residential building with Li-ion
  - $92,000 per commercial building with Li-ion

Battery storage to address duck curve is doable from a national infrastructure perspective, but too burdensome for lower income households

https://www.marketwatch.com/guides/home-improvement/tesla-powerwall-cost/

National scale of storage

- The US electric grid: about 1 TW electrical power
- Example 2: storage for 100% of 1 TW for 24 hours: 24 TWh energy
- This equates to an average of:

  (address resilience)

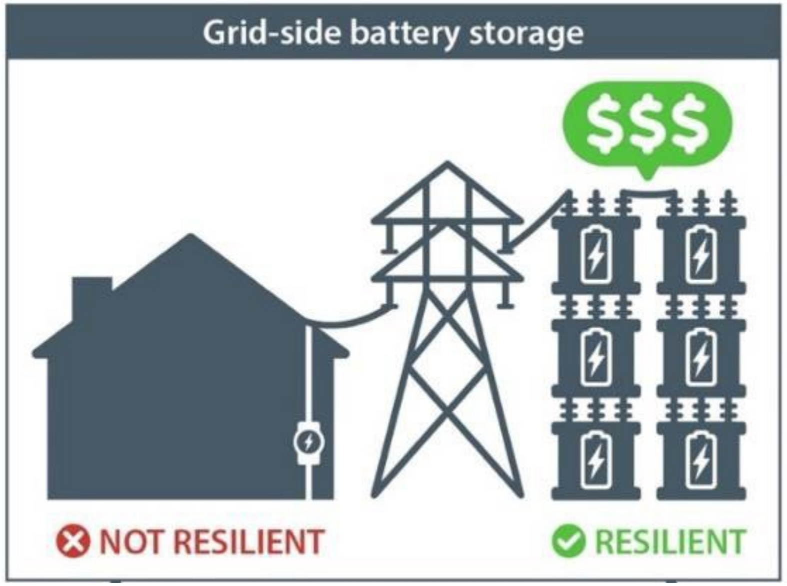
  - 88 kWh per residential building and
  - 2.16 MWh per commercial building
  - (assuming each sector has half the nation's storage).
- At rate of $11.5k installed per 13.5 kWh Li-ion battery, this implies:
  - $75,000 per residential building with Li-ion
  - $1,840,000 per commercial building with Li-ion

Battery storage to address resilience requires innovation to lower cost

https://www.marketwatch.com/guides/home-improvement/tesla-powerwall-cost/

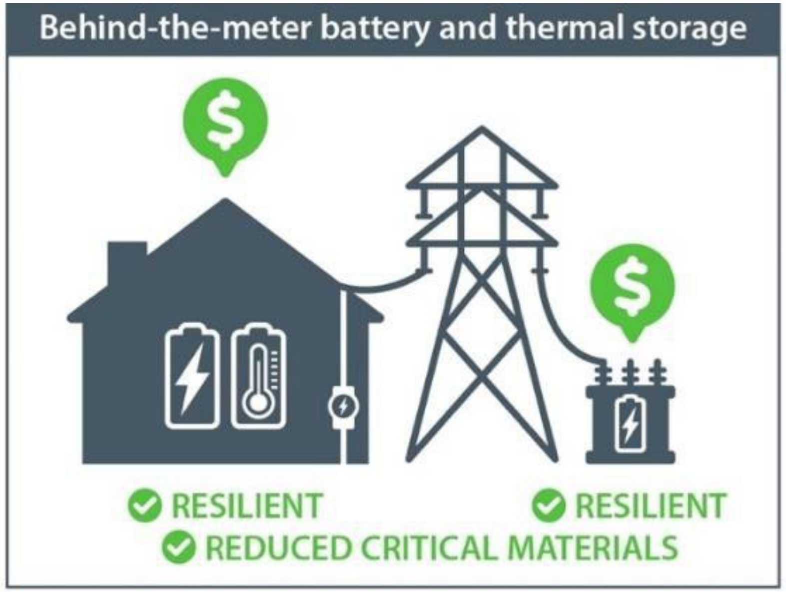
Future scenarios

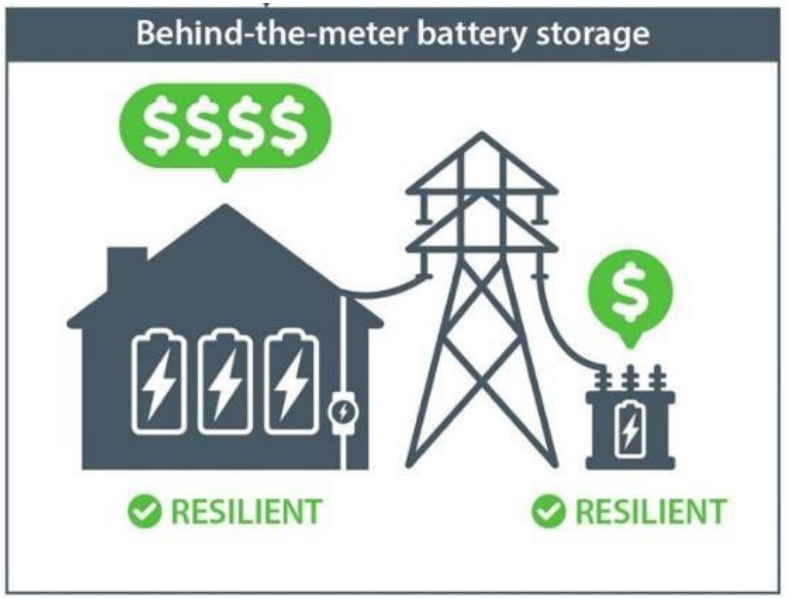
Current trajectory: electrical storage on grid-side



- Buildings consume 74% of electricity in US (will increase with electrification of heating)
- Heating and cooling of buildings is projected to account for over 50% of building electricity demand

Future scenario: thermal and electrical storage in buildings





Future scenario: electric-only storage in buildings

Physical installation options

- Multitudinous options for integration between TES and building
  - Heating, cooling, water heating, and refrigeration system
  - Building envelope (wall, roof, floor)
- Advanced controls for TES

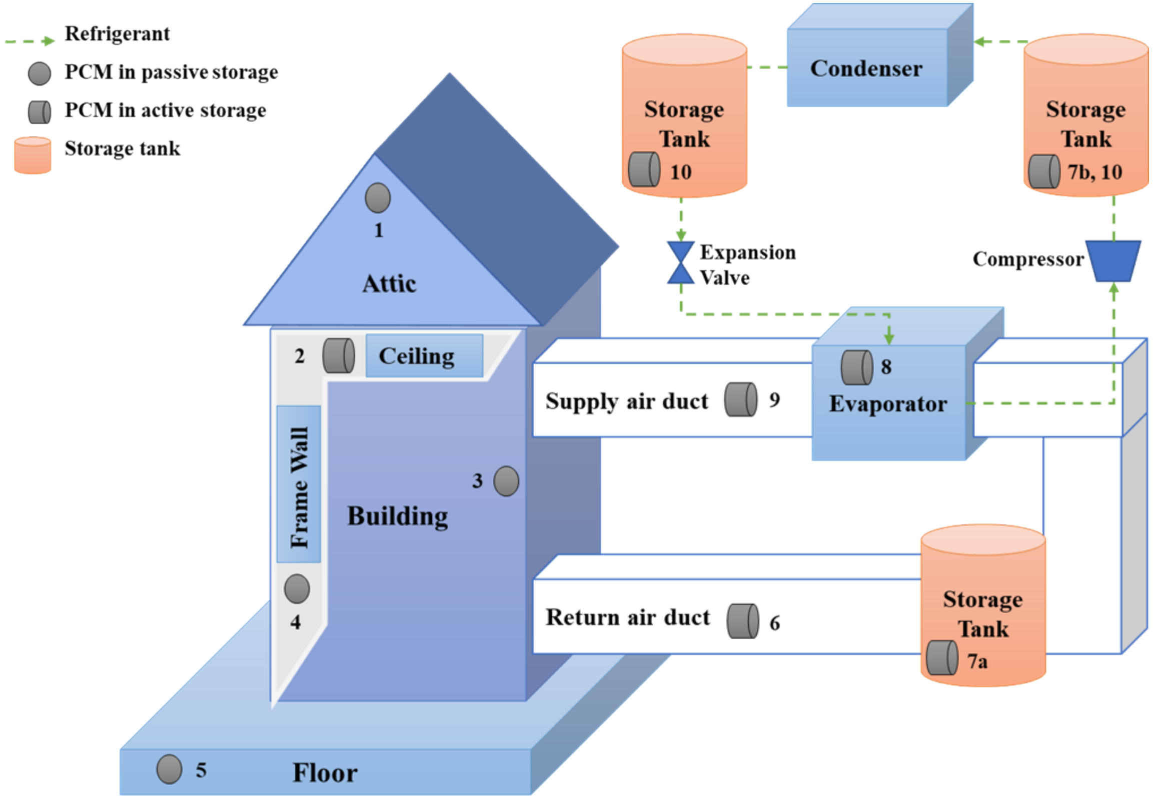


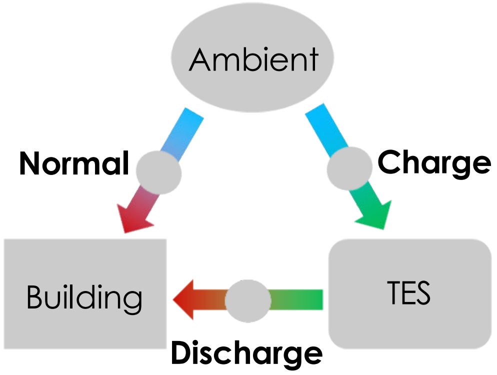
Figure: Sultan, Sara, Kyle R. Gluesenkamp (2021). "The State of Art of Heat-Pump integrated Thermal Energy Storage for Demand Response," in Heat Pumping Technologies Magazine, an IEA Heat Pump Center product, Vol. 40 No. 2/2021: 27-30. ISSN 2002-018X. (August 2021) https://doi.org/10.23697/62tr-nt79

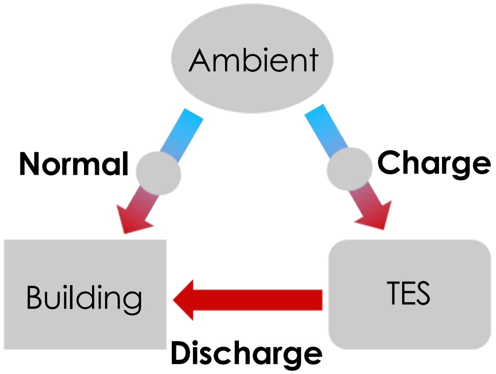
Thermodynamic options for TES-HP

All heat transfers mediated by the vapor compression cycle

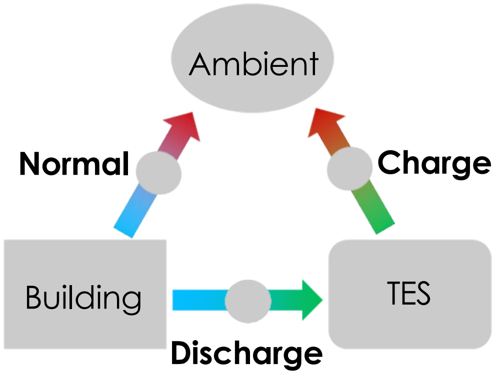
Hot TES allows direct discharge to building in heating season

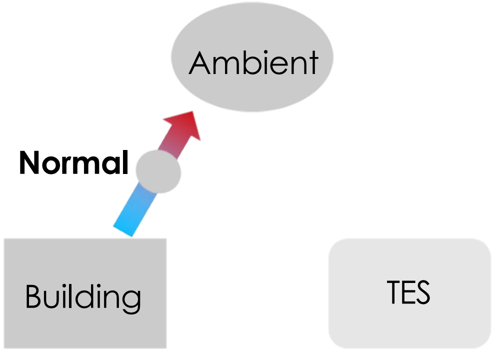
Heating season





Cooling season

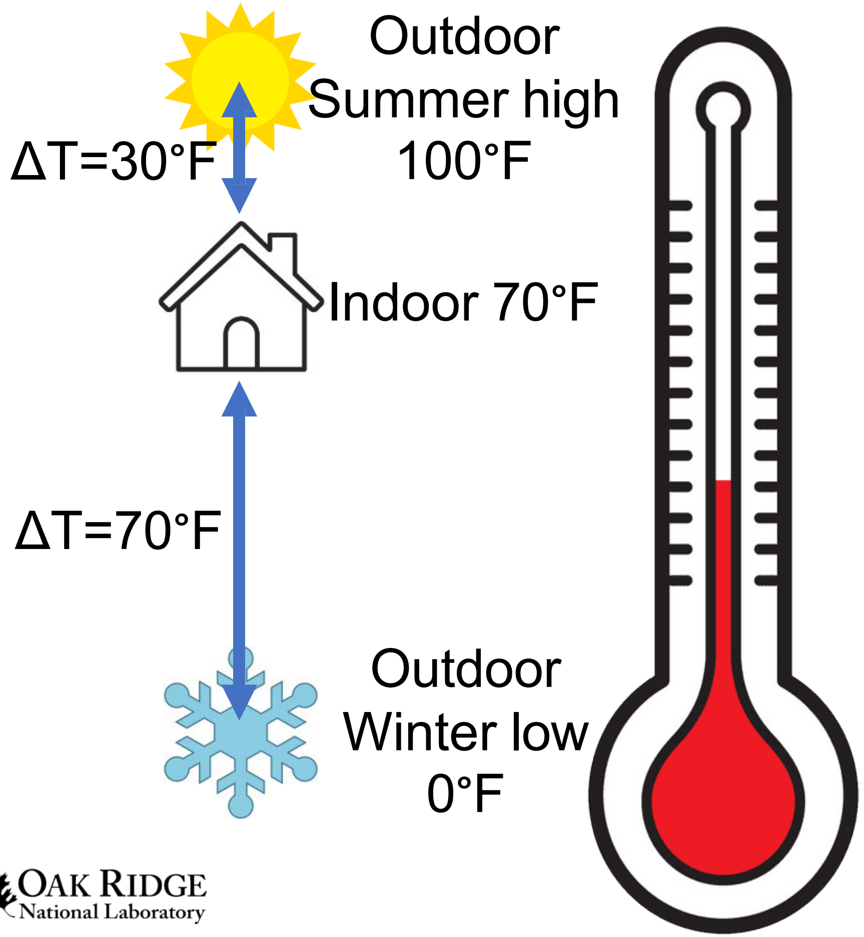




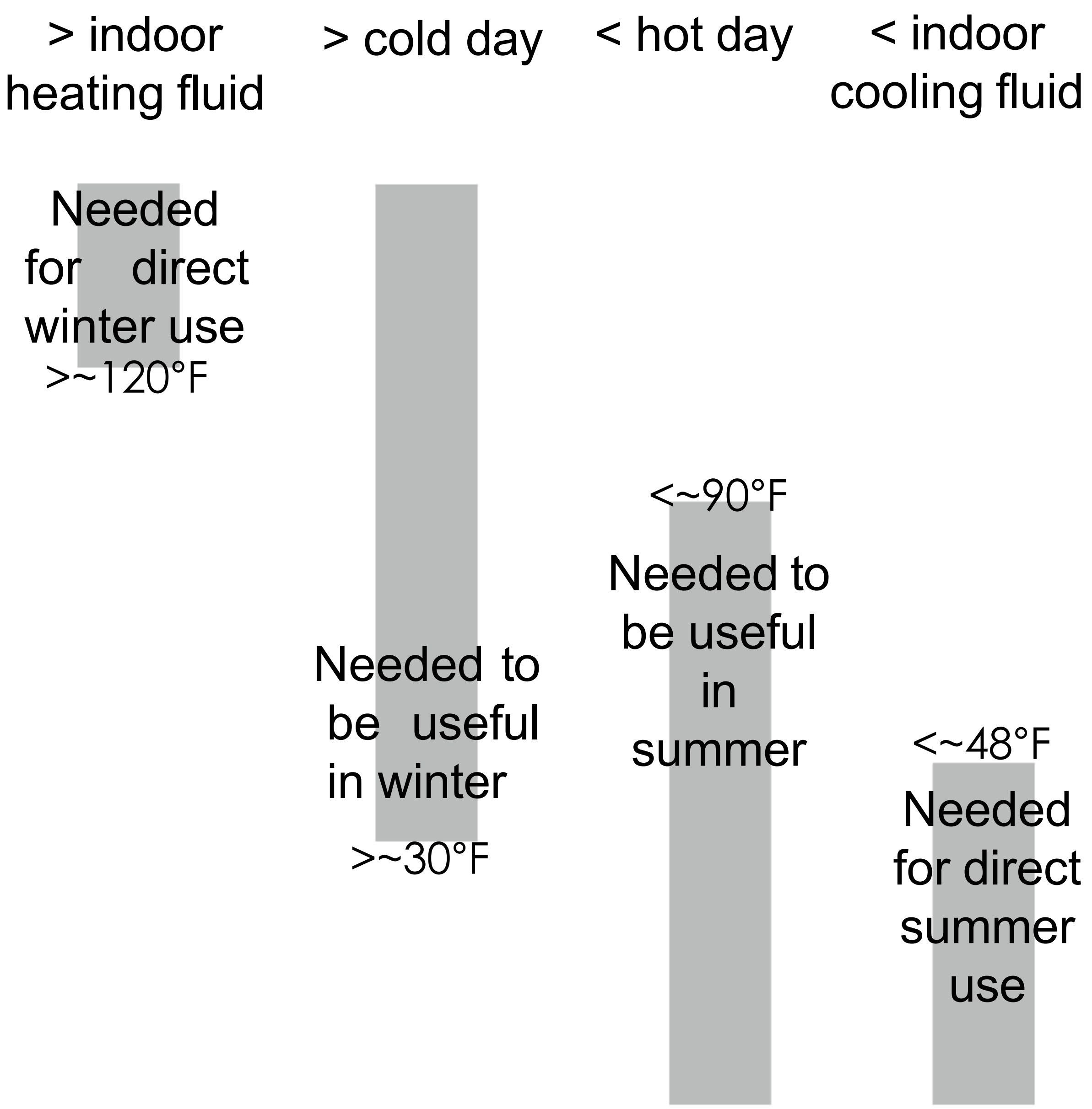
If TES temperature is above peak outdoor temp, TES isn't useful in cooling season

There are 6 fundamental modes of operation

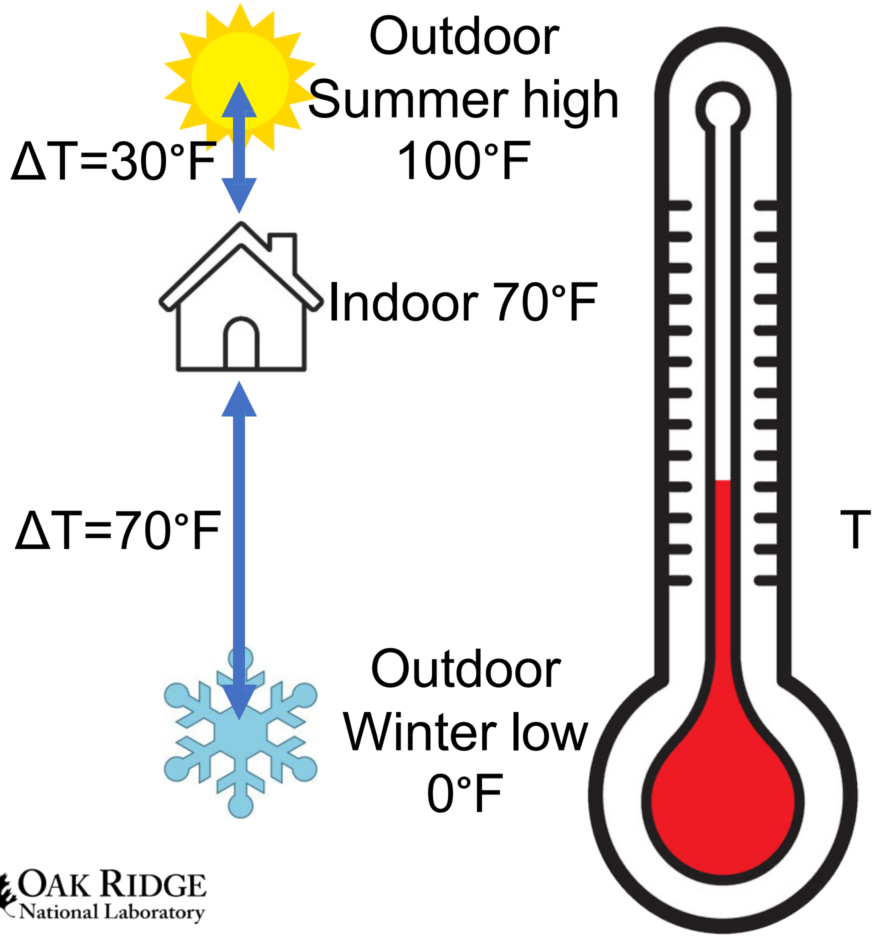
Options for T_{TES}

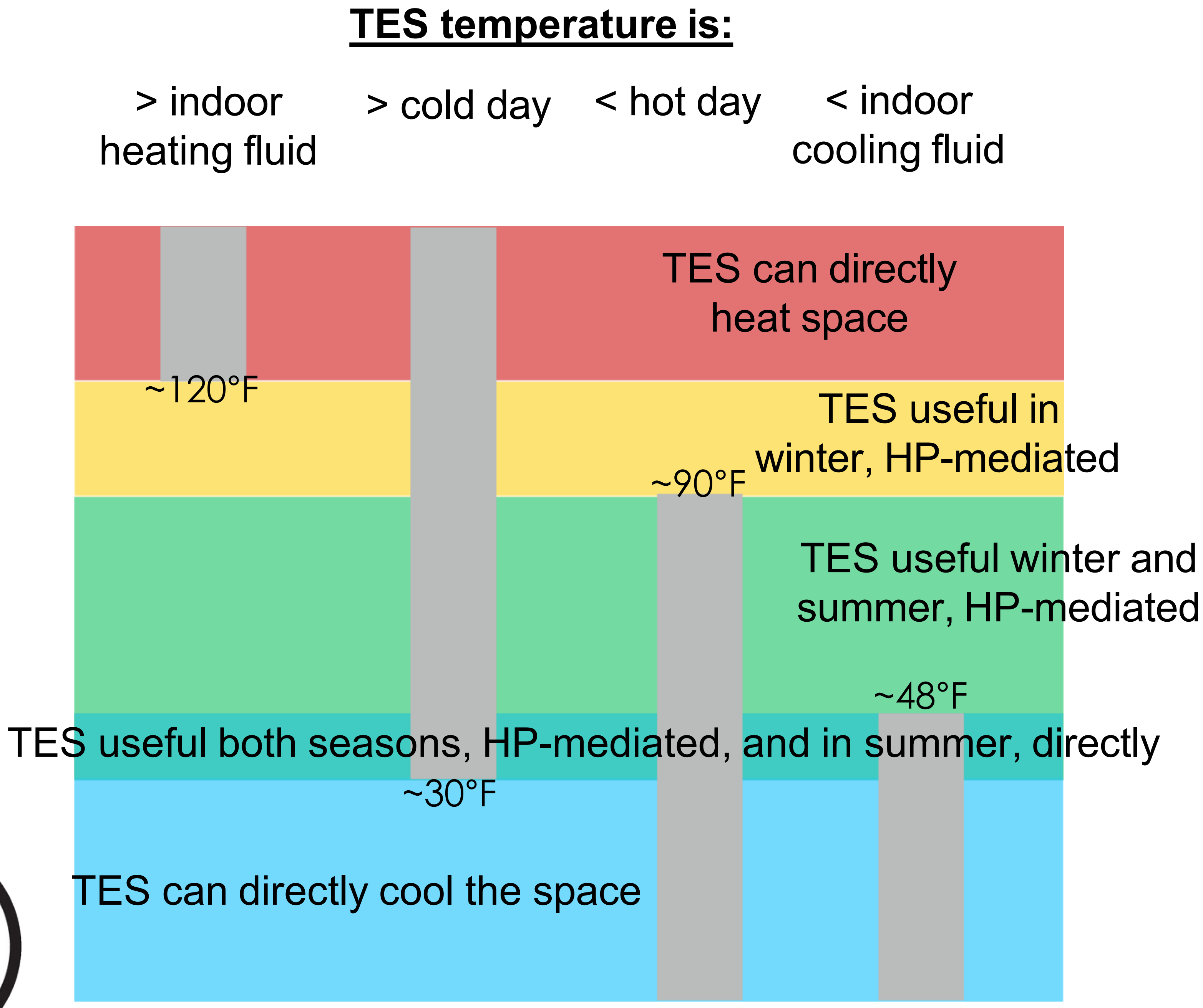


TES temperature is:

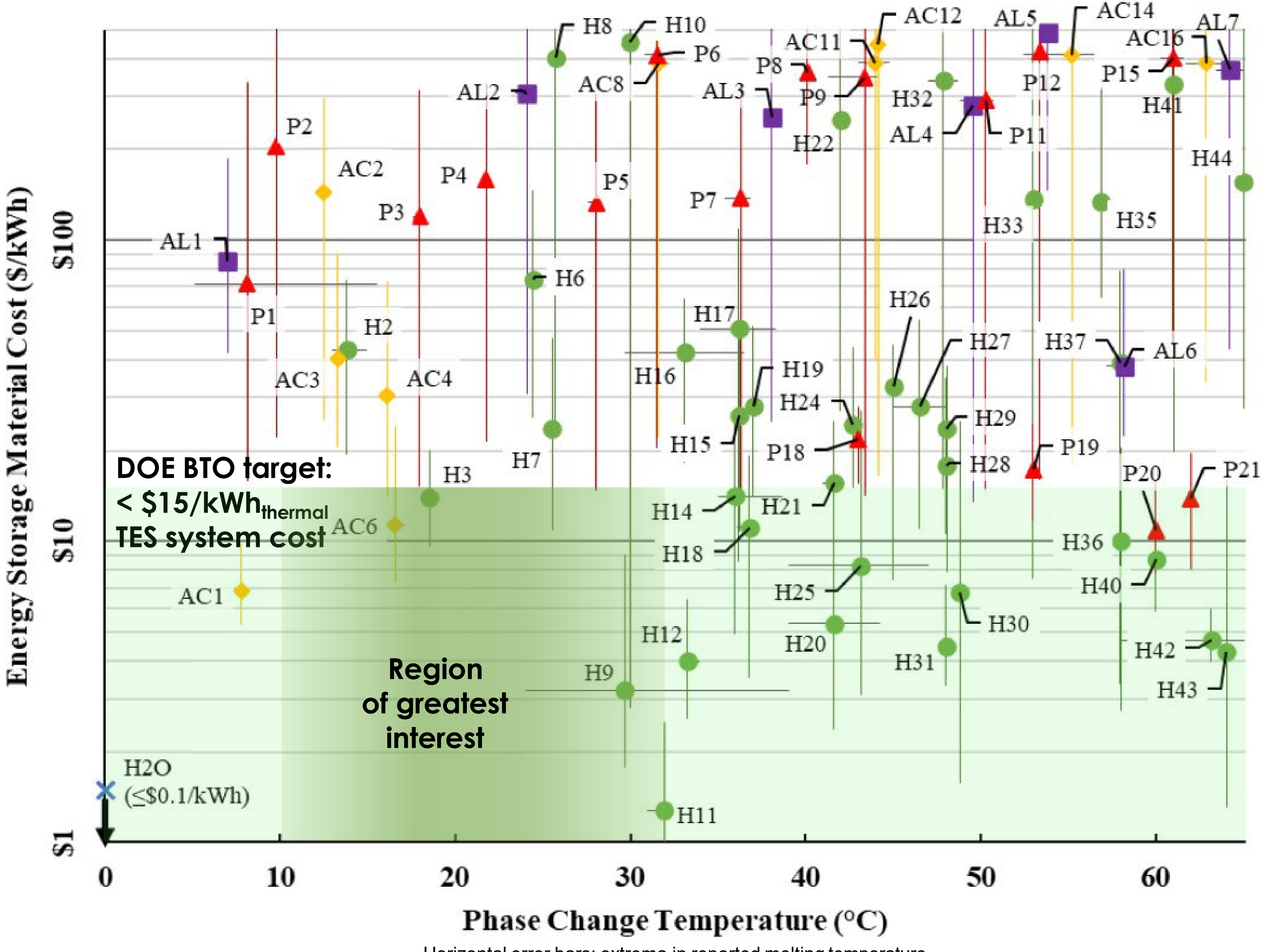


Options for T_{TES}





PCM Options for Buildings



Horizontal error bars: extrema in reported melting temperature
Vertical error bars: extrema in reported material cost *and* melting enthalpy

- Salt Hydrates
- Fatty Acids
- Fatty Alcohols
- Water
- Paraffin (sol-liq)

Notable Labels:

AC1	Formic Acid
AC6	Acetic Acid
H9	Calcium Chloride Hexahydrate
H11	Sodium Sulfate Decahydrate

BTO's goal is to enable shifting 50% of thermal loads over 4 hours with the system targets:

- <$15/kWh thermal
- >80 kWh/m³ energy density
- >10,000 cycles
- >200% charge/discharge rate over SOA

https://www.energy.gov/eere/buildings/thermal-energy-storage

Figure adapted from:

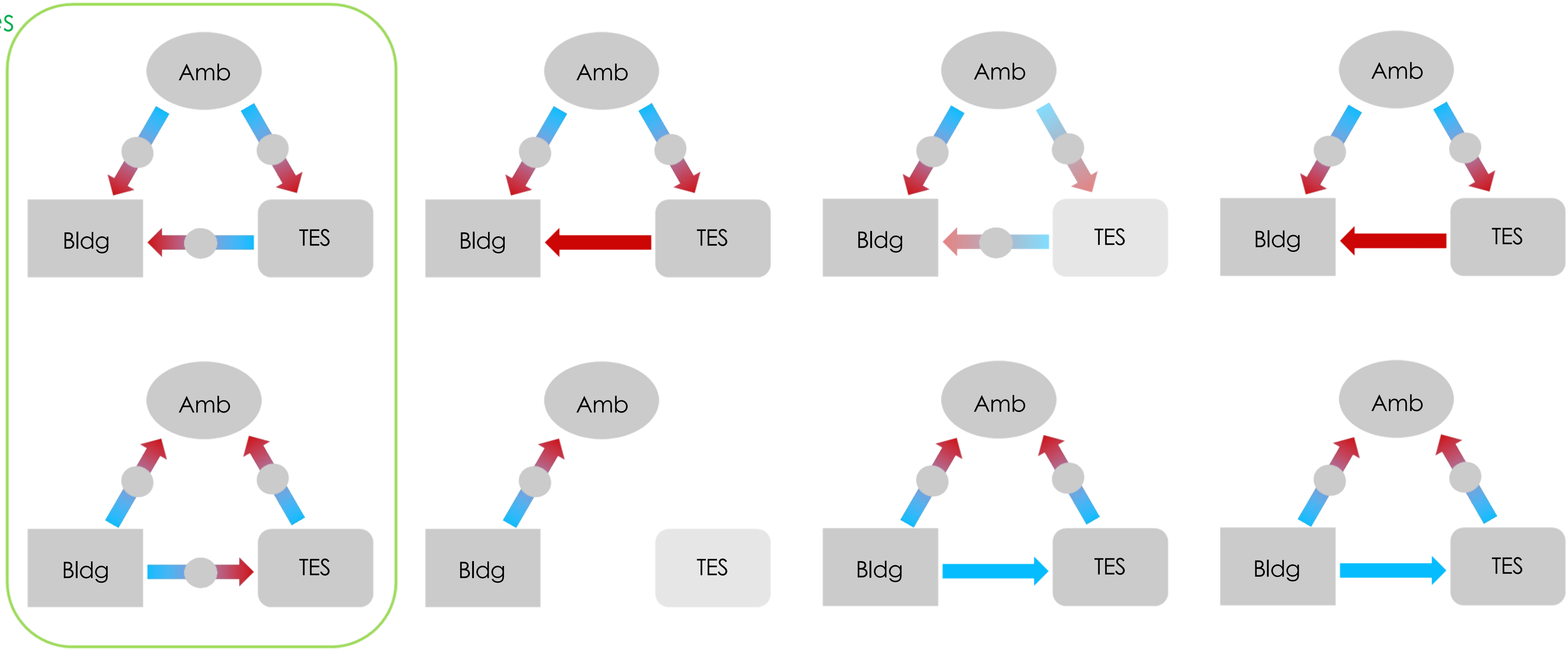
1. Manuscript under preparation
2. Hirschey, Jason R.; Navin Kumar, Tugba Turnaoglu, Kyle R. Gluesenkamp, Samuel Graham (2021). "Review of Low-Cost Organic and Inorganic Phase Change Materials with Phase Change Temperature between 0°C and 65°C," 6th *International High Performance Buildings Conference*, virtual online, May 24-28, 2021.

Thermodynamic options for TES-HP

Each has 6 fundamental modes of operation

Focus of next slides

	Fully HP-mediated	Hot TES	Cold TES	Variable-temperature TES
Heating season				
Cooling season				



Useful winter and summer, but least demand reduction potential

Best winter demand reduction, but not useful in summer

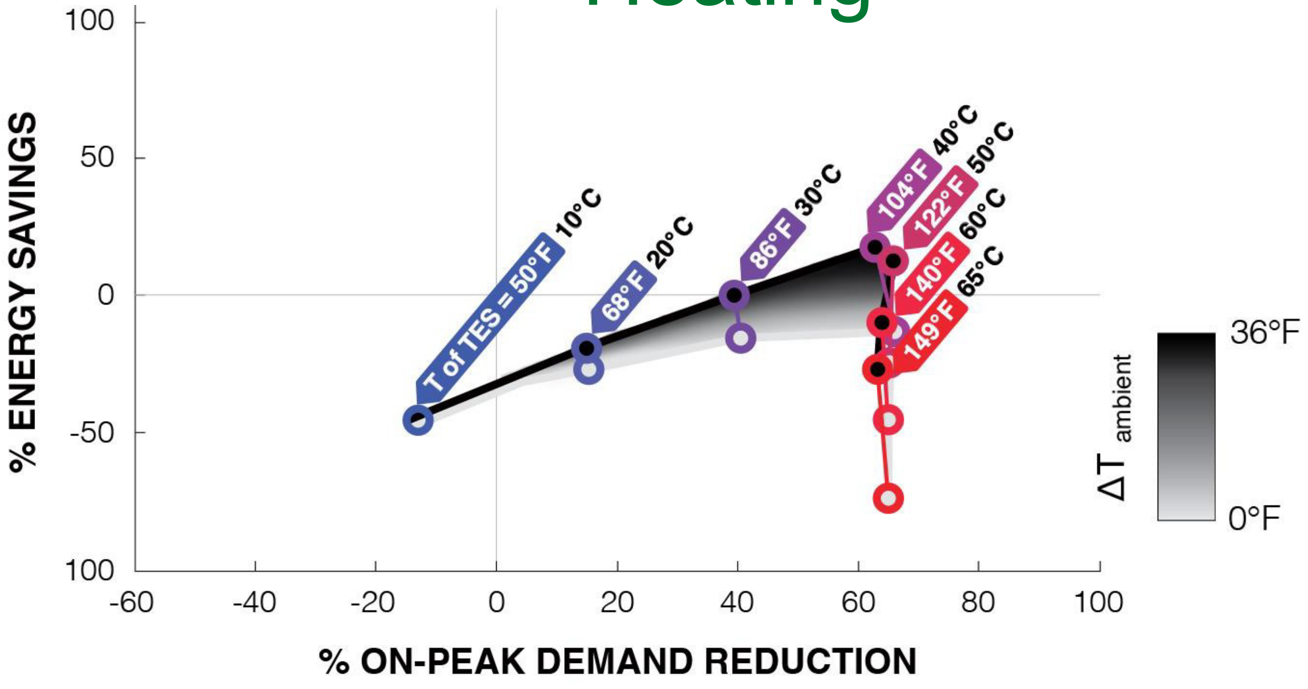
Best summer demand reduction, but less useful in winter

Can be accomplished with sensible storage or two PCMs

Energy and demand limits for HP-mediated TES-HP

Calculated using realistic model of vapor compression cycle

Heating

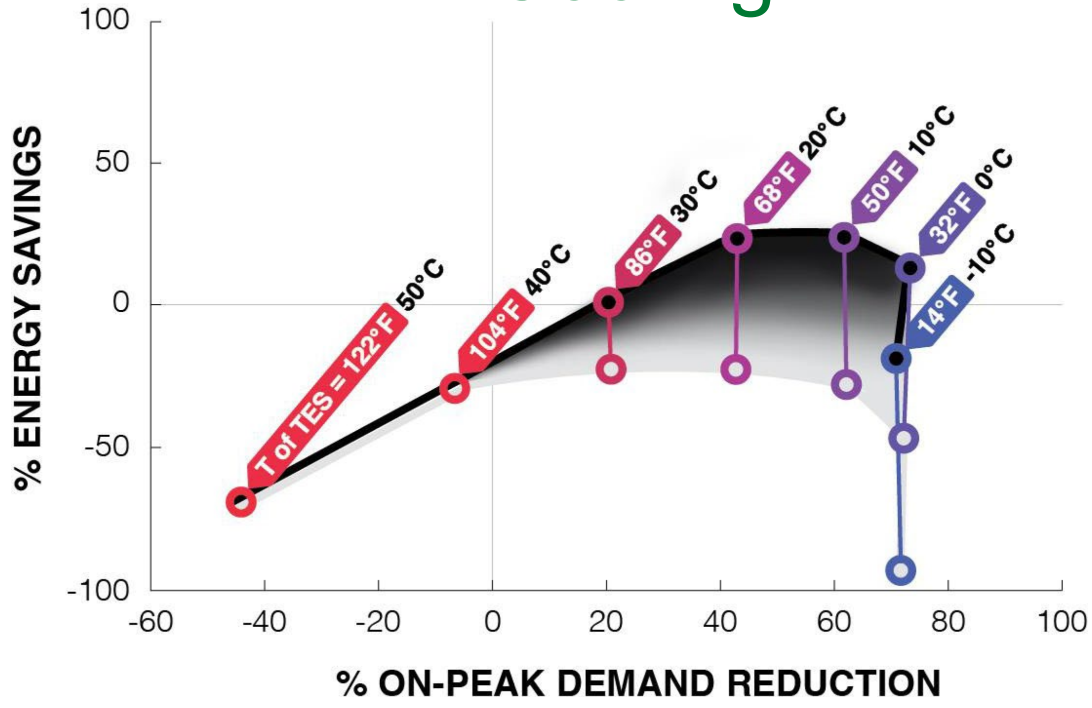


$T_{application}$ = 113°F (45°C)

$T_{ambient,\ low}$ = 14°F (-10°C)

$T_{ambient,\ high} = T_{ambient,\ low} + \Delta T_{ambient}$

Cooling



$T_{application}$ = 44.6°F (7°C)

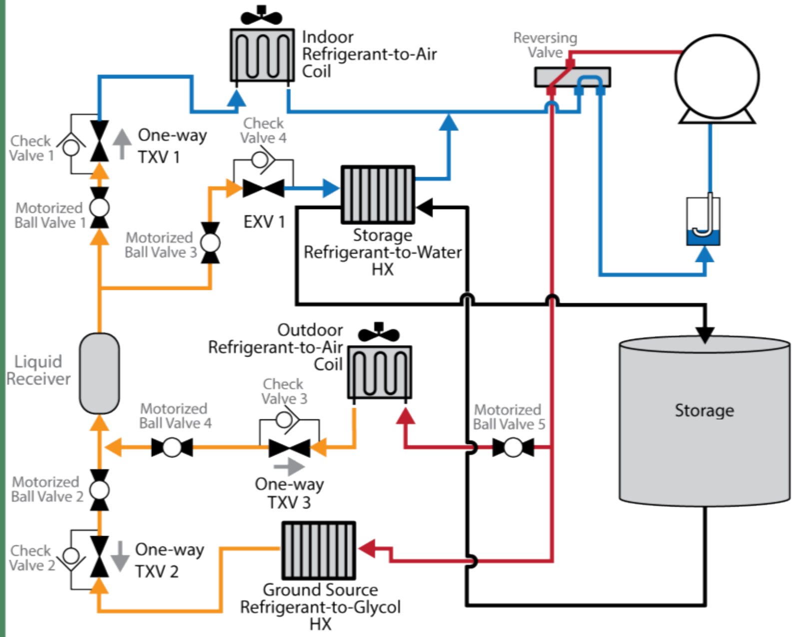
$T_{ambient,\ high}$ = 104°F (40°C)

$T_{ambient,\ low} = T_{ambient,\ high} - \Delta T_{ambient}$

Figure generated at ORNL using the methodology described in:
Jason Hirschey, Zhenning Li, Kyle R. Gluesenkamp, Tim J. LaClair, Samuel Graham (2023) "Demand Reduction and Energy Saving Potential of Thermal Energy Storage Integrated Heat Pumps" International Journal of Refrigeration https://doi.org/10.1016/j.ijrefrig.2023.01.026

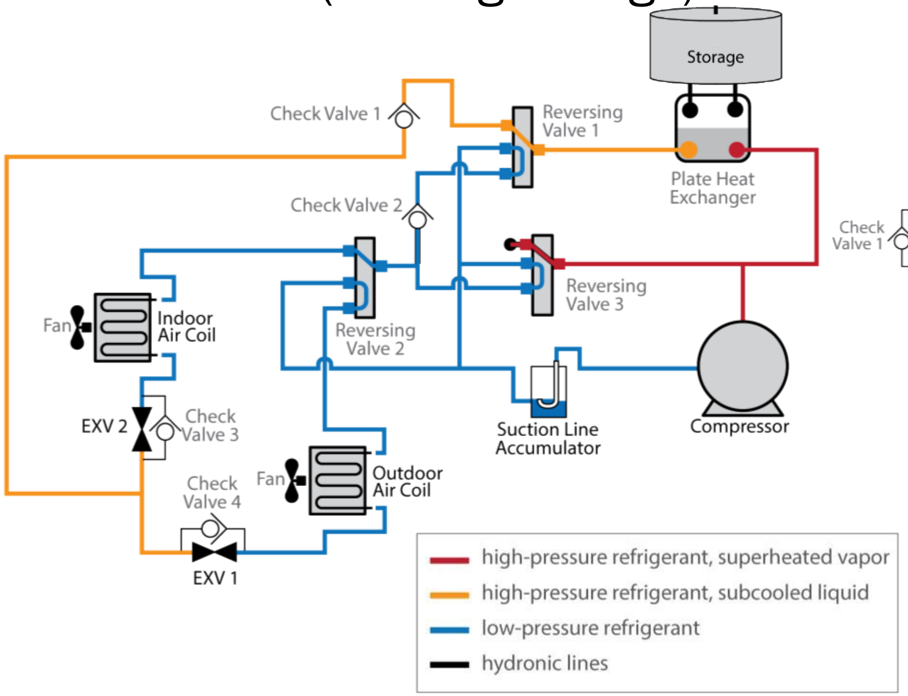
HP-TES hardware configuration options

Dual source HP



Lingshi Wang, Xiaobing Liu, Bo Shen, Xiaoli Liu, Anthony Gehl, Liang Shi, and Ming Qu. "Experimental Performance Analysis of a Dual-Source Heat Pump Integrated with Thermal Energy Storage." *IGSHPA Research Track*, Las Vegas NV, Dec 6-8, 2022.
Provisional Application 63/446,366

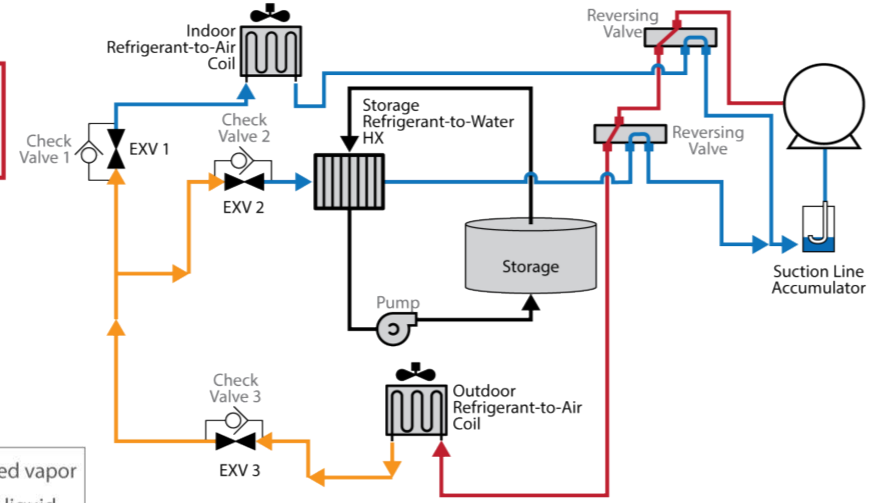
Cold climate integrated HP (heating storage)



Can access 4 of the basic operating modes.
Can access a desuperheat mode during heating, to maintain DHW temperatures during low ambient conditions.
Uses commoditized valves.

Bo Shen, Jeff Munk, Kyle Gluesenkamp "Cold Climate Integrated Heat Pump", *19th International Refrigeration and Air Conditioning Conference at Purdue*, July 10 - 14, 2022.
Provisional application 63/358,298

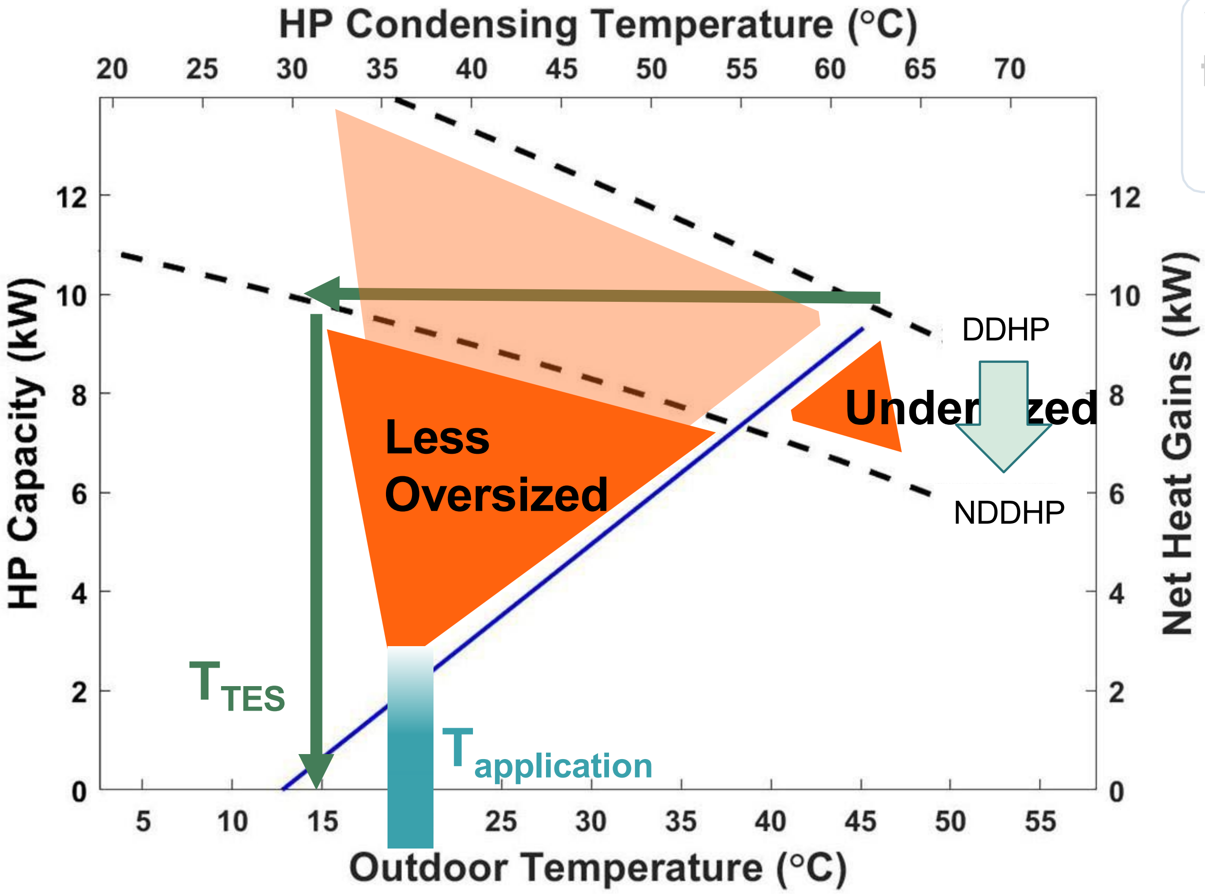
Split system (heating and cooling storage)



Can access all 6 basic operating modes.
Uses commoditized valves.

Bo Shen, Kyle Gluesenkamp, Zhenning Li, Jie Cai, Philani Hlanze, Zhimin Jiang "Cold Climate Integrated Heat Pump with Energy Storage for Grid-Responsive Control", *ASHRAE and SCANVAC HVAC Cold Climate Conference 2023*
Provisional Application 63/446,366

Method to determine reduced HP and TES temperature



1. Determine application heat load at the Design Day (DD) condition
   - ACCA Manual J, ASHRAE Standards, Building energy modeling
2. Select HP to meet DD conditions (DDHP)
   - ACCA Manual S, Contractor oversize
   - HP availability
3. Identify new DD (NDD) conditions –OR– Select smaller HP (NDDHP)
   - Building energy calculations
   - Climate consideration
4. Determine TES temperature
   - NDDHP meets DD conditions

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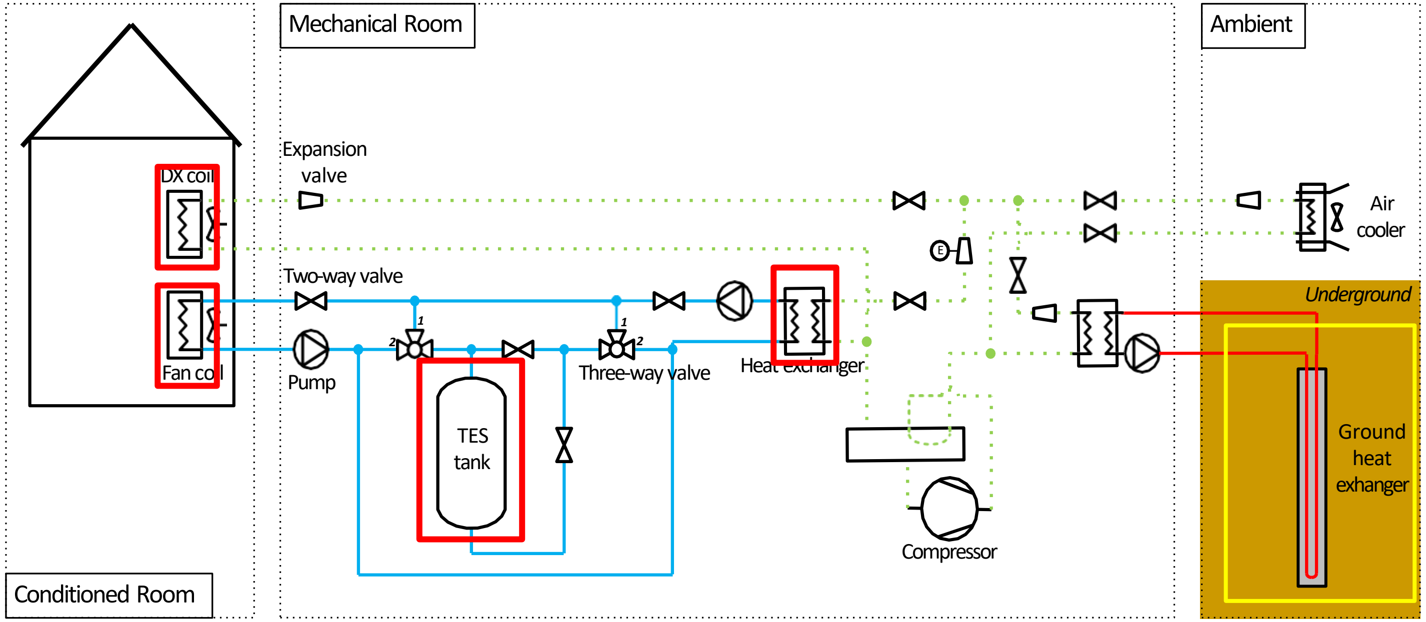
Jason Hirschey, Kyle R. Gluesenkamp, Bo Shen, Zhenning Li, Samuel Graham. "A proposed methodology to reduce heat pump size with integrated thermal energy storage," *14th IEA Heat Pump Conference,* May 15-18 2023, Chicago, IL. https://www.osti.gov/biblio/1975341

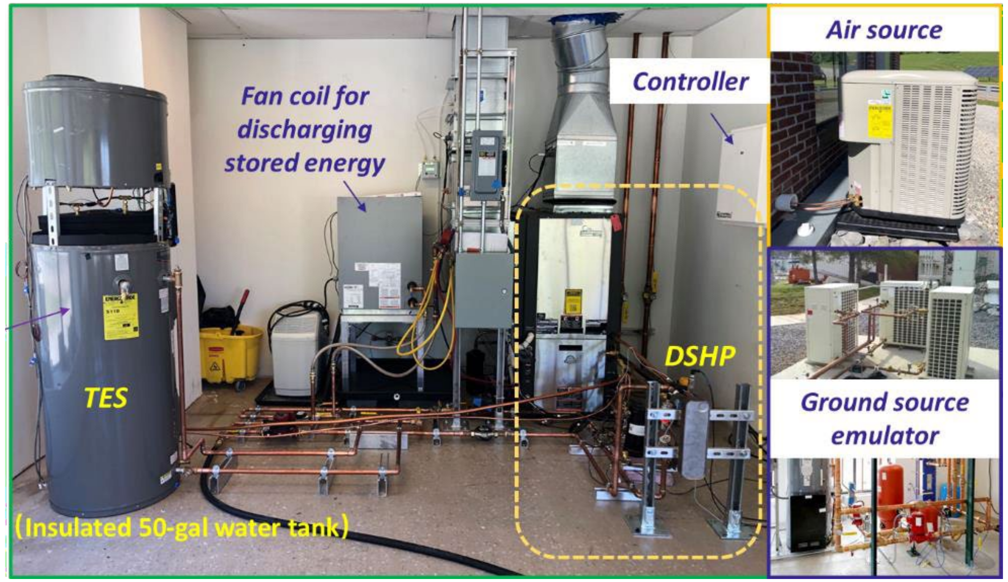
Dual source HP experiment

- Field tests were conducted in a real building exposed to real weather conditions and with emulated occupancy
- The test bed uses cyberinfrastructure to enable remote control and performance monitoring

Flexible Research Platform at ORNL



DSHP-TES system diagram



Experiment setup

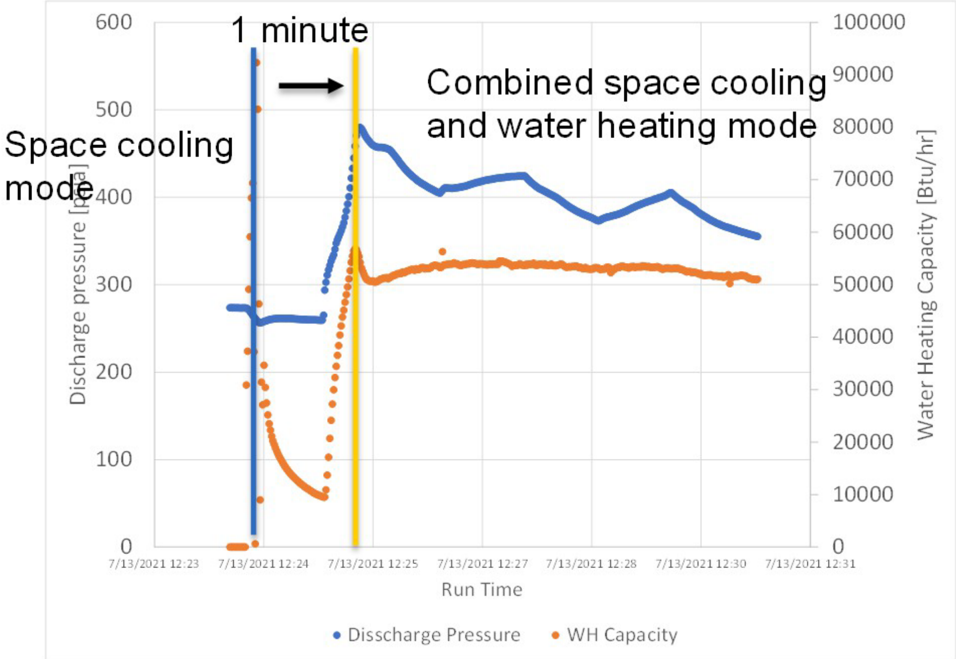
OAK RIDGE National Laboratory

Cold climate integrated HP laboratory experiment

Outdoor unit connected in the laboratory

Indoor air hander, compressor, suction line accumulator, brazed plate heat exchanger, and 50-gallon water tank

Using the refrigerant valve switching, the system was experimentally demonstrated to transition modes and establish new charge distribution within one minute.



Mode switch within one minute

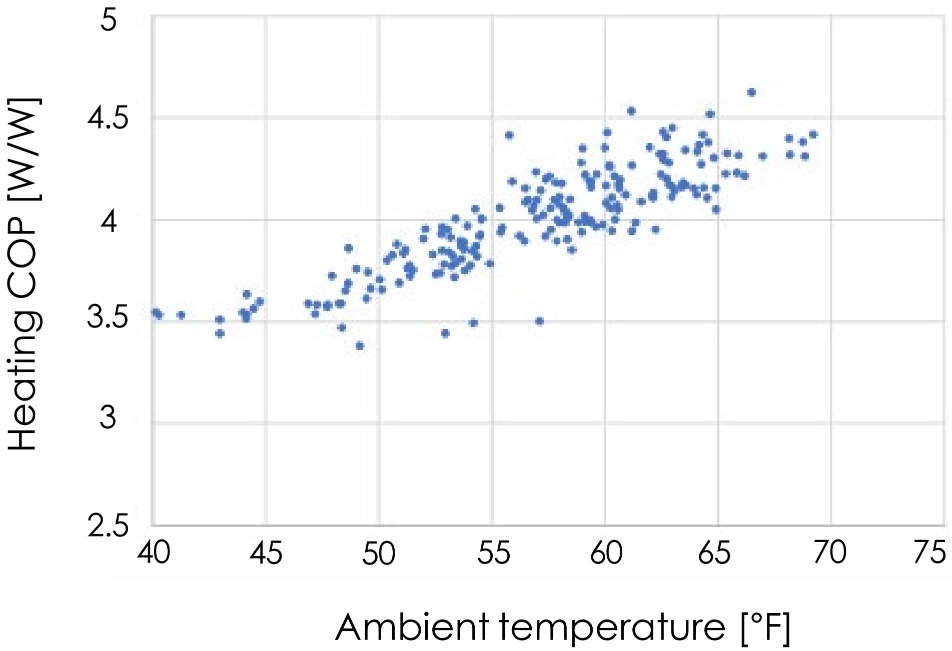
Bo Shen, Jeff Munk, Kyle Gluesenkamp "Cold Climate Integrated Heat Pump", *19th International Refrigeration and Air Conditioning Conference at Purdue*, July 10 - 14, 2022.

Cold climate integrated HP field experiment

Outdoor unit installed in 2023 for field test in Syracuse, NY

Indoor unit and 50-gallon domestic hot water tank installed in the field site

Dedicated water heating COP at the compressor high (3rd) stage in field tests



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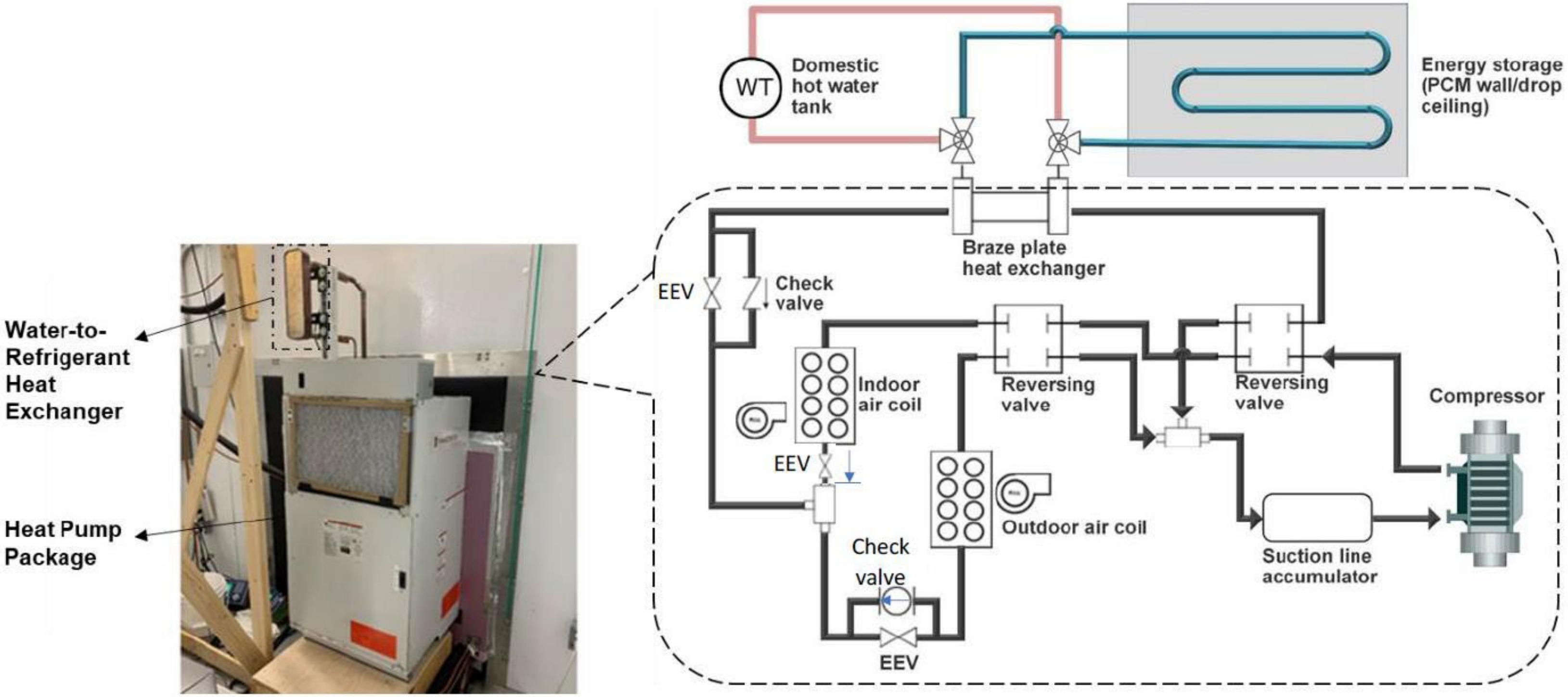
Heating and cooling experiment



Experimental installation of packaged HP

Test results showed that application of the proposed control strategy to the PCM-integrated heat pump could achieve cost savings of 24.2%, compared to a baseline case without PCM storage, under a time-of-use rate tariff.

The TES in this case was a mat of encapsulated PCM sandwiched with hydronic lines, in a drop ceiling

Bo Shen, Kyle Gluesenkamp, Zhenning Li, Jie Cai, Philani Hlanze, Zhimin Jiang "Cold Climate Integrated Heat Pump with Energy Storage for Grid-Responsive Control", [ASHRAE and SCANVAC HVAC Cold Climate Conference 2023]

Conclusions

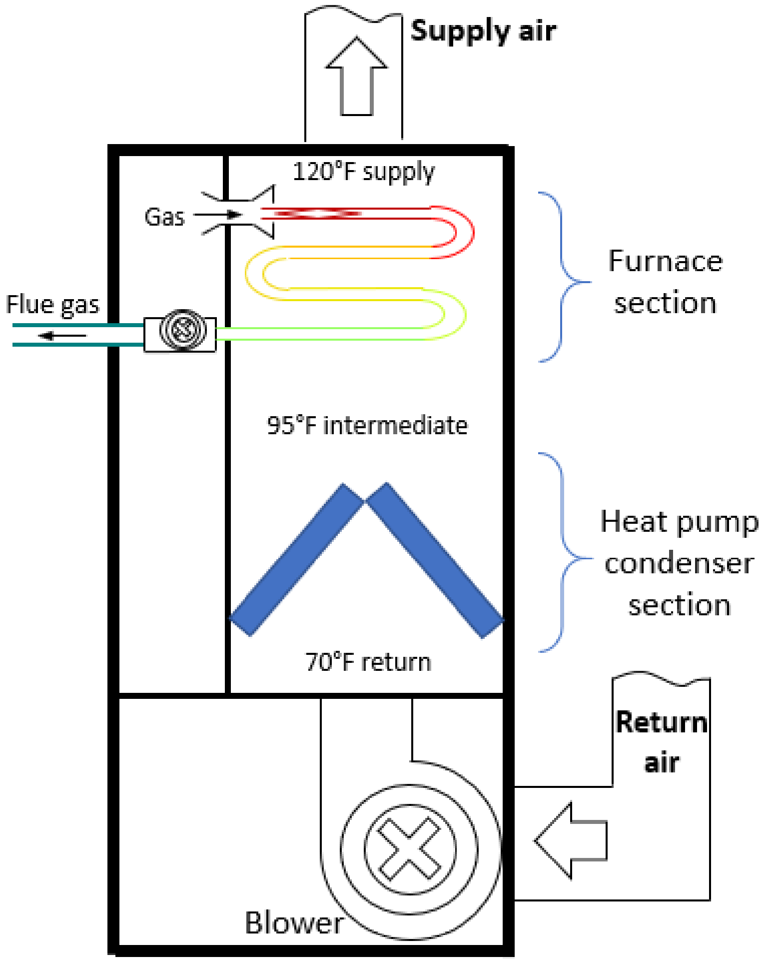
- Lower cost storage on a massive scale is needed to deliver national goals for resilience, decarbonization, and electrification
- Thermal storage with heat pumps (TES-HP) may provide a low-cost method of storage
- TES-HP can deliver compelling demand reduction benefits
- Several technology options are in development for thermals storage with heat pumps

Optimized Controls for Dual Fuel Heat Pump

(marginal grid emissions, variable utility pricing)

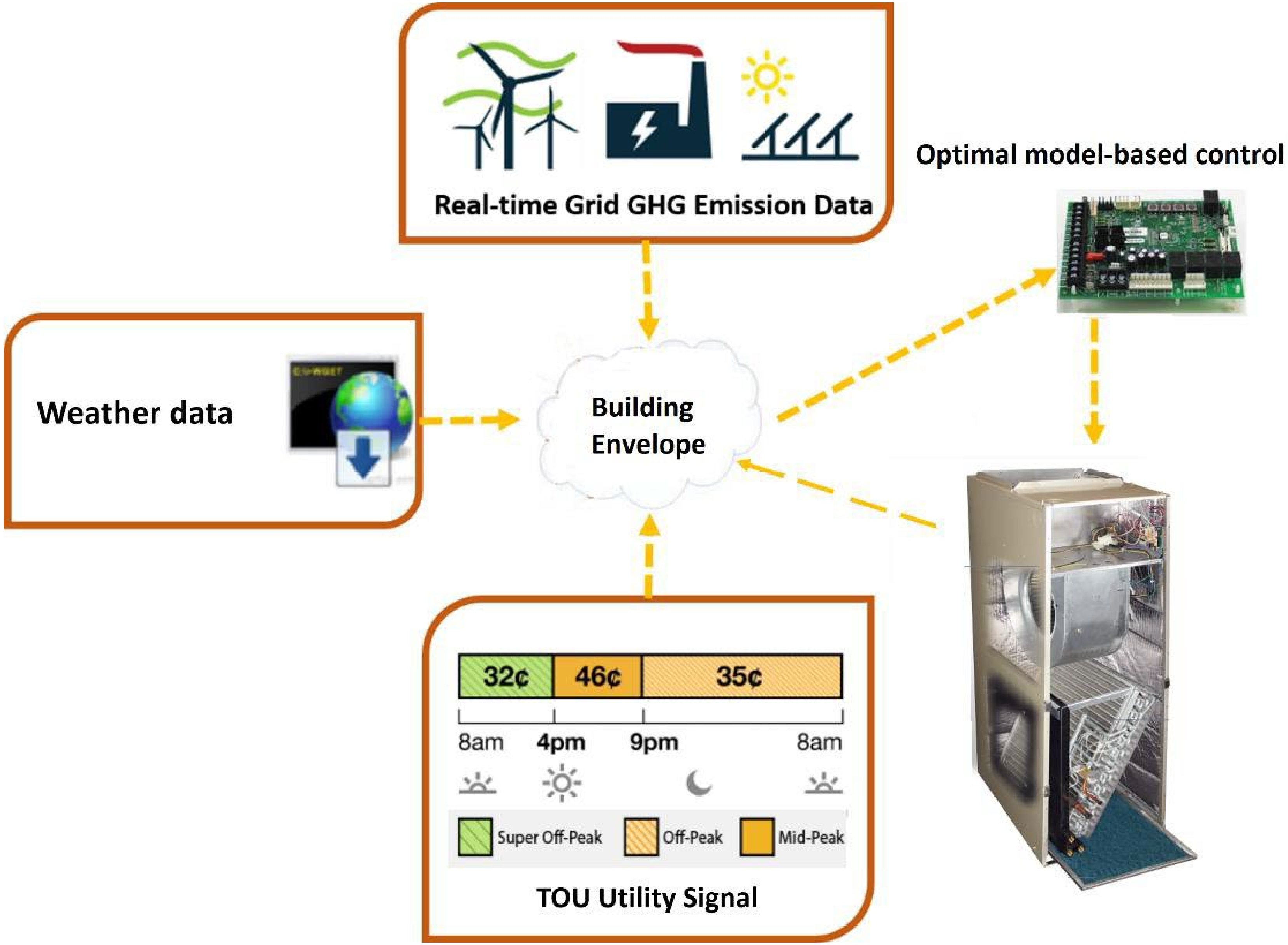
Dual Fuel Systems

- Conventional dual fuel heat pump (DFHP)
  - Switch between gas furnace or electric heat pump
  - Switching temperature decided by the balancing point between load and capacity o the compressor has a lockout outdoor temperature
- Seamlessly fuel flexible heat pump (SFFHP)
  - simultaneously consumes gas and electricity
  - continuously adjust the capacities of HP and furnace based on the foreseen weather data, utility price signals, and marginal grid emission signals



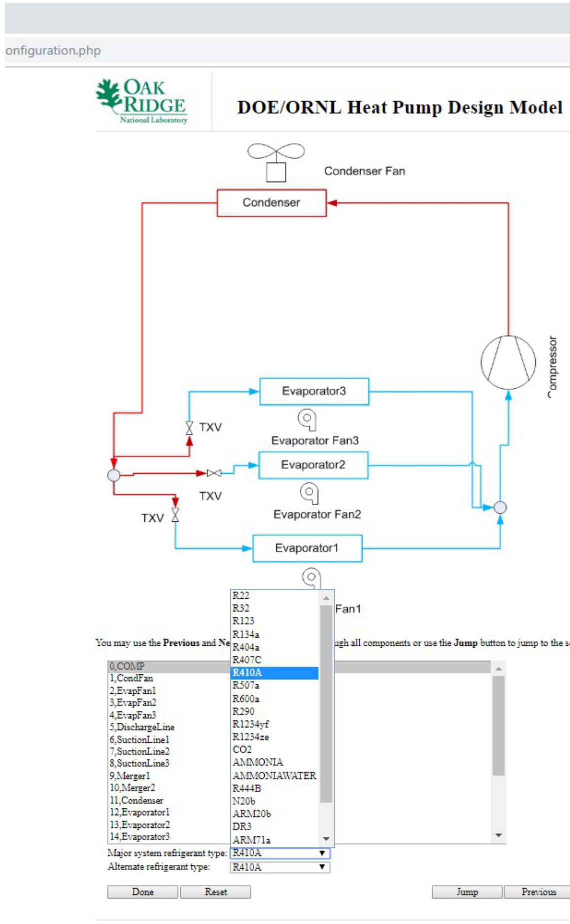
Seamlessly Fuel Flexible Heat Pump

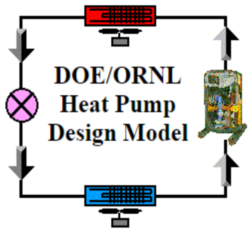
Optimal Model-based Control Strategy of SFFHP



Methodology

- DOE/ORNL Heat Pump Design Model[1] is used to model the performance of a 3-ton cold climate heat pump sub-system and a furnace with 95% AFUE
- The optimal model-based control is formulated as a bi-objective problem





Problem Formulation:

$Objective\text{-}1: Minimize(Utility\ Cost)$

$Objective\text{-}2: Minimize(CO2Emission)$

Design Variable: $Ratio_{HPtoTotal}$ for every hour

Objectives Normalization:

$$Objective-1: Utility\ Cost^{norm} = \frac{Utility\ Cost(Ratio_{HPtoTotal}) - Utility\ Cost_{\min}}{Utility\ Cost_{\max} - Utility\ Cost_{\min}}$$

$$Objective-2: CO2Emission^{norm} = \frac{CO2Emission(Ratio_{HPtoTotal}) - CO2Emission_{\min}}{CO2Emission_{\max} - CO2Emission_{\min}}$$

$$fitness = w_1 \times Utility\ Cost^{norm} + w_2 \times CO2Emission^{norm}$$

$$where\ w_1 + w_2 = 1$$

Utility cost and emission calculation:

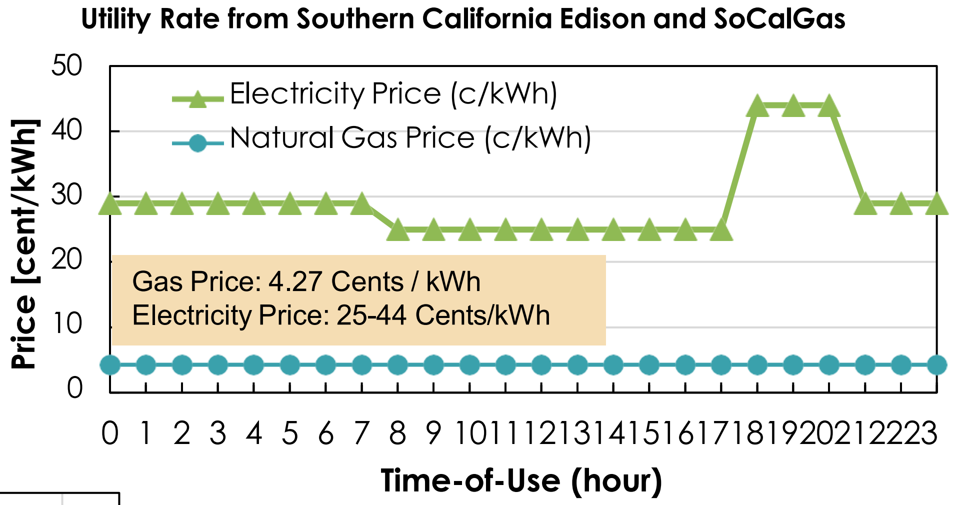
$$Utility\ Cost(t) = \frac{Ratio_{HPtoTotal} \times Q_{building}(t)}{COP_{HP}(t)} \times price_{electricity}(t) + \frac{(1 - Ratio_{HPtoTotal}) \times Q_{building}(t)}{\eta_{furnace}} \times price_{Natura\ lGas}$$

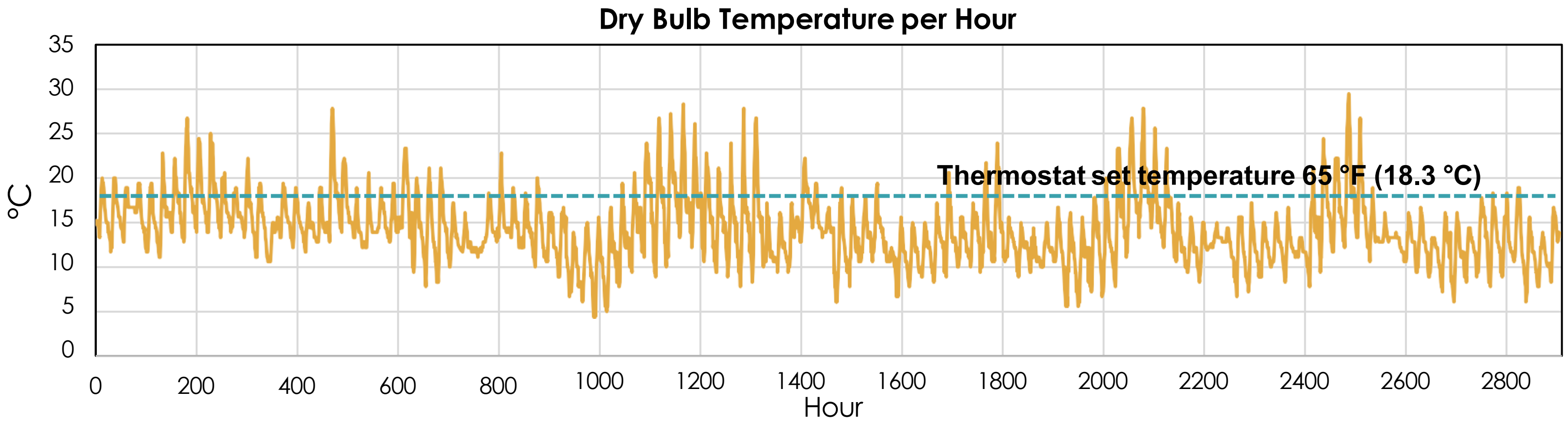
$$Emission(t) = \frac{Ratio_{HPtoTotal} \times Q_{building}(t)}{COP_{HP}(t)} \times Emission_{GridMarginal}(t) + \frac{(1 - Ratio_{HPtoTotal}) \times Q_{building}(t)}{\eta_{furnace}} \times Emission_{NaturalGasPerkWh}$$

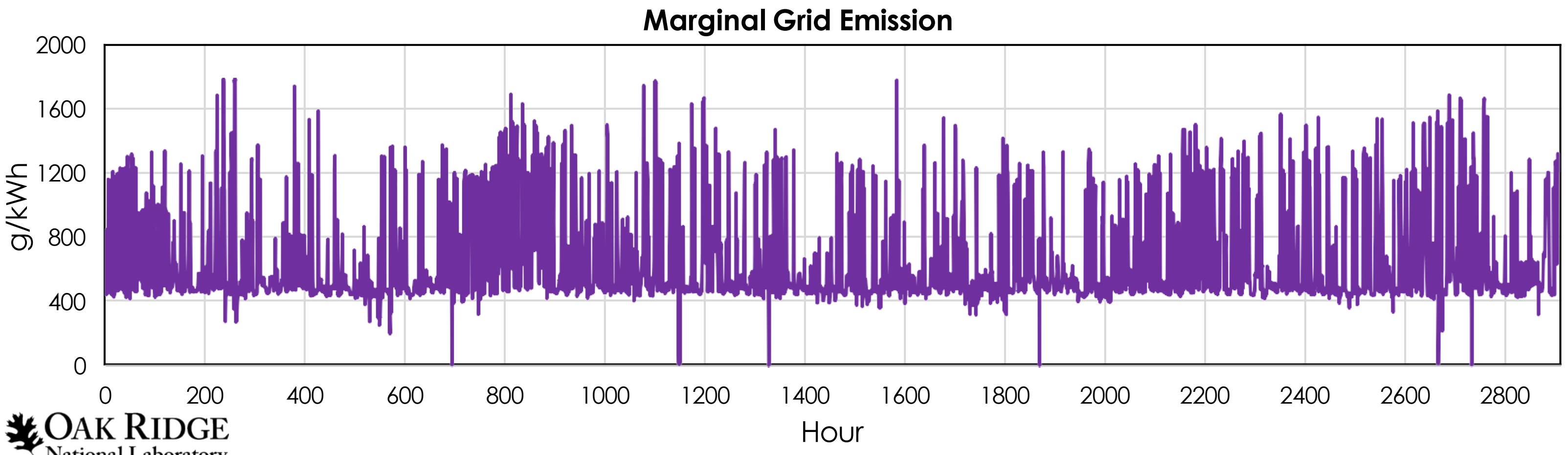
[1] https://hpdmflex.ornl.gov

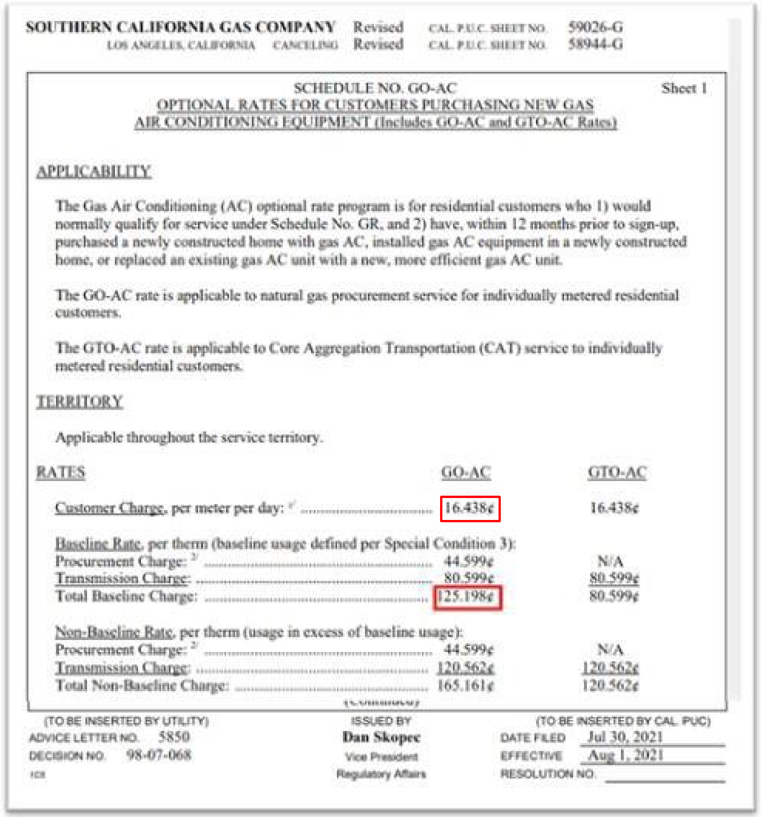
Case Study in Los Angeles

1. Los Angeles Weather Data for November 2019- February 2020
2. 65 °F as heating set point temperature
3. Time-of-Use utility rate from Southern California Edison (SCE)
4. Gas price from SoCalGas including the daily meter charge
5. Marginal grid emission data from WattTime









SOUTHERN CALIFORNIA GAS COMPANY Revised CAL. P.U.C. SHEET NO. 59026-G
LOS ANGELES, CALIFORNIA CANCELING Revised CAL. P.U.C. SHEET NO. 58944-G

SCHEDULE NO. GO-AC Sheet 1
OPTIONAL RATES FOR CUSTOMERS PURCHASING NEW GAS
AIR CONDITIONING EQUIPMENT (Includes GO-AC and GTO-AC Rates)

APPLICABILITY

The Gas Air Conditioning (AC) optional rate program is for residential customers who 1) would normally qualify for service under Schedule No. GR, and 2) have, within 12 months prior to sign-up, purchased a newly constructed home with gas AC, installed gas AC equipment in a newly constructed home, or replaced an existing gas AC unit with a new, more efficient gas AC unit.

The GO-AC rate is applicable to natural gas procurement service for individually metered residential customers.

The GTO-AC rate is applicable to Core Aggregation Transportation (CAT) service to individually metered residential customers.

TERRITORY

Applicable throughout the service territory.

RATES	GO-AC	GTO-AC
Customer Charge, per meter per day:	16.438¢	16.438¢
Baseline Rate, per therm (baseline usage defined per Special Condition 3):		
Procurement Charge: 2/	44.599¢	N/A
Transmission Charge:	80.599¢	80.599¢
Total Baseline Charge:	125.198¢	80.599¢
Non-Baseline Rate, per therm (usage in excess of baseline usage):		
Procurement Charge: 2/	44.599¢	N/A
Transmission Charge:	120.562¢	120.562¢
Total Non-Baseline Charge:	165.161¢	120.562¢

(Continued)

(TO BE INSERTED BY UTILITY)
ADVICE LETTER NO. 5850
DECISION NO. 98-07-068

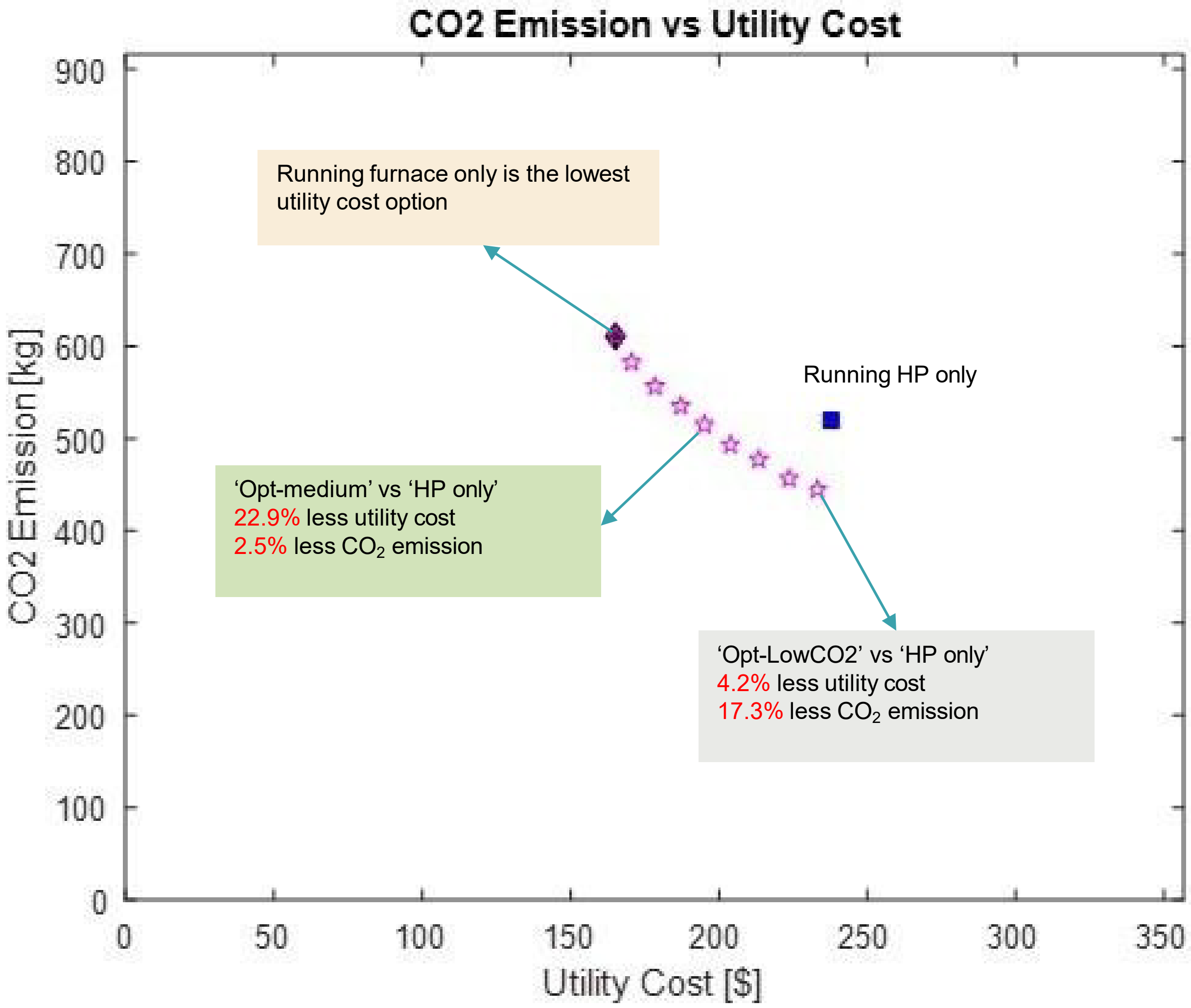
ISSUED BY
Dan Skopec
Vice President
Regulatory Affairs

(TO BE INSERTED BY CAL. PUC)
DATE FILED Jul 30, 2021
EFFECTIVE Aug 1, 2021
RESOLUTION NO.

OAK RIDGE National Laboratory

Control Strategy Optimization for SFFHP in Los Angeles

- Each optimal points represents one operation strategy for SFFHP
- The number of optimal designs is determined by weights combinations



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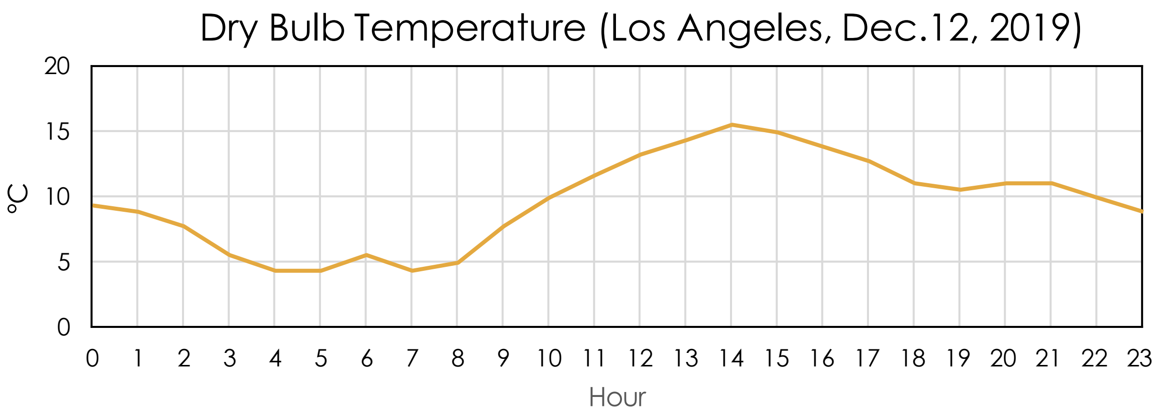
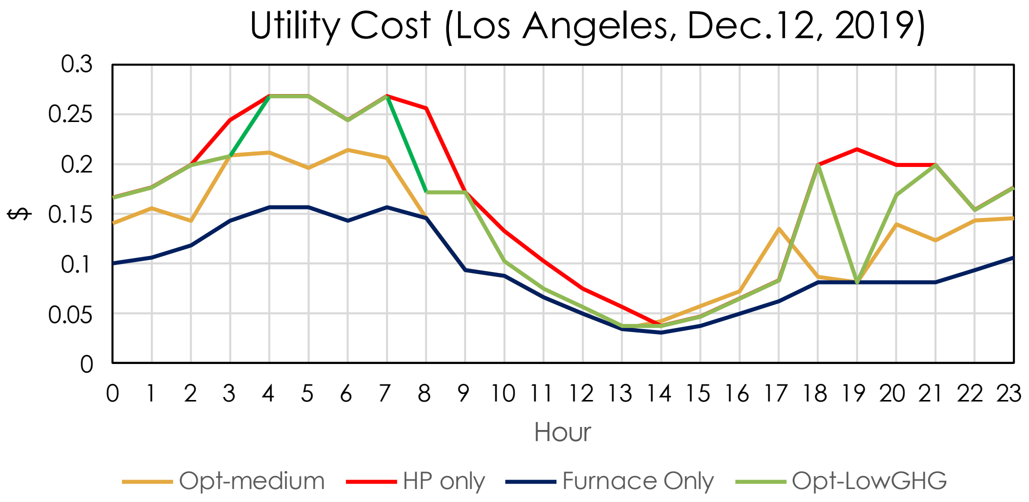
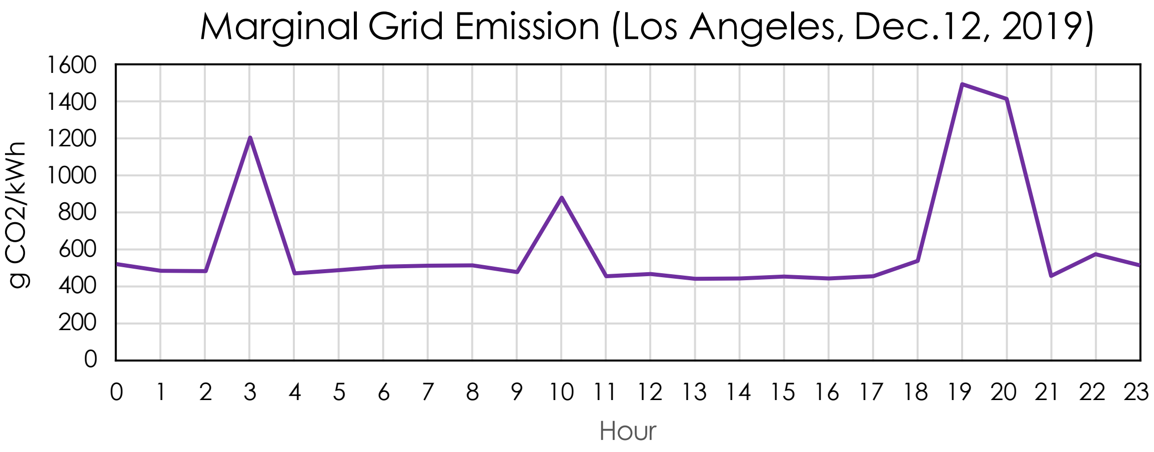
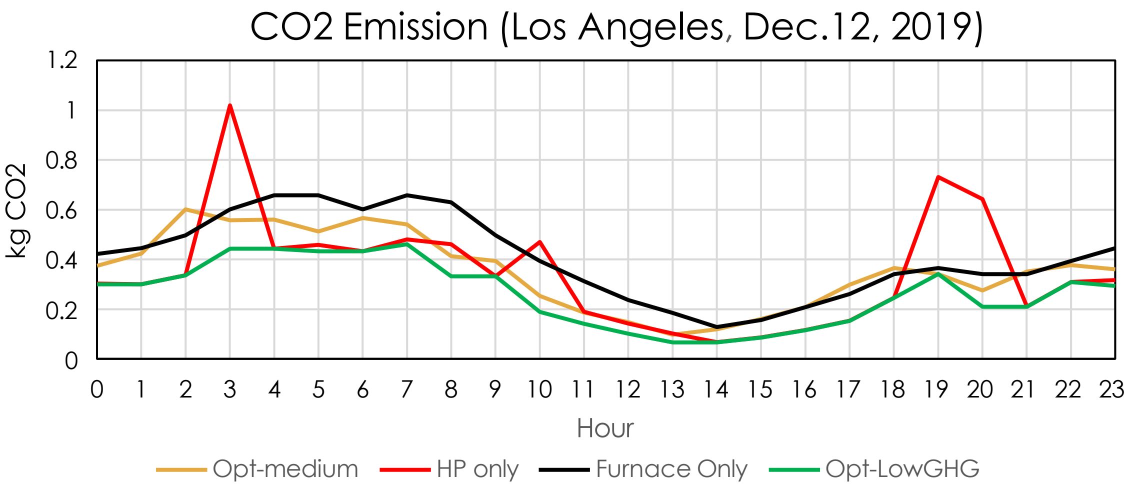
* Genetic Algorithm Setting: PopulationSize=200, NGeneration=400, MutationRate=0.15, CrossoverRate=0.3

Analysis of SFFHP Performance in December 12th, 2019





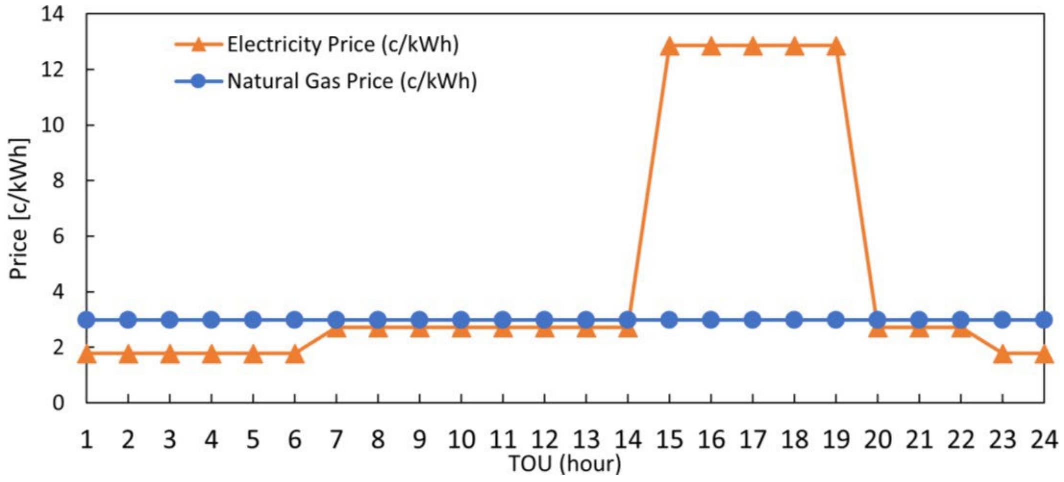




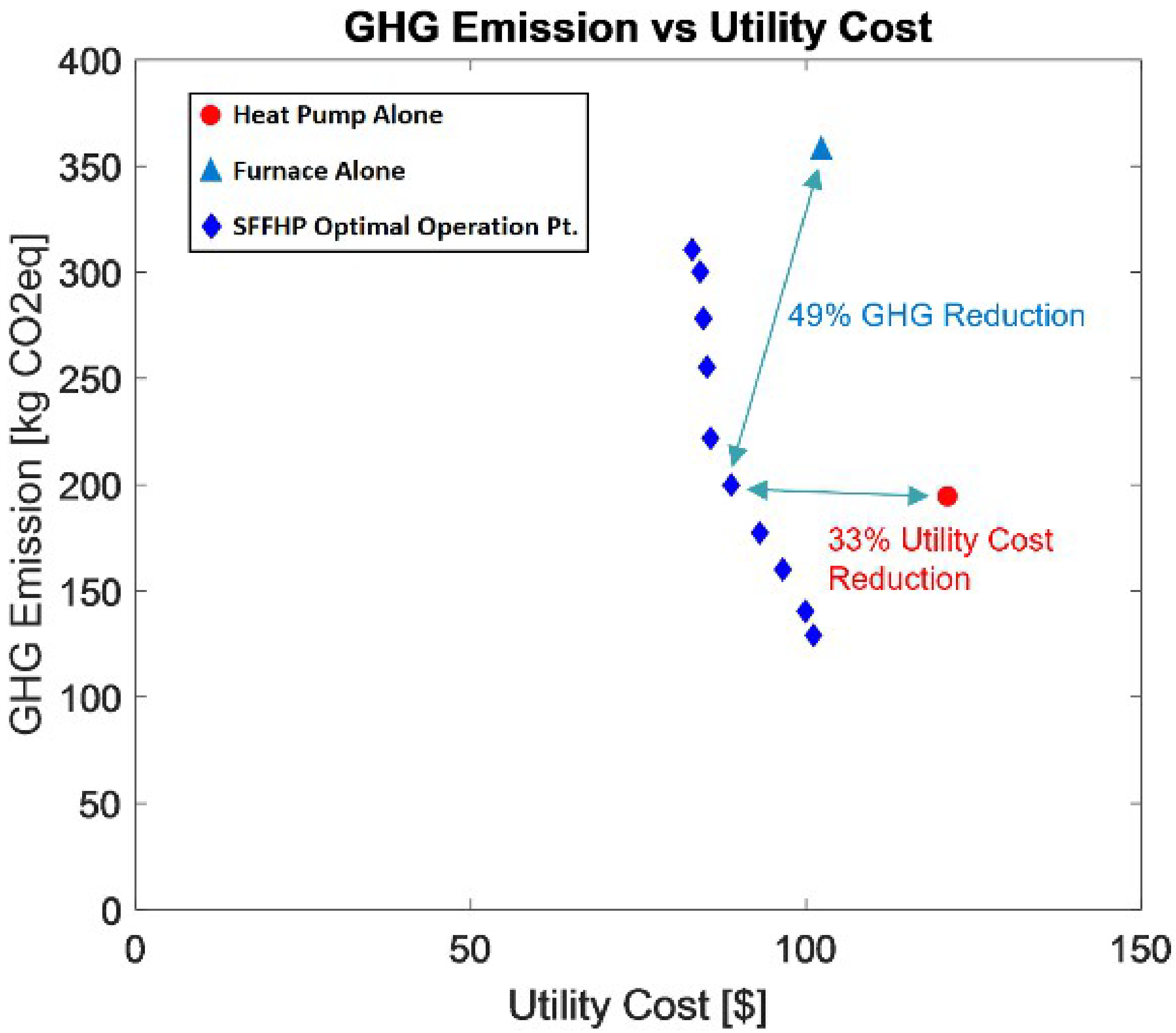
OAK RIDGE National Laboratory

Case Study in Chicago

- Weather data from January 1st, 2020, to February 29th, 2020
- Time-of-Use utility rate is from ComEd
- The natural gas price is adopted from Peoples Gas company



Utility Rate from ComEd and Gas Price in Chicago



Conclusion

- Introduce a transitional heat pump product - Seamlessly Fuel Flexible Heat Pump (SFFHP) that pairs an electric heat pump with a gas furnace with simultaneous operation
- SFFHP adjusts operation of each sub-system based on TOU, gas price and grid emission signals
- Case studies demonstrate that when SFFHP is operated under optimal control strategies, it can deliver
  - up to 23% utility cost reduction and up to 17 % CO_2 emission reduction in Los Angeles
  - up to 33% utility cost reduction and up to 49 % CO_2 emission reduction in Chicago

For more information, contact:
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Pause for discussion

Oak Ridge National Laboratory

Funding mechanisms and Collaboration mechanisms

Ways to fund research at ORNL

- AOP (DOE)
- Lab Call (DOE)
- FOA (DOE)
- SPP (non-DOE)
- SEED and LDRD (ORNL)

Ways other organizations can work with ORNL

- CRADA
- Subcontract
- Co-funded partner (FOA)
- Informal advisory role

Industry 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

Acknowledgements

- Contributors to these slides: Bo Shen, Zhenning Li, Xiaobing Liu, Jason Hirschey, Sara Sultan, Chad Malone, Brian Fricke, and more from ORNL team
- This work was sponsored by the U. S. Department of Energy's 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. The authors would like to acknowledge Mr. Sven Mumme, Payam Delgoshaei, and Wyatt Merrill, Technology Managers, U.S. Department of Energy Building Technologies Office.
- 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.

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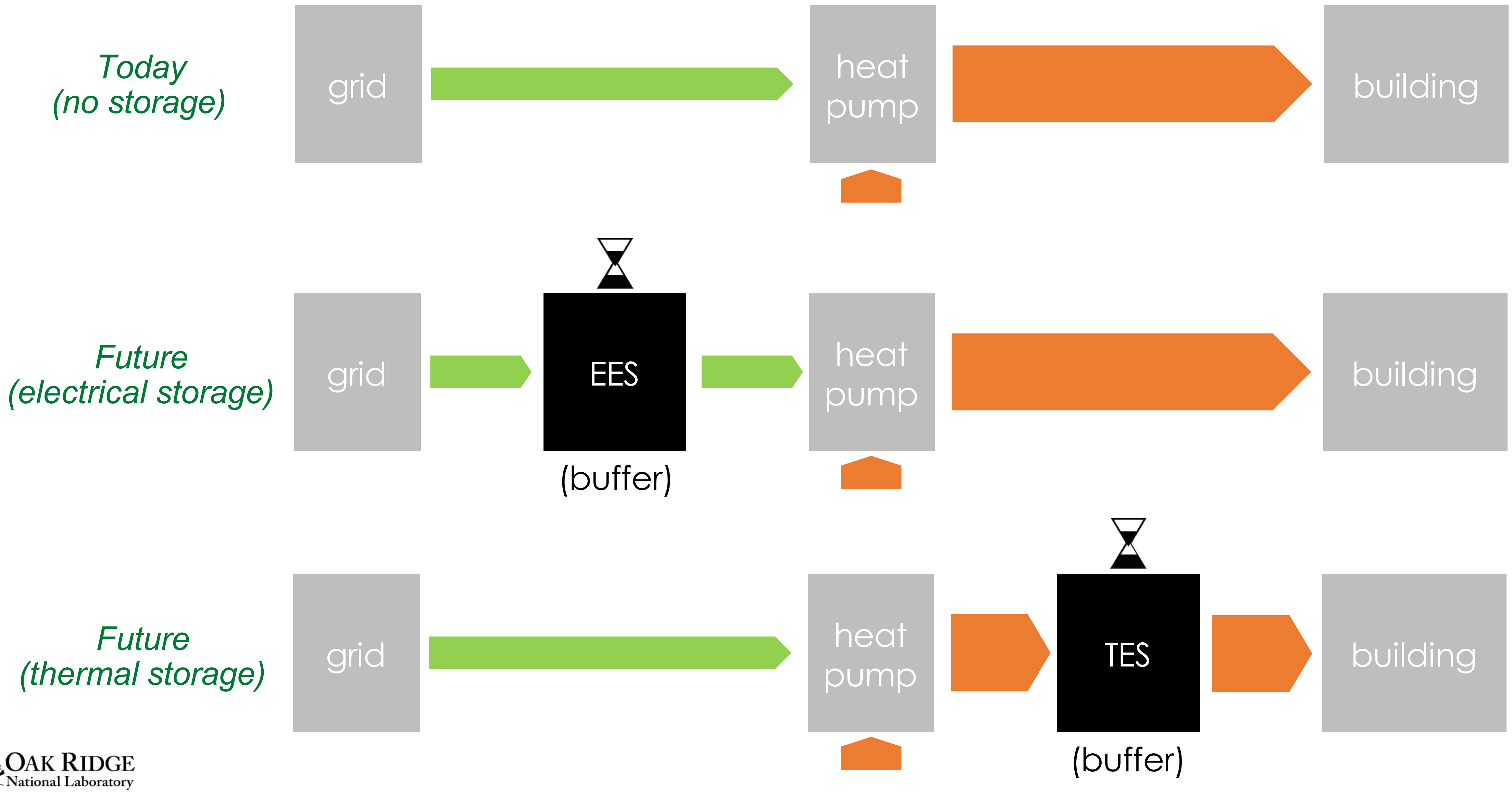
Oak Ridge National Laboratory

How does thermal storage work? (big picture)



Heat Pump Integration System Configuration

ORNL Developed an approach with HP integrated with TES that can accommodate a large number of operating modes, with low cost, higher flexibility, and ease of installation

Approach	Type of Heat Exchange with PCM	Mechanism of Switching Operating Modes	Challenges	Strengths
Fully refrigerant-based	DX refrigerant-based	Refrigerant valves	Large refrigerant charge	The best charge and discharge rates
Fully hydronic	Hydronic-coupled	Hydronic	Charge migration issues for parallel HXs	Uses commercially available components
Air distribution, hydronic TES coupling	Hydronic-coupled	Refrigerant valves	Many valves required on refrigerant-side	Solves the charge migration issues – extra charge stored in SL accumulation, and EXV balances charge in multiple modes
TES in supply air duct	Air-side coupled		Difficult installation Low flexibility Sensitive to PCM temperature	Conventional HP can be used.

Not feasible with A2L or A3 refrigerants

Limited US market due to lack of hydronic products in the US

ORNL's innovative approach leverages low-cost commoditized valves

Limited market due to installation challenges

HX: Heat Exchanger, DX: Direct Expansion

Tell Us What You Think…

- What did you find most helpful in this segment?
- What would you like to learn more about?

Drop your thoughts into the chat!

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Break

Agenda

8:30 am	Welcome and Announcements
9:00 am	*New!* ORNL Emerging Technology Update
10:15 am	*Break*
10:30 am	*New!* ACEEE Hot Air & Hot Water Forum Roundtable
11:00 am	*New!* NEEA Emerging Technology Update
12:00 pm	Wrap-Up

ACEEE Hot Water & Hot Air Forum Roundtable

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ACEEE Hot Air & Hot Water Forums

- Took place in Atlanta, GA March 12 – 14
- The Hot Air forum was from March 12 to March 13
- The Hot Water Forum was from March 13 to March 14
- Speakers and presenters from NEEA, National Labs, Center for Energy and Environment, utilities, efficiency organizations, and industry experts
- 10 groups of sessions
- Program & presentation materials are available off the ACEEE website: https://www.aceee.org/sites/default/files/pdfs/Program%20%2B%20Presentations_2.pdf

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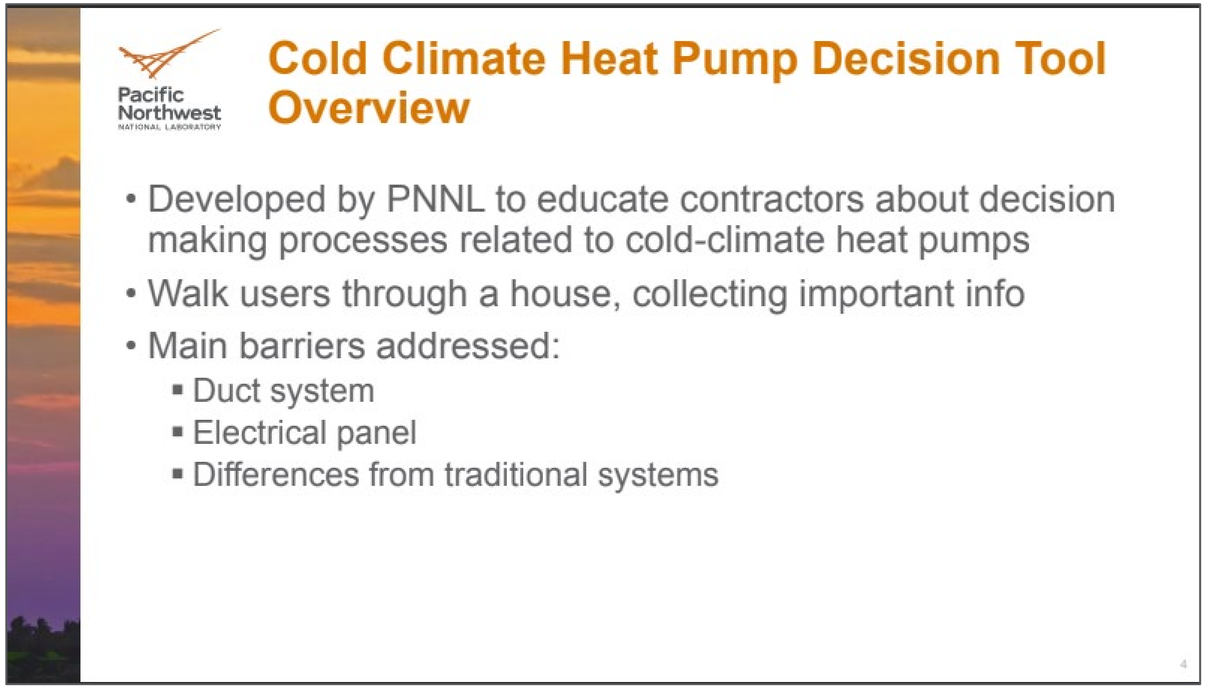
ACEEE Hot Air & Hot Water Forums – Big Topics

- Connectivity, Demand Response, Grid Interactivity
- Dual Fuel
- Market Transformation
- Cold Climate ASHPs and HPWHs and Design & Decision Tools
- Micro (window) Heat Pumps
- Modeling
- Workforce Development
- Central HPWHs
- Multifamily HPWH applications
- Thermal Energy Storage

ACEEE Hot Air Forum Samples

Technical Challenges and M&V Approaches for Packaged Window Heat Pumps – Taitem Engineering



Better Together: Cold Climate Heat Pump Decision Tool & Heat Pump List – PNNL & NEEP

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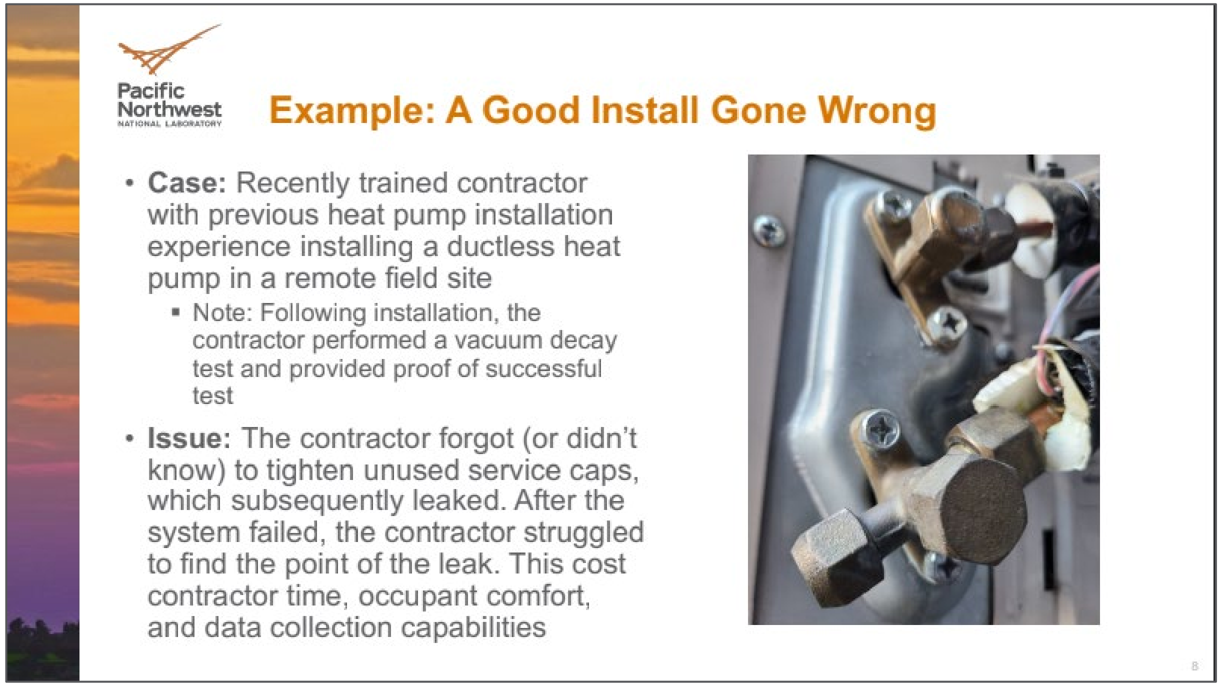
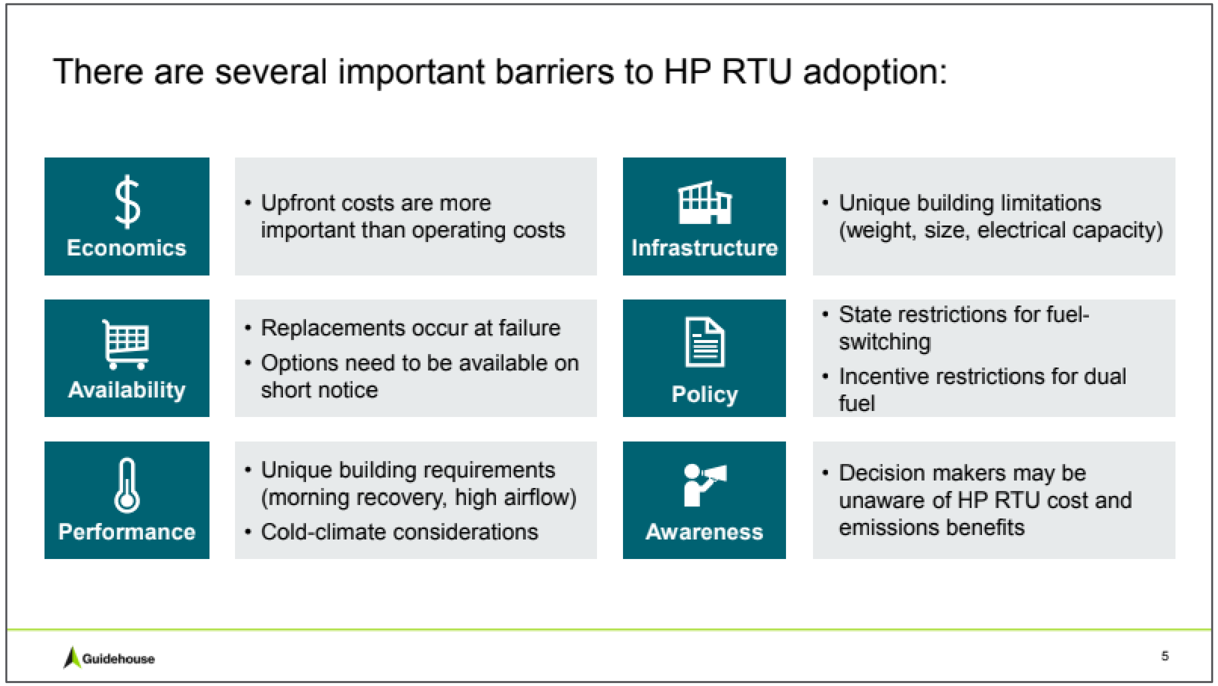
ACEEE Hot Air Forum Samples



Notes From the Field: Lessons Learned from Heat Pump Field Research – PNNL



Heat Pump Rooftop Units: Underutilized Decarbonization Strategy for Low-Rise Commercial Buildings - Guidehouse

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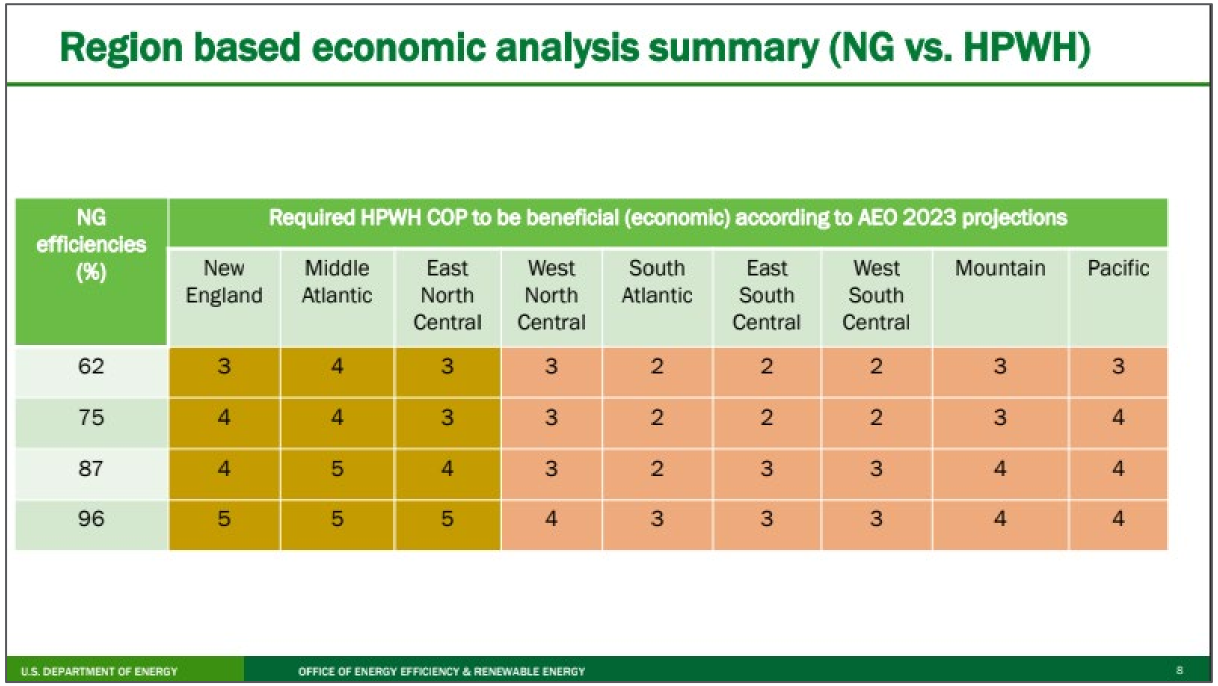
ACEEE Hot Water Forum Samples



Region based economic analysis summary (NG vs. HPWH)

NG efficiencies (%)	Required HPWH COP to be beneficial (economic) according to AEO 2023 projections								
	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific
62	3	4	3	3	2	2	2	3	3
75	4	4	3	3	2	2	2	3	4
87	4	5	4	3	2	3	3	4	4
96	5	5	5	4	3	3	3	4	4

U.S. DEPARTMENT OF ENERGY | OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY | 8

Cost Compression of Heat Pump Water Heaters for Multifamily Housing in Cold Climates (CC HPWH MH CC) – ORNL

Existing Multifamily DHW Distribution Issues – Association for Energy Affordability Inc.

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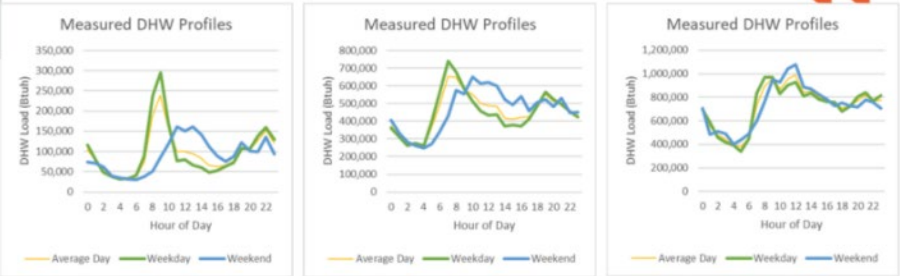
ACEEE Hot Water Forum Samples

Who is home and when?



- Luxury with many younger people working 9-5 out of the home
- 112 units, 127 BRs

- Gentrifying, mix of singles/families home during the day and people working out of the home
- 112 units, ~220 BRs

- Affordable housing with more people home during the day (including more seniors)
- 312 units, ~624 BRs

Steven Winter Associates, Inc. 10

Bringing Hot Water System Sizing into the 21st Century – Steve Winter Associates, Inc, Ecotope, AEA

Preliminary Results – Load Shifting

- Participants successfully shifted load off peak
- Large households with higher usage can shift more energy, but lower occupancy households sometimes shift a larger percentage of load
- Minor increase in total daily energy consumption due to rebound after long events did not outweigh the load shifting benefits based on TOU rates
- Estimated annual water heating electricity cost savings of $40 from shifting load, based on TOU rate, compared to non-shifting baseline

Shifting Schedule*	Shed Periods	Morning Load Shifted as % of Baseline	Evening Load Shifted as % of Baseline
Summer - Hot	Evening: 1-9 p.m.	-	23%
Winter - Shoulder	Morning: 6 a.m.-12 p.m. Evening: 4-9 p.m.	15%	17%
Winter - Cold	Morning: 6 a.m.-1 p.m. Evening: 4-9 p.m.	9%	24%

** Insufficient data available to report results for Summer-Shoulder period*

22

North Carolina Demand Response Heat Pump Water Heaters for Low-Income Homes – Energy Solutions.

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Cold Climate Window Heat Pump Update

Outline

- Quick Technology Overview
- NEEA 2023 MicroHP Research
- New Cold Climate Products
- Test Procedure and Tax Credits
- Pilot / Field Test Opportunity?

Window Heat Pumps Both Heat & Cool

(also called window AC w/ reverse cycle)

- Twice as efficient in heating than electric resistance

Window AC

w/reverse cycle

Portable

(dual hose)

Dual hose is very important to performance

Saddlebag

U-shape not yet sold as heat pump

 |

Window Heat Pumps are relatively new

- Defined as Window AC with reverse cycle (mechanically very similar to window ACs)
- Not well differentiated in the market – Not test procedure to rate their heating performance
- Need to be capable of defrost cycle

 |

Window Heat Pump Climate Categories

Category	Heating Range (outdoor Temp)	Defrost	Notes
AC with Electric Heater	5 - 75°F	-	Inefficient during heating
Mild Climate Heat Pump	40 - 75°F	no	Very limited heating range
Cool Climate Heat Pump	17 - 75°F	yes	Very limited availability
Cold Climate Heat Pump	**5 - 75°F**	**YES**	**Limited Availability**

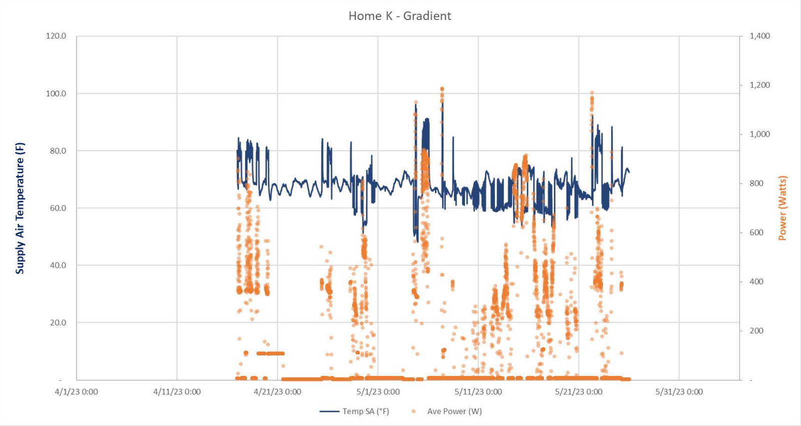
BARRIER: There is currently **NO** seasonal efficiency rating for window heat pumps. Consequently, they do not qualify for a 30% federal heat pump tax credit.

2023 NEEA Micro HP Research

1. Understand the customer experience installing, operating and their expectations of what a window heat pump is and does.

2. Understand, installation, noise, and any mechanical limitations that may impact performance or customer experience.

3. Understand how users changed behavior such that the window HP displaced heating and cooling from preexisting sources.



Aug 1 - Product Council Presentation Recording

[Northwest Energy Efficiency Alliance (NEEA) | Product Council]

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Phase 1 – Potential Customer Rsearch

- Energy and Comfort top priorities
  (Note - efficiency was not top priority once installed)
- Customers already use multiple products to heat and cool their homes – most are familiar with portable products
- 72% completely agree the concept of a dual heat/cool window unit is appealing
- Portability and 120V outlet compatibility drive interest
- Intended use will likely be to improve comfort in rooms or areas not currently well served by existing heating system

 |

Phase 2 – Field Testing 1st Generation Products

- Most participants were at least somewhat satisfied across all attributes . Participants were most satisfied with the ease of use , followed by overall heating performance , then noise level
- Units worked as expected
- Although installation was considered easy overall, there were some issues
- Once instructed, participants used product for primary heat in space, but w/o guidance they didn’t and use was significantly compromised
- Potential deal breakers : 40F limit, aesthetics, physical barriers, noise level

New Products – Cold Climate Capable

Gradient "All Weather"

125 lbs – 26" min window

- Midea "PWHP"

130 lbs – 27" min window

New Products – Specifications *(not certified)*

Electrical Requirement	Voltage	Phase	Circuit Amps
	120 VAC	60 Hz	15 A
Thermal Performance	Outdoor Temp	Capacity	Efficiency
	95 °F (35 °C)	9000 BTU/h	10.0 (EER)
	47 °F (8.3 °C)	9000 BTU/h	4.00 (COP)
	17 °F (-8.3 °C)	9000 BTU/h	2.60 (COP)
	5 °F (-15 °C)	7200 BTU/h	2.35 (COP)
	-7 °F (-21.7 °C)	4900 BTU/h	1.71 (COP)
Weight	125 lbs		
Refrigerant	R32		
Indoor Sound Level	High	Medium	Low
	47 dB(A)	44 dB(A)	38 dB(A)

*Specifications are subject to change.

	Outdoor Condition	Capacity (BTU/hr)	Efficiency
Cooling Mode	95 °F (35 °C)	9010	11.81 EER
Heating Mode	47 °F (8.3 °C)	9050	4.05 COP
	17 °F (-8.3 °C)	9060	2.42 COP
	5 °F (-15 °C)	9000	2.0 COP
Min Temp	-13 °F (-25 °C)	5050	1.41 COP
CEER	16		
SEER2	18.76		
HSPF2	10.12		
Indoor Sound Pressure Level	High	Low	Silent
	51 dB(A)	43 dB(A)	26 dB(A)
Unit Weight	130 lbs		

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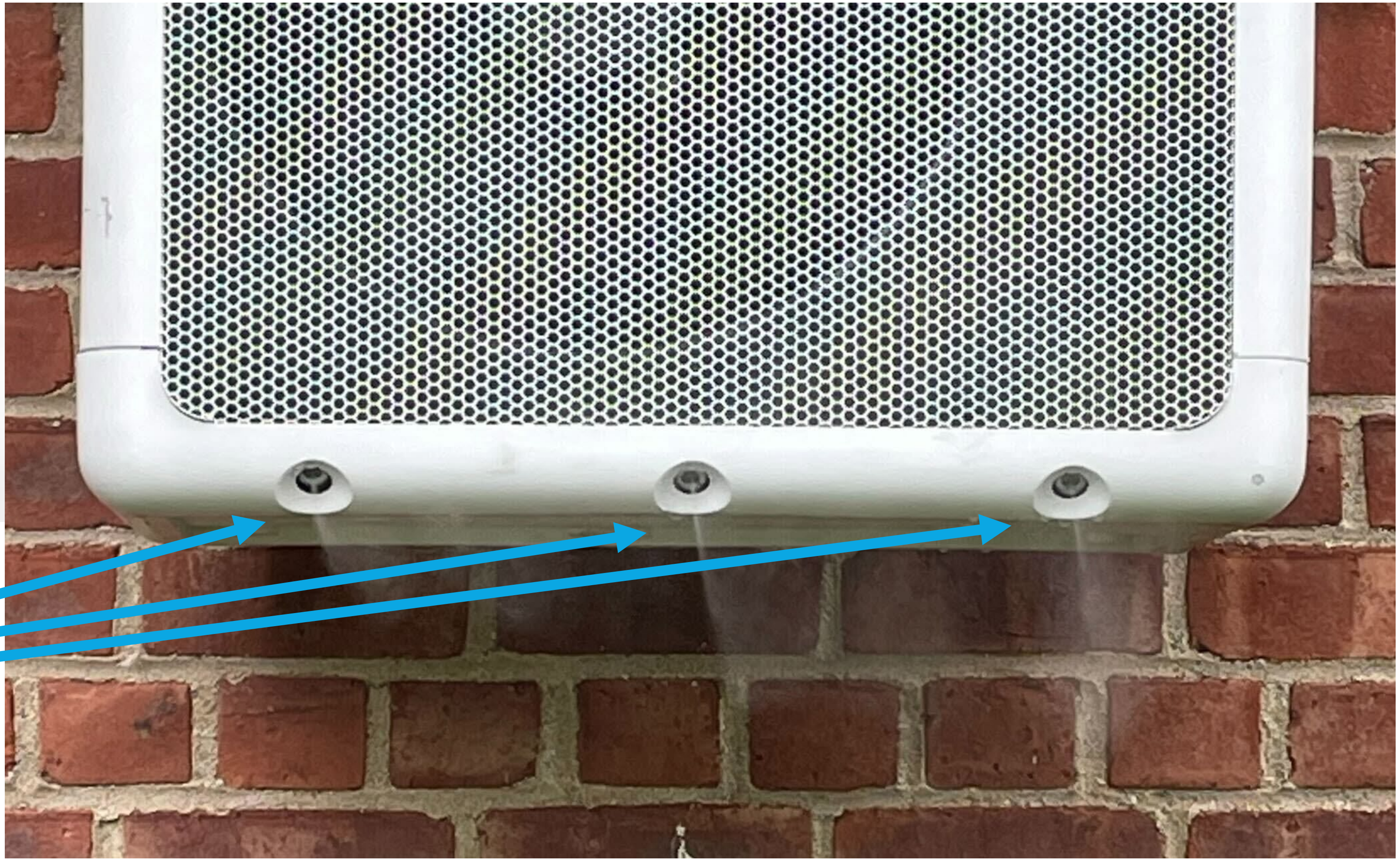
Key Innovation – Condensate Atomizer



Atomizer uses very little energy to generate tiny water particles

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Current Actions

- DOE / EPA is developing a new test procedure which will generate a new heating rating for window heat pumps.
- CEE ResHVAC Committee is looking to create a new product category “Window Heat Pump” that will enable systems to qualify for a 25C Tax Credit.
- NYSERDA/NYCHA are testing systems, if successful they will purchase 30,000 units.

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Projects

- Confirmed Field Test
  - NYSERDA 60 systems in 2 high-rise multifamily bldgs.
- Potential/Developing Field Tests
  - Efficiency Vermont
  - Center for Energy and Environment
  - National Grid
  - CalMTA
  - Others?
- 3rd Party Lab Testing
  - CalNEXT & NEEA

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Field Test?

- Research Questions:
  - How are window heat pumps used? (operating hours, time of use, settings, use behaviors)
  - What information do customers need to know about advanced window heat pumps to accelerate adoption and enhance savings potential?

- Research Objectives:
  - Collect consistent set of heat pump use data that can be used to calculate energy savings from window heat pumps compared to other heating and cooling systems.
  - Collect consistent set of customer experience data that can be used to develop program recommendations that increase customer value propositions and remove adoption barriers.
  - Help build market interest and confidence in window heat pumps through development of case studies and earned media coverage.

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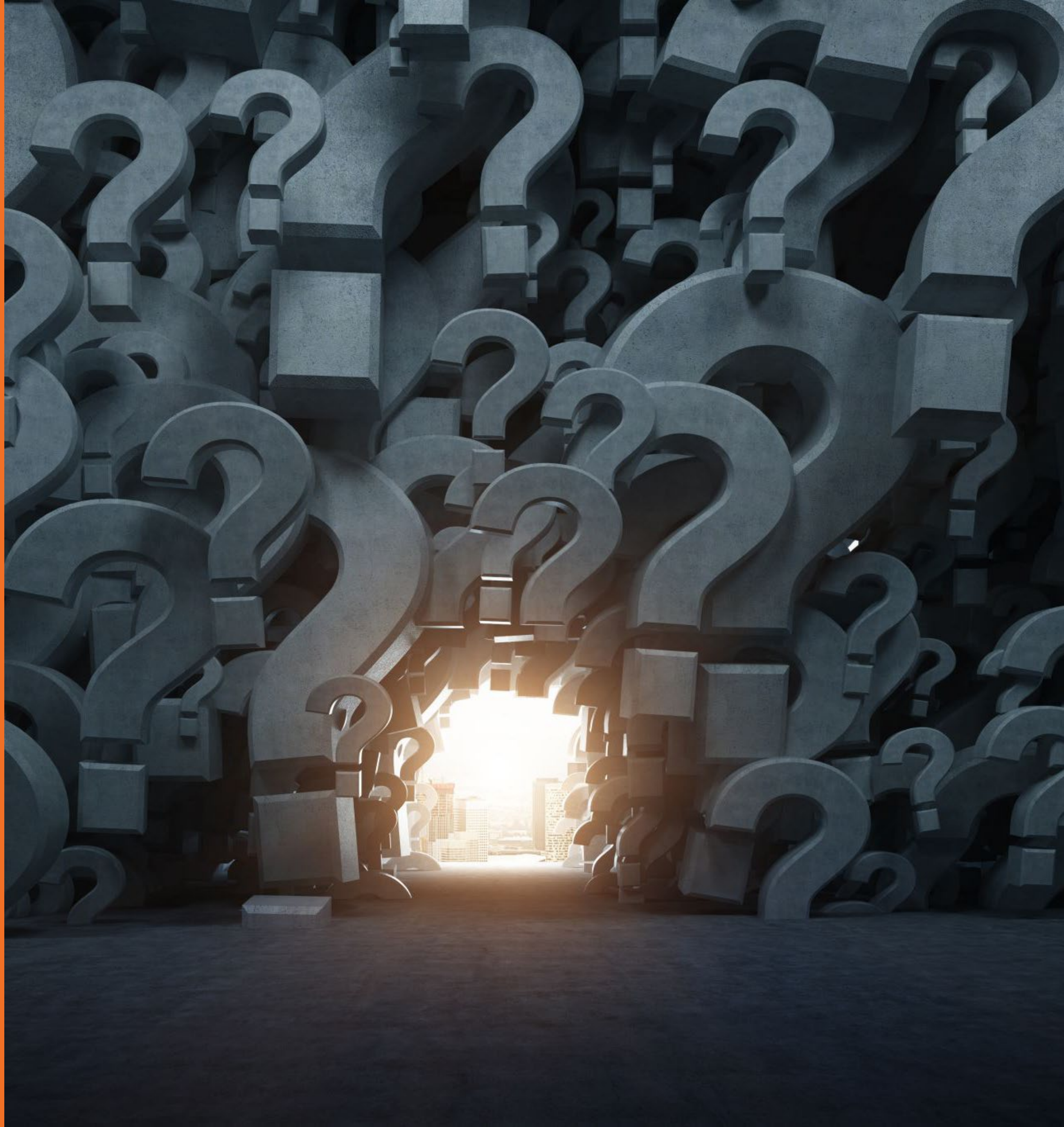
Questions and Discussion



Consumer Product Updates

Consumer Products Year in Review 2023

- Ultra High-Definition TVs
  - DOE Adopted NEEA Test Procedure
  - Voluntary Agreement progressing slower than anticipated
- Residential Laundry Field Study
  - Fielding Completed – Final Results Q2 2024
- Heat Pump Dryer QPL
  - 8 models added to QPL

Focus Areas for 2024

- Ultra High-Definition TVs
  - Continue current path
- Residential Laundry Field Study
  - Inform EPA Residential Dryer Specification Development
- Combo and Laundry Center Testing
  - Testing beginning in Q2
- Commercial Heat Pump Dryer Testing
  - Testing beginning in Q1 2024

2024 Favorable Momentum for Heat Pump Dryers

- **Consumers value convenience, and changing laundry from the washer to dryer is a pain point**
- **GE launched an UltraFast Combo Washer & Dryer which features a heat pump dryer**
  - High consumer and retailer acceptance (4.6 of 5 stars, over 3000 reviews)
  - The ONLY heat pump dryer featured on floor at major retailers
  - Full-size capacity (>4.4 cu. ft.)
  - Far outselling other heat pump dryers
- **Other Brands are Following**
  - LG launched in Q1
  - Samsung debuted at CES and KBIS,
  - expected to start shipping in April

2024 Initiative to Influence New Test Method

GE Profile - 4.8 cu. ft. UltraFast Combo Washer & Electric Dryer with Ventless Heat Pump Technology - Carbon Graphite

LG - 5.0 Cu. Ft. Extra-Large Capacity WashCombo All-In-One Electric Washer/Dryer with Steam and Ventless Heat Pump Technology - Black Steel

Samsung - Bespoke AI Laundry Combo 5.3 Cu. Ft. Ultra Capacity All-in-One Washer with Super Speed and Ventless Heat Pump Dryer - Dark Steel

Highlights KBIS Show 2024

Blurring of Product Categories

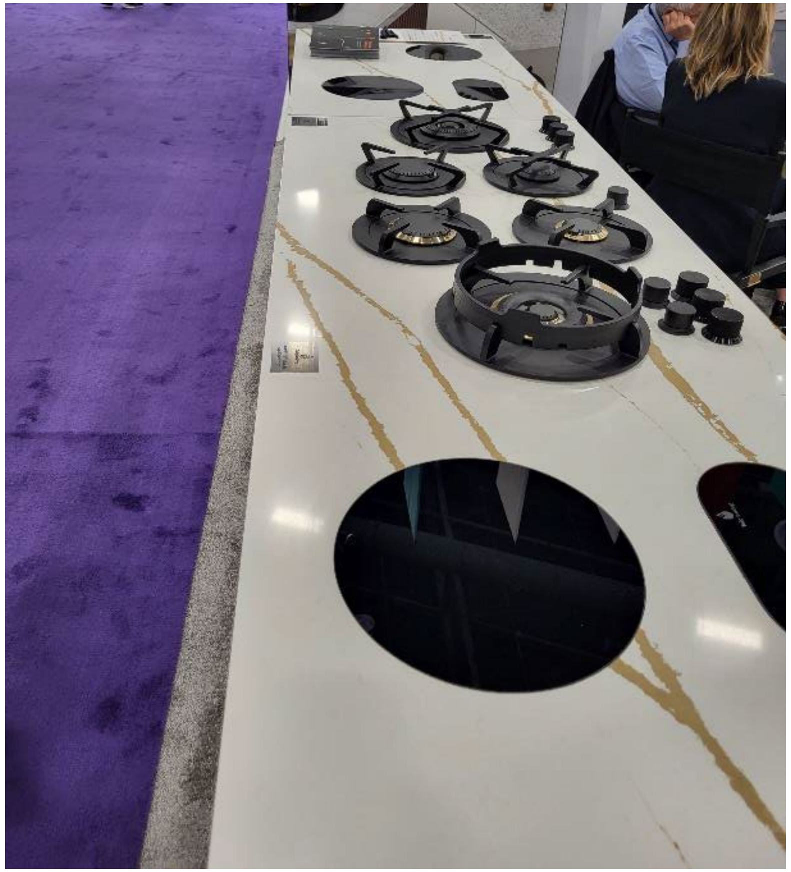
- Microwaves that Air Fry
- Ovens that Air Fry (Convection) and Sous Vide
- Wine Chillers with Refrigerator or Freezer Compartments
- Cook Tops with Built In Venting

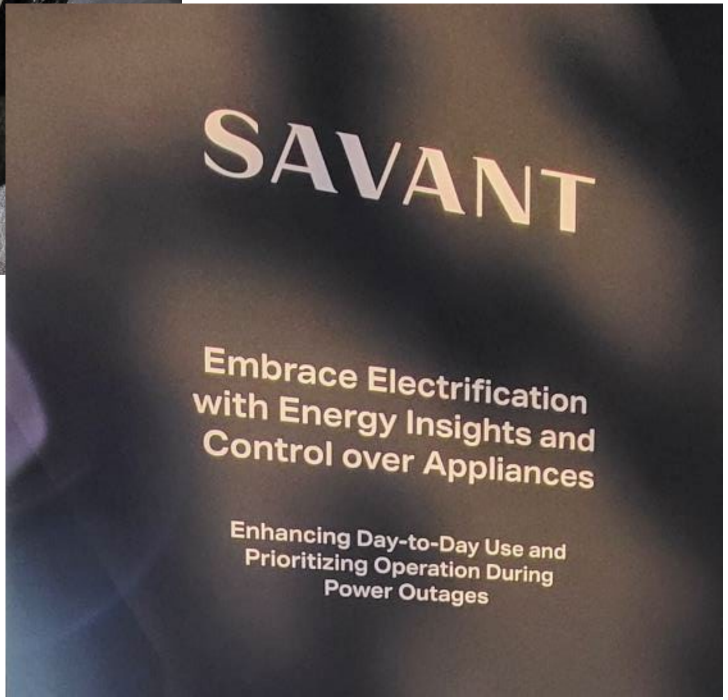
Whirlpool SLIMTECH™ Insulation

- 50% more Energy Efficient
- OR 25% More Capacity
- Featured on JennAir Door
- Expected to Roll Through Other Brands
- Radically Different Manufacturing Process

Highlights KBIS Show 2024

Counter-top integrated Cooking





GE Net Zero Project

- Ford F150 as Home Generator
- Heat Pump HVAC System
- Charging Station
- Working with Savant on Grid Flex

Highlights KBIS Show 2024

Cube Lifts: Pneumatic Vacuum Elevators

Commercial Heat Pump Dryers

- Now available in the U.S. up to 45 lb. capacity
- Testing against similar sized gas & electric models
- Using a variety of textiles
- Quantify the energy use vs. gas and electric dryers
- Develop a regional model of energy use and savings estimates in the region
- Understand the cycle time differences and impacts on capital, operational, and labor costs

Motor Driven Systems

Motor-Driven Systems – Fans & Blowers

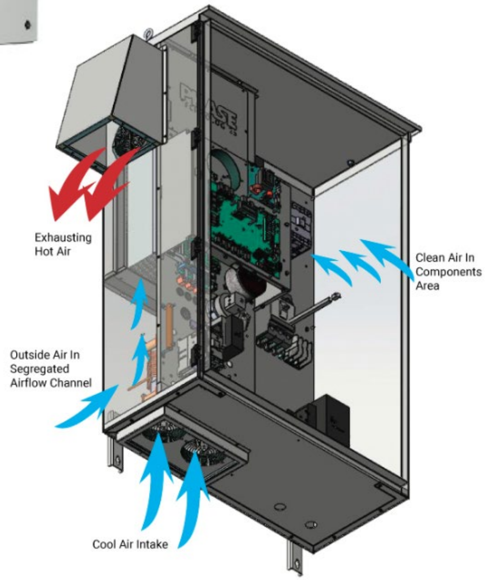
- Fans & Blowers
  - DOE Adopted AMCA-214 Test Procedure
  - Final Regulation Anticipated in 2024
  - Will require C&I fans >1 hp to meet a minimum FEI (fan energy index)
- Upcoming Work in 2024:
  - Characterizing Fan Types for Exhaust and Custom AHU Applications
- Fan Arrays
  - New mover in the market that features a Plug & Play setup

Motor-Driven Systems – XMP Pumps

- Program Updates
  - Created Energy Rating (ER) Label
  - Clean water pumps 1-50 hp
  - Midstream incentives for ESCC, ESFM, IL, RSV, & ST pumps with ER>12 (CL) & 52 (VL)

- Upcoming Interests
  - Agriculture, ANSI/ASME (B73), chemical processing, fuel transfer opportunities

Motor-Driven Systems – Variable Speed Drives



- Assessing Opportunity for Retrofitting Commercial & Industrial Fans and Pumps with Speed Control (5-50 hp)
- Increasing Concerns and Awareness Regarding Harmonic Distortion and Power Quality
  - Idaho Power Rule K:
    - Customer requirements: harmonic controls, protection of their own electrical equipment, give notice before making significant changes to equipment
    - Conducting testing on large industrial loads & non-agriculture water supplies >50 hp or those operated with VSD, VFD, ASDs
  - Harmonic Mitigation Technologies
    - Filters
    - Active front ends

What else are we interested in?

Tell Us What You Think…

- What did you find most helpful in this segment?
- What would you like to learn more about?

Drop your thoughts into the chat!

CLOSING

- Public Comments/Q&A
- Poll Questions

Poll Question…

How would you rate the overall value of today's session?

If the poll didn't work for you, please let us know in the chat box what the problem was: if you used the app or browser, and the error message you got, if any.

Thank You!!