Advanced Heat Pump Coalition

Spring Webinar, April 10th, 2023

TOPIC: Air to Water Heat Pumps

Agenda

General Information	**5 minutes**
• Advanced HP Coalition Intro	
• Workgroup Updates	
Project Updates	**70 Minutes**
• 6 presenters	
Questions and Discussion	**10 minutes**

Objective: Increase collaboration

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 semi-annual webinars, provide feedback

Committees

- Steering Committee
  (NEEA, NEEP, MEEA, CEC, NRCan, EPA, NYSERDA)
- WG #1 – Improved Test Procedure and QPL
- WG #2 – Roadmap Specification and Mfr Engagement

Brightest heat pump minds
from organizations such as these:

Workgroup 1 – Improved Test Procedure & QPL

Vision

- The marketplace (Efficiency Programs/manufacturers/contractors) can identify ASHP products that will deliver *actual* performance

Desired Outcomes

- An improved test procedure is developed and validated to show enhanced representativeness of ASHPs
- An Advanced ASHP Qualified Product List (QPL), based on the results of an improved test procedure, is built
- Efficiency Programs use QPL to incentivize adoption of advanced ASHPs that deliver real world performance, increasing savings
- Long term- Federal Standards program ultimately more representative test procedure and rating

Mechanism employed

- Improved Test Procedure
- Qualified Products List

Workgroup 1 – Update

CSA EXP07 has become SPE07:22

- 2022 version is being prepared for publication
- ANSI Accreditation work has begun

Representativeness Project

- Phase 1 – Field testing in Lincoln Nebraska ------ COMPLETED!
- Phase 2 – Lab testing at UL in Plano TX, Q2 2023
- NEEP is project manager
- DNV is prime contractor, support from University of Nebraska

Publications

- 2020 EXP07 Interim results
- 2022 Purdue University Reports (various)
- 2023 IEA Heat Pump Conference
- Why Metrics Matter Report

Workgroup 2 – Roadmap

Vision

- Heat pump capabilities that enhance in-field performance are well supported by utility programs and provide additional value to the HVAC industry

What is a “Roadmap Specification”

- It is not program specification
- It includes MT fulcrum items
- It leverages industry direction

Desired Outcomes

- Manufacturers have clear understanding of what Utilities need
- Widespread utility program support exists for the features specified

Workgroup 2 – Update

2023 Activities

- Coordinated Meetings at AHR Expo with 9 Heat Pump manufacturers

Publications

- None to date

Workgroup 3 – Best Practices

Workgroup has been disbanded

Work continues through the CEE Quality Installation Project

- Multiple Technical working groups
- Alice Rosenberg is project lead

Publications & Outcomes

- Defined areas of focus
- Best Practices Gap Analysis Report completed – TRC, 2021
- 10 workforce development Presentations at Spring 2022 AHPC Webinar

Fall 2022 Webinar – Research Update

Presentations

• Representativeness Project	Jennifer McWilliams	DNV
• Advanced Refrigerants	Sam Yana Motta	ORNL
• NEEP Sizing & Selection Tool	Dave Lis	NEEP
• ASHP Integrated Controls Strategies	Karen Fenaughty	FSEC
• Hybrid HP Tools	Jeremy Sager	NRCan
• GSHP and ASHP Research	Martin Kegel	NRCan
• Features and Capabilities	Christopher Dymond	NEEA
• E4theFuture – CCHP	Christine Amero	Cadmus
• Hot Air Forum	Amber Wood	ACEEE

Recording at AHPC Website
[The Advanced Heat Pump Coalition]

Spring 2023 Webinar – Air to Water

Presentations

• Design Experience	John Siegenthaler	Heat Spring
• Residential Field Study	Abram Conant	Proctor Engineering
• AWHP Market Conditions	Matt Christie	TRC Companies
• Commercial Systems	John Arent	Noresco
• Storage and Combined Systems	Spencer Dutton	LBNL
• European AWHP Market	Kelly Hearnsberger	Daikin

Questions will be answered after all presentations have been given

Type them into comments or hold them for the end

John Siegenthaller
Heat Spring

What is an air-to-water heat pump?

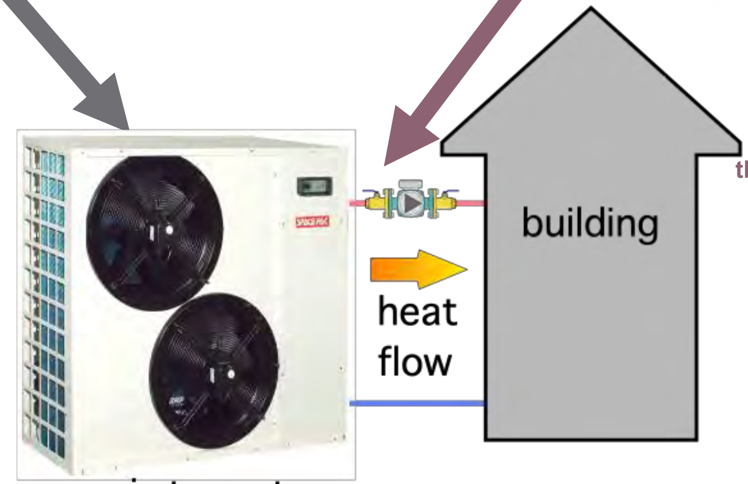
- Most North America heating pros are familiar with *ductless heat pumps*.
- **Most are also familiar with *geothermal heat pumps***
- ***Far fewer are currently familiar with air-to-water heat pumps.***

Heat pump "flavors"

"Ductless", "mini-split"
air-to-air heat pump

air is the source of the heat

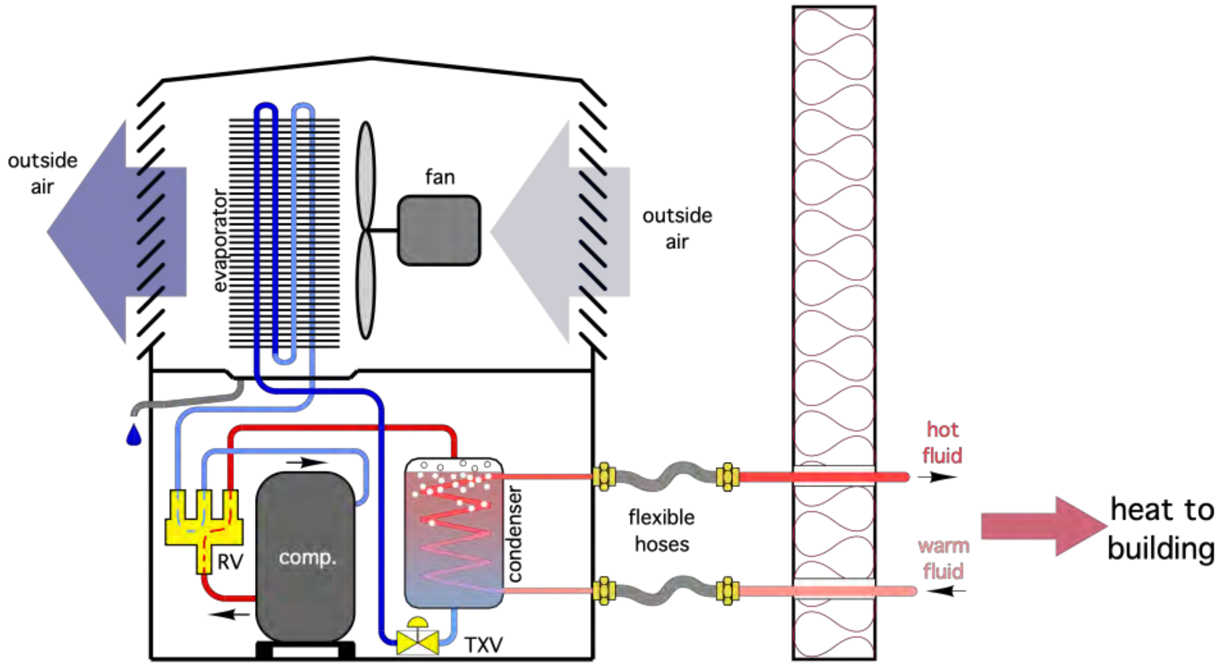
water-to-water
heat pump



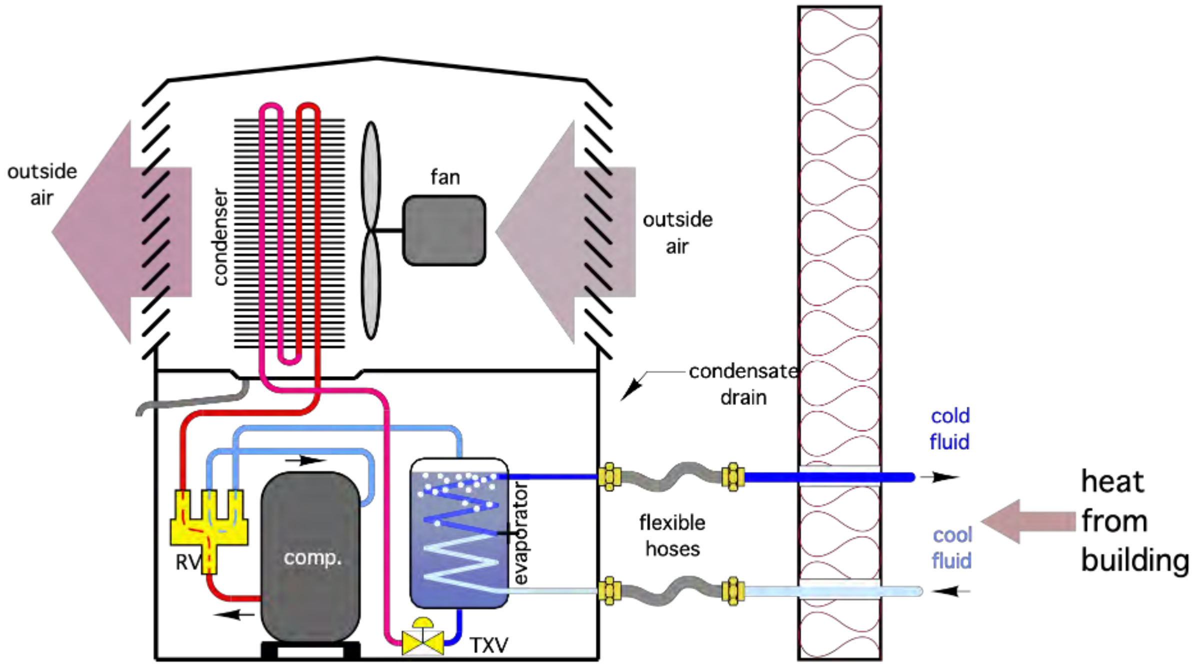
air-to-water
heat pump

water is the "conveyor belt" moving heat to the building

Internals of a monobloc air-to-water heat pump



(heating mode)



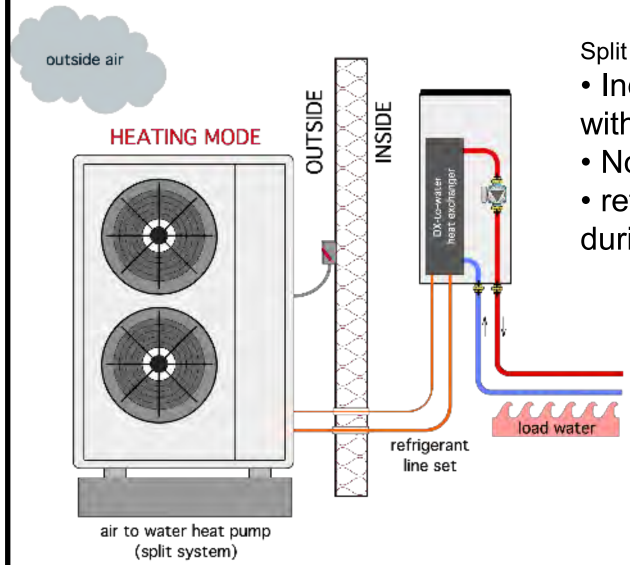
(cooling mode)

In heating mode: The heat pump extracts low temperature heat from outside air, and transfers it to a fluid stream (water or water & antifreeze) to be used by a hydronic distribution system.

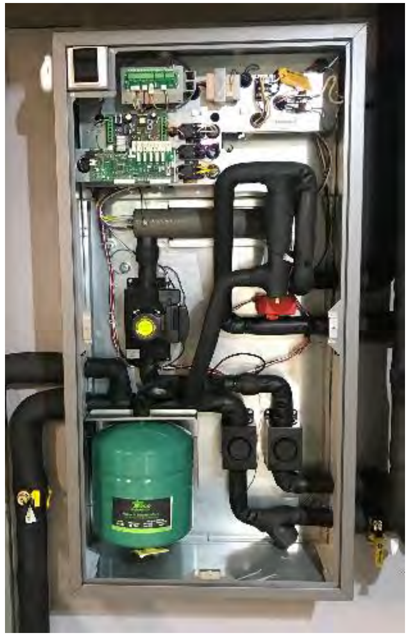
In cooling mode: The heat pump extracts low temperature heat from a fluid stream (chilling it), and dissipates that heat to outside air.

Air-to-water heat pump physical configurations

Monobloc
- Self-contained
- All heat pump components outside
- Factory charge w/ refrigerant



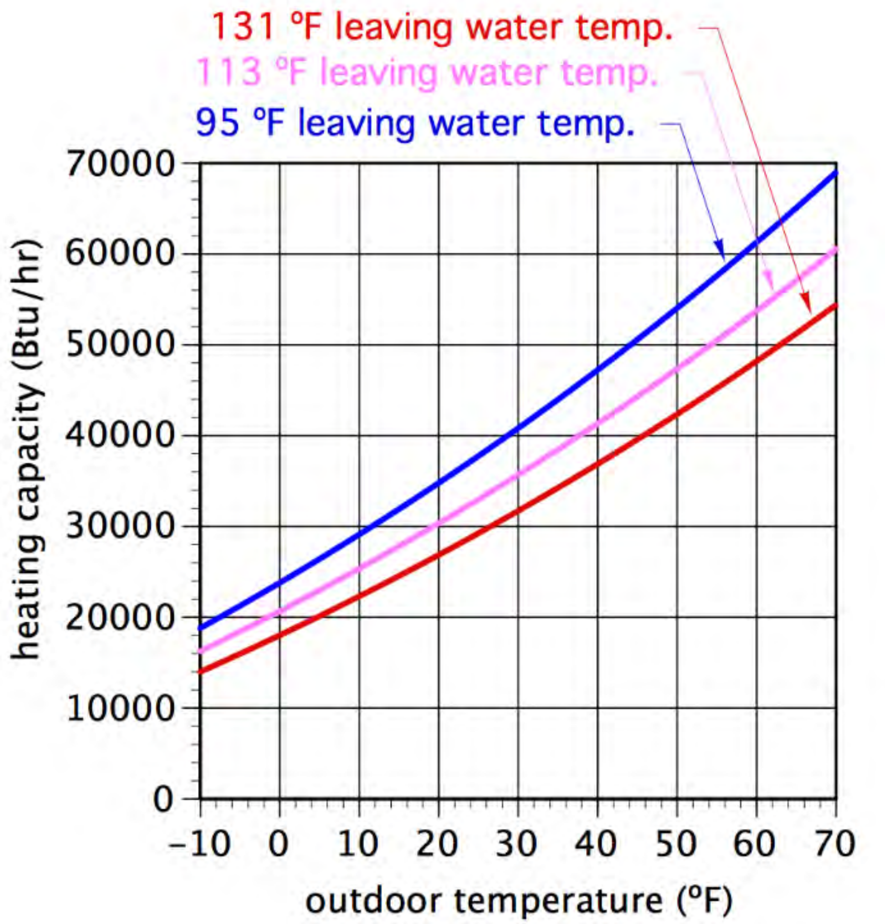
Split system
- Indoor + outdoor units connected with refrigerant line set
- No water outside
- refrigerant system commissioned during installation



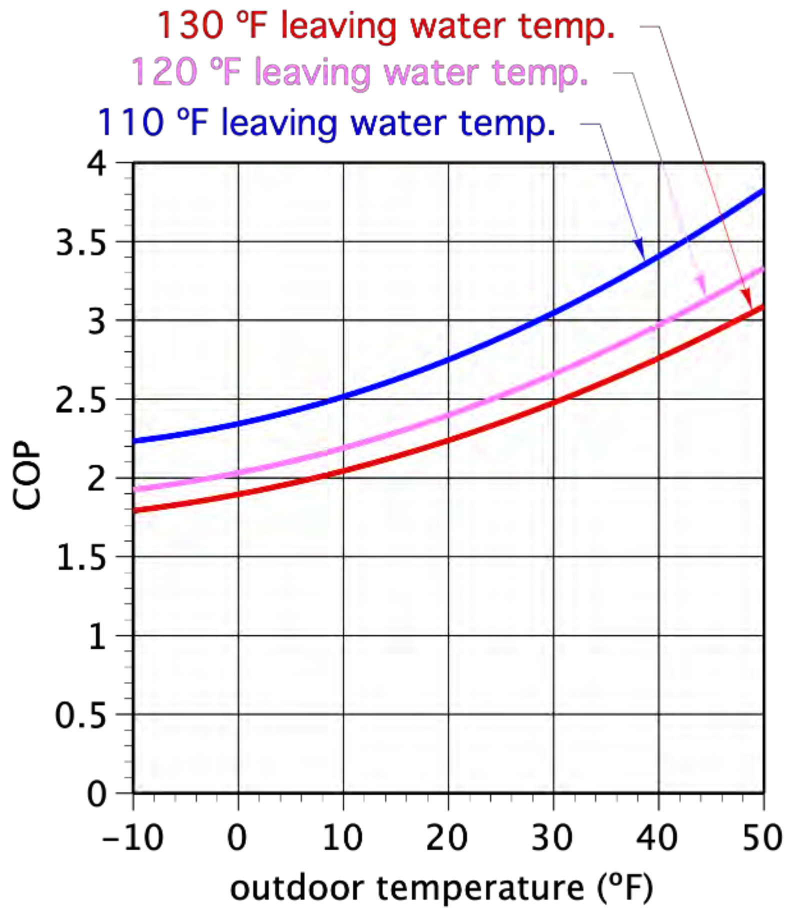
Hydro-split system
- Indoor + outdoor units connected with ***<u>water-based antifreeze solution</u>***

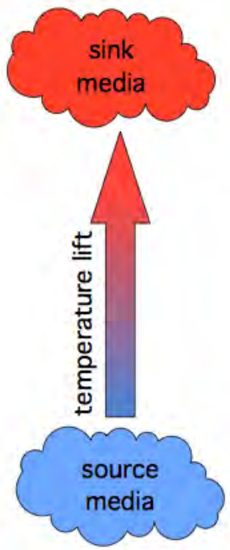
Heating Performance

The heating capacity of most AWHPs decreases with increasing condenser temperature.



The COP also decreases with increasing condenser temperature.

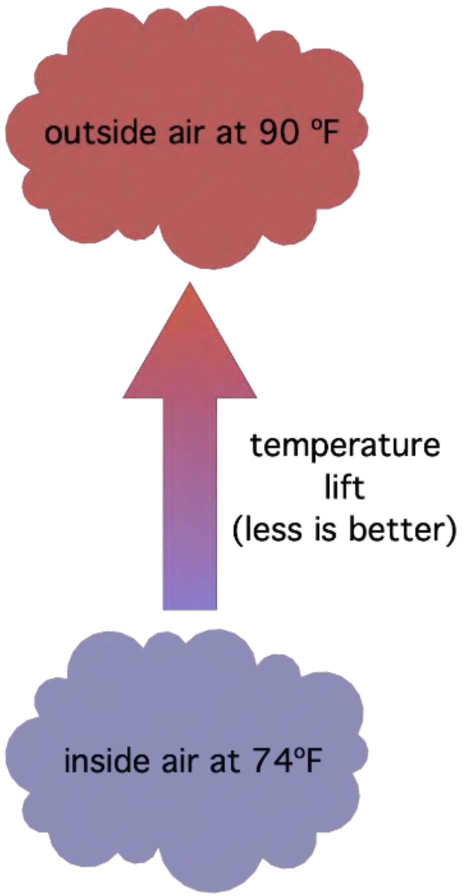


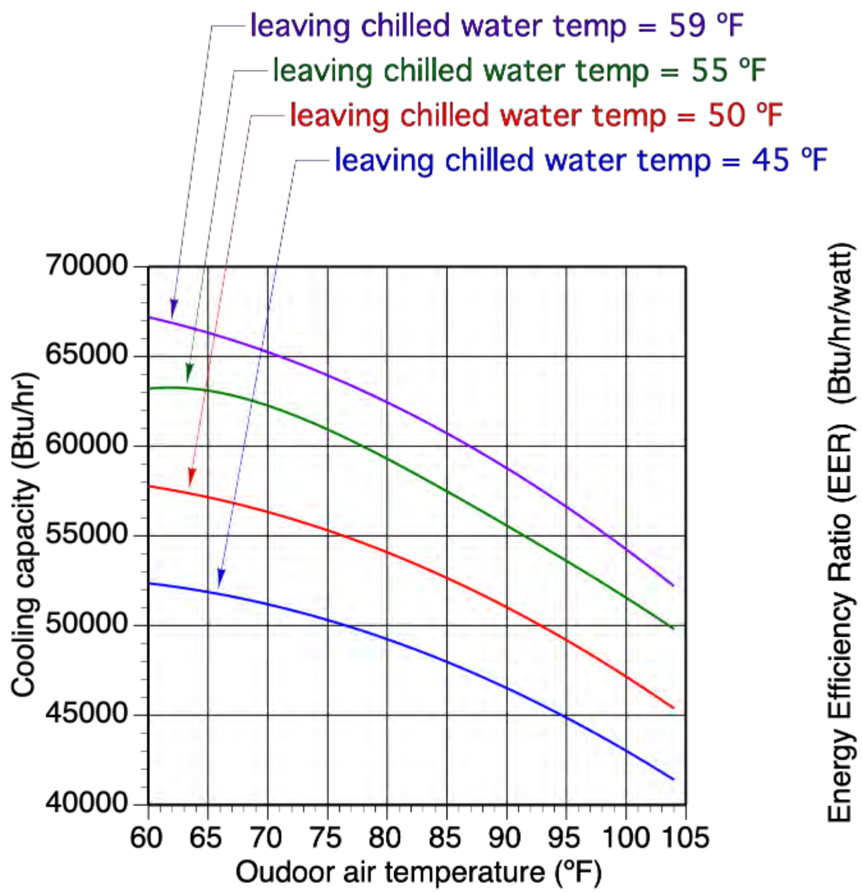


The smaller the "temperature lift" between evaporator and condenser, the higher the heating capacity and COP.

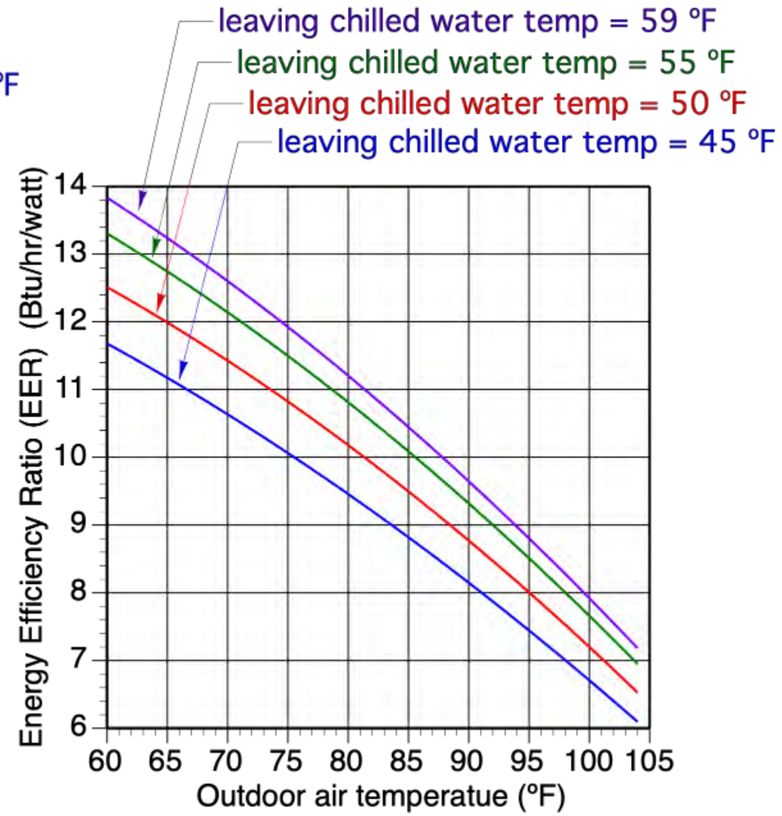
Cooling Performance

Cooling capacity & EER are very dependent on the operating conditions.
Both increase as the difference between the source (inside air temperature) and outdoor air temperatures decreases, and vice versa.





Cooling capacity for a specific AWHP



EER for a specific AWHP

NYSERDA funded development of an air-to-water heat pump simulator

NYSERDA Air to Water Heat Pump Simulator Beta 1.01

Automatic Calculations ON Checked

Current Date: 2/4/22

Apply Defrost Data

Use Alternate Heat Pump

Go to Help Sheet

Inputs

BUILDING LOAD INPUTS			Range
Design Heating Load Building	40,000	Btu/hr	10,000 to 200,000
Inside air temperature required	70	°F	60 to 80
Outdoor temperature at design load	2	°F	-10 to 40
Average hourly internal heat gain	3,413	Btu/hr	0 to 17,000
Space heating supply water temperature required at design load	100	°F	100 to 180

HEATPUMP SELECTION	
◉	SpacePak LAHP air to water heat pump
○	Enertech AV060 air to water heat pump
○	Nordic ATW-65 air to water heat pump

LOCATION OF STUDY	
○	Albany
○	Binghamton
○	Brooklyn
○	Buffalo
○	Glens Falls
○	Jamestown
○	Lake Placid
○	Massena
○	Old Forge
○	Plattsburg
○	Rochester
◉	Syracuse
○	Utica
○	Watertown

ENTER HEAT PUMP CIRCULATOR POWER			Range
Electrical power required by heat pump circulator	150	watts	0 to 500

DOMESTIC WATER HEATING INPUTS			Range
Gallons per day domestic hot water required	60	gallons	0 to 120
Required domestic hot water delivery temperature	120	°F	100 to 140
Seasonal average cold water temperature at site	50	°F	40 to 65

BUILDING COOLING LOAD INPUTS			Range
Inside air temperature required for cooling comfort	75	°F	72 to 82
Chilled water temperature required by cooling coil	50	°F	40 to 60
Sensible heat ratio	0.70		0.60 to 0.90
SEER of supplemental cooling source	14.0	Btu/hr/watt	7 to 22

Inputs

FINANCIAL INPUTS			Range
Installed cost of air-to-water heat pump system	$20,000		$5,000 - $60,000
% Downpayment applied installation cost	0	%	% of IC, 0-100%
% Upfront rebate to deduct from installed cost	0	%	0 to 50% of IC
Term of loan (if any) to finance system installation	5	Years	0 to 20 years
Design life of heat pump system	15	Years	10 to 25 years,
Cost of electricity	0.15	$/kwhr	0.03 to 0.50 $/kwhr
Annual % increase in electrical cost	1.0	%	0 to 5 %
Annual % interest earned on capital if downpayment remained invested	1.0	%	0 to 5 %
% Income tax rate of owner	25.0	%	0 to 40 %
% Interest rate for loan	5.0	%	0.5 to 15 %

ALTERNATE HEAT PUMP THERMAL INPUTS			Range
Alternate heat pump seasonal average COP	3.0		1.5 to 4.0
Alternate heat pump seasonal average SEER	14	Btu/hr/watt	10 to 22
Supplemental cooling source SEER	14	Btu/hr/watt	10 to 22
% of space heating load covered by alternate heat pump	95	%	75 to 100
% of cooling load covered by alternate heat pump	100	%	75 to 100

ALTERNATE HEAT SOURCE FINANCIAL INPUTS			Range
Installed cost of alternate heat pump system	$20,000		$5,000-$60,000
% downpayment on alternate heat pump system	50	%	% of IC, 0-100%
Rebate (if any) on alternate heat pump system (% of installed cost)	0.0	%	0 to 50%
Term of loan (if any) to finance alternate heat pump system	5	years	0 to 20
% Interest rate of loan (if any) to finance alternate heat pump system	5	%	1 to 10%
Design life of alternate heat pump system	15	years	10 to 25

Outputs

HEATING OUTPUTS for air-to-water heat pump		
Annual building space heating energy required=	87.26	MMBtu
Heating season space heat & DHW energy supplied by air-to-water heat pump=	96.71	MMBtu
Heating season space heat & DHW energy supplied by auxiliary heat source=	3.324	MMBtu
Annual hours of air-to-water heat pump HEATING operation=	2,208.4	hrs
Heating season average COP of air-to-water heat pump =	3.10	

COOLING OUTPUTS for air-to-water heat pump		
Annual building cooling energy required =	1.056	MMBtu
Annual cooling energy supplied by air-to-water heat pump =	1.056	MMBtu
Annual cooling energy supplied by supplemental cooling source =	0.000	MMBtu
Annual hours of air-to-water heat pump cooling operation =	23.0	hrs
Seasonal average EER of air-to-water heat pump =	11.08	Btu/hr/watt

FINANCIAL OUTPUTS for air-to-water heat pump	
Total building heating cost over system design life =	$24,420.14
Total building cooling cost over system design life =	$230.14
Downpayment =	$0.00
Monthly loan payment =	$377.42
Total owning & operating cost over system design life =	$47,295.75

ALTERNATE HEAT PUMP FINANCIAL OUTPUTS	
Total building heating cost over system design life =	$19,549.34
Total building cooling cost over system design life =	$182.11
Downpayment =	$10,000.00
Monthly loan payment =	$188.71
Total owning & operating cost over system design life =	$36,813.61

Detailed models for heat pumps, hydronic heat emitters, and building loads.

Simulates specific air-to-water heat pumps in a range of NYS climates.

Allows input for domestic water heating load, as well as space heating and cooling loads.

Allows comparison with other heat pump options.

Spreadsheet system simulation results

4-ton low-ambient air-to-water heat pump in house w/ 36,000 Btu/hr design load

Outdoor temperature data based on PLATTSBURG, NY

supply water temp. required @ design load	Seasonal ave COP no DHW	% space heat energy supplied from HP no DHW	Seasonal ave COP w/ 60 GPD DHW	% space heat + DHW energy supplied from HP w/ 60 GPD DHW
100 ºF	2.81	100%	2.88	95.7%
120 ºF	2.80	100%	2.86	95.8%
140 ºF	2.73	100%	2.79	96%
160 ºF	2.65	97.4%	2.72	94%
180 ºF	2.60	91.3%	2.67	89%

January 2022 energy prices in central NY (NYSERDA data)

Natural gas: $1.383/therm
@ 92%AFUE = **$15.03/MMBtu**

#2 fuel oil: $4.88/gal
@ 86%AFUE = **$40.51/MMBtu**

Propane: $3.58/gal
@ 92%AFUE = **$42.41/MMBtu**

electricity: $0.167/kwhr
@ $COP_{(ave)}$=2.75 =
$17.80/MMBtu

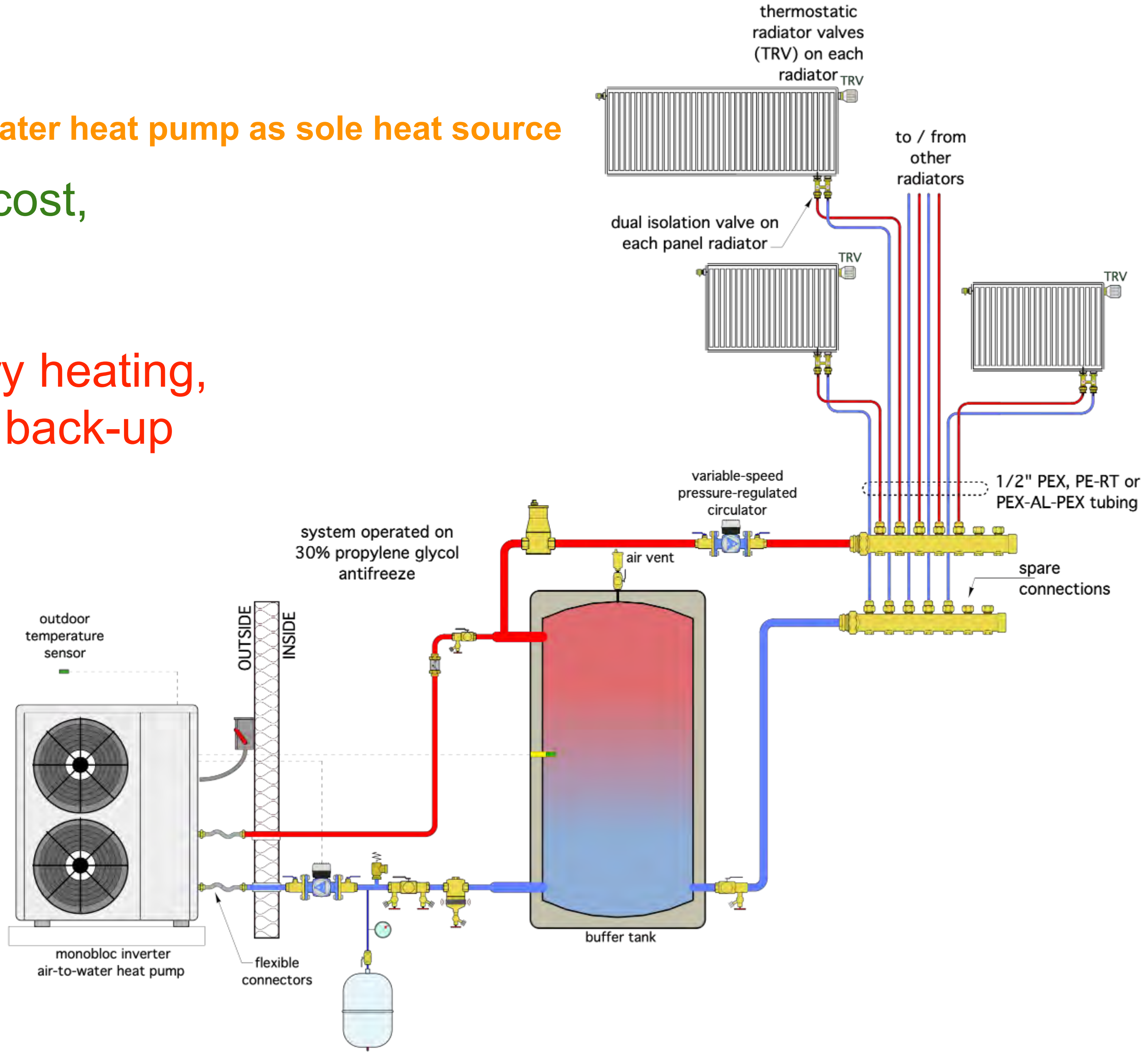
System configurations

Space heating only (zoned), with air-to-water heat pump as sole heat source

PROS: Simple, relatively low cost, extensive zoning is possible.

CONS: No cooling, no auxiliary heating, no domestic water heating, no back-up

Be sure to use a buffer tank if the distribution system is zoned.



System piping configurations

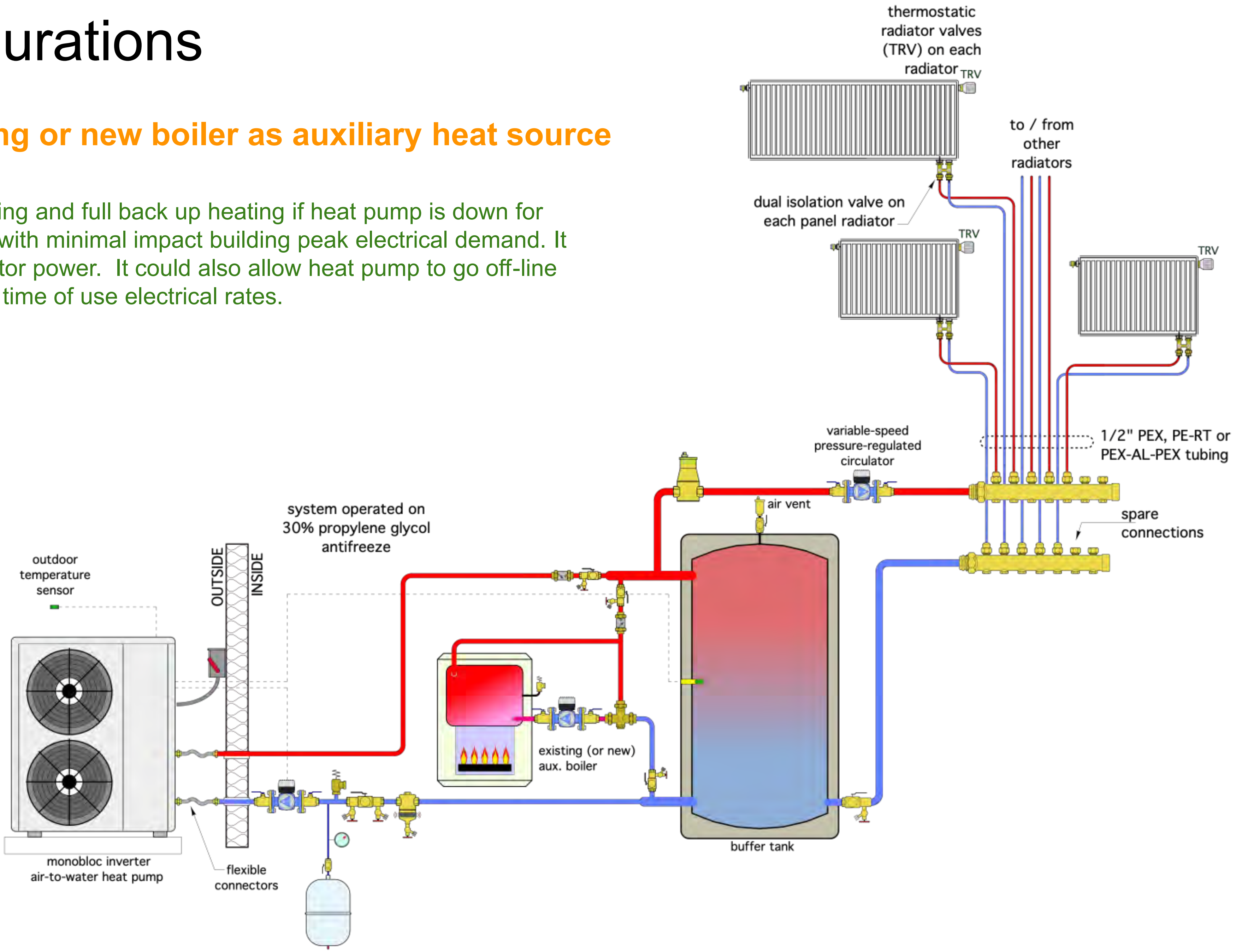
Space heating only, with an existing or new boiler as auxiliary heat source

PROS: Auxiliary boiler provides supplement heating and full back up heating if heat pump is down for service. If aux boiler is fossil fuel - it can operate with minimal impact building peak electrical demand. It could also operate on minimal emergency generator power. It could also allow heat pump to go off-line during peak utility demand or be coordinated with time of use electrical rates.

CONS: No cooling, no domestic water heating

Well-suited to retrofitting existing hydronic heating systems with conventional boilers.

Can also be used with a mod/con boiler - would not require anti-condensation valve.

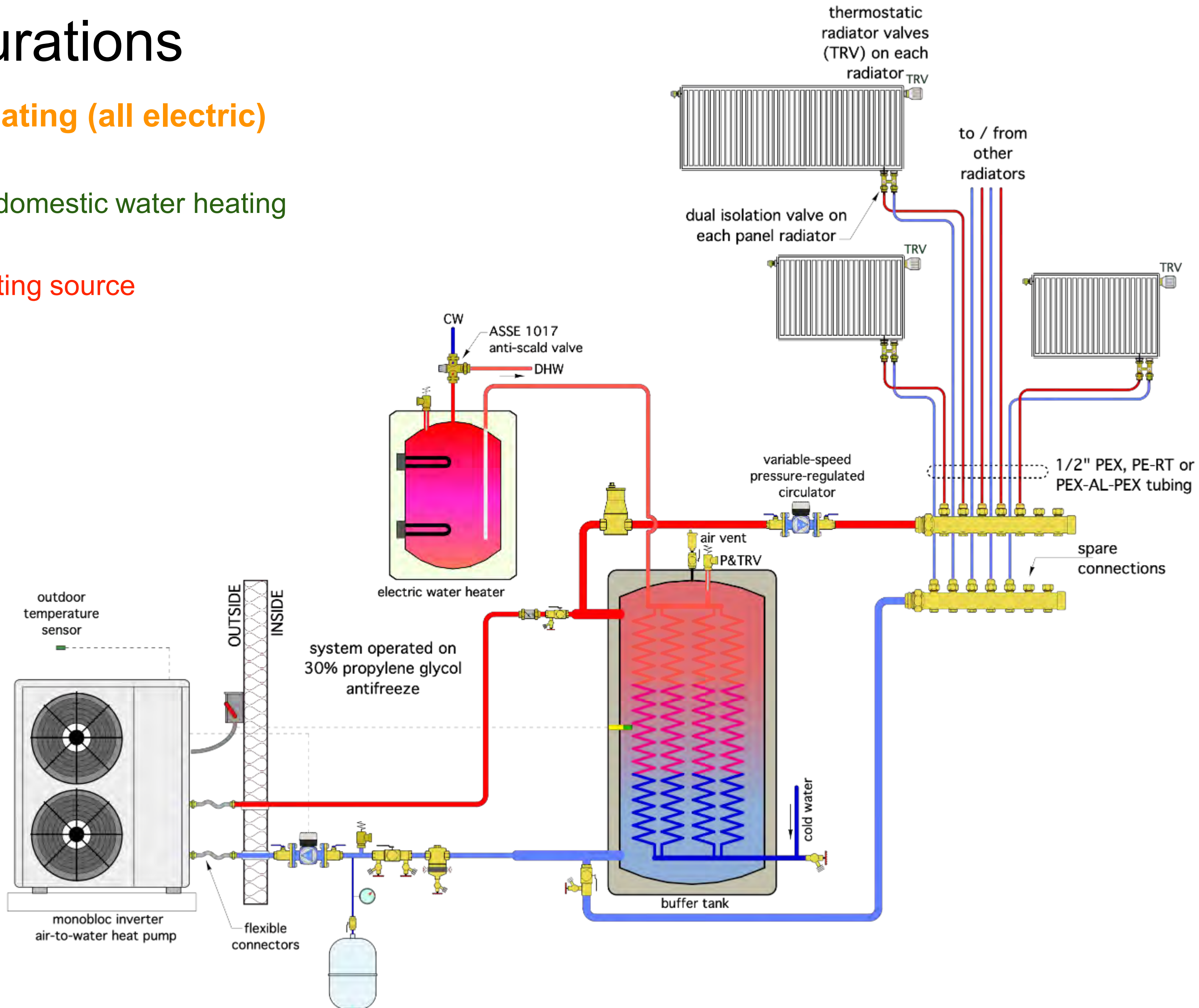


System piping configurations

Space heating + domestic water heating (all electric)

PROS: All electric, full backup capacity for domestic water heating

CONS: No cooling, no auxiliary space heating source

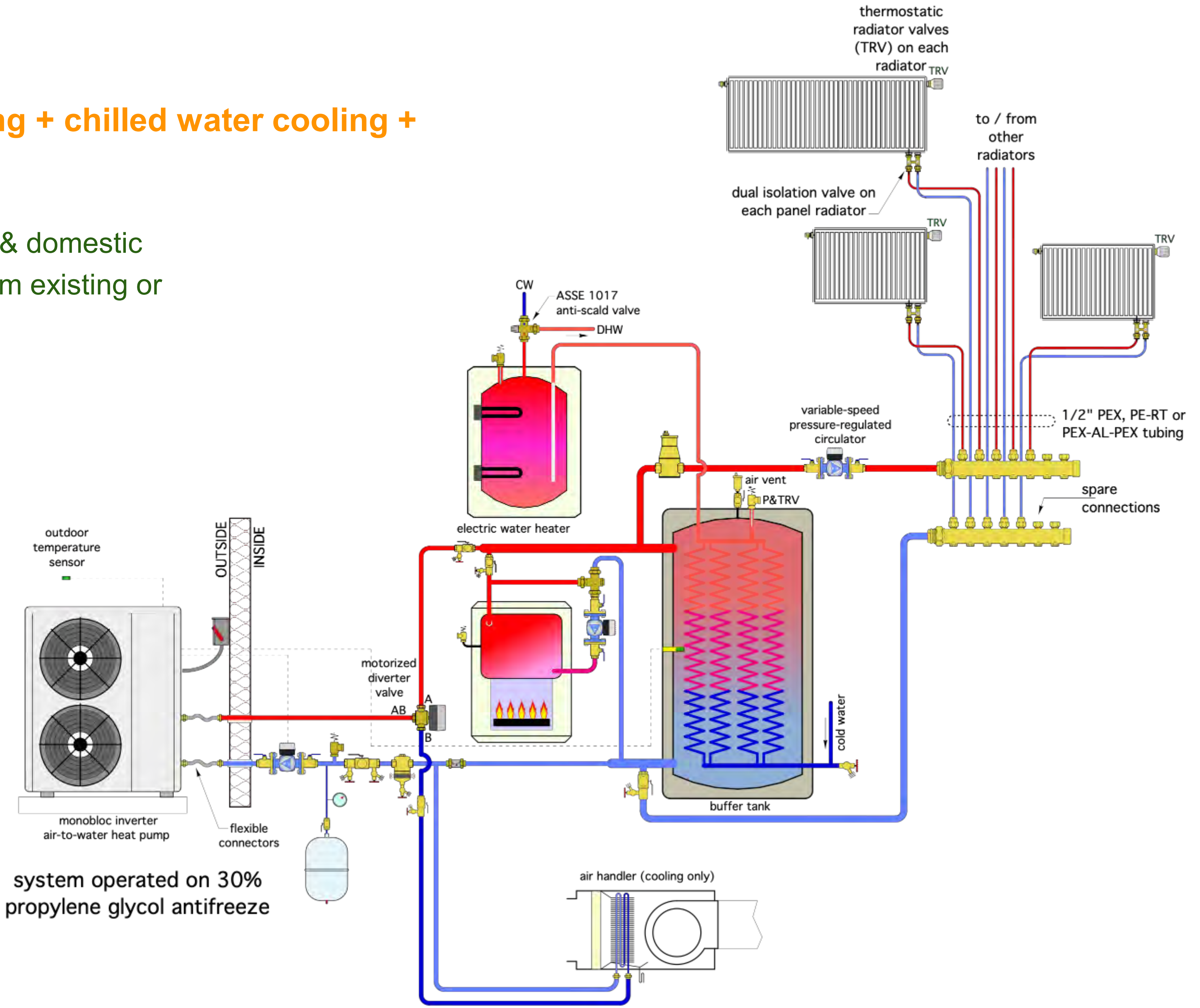


System configurations

Space heating + domestic water heating + chilled water cooling + non-electric auxiliary boiler

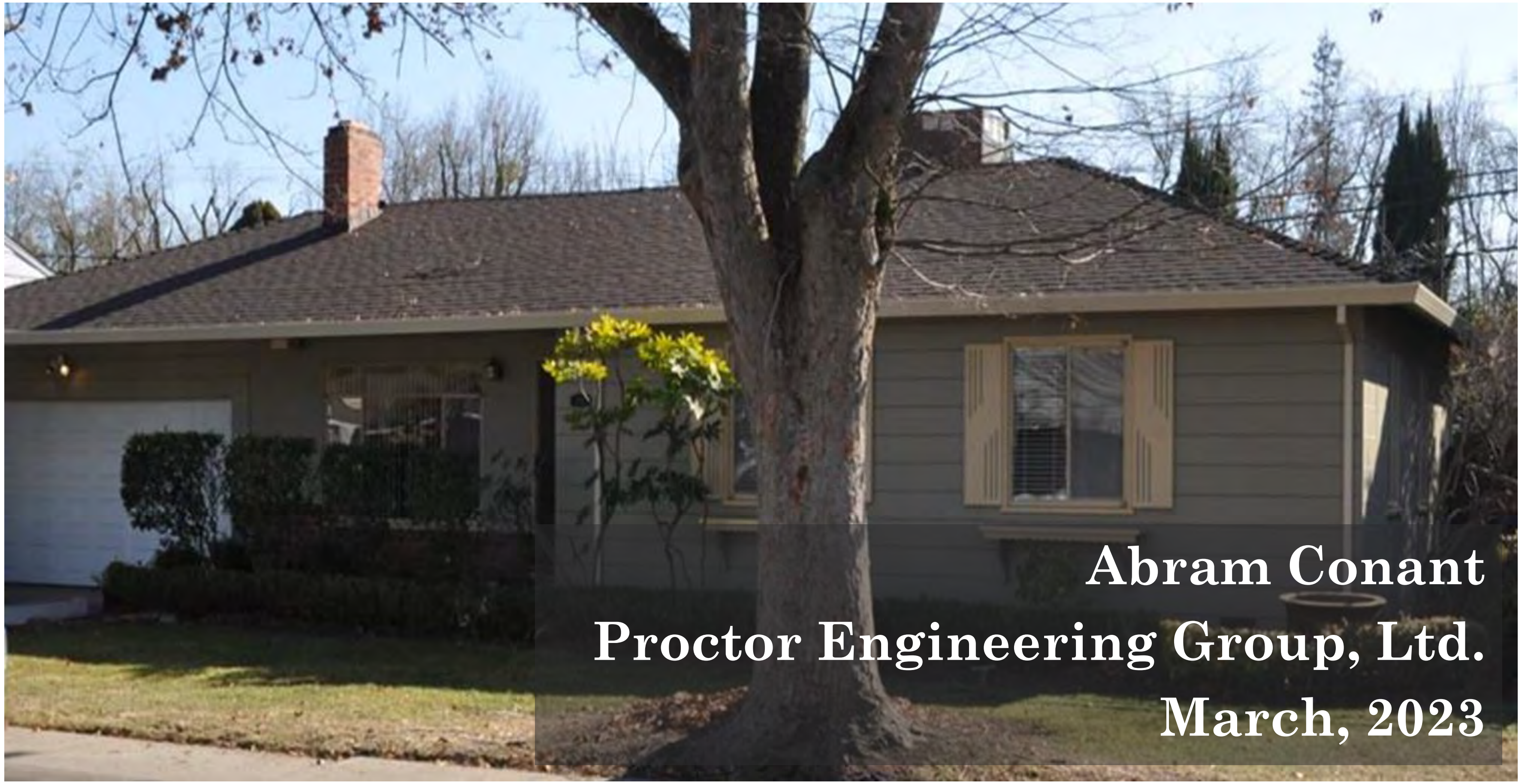
PROS: Full backup capacity for space heating & domestic water heating, low electrical power demand from existing or new non-electric boiler, chilled water cooling

CONS: Not all-electric



Abram Conant
Proctor Engineering

Smart Integrated Near Zero GWP Space Heat and Hot Water



Abram Conant
Proctor Engineering Group, Ltd.
March, 2023

Central Valley Research Homes - Project Team

Pacific Gas and Electric Company

Frontier Energy

Bruce Wilcox, P.E.

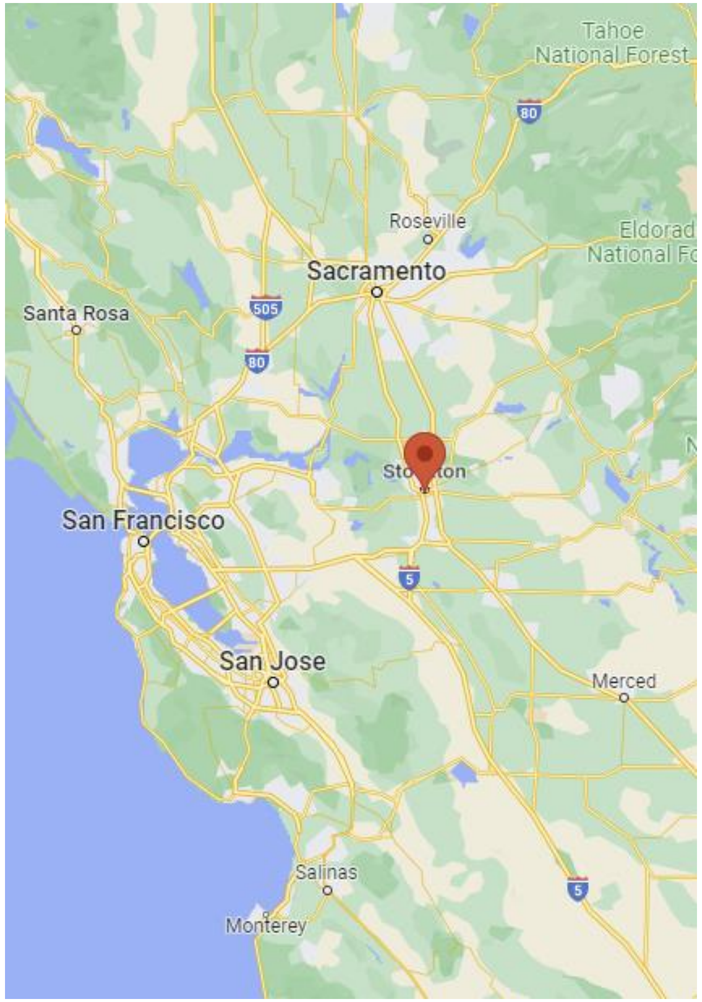
Proctor Engineering Group

Mike MacFarland, Energy Docs

California Energy Commission

Building Characteristics

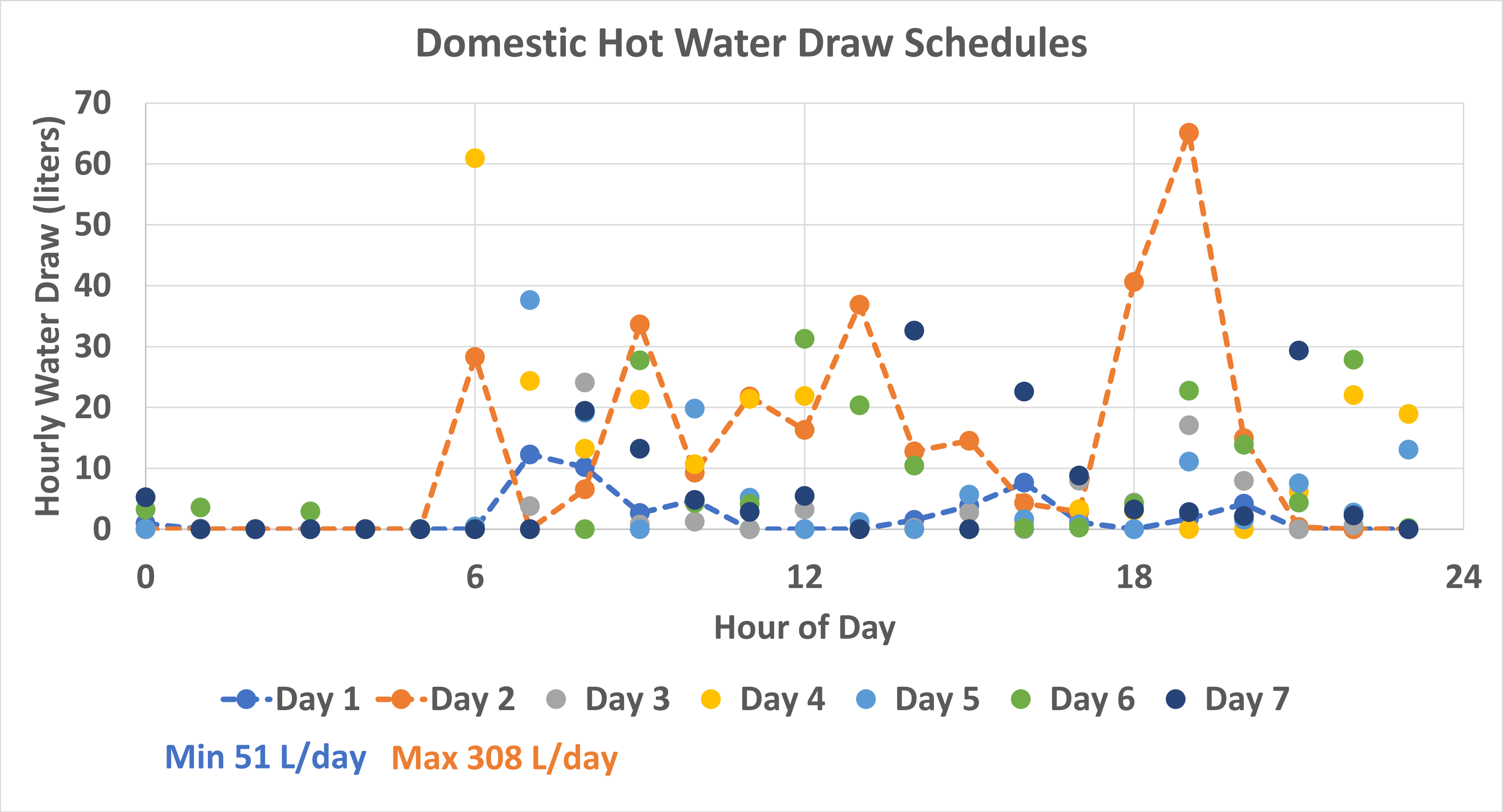
- 3BR, single story 1104 ft^2, crawlspace
- Built 1953, deep energy retrofit 2013
- 13,198 BTU/h Manual J heating load
- Air handler and ducts entirely inside conditioned space
- No occupants, internal gains simulated to match CA Title 24 assumptions



Continuously Monitored

- Extensive instrumentation
- Data collected every 20 seconds, recorded every minute, downloaded to offsite storage every 20 minutes
- Daily data review by research team

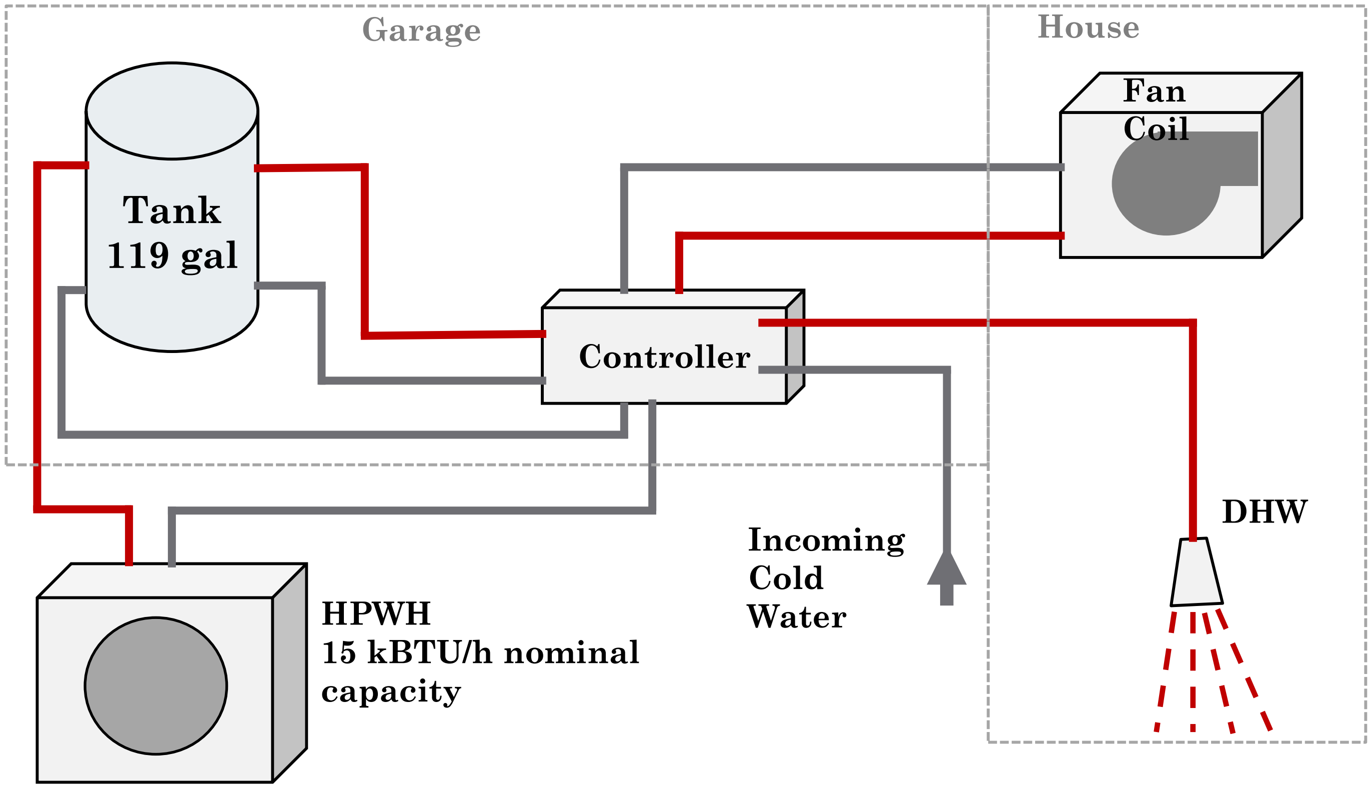
Domestic Hot Water Draws



- Continuously rotating 7 day schedule representing a range of use patterns documented in CA homes
- Based on Title 24 DHW characterization study

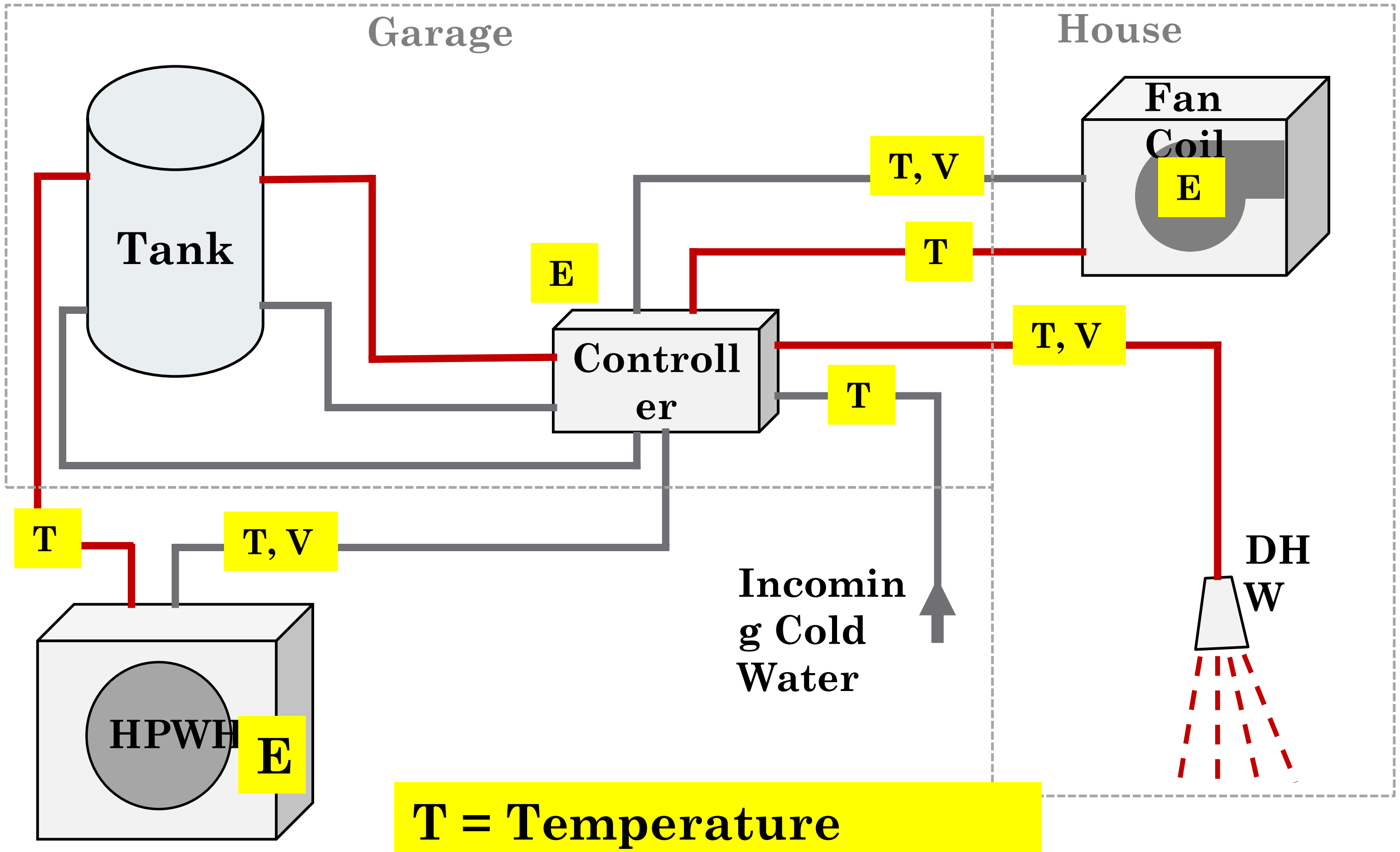
HPWH System

- CO_2 refrigerant, GWP = 1
- Complete system, integrated through smart web enabled control module



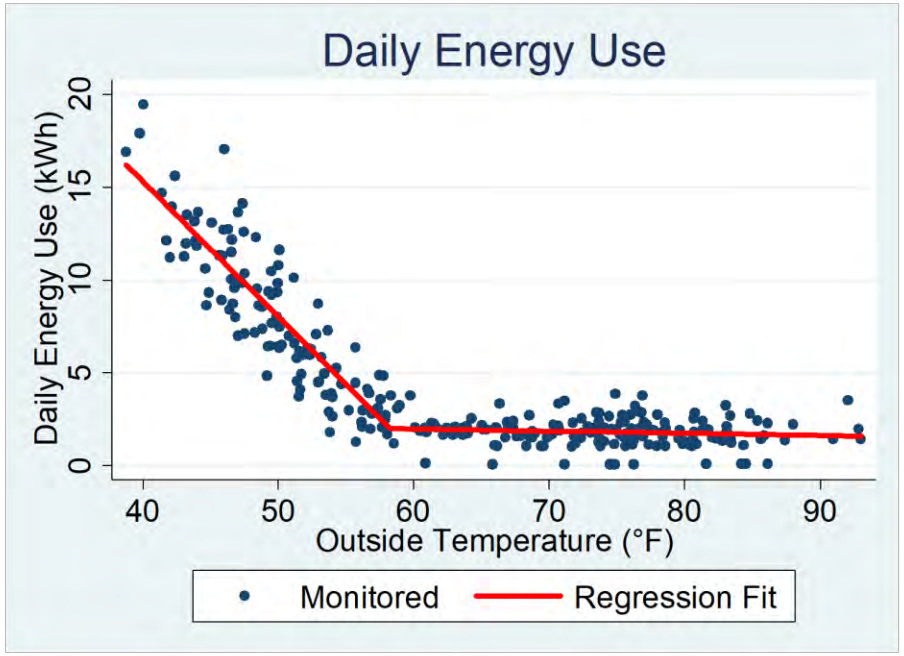
HPWH System

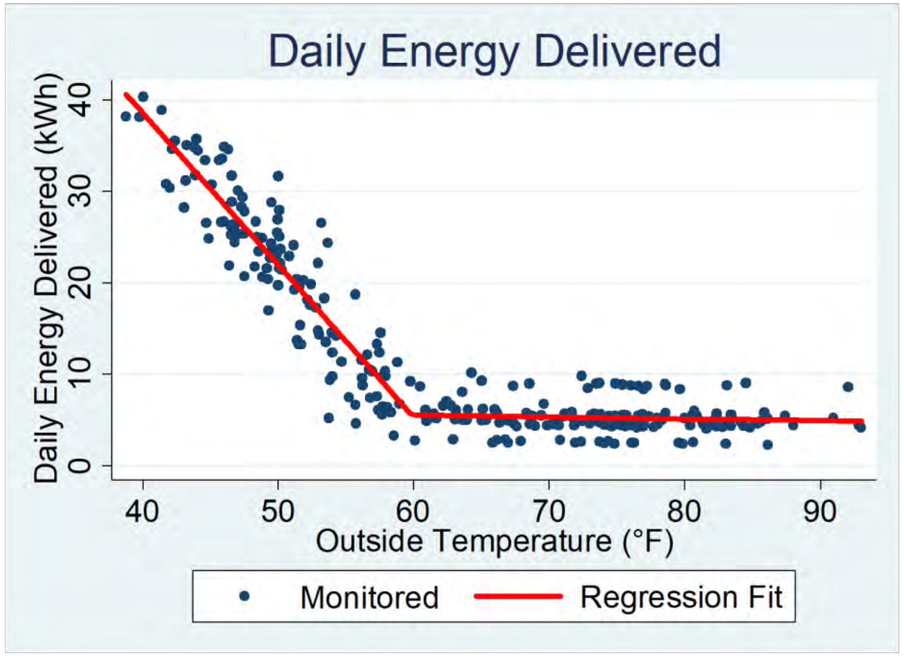
Key Monitored Data Points



T = Temperature
V = Water Flow Volume
E = Input Energy

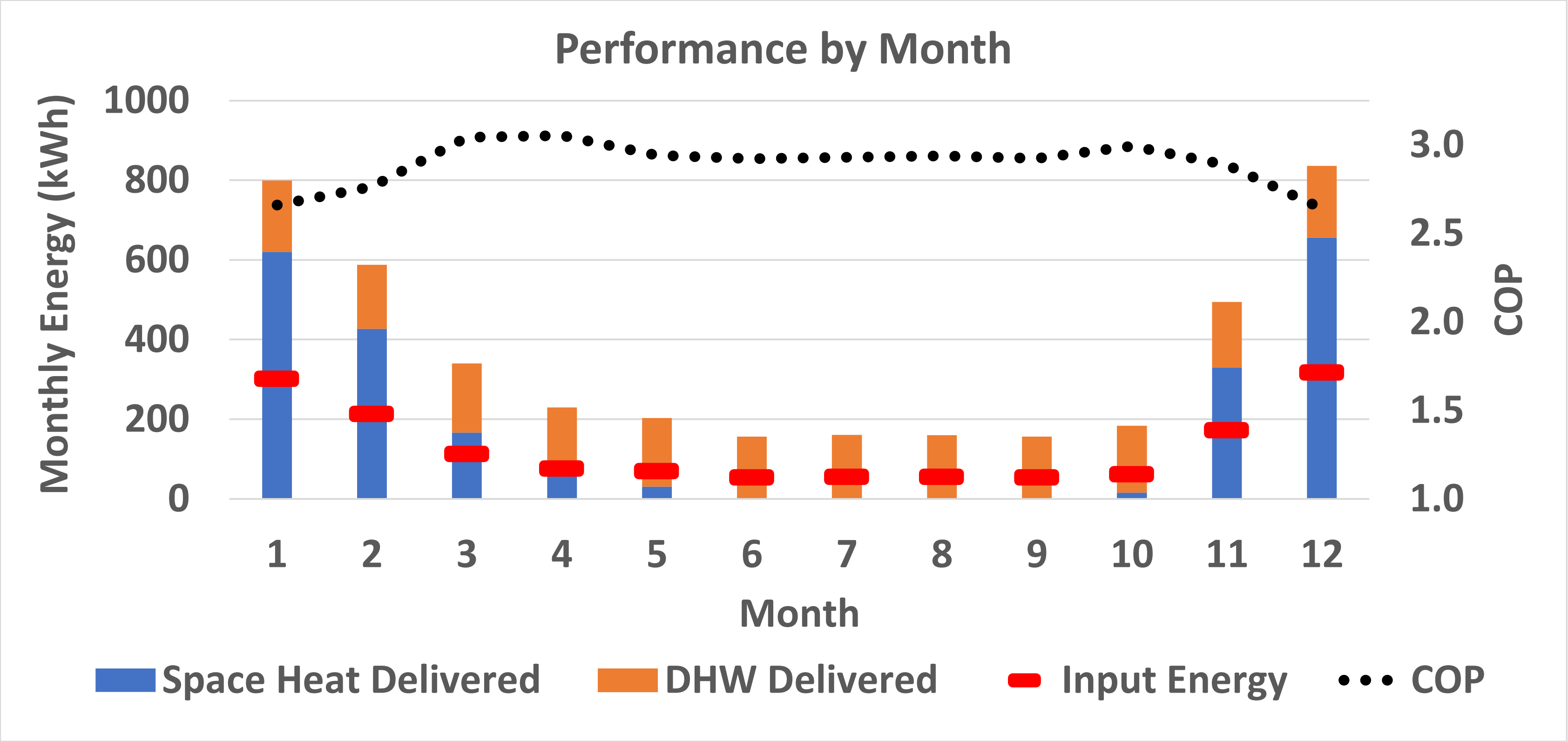
Annualized Performance Estimate





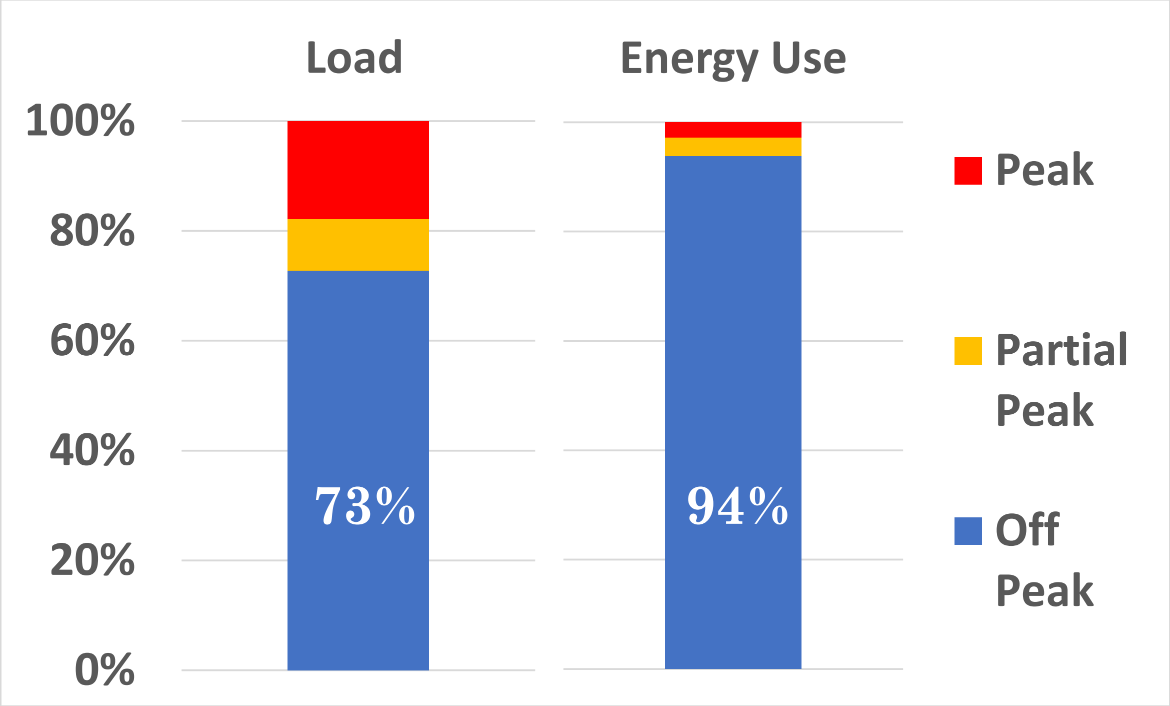
- Daily energy use and energy delivery projected from 277 days monitored to 365 day year by linear regression

Annual Performance



- Estimated annual COP 2.81
- Domestic hot water maintained above 115 °F 99% of time
- House temperatures never fell more than 2 °F below setpoint

Load Shifting



- 21 % of energy use shifted off peak
- 14% lower energy cost
- compared to energy use coincident with loads

PG&E EV2-A Rate Plan		Winter	Summer
Off Peak	Midnight - 3PM	\$0.24	\$0.24
Partial Peak	3PM-4PM, 9PM-Midnight	\$0.41	\$0.44
Peak	4PM-9PM	\$0.43	\$0.55

For More Information

Final report will be posted at

California Emerging Technologies Coordinating Council
https://www.etcc-ca.com/

- *CVRH Project Team: Pacific Gas and Electric Company Frontier Energy Bruce Wilcox, P.E.*
- *Proctor Engineering Group, Ltd. Mike MacFarland, Energy Docs California Energy Commission*

Matt Christie
TRC

Air to Water Heat Pump – Market Conditions

May 10, 2023

Matt Christie, Director Residential Electrification - TRC

State of Residential Electrification

- Residential heat pumps are a **critical** technology to meet state and utility goals across the nation

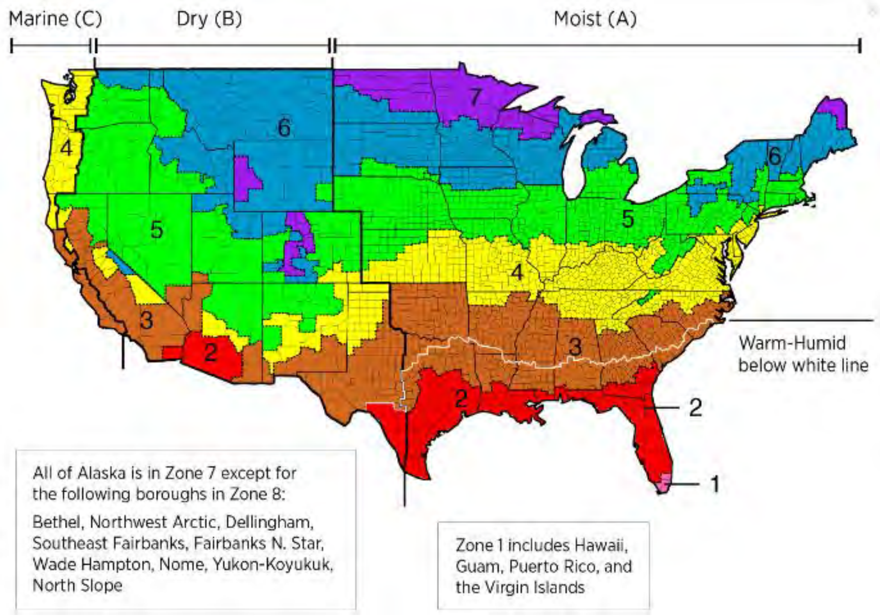
- Multiple states are actively, and aggressively pursuing residential electrification. NY, MA, ME, and VT are leaders in this space. All cold-climate states

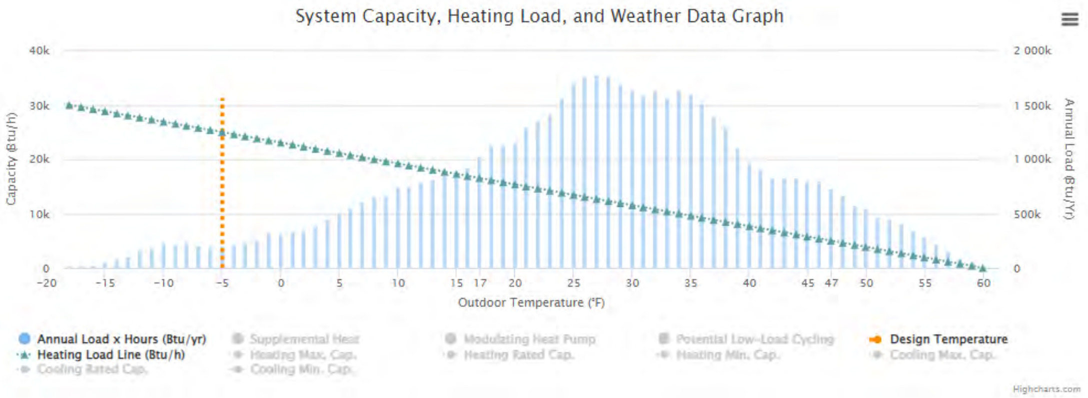
- Current limitation to accelerated adoption for ASHP *isn't* technology based, its **market** and **workforce** based

- There *is* a technology gap to electrify homes currently heated with **hydronic baseboard** heating

Product Needs for Cold Climate

- Cold climate performance
  - Is there a compressor cutoff?
  - How does capacity reduce below 5F?
  - How does COP reduce below 5F?
- Winning-product
  - Meets design loads
  - Seasonal heating COP ≥ 2.5
  - Peak COP ≥1.5 @ 5F
  - Peak COP ≥1.25 @-5F
  - Can still provide heating as low as -20F
    - Acceptable via thermal storage





Product Needs for Existing System Replacements

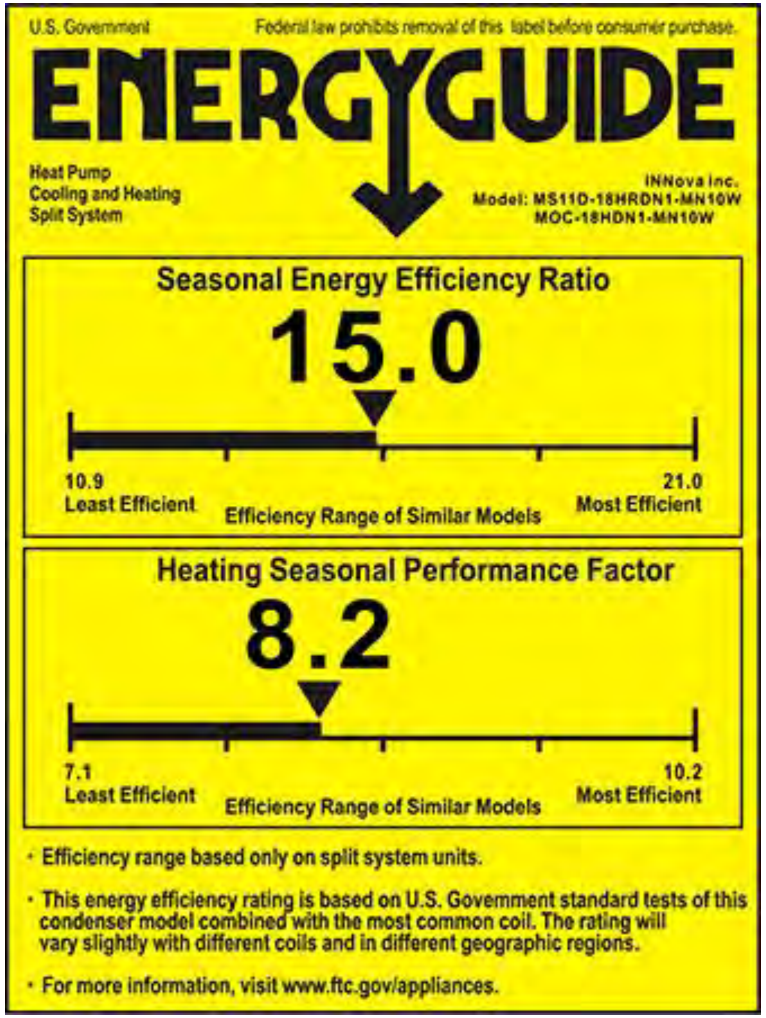
- Supply temperature
  - Most on the market max out at 140F (but with a severe efficiency penalty, best at ~110F)
  - Most existing hydronic baseboard are sized to use 180F or 190F
  - Using 140F means ~50% capacity reduction
  - Using 110F means ~65% capacity reduction
  - Requires either:
    - Additional radiating surfaces (often cost prohibitive in retrofit)
    - Deep envelope retrofit to reduce load (also cost prohibitive, but desirable for general efficiency reasons)
    - Also viable in new construction or with full-distribution replacement

Product Challenges – Lack of Standards

- No industry or federal standard to measure efficiency – HSPF or SEER equivalents

- Made more difficult with variability of **capacity** and **efficiency** with both outdoor air-temp and heating supply temp

- Utilities will be dubious of manufacturer reported data until field-verified



Known ATW Incentive Programs

- Efficiency Vermont
  - Launched 2022
  - $1,000/ton, up to 6 tons plus a $500 bonus for income eligible households
  - Efficiency Vermont developed and maintain a Qualified Product List (QPL): https://www.efficiencyvermont.com/Media/Default/docs/rebates/qpls/efficiency-vermont-awhp-qpl.pdf
  - COP ≥1.7 at 5F air temp to supply 110F water.
  - AERMEC ARCTIC Chiltrix ENERTECH NORDIC SPACEPAK
  - Aiming for ~40-50 per year to start.
  - Program is probing the market. Get traction. Get data. Decide what to do next.

- Mass Save
  - Launched 2022
  - Same QPL
  - Aiming for ~25 per year (only 2 in Q1 2022)

Known ATW Market Initiation

- New York – Technical Resource Manual (TRM)
  - Draft ATW measure delivered April 28, 2023
  - Could trigger program development statewide

- CEE-MN
  - Conducting a field study – 2021-2023
  - https://www.mncee.org/discovering-air-water-heat-pumps

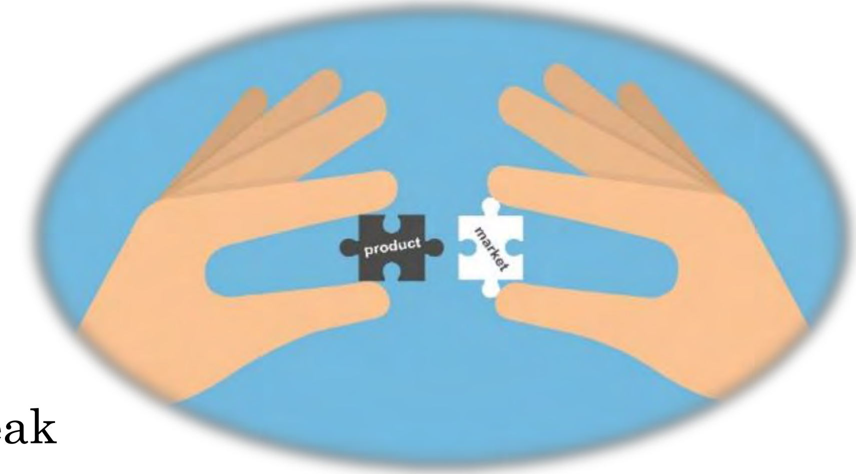
- Rhode Island
  - Included as a technology option in some existing programs, but collateral cites HSPF and SEER requirements.

Challenges for Incentives

- Programs won't be able to scale up with current informational status quo
- Savings claim math to-date – entirely based on 110F supply. Assumes homeowners will use it that way
- Not collecting corroborating data
- Not looking at cooling savings
- Not looking at DHW savings
- Leveraging manufacturer's expanded performance data

Market Needs for ATW

- Case studies showing sufficient whole-home heating without fossil backup through cold-climate winters (design temps as low as -10F.)
- Field studies showing manufacturer's performance data is met in-field
- Industry standards on seasonal and peak efficiency metrics
- Best if institutionalized through AHRI and/or DOE
- Industry standards on reported expanded performance efficiency and capacity values



Thank You

Matt Christie
TRC
mchristie@TRCcompanies.com

John Arent
Noresco

Air-to-Water Heat Pumps (AWHP) for Central Space Heating

Updates to the California Energy Efficiency Code

California Tite 24 2025 Update

Eric Shadd, John Arent,Rahul Athalye, NORESCO

Bach Tsan , California Energy Commission

NORESCO

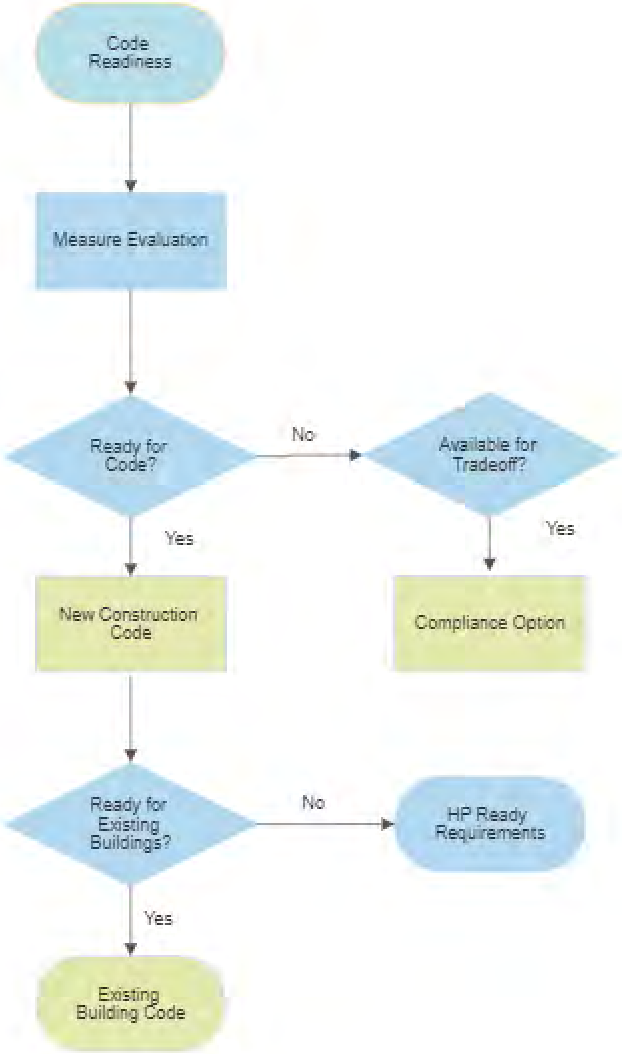
HEAT PUMPS, BUILDING DECARBONIZATION, AND ENERGY CODES

Code Development

- "Push" (prescriptive standards, federal minimums) vs.
- "Pull" (compliance options, incentive programs, building performance standards)

California's approaches to increasing the use of heat pumps

- Energy currency now includes a measure of source emissions
- Develop compliance options through validated energy modeling approaches
- Initial focus on **new construction**, followed by *Electric Ready* buildings and existing buildings



NORESCO

Air to Water Heat Pumps

Air-to-water heat pumps are a proven design option for electric central space heating in larger office, laboratory, and municipal buildings.

J. Craig Ventner Building, San Diego **MEP: Integral Group**

Heat Recovery chillers, air-to-water heat pumps – COP to 4.1

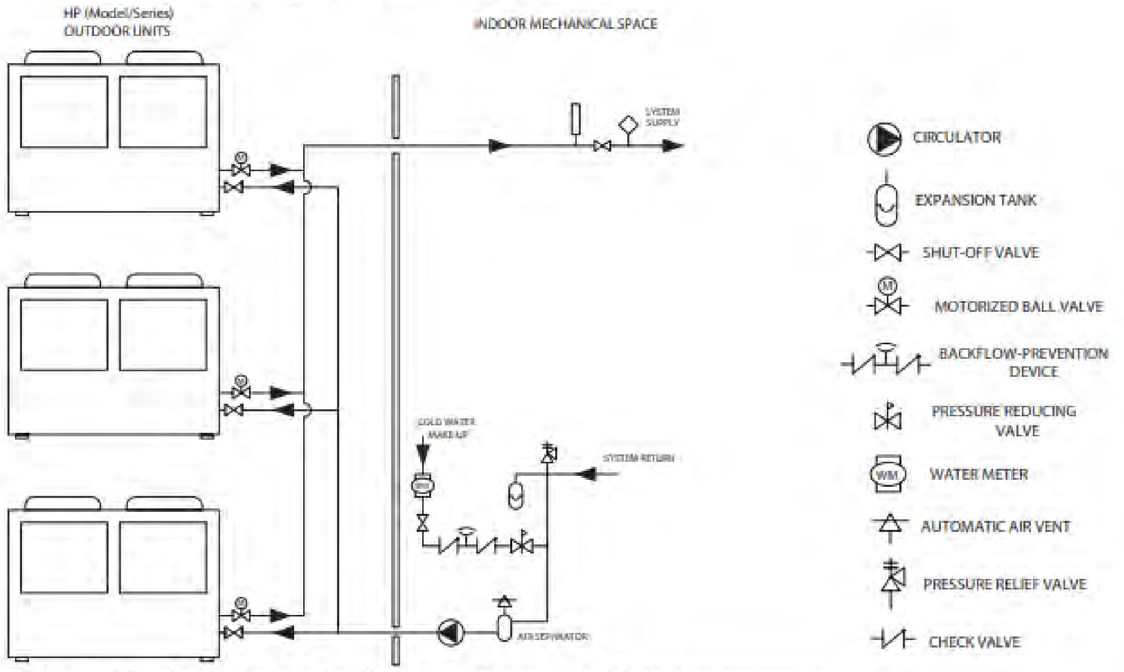
Thermal Energy Storage

Cooling Towers run at night as cooling source

Air to Water Heat Pumps

Air-to-water heat pumps are a proven design option for electric central space heating in larger buildings.

Figure 6 Typical Multiple Heat Pump Reverse Return Piping (RECOMMENDED)



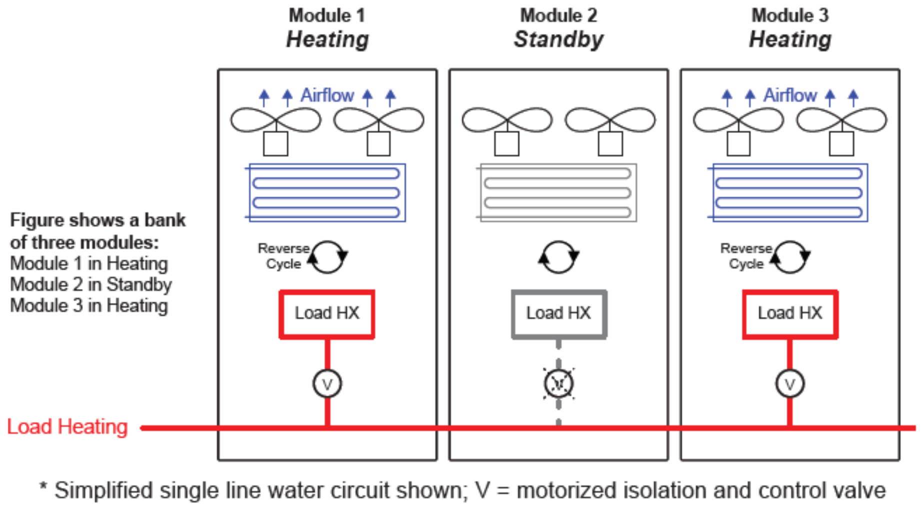
NOTE: Not all system valves may be shown. Consult local codes for additional system components which may be necessary.

Courtesy: Mestek

Configurations: 2-Pipe, 4-Pipe, Heat Recovery

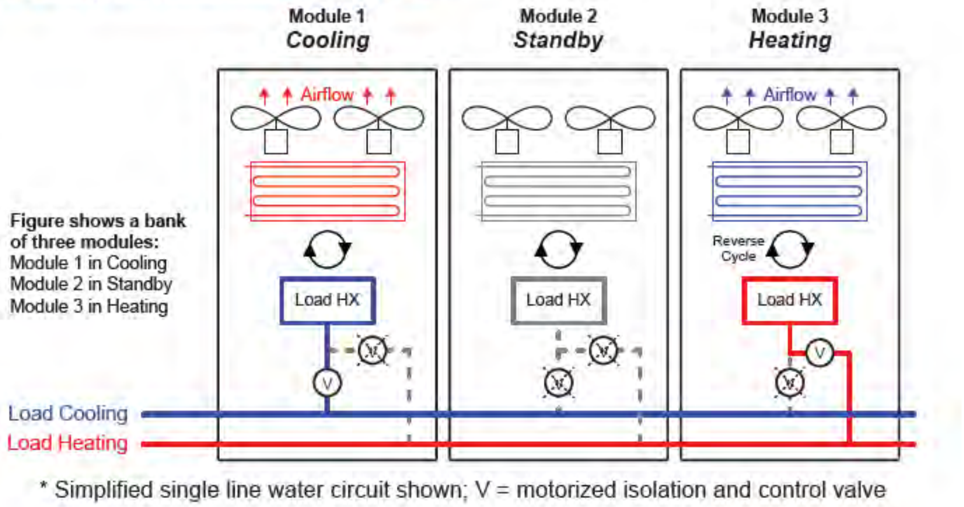
Two-Pipe: Heat or Cool

Figure 12 UCA, Heat Pump



Four-Pipe: Heat and Cool

Figure 13 UCA SHC, Heat Pump, 4 pipe



Modular System Advantages:

1) Greater system turndown

2) Adaptable and easily scalable

3) Good part-load performance

NORESCO

Other System Design Options

4-pipe Air-to-Water Heat Pump (Heat or Cool)

Air to Water Heat Pump with Heat Recovery (Heat AND Cool)

VRF zonal systems with DOAS ventilation

Water Source Heat Pumps

VAV with Electric Reheat?

Air to Water Heat Pump – Cascade with WWHP for larger buildings

Design Approaches

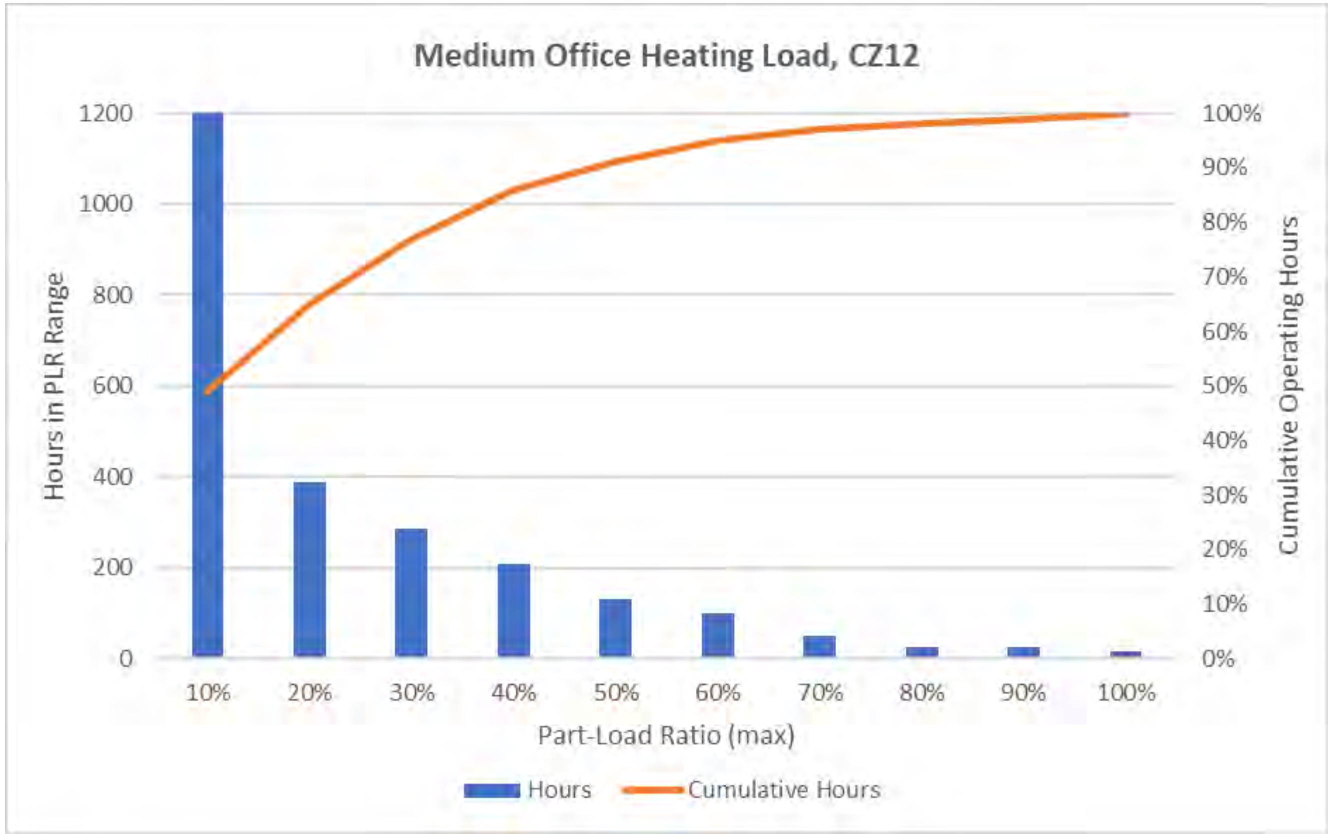
Standard Design Approaches will not work with AWHP.

NORESCO

STANDARD DESIGN APPROACHES WILL NOT WORK WITH AWHP

System sizing: AWHP provides only 50% of design load, remainder from supplemental heat

System Sized for 50% of design load can meet load for over 90% of operating hours



NORESCO

Standard Design Approaches will not work with AWHP

Systems require smaller delta T (10F vs. 30F for boilers) and larger coils

Storage:

- Large Amounts of storage needed as a buffer tank
- 8 to 10 gallons per nominal heating ton for hydronic loop volume
- Typically requires storage tank (~2-5 gallons per ton) depending on hydronic system layout

Additional hot water storage can provide multiple benefits:

- Can be used for morning warm-up when heat pump would have relatively low COP
- By handling peaks, can reduce required system size, reducing first cost

Heating System Cost Increment; Total System Cost close to neutral

Medium Office Building

- Base System: PVAV, Gas Boiler, VAV Terminal Units with hot water coils
- (Good) AWHP System: PVAV, AWHP 2-Pipe, VAV Terminal Units with hot water coils
  - Incremental Cost of $1.75-$2.00/sf just for AWHP over gas boiler
  - Additional System Costs – backup electric resistance heater, thermal storage tank
- (Better) VRF System: combined system for heating and cooling, costs comparable to base system

Large Office Building

- Base System: water-cooled chiller, tower, gas boiler, built-up VAV AHU
- (Good) AWHP System: water-cooled chiller, tower, AWHP, built-up VAV AHU
  - Incremental Cost: AWHP, thermal storage tank
- (Better) AWHP + DOAS: Water-cooled chiller, tower, AWHP, DOAS system, four-pipe fan coil
  - Reduced Costs of air distribution system

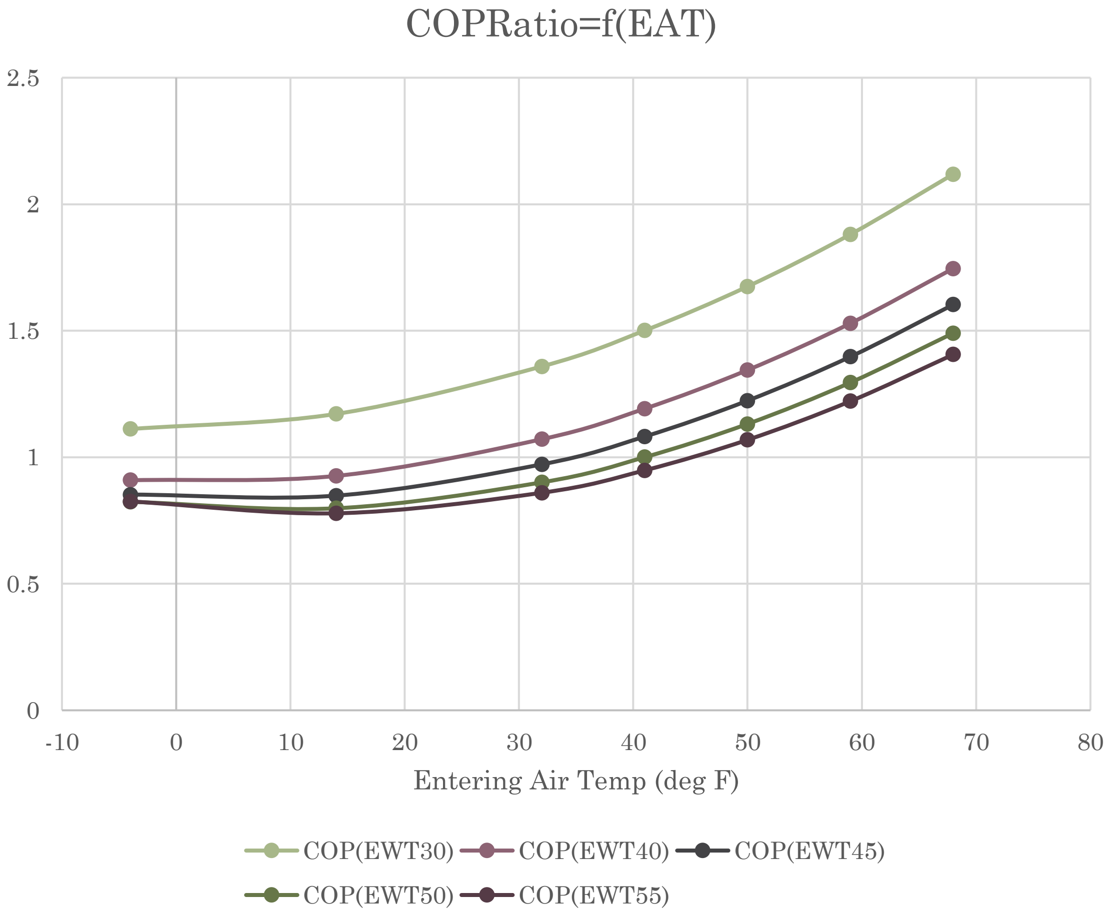
NORESCO

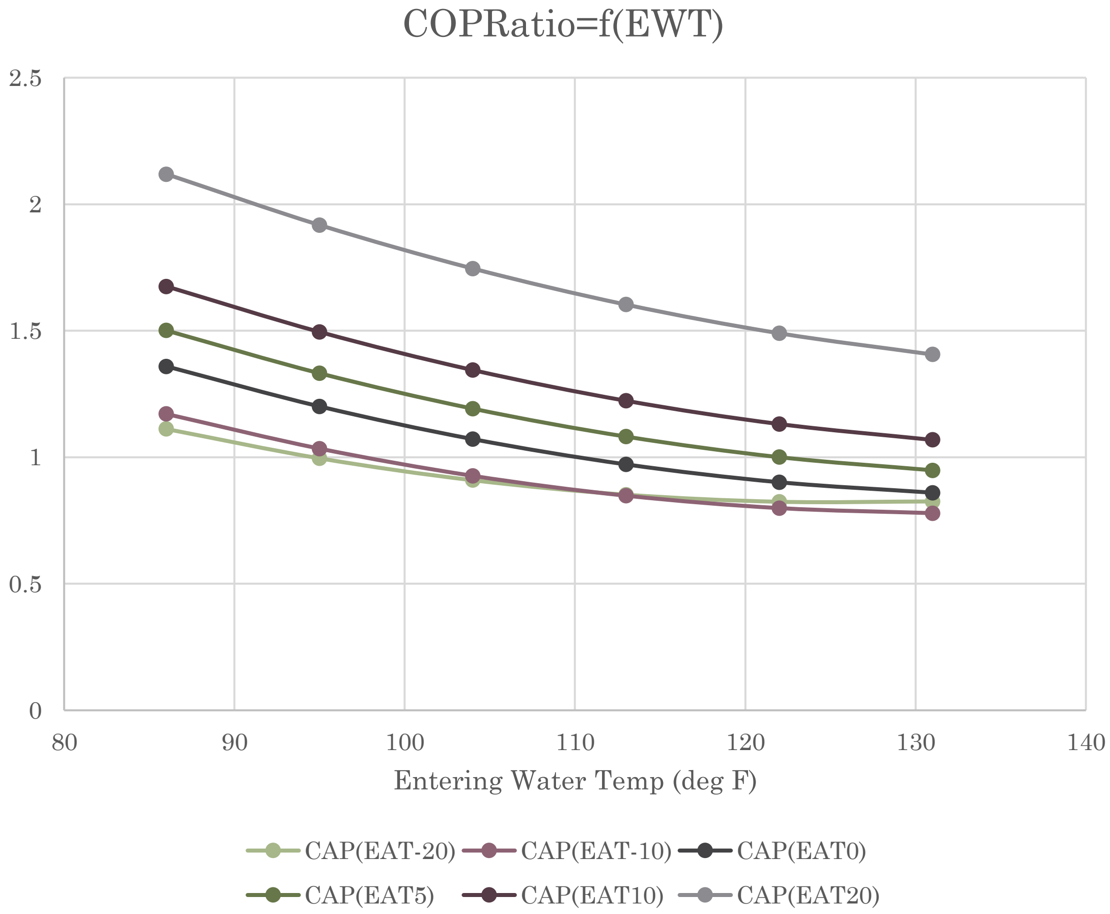
System Comparison with Gas Boilers

An air-to-water heat pump cannot compete with a gas boiler for total life-cycle cost.

Or can it?

AWHPs in California – Performance Modeling

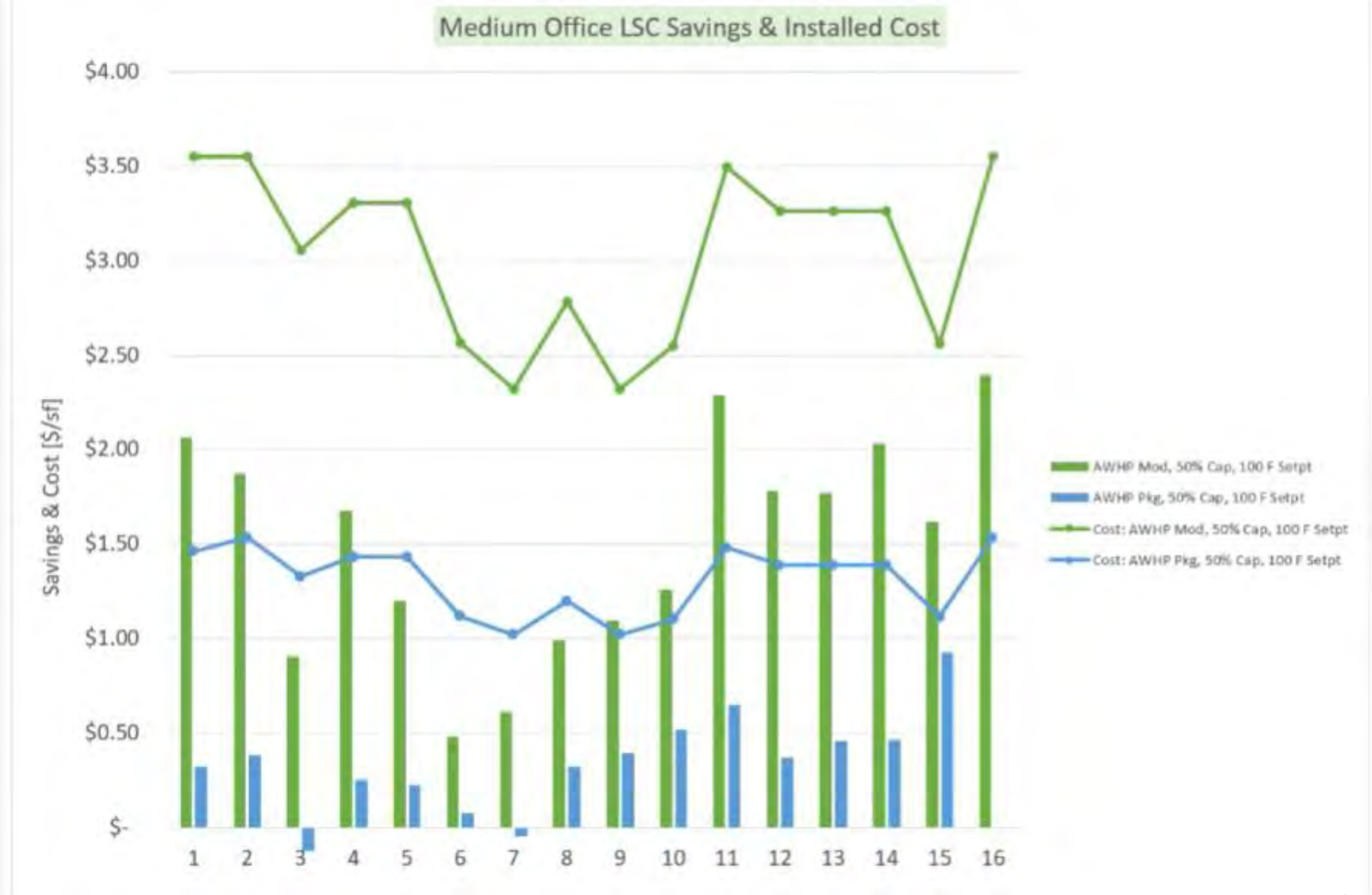




Improved Performance Modeling provides better comparison with other system types, when using a Performance Compliance Approach.

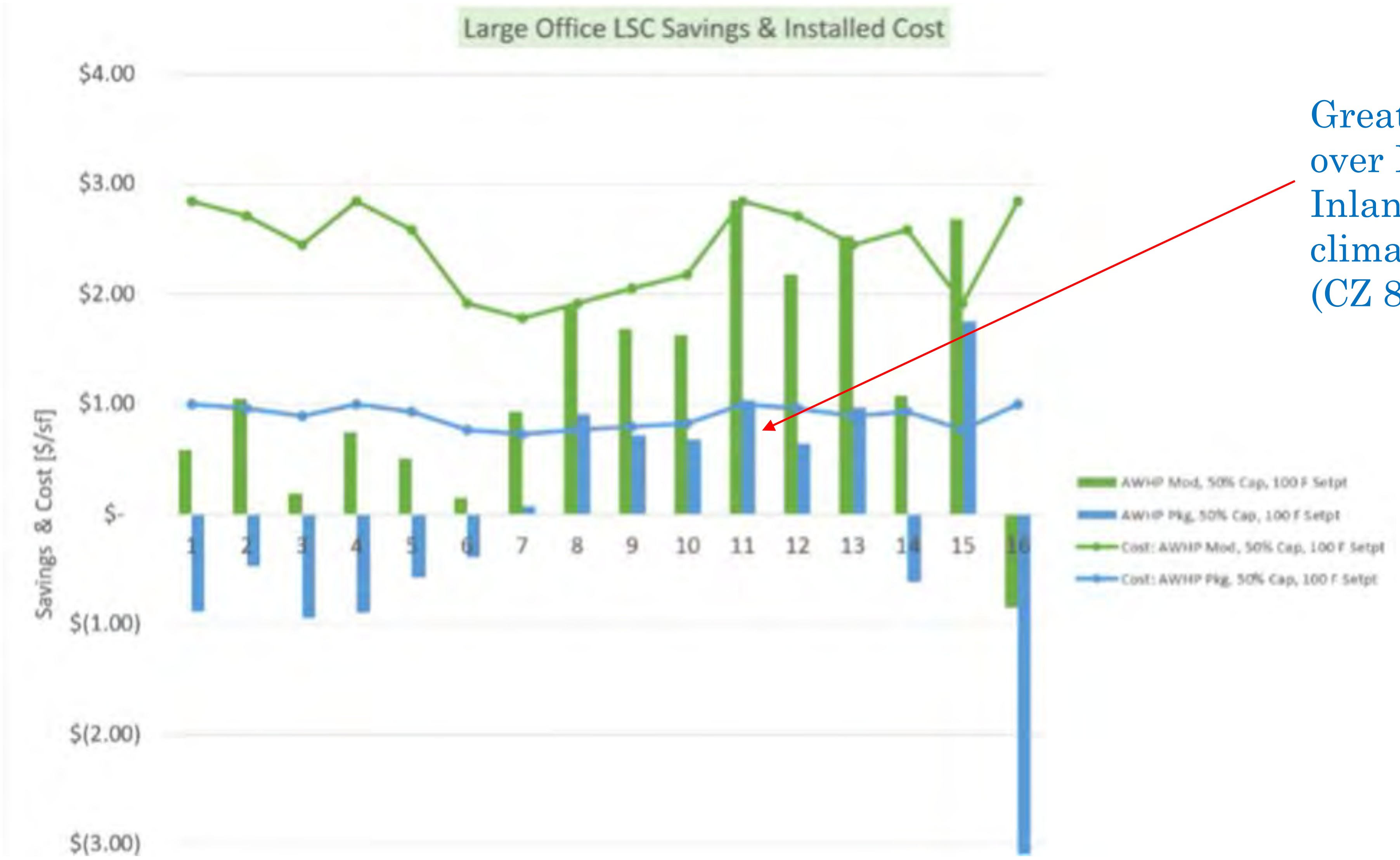
NORESCO

Medium office (3-story) Preliminary Modeling Results



NORESCO

Large office preliminary Modeling Results



Greatest Savings over Baseline in Inland Valley climates and desert (CZ 8-13, 15)

NORESCO

Next Steps / Conclusion

Cost-effectiveness can be a challenge for AWHP systems

- Has gained traction in all-electric buildings / jurisdictions

Alternate design options may show promise as a cost-effective measure:

- Increased storage to handle morning warm-up
- Heat recovery chillers or four-pipe systems
- VRF systems with DOAS for smaller buildings
- VAV with electric reheat and heat recovery

Spencer Dutton
LBNL

Why coupling TES with HPs is really impactful?

Why couple heat pumps with TES?

- **Supporting Electrification, helping reduce peak demand requirements of electrified devices.**
- **Enabling and Amplifying Benefits of On-Site Renewables Integration**
- **Enhancing Resilience and Reliability**
- **Supporting Grid Interactivity for Energy Cost Reduction and Carbon Mitigation**
- **Diverse Applications, a versatile solution for energy management in buildings.**

DOE sees behind the meter storage as critical to decarbonizing building stock. TES enables broader applications of heat pumps, and amplifies benefits.

And why the explosion of research interest all of a sudden?

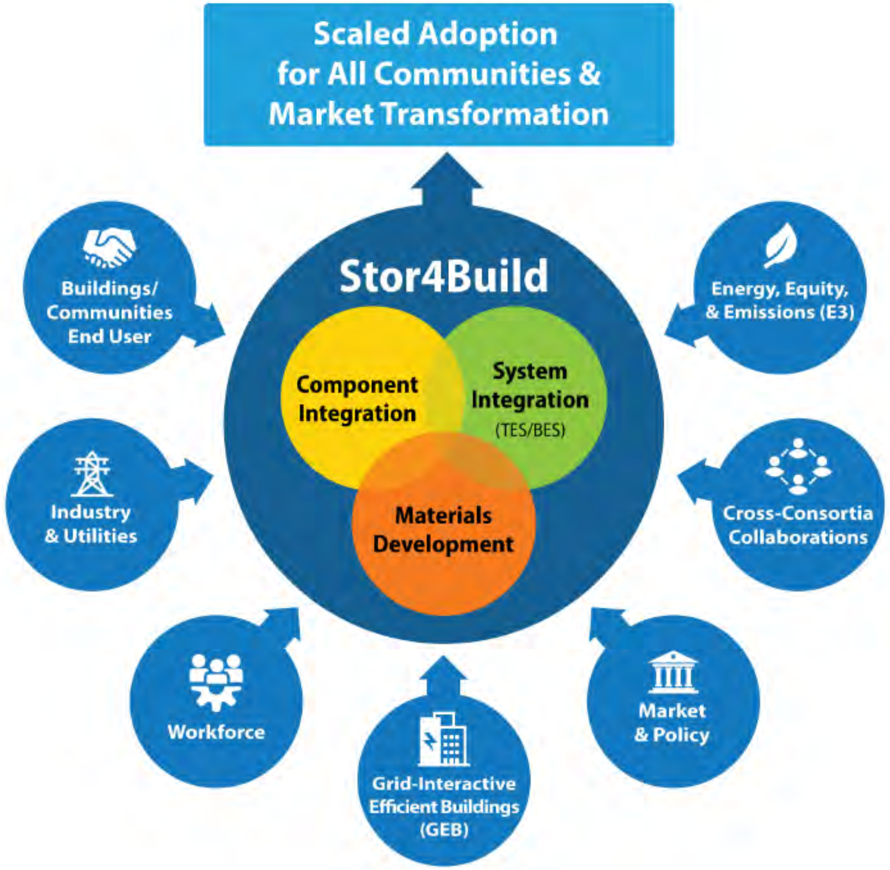
Stor4Build Building Energy Storage Consortium

Accelerating the growth, optimization, and deployment of energy storage technologies in buildings

Thermal Energy Storage RDD&D for Building Decarbonization

Stor4Build is a multi-lab consortium and includes active participants from industry, utilities, nonprofit organizations, communities, building owners, academia, government, and other research institutions.

The cross-cutting team address the need for equitable solutions using energy storage technologies that will enable widespread building electrification and decarbonization. *Stor4Build*'s 5-year plan includes a community-scale demonstration of technologies, which will serve as a foundation for large-scale deployments of thermal and battery energy storage and systems capable of satisfying both the heating and cooling needs in buildings.



U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY | BUILDING TECHNOLOGIES OFFICE

NREL Transforming ENERGY

BERKELEY LAB

OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

ACEEE American Council for an Energy-Efficient Economy

NREL

NREL core strengths and example projects

- Detailed models and design tools, PCM material synthesis/selection, characterization and enhancement. Component development (TES heat exchangers) Testing facilities for experiments from 100 W to 100 kW.
- POC: Jason.Woods@nrel.gov

Current projects:

- Multi-function split system with PCM storage, integrated heat pump serving space cooling, space heating, and water heating.
- Refrigerant-coupled PCM storage, for easy integration with split heat pumps, integrating a ‘plug-and-play’ PCM storage directly into an off-the-shelf VC system.
- HPWH for low-income communities. Design a low cost 3D printed PCM HX, that will integrate with off-the-shelf water heater.

NREL
Transforming ENERGY

ORNL

Yarnell Station Research Home

ORNL prototype cold climate heat pump under field test

ORNL core strengths

- 60,000 ft^2 research space, including environmental chambers, unoccupied residential research home, unoccupied commercial buildings, and TES-HP test bed.
- 40+ year history in development of heat pumps for space and water heating
- Building Technologies Research and Integration Center, a designated DOE User Facility established in 1993
- POC: gluesenkampk@ornl.gov

Example current projects:

- Integration of heat pumps with thermal energy storage
- Development of low-cost salt hydrate phase change material
- Thermally anisotropic building envelopes

OAK RIDGE National Laboratory

LBNL

Prototype RTU/VPU replacement with PCM-TES cold/hot

LBNL core strengths

- PCM material characterization (Energy Storage)
- Modeling tools, to predict impacts of HVAC-TES in buildings (Building Technologies)
- PCM-TES prototype demos, residential and commercial buildings.
- POC: smdutton@lbl.gov

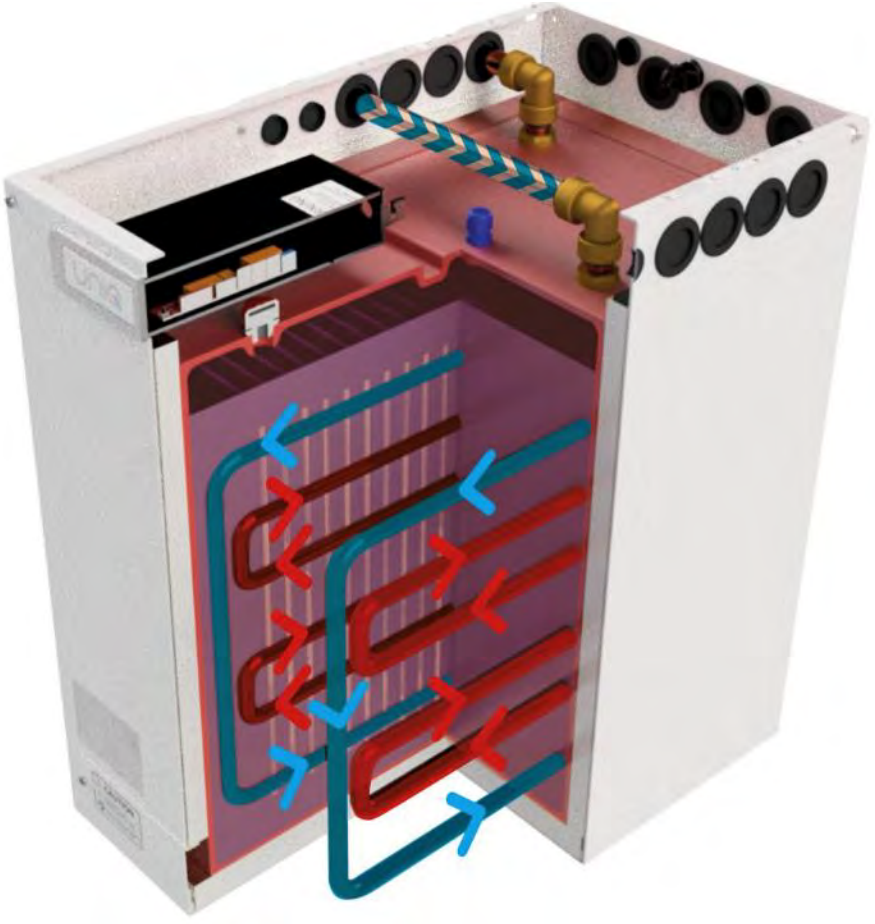
Example current projects:

- Reduced Cost Heat Pump Space- And Water-heating In Cold Climates: Polymer HX for PCM-TES, packaged HP +PCM-TES, coupled with low GWP refrigerant HPs.
- Residential field deployment of R32 AWHP + PCM-TES
- Collaborations with commercial HP+TES (Harvest, ZYD energy)

BERKELEY LAB

Solid-Liquid Phase Change Material (PCM)

- Sunamp phase change material TES
- High energy density (4X hot water)
- Non-toxic, non-flammable, >60k cycles.
- No resource constrained materials
- Lower cost (heading to below $50/kWh)

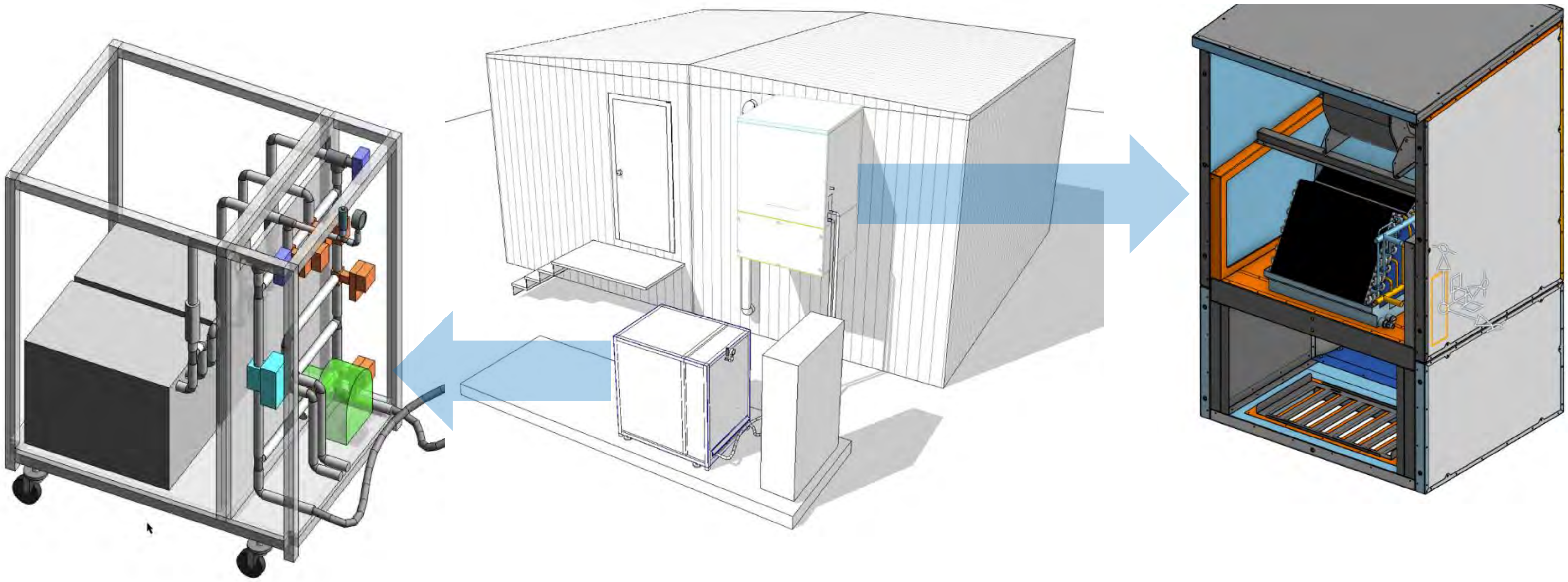


Residential field evaluation of integrated system

Small commercial building field evaluation

Project details

- Small 3-5 ton demonstrator, modular office building at LBNL (proposed)
- Space heating, cooling, cold and/or hot storage 24kWh max (7 ton hours)



LBNLs Research takeaways

LBNL performed simulation studies of HP+TES and HP only baselines, in multifamily applications.

- Combining TES with HP can deliver significant energy cost and GHG savings compared HPs alone, however impacts highly dependent on tariff and gird mix.
- Adding TES can enable a reduction in required HP capacity, by up to 60%, by spreading load though out the off peak period.
- Downsized heat pump capacity enables significant electricity demand reduction across the year, aiding decarbonized heating on an increasingly electrified grid.

Kelly Hearnsberger

Daikin

Kelly Hearnsberger

Daikin

Market evolution

European heat pump market heading towards 10 million units by 2030

Europe to Become Climate Neutral By 2050

1 T€ Investment
EU Green Deal
Next Gen. EU **€750 bn**
Other markets follow

Decarbonizing
the heating sector
will be key
Heat Pump will be **key**

EU commission targets **40% penetration of renewables** in heating and cooling by 2030.

RePowerEU:
measures taken to **accelerate the transition** from gas to **renewable heating**

Feel Good Technology

DAIKIN

Massive Potential To Decarbonize Heat Will Lead To Building Sector Transformation

36% of CO_2 emissions by building stock	**50%** of energy use for heating & cooling	**80%** of it used in buildings
In-efficient buildingstock **195 million**	Buildings date <2000 **220 million**	Heated with coal & oil **> 30 million**

Heat pump recognition by the EU

Barely mentioned

Breakthrough

Close to full recognition

<u>2002</u>

EPBD

"Heat pumps under certain conditions"

<u>2009</u>

Renewable energy Directive

Heat pumps defined as a renewable technology

<u>2020</u>

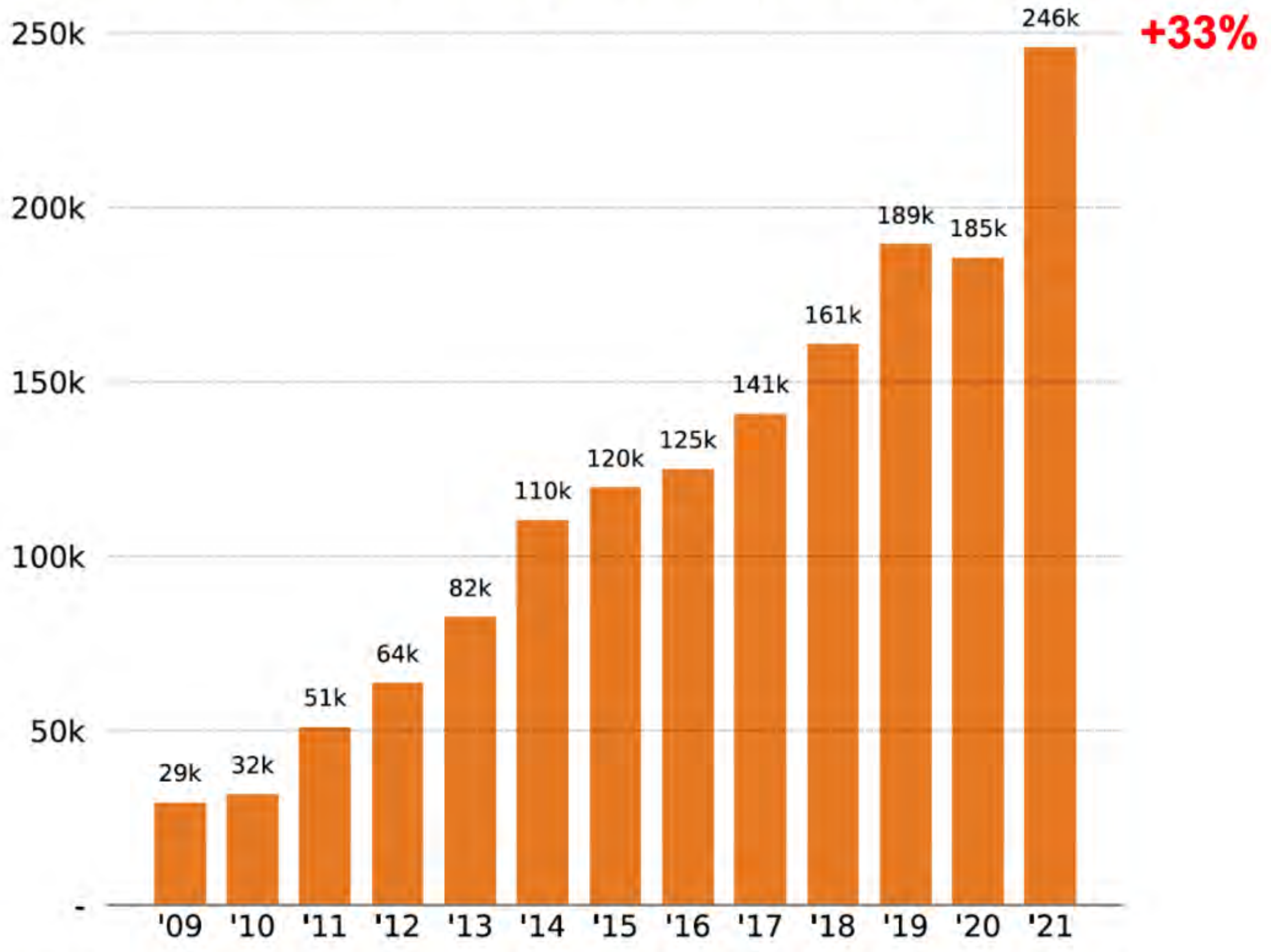
Energy system integration strategy

Heat pumps described as the most important technology for decarbonisation of buildings

"The share of eletric based heat expected to become
40% by 2030 and 50-70% by 2050"

Market growth '10 – '21 | HP stock^{2021}: 17 mill. installed

Sales of sanitary hot water heat pumps 2008 - 2021



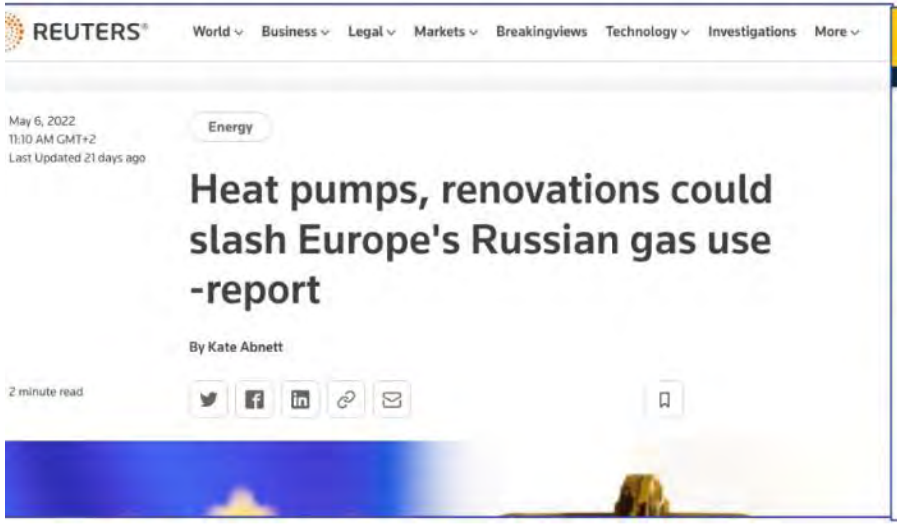
A great entry solution, immediate savings

Hydronic Heat Pump Market outlook

Feel Good Technology

DAIKIN

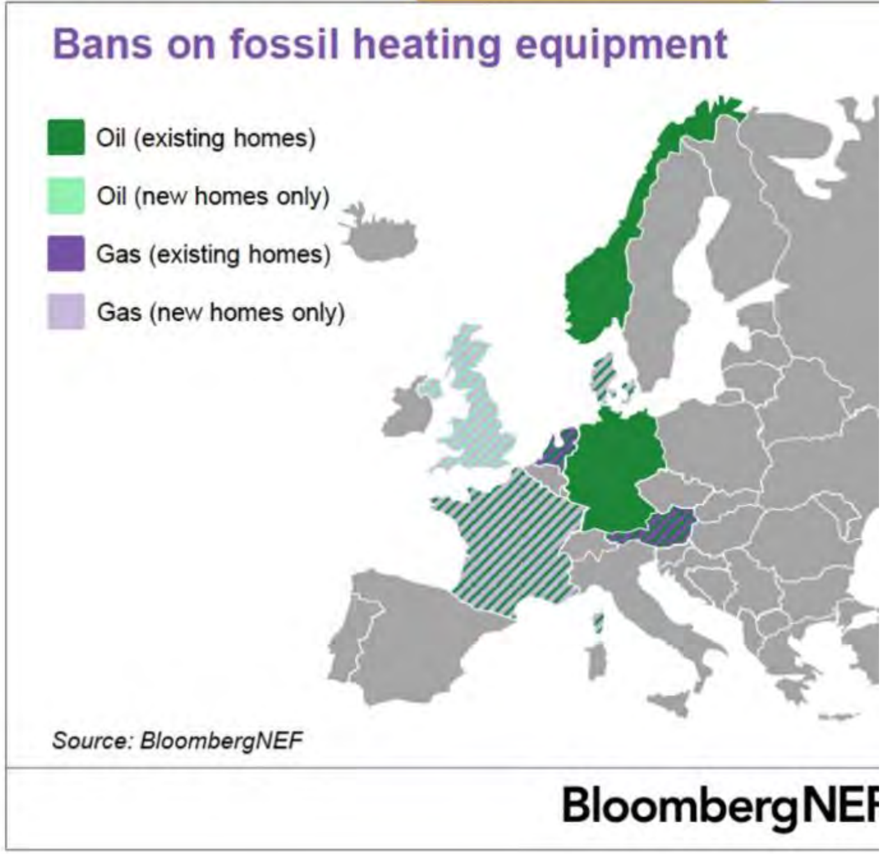
Heat pumps dominate the headlines



ehpa

National policies: Phase out of fossil-only boilers

- Austria: 1.1.2023 no gas in new buildings
- Flanders: 1.1.2025 no gas in new buildings
- France: 1.7.2022 bans oil boilers
- Germany: 1.1.2024 - share of 65%RE
- Netherlands: 1.1.2026 – min. hybrid heat pump
- Denmark
- European Union - tbc: 2029 via Ecodesign



Daikin Europe Launches Altherma 4 @ ISH

Heating, hot water and cooling ideal for new built and high insulated houses

- For heating, hot water and cooling
- Powered by 75% air and 25% electricity
- Optional solar support
- Ideal for new homes and Green Buildings

Heating, hot water and cooling while keeping your existing piping and recent radiators

- For heating, cooling and domestic hot water
- Powered by 75% air and 25% electricity
- Optional solar support
- Connects to existing piping system and recent radiators
- Ideal for renovations and replacement of gas boilers

Heating and hot water while keeping your existing radiators

- For heating and domestic hot water
- Powered by 65% air and 35% electricity
- Optional solar support
- Connects to existing piping system and high temperature radiators
- Ideal for renovations and replacing old boilers

Daikin Altherma 3 R MT

Daikin Altherma 3 H MT is an investment in comfort and energy savings. This air-to-water heat pump delivers heating, cooling and instant hot water—and uses less energy to do it. This system is ideal for homeowners who want to upgrade their boiler or traditional heating system to a greener and more cost-effective solution.

Daikin Altherma 3 R F

Floor standing unit integrated with different temperature zones management.

Daikin Altherma 3 H HT

Daikin Altherma 3 H HT is an investment in comfort and energy savings. This air-to-water heat pump delivers heating, cooling and instant hot water—and uses less energy to do it.

Daikin Altherma 3 H MT W

Wall mounted heating only air to water

Daikin Altherma Domestic hot water tank

Daikin Altherma 3 M

Daikin Altherma low temperature monobloc

Key Insights from Europe

- **Energy costs are a key driver in Europe and US market still enjoys lower cost fuels.**
- **Hydronic heating is the primary comfort method and thus more adoption possible for A2W systems.**
- **Europe officially recognized Air Source Heat Pumps as a ”Renewable Source” and the US DOE has not taken this step.**
- **Regulatory and Utility incentives will play a major part in the US adoption of A2W heat pumps.**
- **Domestic Hot Water solutions in the US are a major gateway to success of technology adoption in this category.**

Questions

Thanks Everyone!

Matt Christie	mchristie@trccompanies.com
John Arent	jarent@noresco.com
Abram Conant	abram@proctoreng.com
John Siegenthaller	siggy0269@gmail.com
Iain Walker	iswalker@lbl.gov
Kelly Hearnsberger	joseph.hearnsberger@daikincomfort.com
Spencer Dutton	smdutton@lbl.gov
Kashif Nawaz	nawazk@ornl.gov
Christopher Dymond	cdymond@neea.org
Lynne Mosley	lmosley@neea.org