06 FEBRUARY 2020

Fossil Fuel Free at Last:

Air-to-Water Heat Pump and Ventilation Retrofit Case Study

Brian Just

Learning objectives

- Learn how air-to-water heat pumps are functioning in New England's Climate Zone 6
- Identify 5 key non-energy benefits that can help move the needle on HVAC retrofit projects
- Understand the basics of how to install an air-to-water heat pump with the benefit of an open-source design and detailed photographs
- Learn the key design features and options for low-temperature distribution, including how to set up a new home for near-seamless retrofittability in the future at minimal cost

Outline

- Goals
- Heat pump basics
- Decisions 101
- Design
- Installation
- Results
- Closing thoughts

Goals

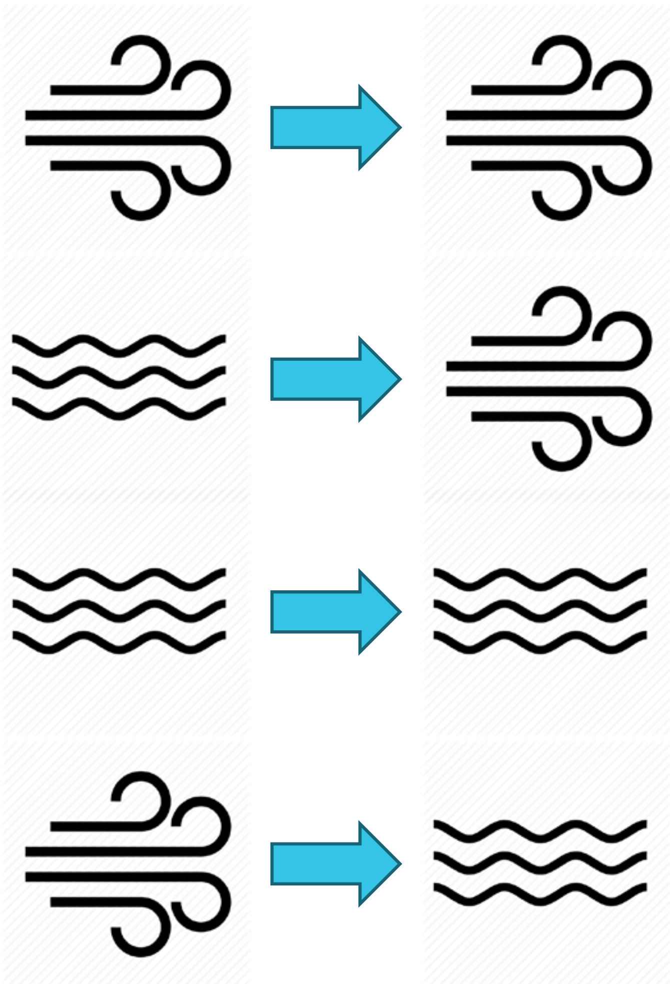
Photo: https://www.space.com/39234-best-astronaut-earth-from-space-photos-2017.html

Not (necessarily) a top goal:

Photo: https://www.science101.com/dirty-money-handling-cash-cards-damaging-health/

Heat pump basics

Types



- Air to Air
- Water/Ground to Air
- Water/Ground to Water
- Air to Water

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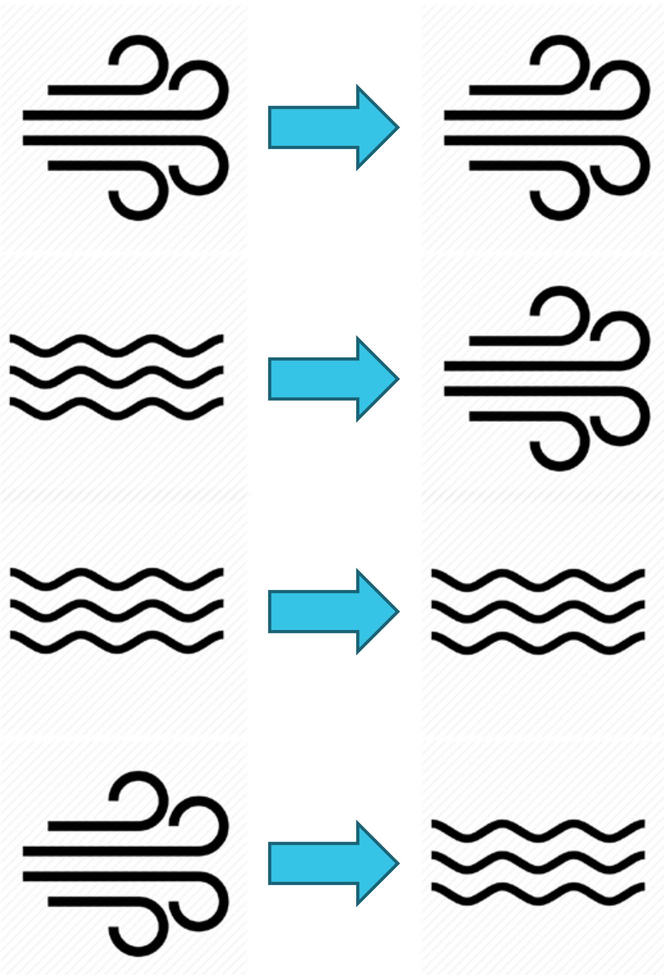
Types



~~Air to Air~~

Water/Ground to Air

Water/Ground to Water

Air to Water

"AWHP"

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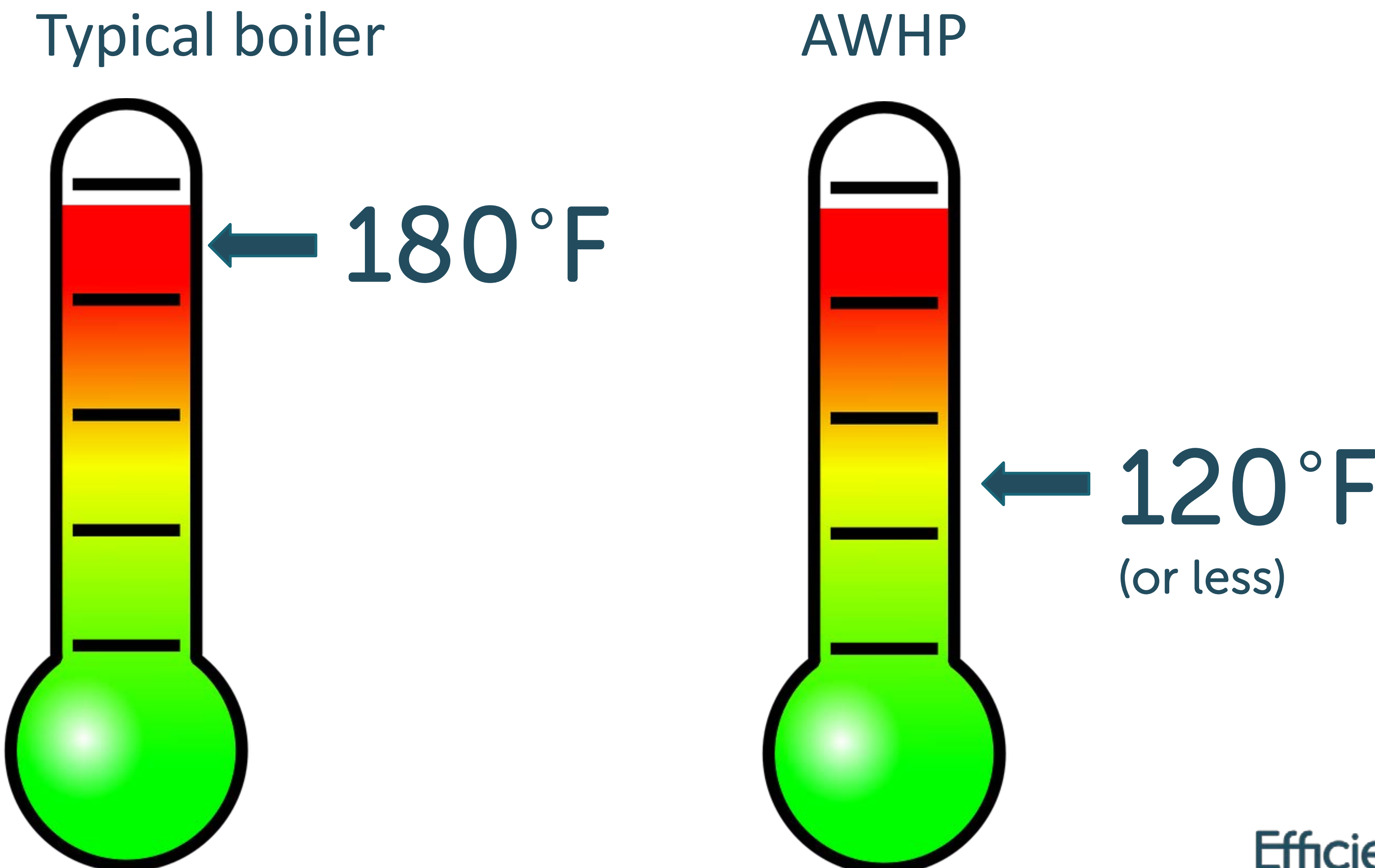
Operating temperatures



Heat pump basics

Intake

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Heat pump basics

Intake

Exhaust

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Advantages of hydronics

- Distribution efficiency
  - Furnace ➔ 30,000 btuh / 750W = 40 btuh/W
  - Boiler ➔ 30,000 btuh / 75W = 400 btuh/W
  - No duct losses (if they leak, you know it)
  - Given volume of water can hold 3500x more heat than air
  - ½" tube compared to large round / rectangular ducts

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  - Quiet
  - With minisplits, can blow cold air during defrost cycle
  - Less movement of dust and allergens

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  - ½" tube compared to large round / rectangular ducts
- No moving air
  - Quiet
  - With minisplits, can blow cold air during defrost cycle
  - Less movement of dust and allergens
- Placement and comfort
  - Put where you want them (e.g. below windows)
  - Invisible if you want (floors, walls, ceilings)
  - Highly tune-able to individual rooms and spaces, even those with very low loads

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AWHP installation pros and cons

Pros

- Contractor network skilled at hydronics
- Boilers in 60% of VT homes
- AWHPs common in developed world

AWHP installation pros and cons

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Cons

- In most cases, not a drop-in replacement
- Distribution system must be (made) compatible
  - Need surface area!
  - Existing baseboard and radiators may only put out 25-30% of the heat (180F vs. 120F)

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Decisions 101

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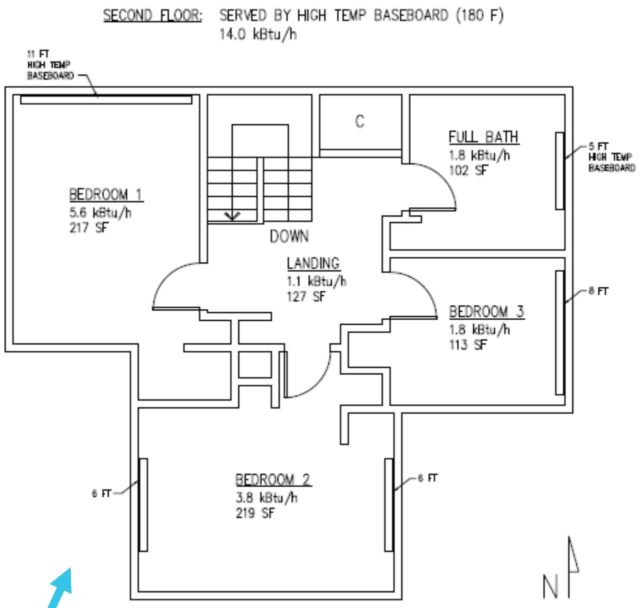
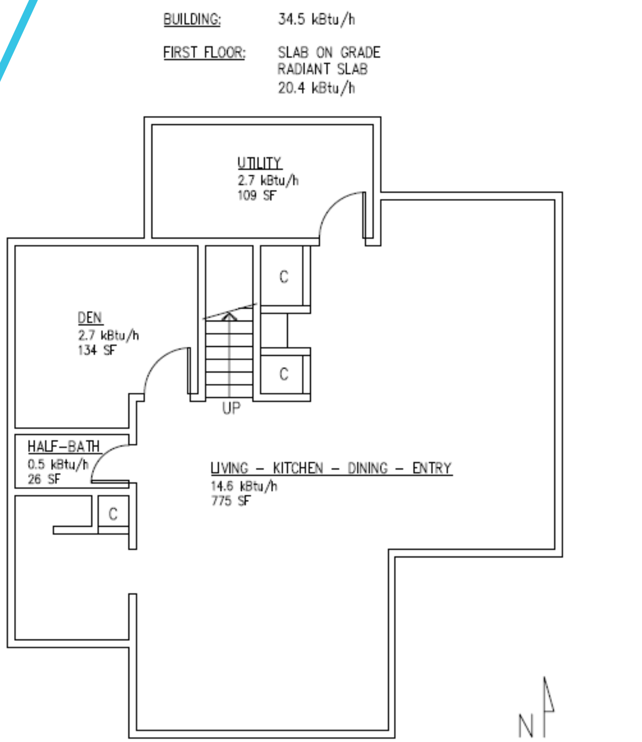
Basics

- 2 stories
- Slab-on-grade (no basement)
- 2100 square feet
- No cooling
- Heating provided by 17-yr-old propane boiler
  - Level 2: Baseboard in 4 rooms
  - Level 1: Radiant slab
  - Indirect tank for hot water





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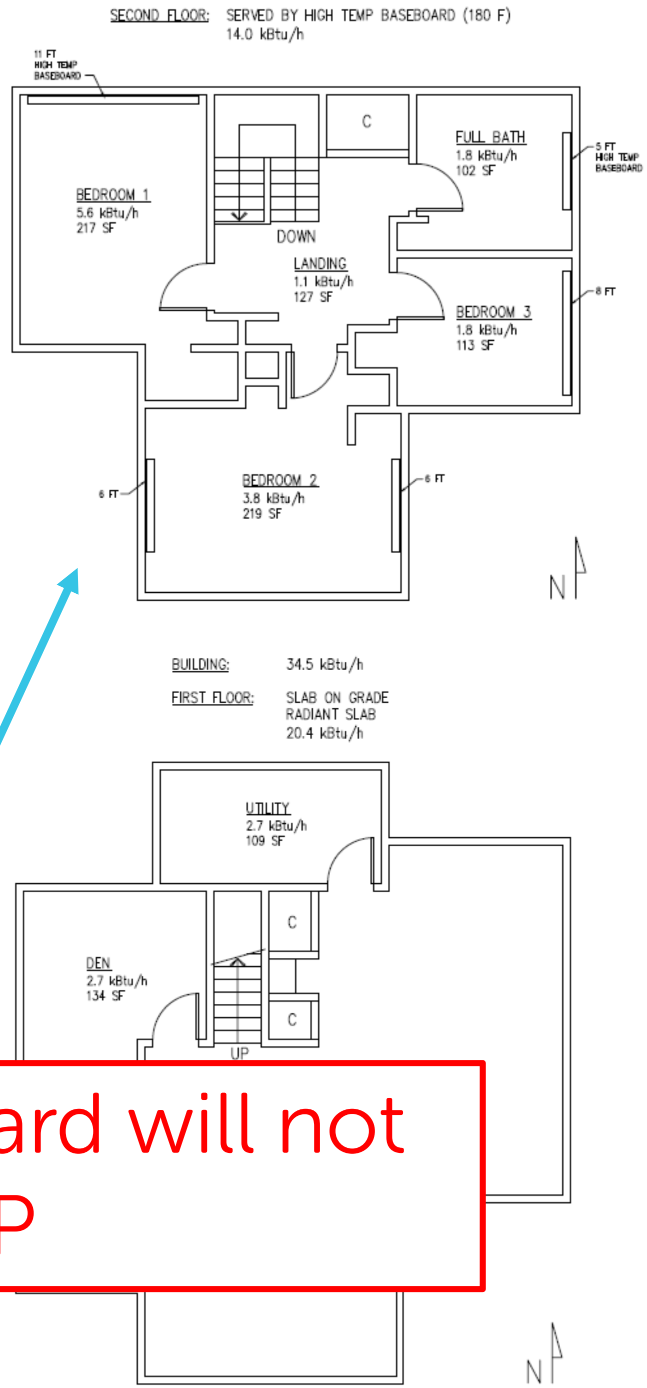
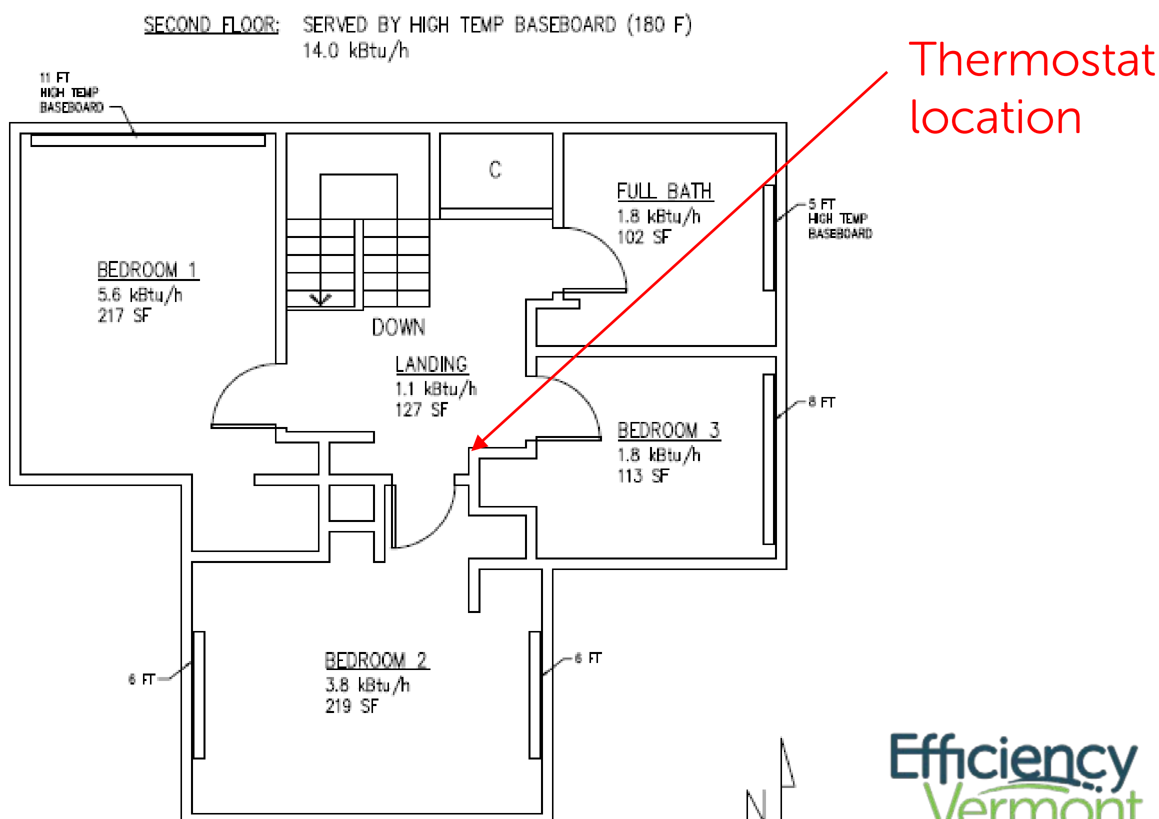
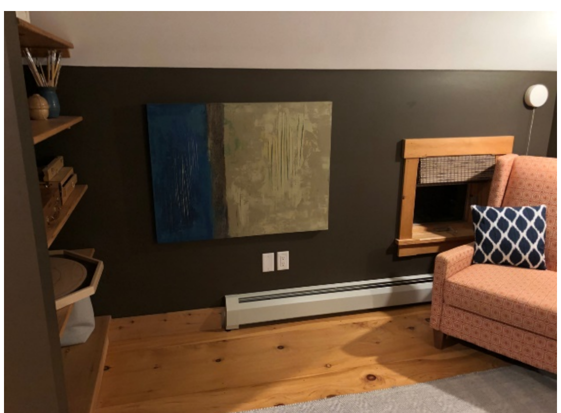


Existing baseboard will not work with AWHP

Is there a problem?

- Upstairs is freezing or sweltering due to poor design





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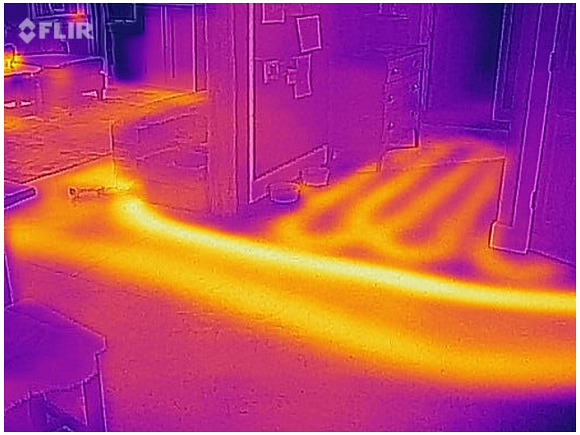
Is there a problem?

- Upstairs is freezing or sweltering due to poor design
- Boiler represents carbon monoxide hazard
- Poor distribution of underfloor slab heat



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- Mechanical room is sauna in summer due to water heat

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Is there a problem?

- Upstairs is freezing or sweltering due to poor design
- Boiler represents carbon monoxide hazard
- Poor distribution of underfloor slab heat
- Mechanical room is sauna in summer due to water heat
- **And more!**

Why air-to-water?

Option 1: (Passive)

- Let this one die
- Emergency installation of replacement boiler

Emergency
HVAC Service
Bundle up,
then give us a call!

Why air-to-water?

Option 1: (Passive)

- Let this one die
- Emergency installation of replacement boiler

Option 2: (Active)

- Install multiple 1/1 minisplits (not a multizone) throughout home
- Abandon hydronic infrastructure

Before:

After:

Photos: EFG

Image: https://www.fujitsugeneral.com/us/residential/what-is-a-mini-split.html

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Why air-to-water?

Option 1: (Passive)

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Option 2: (Active)

- Install multiple 1/1 minisplits (not a multizone) throughout home
- Abandon hydronic infrastructure

Option 3: (Active)

- AWHP or hybrid system
- Utilize and enhance hydronic infrastructure

Air-to-Water Heat Pumps
Qualifying Products (Sorted by Manufacturer)
Effective 1/1/2019

Manufacturer	Model #	Model/Series Name	System Type	Nominal Capacity	COP @ A5W110*	Product Incentive
Aermec	ANK030H	ANK	Mono-bloc	2.5	1.85	$2,500
	ANK030HP			2.5	1.85	$2,500
	ANK030HA			2.5	1.85	$2,500
	ANK045H			3	1.95	$3,000
	ANK045HP			3	1.95	$3,000
	ANK045HA			3	1.95	$3,000
	ANK050H			4	2.07	$4,000
	ANK050HP			4	2.07	$4,000
	ANK050HA			4	2.07	$4,000
Arctic Heat Pumps	020A	EVI - Cold Climate	Mono-bloc	2.5	2.26	$2,500
	040A			4	2.18	$4,000
	060A			5	2.26	$5,000
Chiltrix	CX34-ODU	CX34	Mono-bloc	3	2	$3,000
Nordic	ATW-45-HACW	ATW Series	Split	3	1.8*	$3,000
	ATW-55-HACW			4	1.8*	$4,000
	ATW-65-HACW			5	1.8*	$5,000
	ATW-75-HACW			6	1.8*	$6,000
SpacePak	LAHP48A4	Solstice Extreme	Mono-bloc	4	2.55	$4,000

* Equivalent value. Equipment automatically reduces outlet water temperature to 105F when ambient conditions drop to 5F

For more information, visit: https://contractors.efficiencyvermont.com/programs/heating-cooling

Trajectory

In addition to goals around **(no) fossil fuels**, **health/safety**, and big-picture **efficiency**,

- Enhance comfort, including room-by-room "tuneability"
- Retain infrastructure (radiant slab)
- Align project with other work in home

Design

~~Problems~~
Opportunity breakdown

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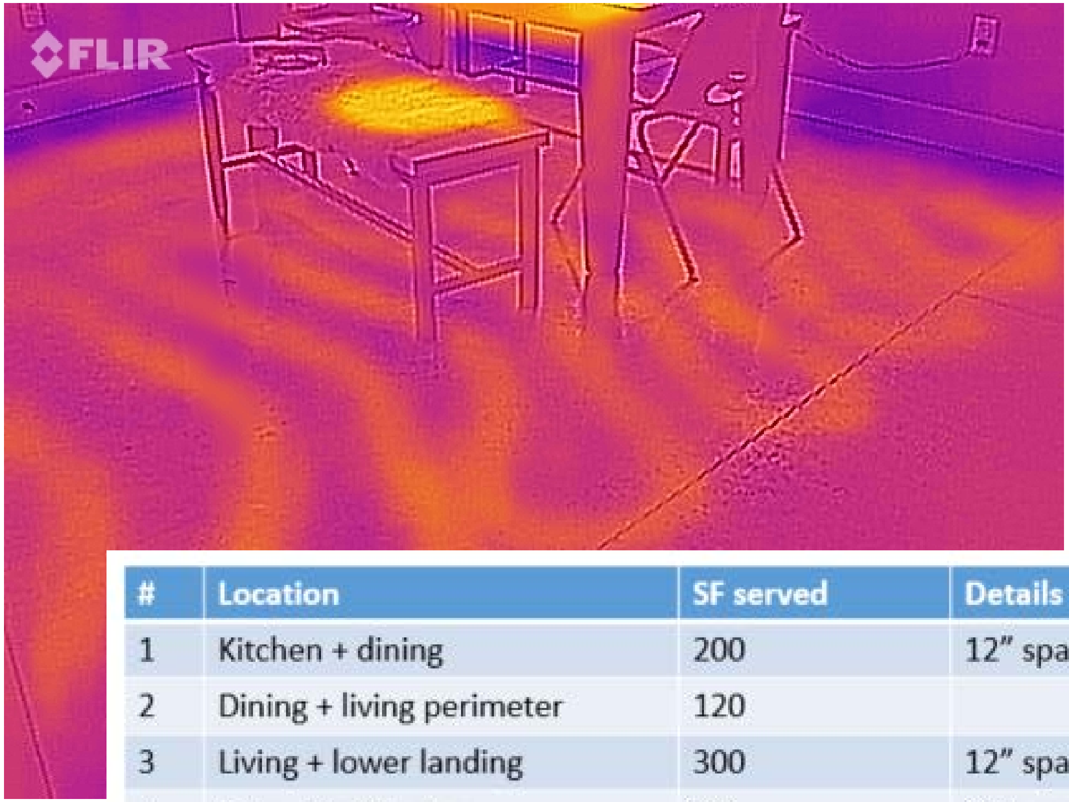
3 spaces to deal with

1. First floor / Zone 1
2. Second floor / Zone 2
3. Mechanical room

1. First floor opportunities

- Unbalanced heating loop lengths



#	Location	SF served	Details	Length, est.
1	Kitchen + dining	200	12″ spacing	250′
2	Dining + living perimeter	120		320′
3	Living + lower landing	300	12″ spacing	380′
4	Entry + hall to den	80	12″ spacing	140′
5	Den + half-bath	160	12″ and 8″ mix	220′

1. First floor opportunities

- Unbalanced heating loop lengths
- No intentional fresh air delivered within home

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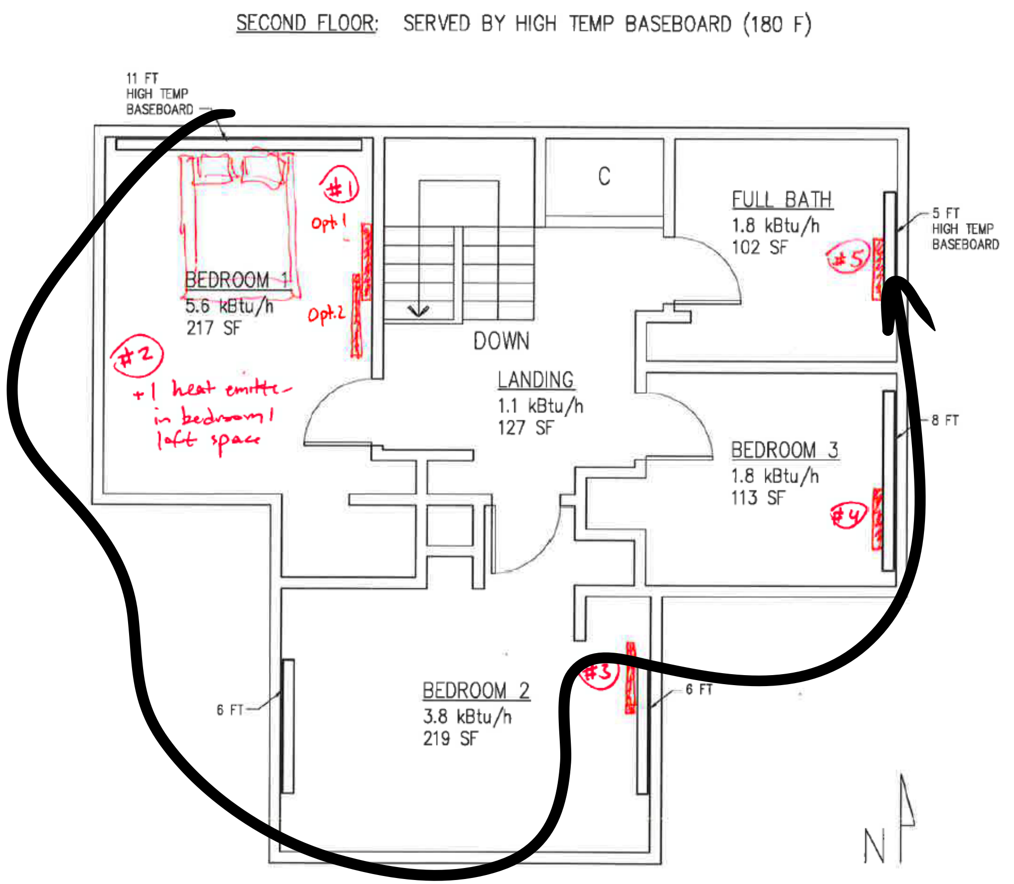
2. Second floor opportunities

- Series heating loop, no room-by-room control



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2. Second floor opportunities

- Series heating loop, no room-by-room control
- Requires 180F water

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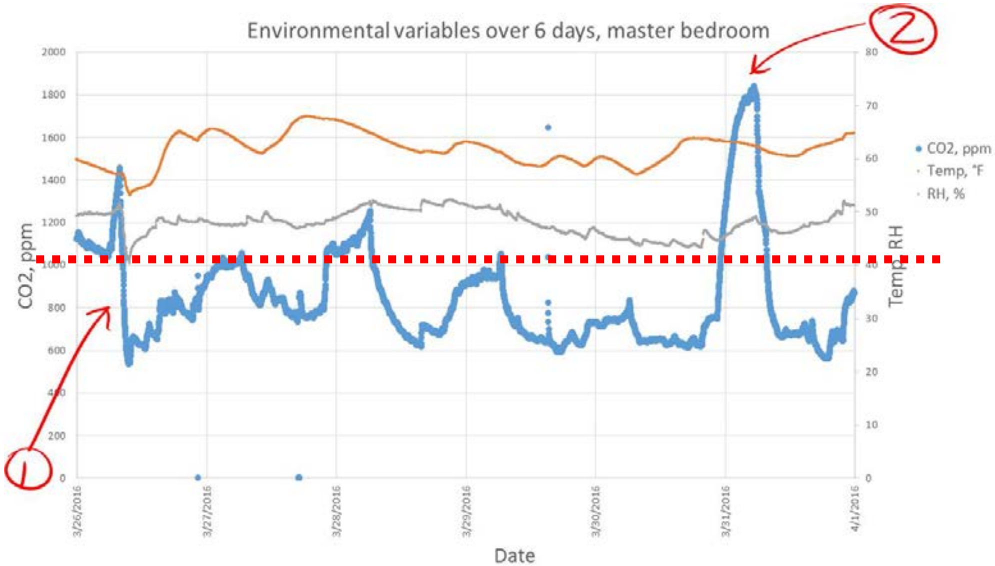
2. Second floor opportunities

- Series heating loop, no room-by-room control
- Requires 180F water
- Thermostat in nonsensical location
- No fresh air provided to bedrooms



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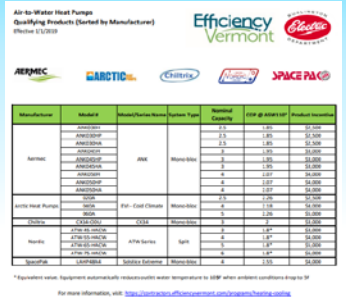
3. Mechanical room opportunities

- Overheats all summer long due to waste heat from boiler heating indirect water tank
- Underutilized space because of temperature instability

1/3. Choose the AWHP

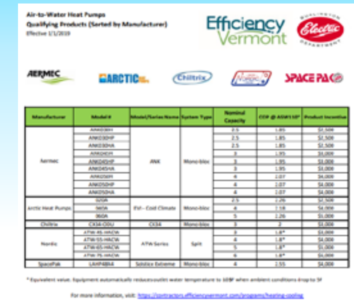
AWHP choices



Manufacturer	Configuration	Available?
Aermec	Mono-bloc	Yes
Arctic	Mono-bloc	Yes
Chiltrix	Mono-bloc	Yes
Nordic	Split (condenser *inside*)	Yes
SpacePak	Mono-bloc	Yes
SpacePak split	Split (condenser *inside*)	?
NIBE (Sweden) / Enertech	Split (condenser *outside*)	?
Dimplex (Germany) / Taco	Split (condenser *outside*)	?
Stiebel Eltron	Split (condenser *outside*)	?
Sanden Eco Runo*	Mono-bloc	?

* Uses CO_2 as refrigerant

AWHP selection



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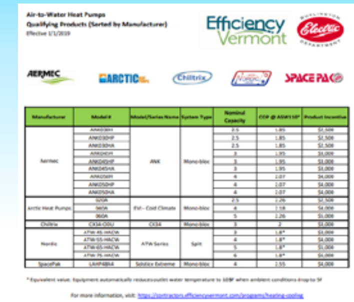

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SpacePak split	Split (condenser *inside*)	2020?
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Stiebel Eltron	Split (condenser *outside*)	2020?
Sanden Eco Runo*	Mono-bloc	?

* Uses CO_2 as refrigerant

More on these later…

Sizing

Heating design load 32.3 kBtu/h (-6F / 68F)

At 5F → 28.1 kBtu/h

Performance Tables ATW-65-HACW-P-1T *R410a, 60 Hz, ZPS51K5E-PFV*

OUTDOOR			ELECTRICAL		INDOOR						
Outdoor Air Temperature	Evaporating Temperature	Heat Absorbed (Btu/hr)	Compressor Current (A)	Input Power (W)	ELT	Condensing Temperature	Liquid Flow (gpm)	**LLT**	Delta T	**Heating (Btu/hr)**	**COP_H**
-5°F	-16°F	7,600	20.7	4730	102°F	110°F			3°F	**23,400**	**1.45**
5°F	-8°F	13,600	19.3	4410	101°F	109°F			4°F	**28,300**	**1.88**
15°F	1°F	19,200	17.8	4100	100°F	109°F			5°F	**32,900**	**2.35**
25°F	9°F	24,800	17.1	3950	100°F	109°F			5°F	**37,900**	**2.81**

Performance Tables ATW-55-HACW-P-1T *R410a, 60 Hz, ZPS40K5E-PFV*

OUTDOOR			ELECTRICAL		INDOOR						
Outdoor Air Temperature	Evaporating Temperature	Heat Absorbed (Btu/hr)	Compressor Current (A)	Input Power (W)	ELT	Condensing Temperature	Liquid Flow (gpm)	**LLT**	Delta T	**Heating (Btu/hr)**	**COP_H**
-5°F	-16°F	6,810	16.7	3870	102°F	110°F			3°F	**19,800**	**1.50**
5°F	-8°F	11,800	15.7	3670	101°F	109°F			4°F	**24,100**	**1.93**
15°F	1°F	16,200	14.8	3470	100°F	109°F			5°F	**27,800**	**2.35**
25°F	9°F	21,400	14.0	3290	100°F	109°F			5°F	**32,400**	**2.89**

Options

Purchased add-ons:

- 15” leg kit ($100)
- Isolation pad for indoor unit ($83)
- Compressor sound jacket ($53)

Plus:

- 70 gallon buffer tank with 9 kW backup
- 9 kW = 30.7 kBtu/h

2/3. Choose heat emitters

Distribution

- Slab works well with 120F water
- Existing baseboard upstairs does not

  ➔ without redesign, **cannot** effectively heat with outside temperatures below 45F

Upstairs options

Low temperature / high output baseboard

- Looks like normal baseboard but works with lower water temperatures
- Examples:
  - Mestek Synergy
  - Smith HE2 Heating Ed
  - Smith HE3 Silent Fin

Image: http://www.mesteksa.com/fileuploads/Literature/DesignLine/DL-SG-3.pdf

Upstairs options

Low temperature / high output baseboard

Panel radiators

- Common worldwide
- Many manufacturers
- Room-by-room control
- No power needed

Image: https://www.bosch-thermotechnology.us/us/en/ocs/residential/buderus-panel-radiators-1098983-p/

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Upstairs options

Low temperature / high output baseboard

Panel radiators

Panel radiators + fan assist

- Higher output
- Needs 24V

Images: https://runtalnorthamerica.com/pdfs/Runtal_NEO_Brochure.pdf

Upstairs options

Low temperature / high output baseboard

Panel radiators

Panel radiators + fan assist

Site-built radiant floors, walls, or ceilings

Photo credits: John Siegenthaler

Upstairs options

Low temperature / high output baseboard

Panel radiators

Panel radiators + fan assist

Site-built radiant floors, walls, or ceilings

Fan coil units

Image: http://spacepak.com/ThinWall.html

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Upstairs options

Low temperature / high output baseboard

Panel radiators

Panel radiators + fan assist

Site-built radiant floors, walls, or ceilings

Fan coil units

~~Existing baseboard and copper piping~~

3/3. Come up with a design that pulls it all together

Scope creep

1. Need to run new distribution upstairs

Scope creep

1. Need to run new distribution upstairs
2. … which helps justify putting in a ventilation system at the same time

Scope creep

1. Need to run new distribution upstairs
2. … which helps justify putting in a ventilation system at the same time
3. … which makes it logical* to do it all at the same time as a full bathroom (only one in the house) gut renovation

* More on this later

Scope creep

1. Need to run new distribution upstairs
2. … which helps justify putting in a ventilation system at the same time
3. … which makes it logical* to do it all at the same time as a full bathroom (only one in the house) gut renovation
4. And then there's the question of what to do about hot water for domestic use

My design ground rules

1. Keep it simple so that it is:
   - Affordable
   - Repeatable
   - Bucks the conception of hydronic systems

Image: John Siegenthaler

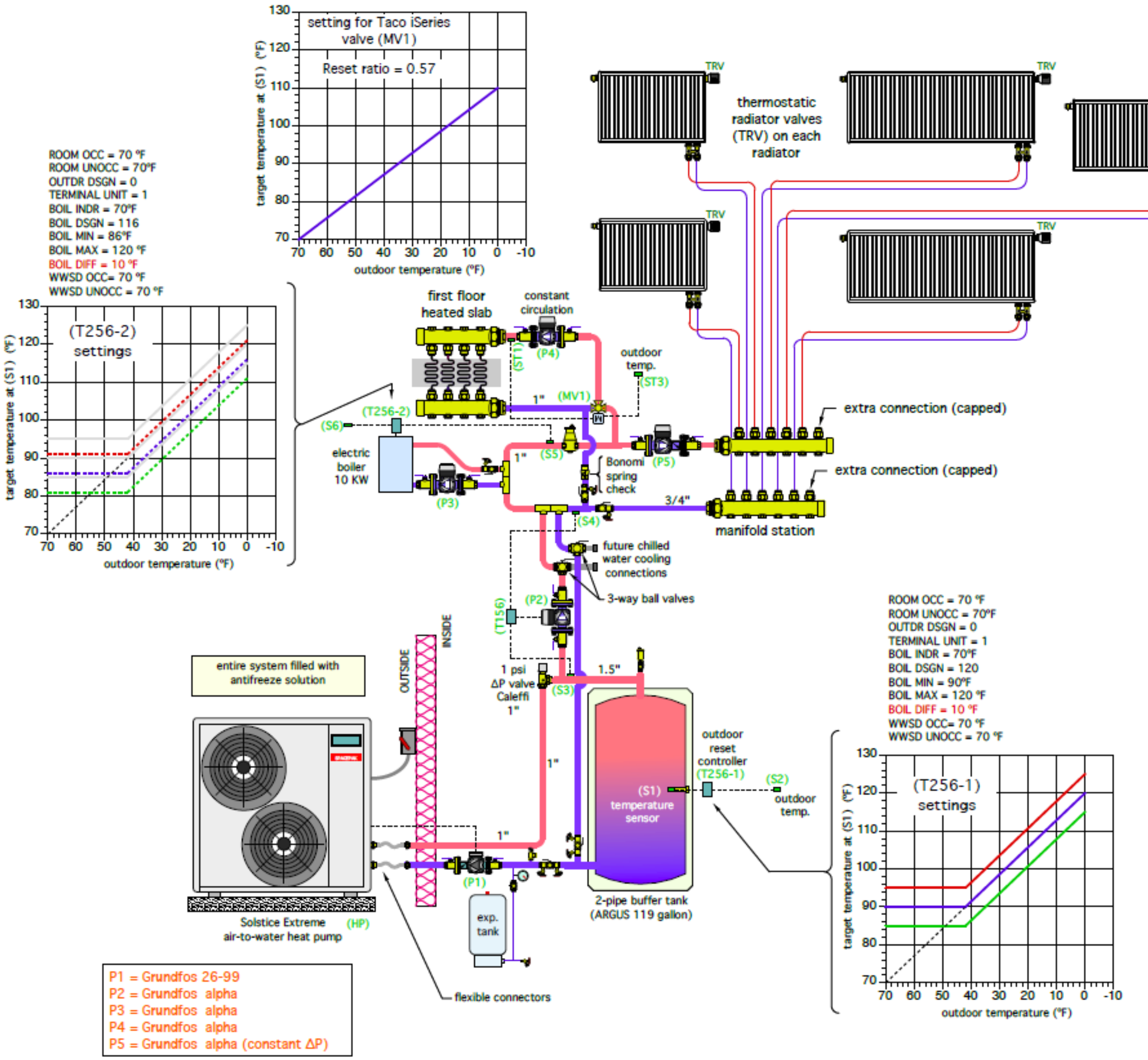
My design ground rules

1. Keep it simple so that it is:
   - Affordable
   - Repeatable
   - Bucks the conception of hydronic systems
2. Consult the pros

Design evolution

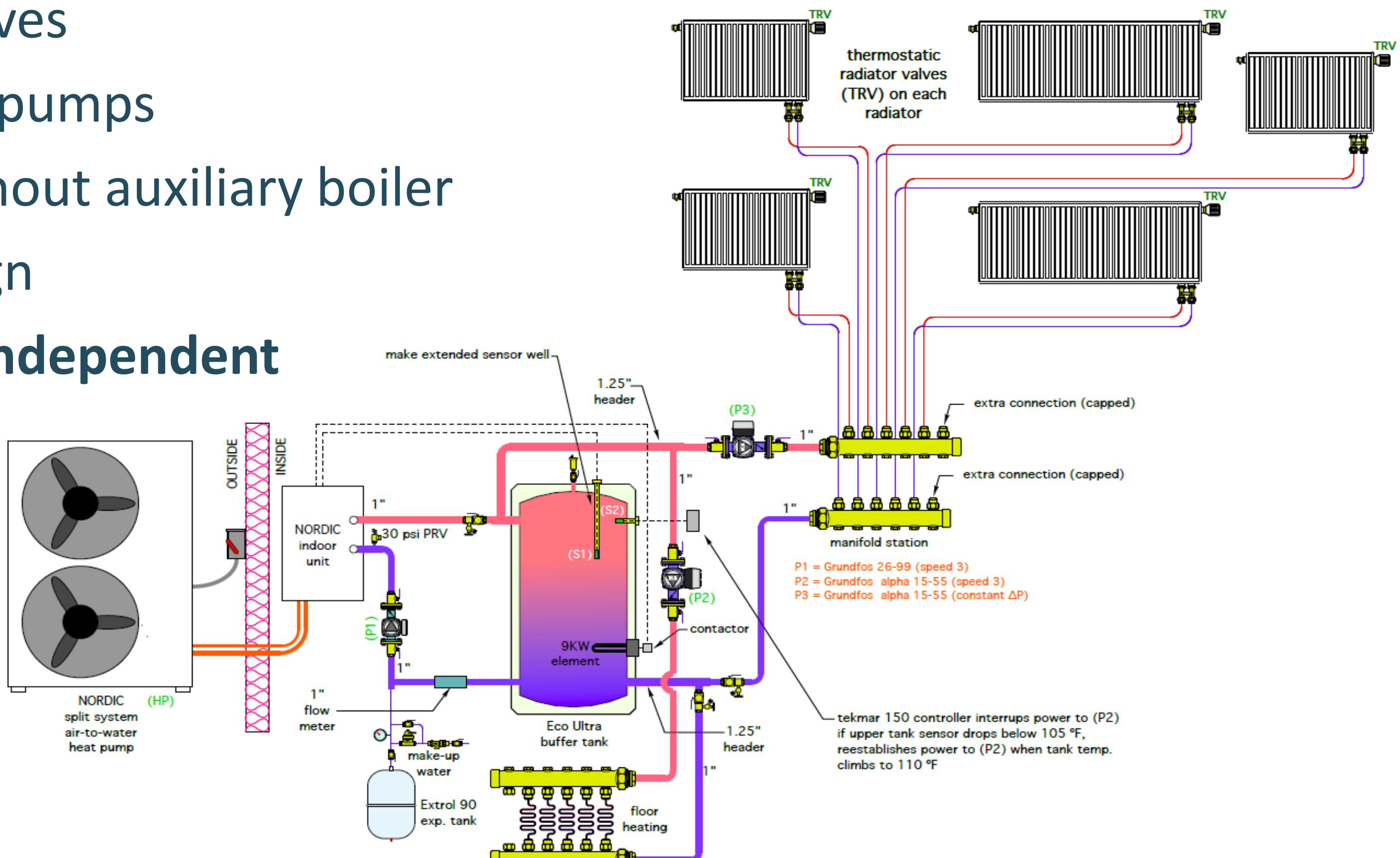
Starting point (circa 2016-17)

- **Mono-bloc** system filled with antifreeze solution
- **Auxiliary boiler** for subzero temps and backup
- Provision for future cooling
- 5 circulator pumps and 2 reset controllers
- No DHW or DHW preheat
- 2-pipe design

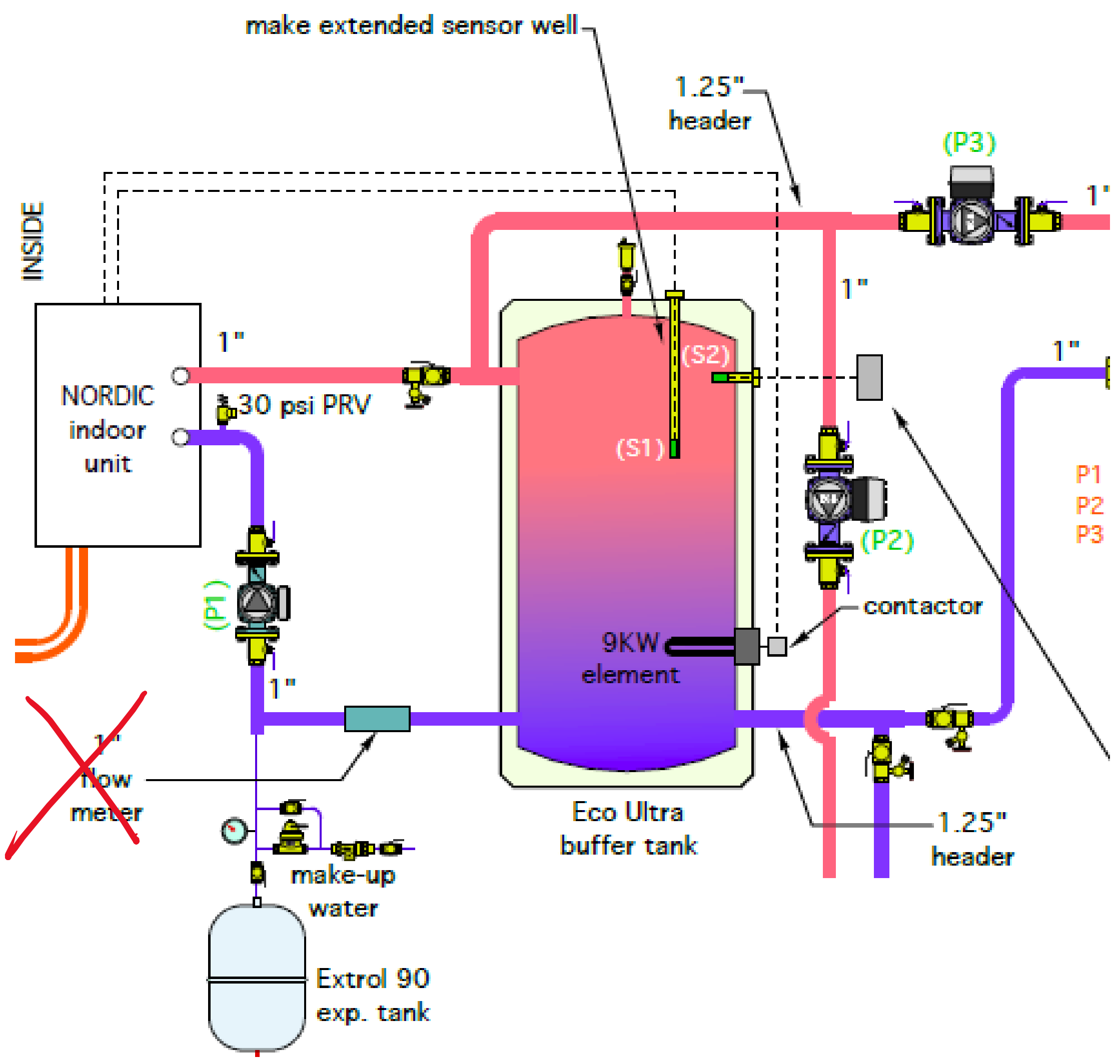


Final design (2-3 iterations later)

- **Split** system (no antifreeze needed)
- No added outdoor reset control
- No zone valves
- 3 circulator pumps
- **Backup** without auxiliary boiler
- 3-pipe design
- **DHW** fully **independent**



Zooming in...



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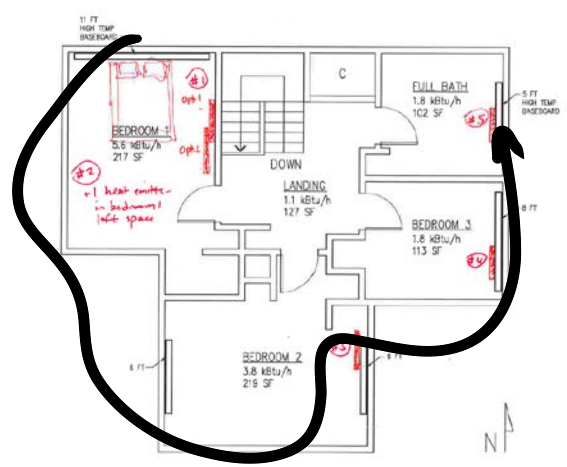
Sizing the distribution system

Sizing the distribution system

Critical: energy modeling

Zone / Room	Design heat load	Output of existing baseboard, 180F*
2 / Bed 1	5600 btu/hr	3700 btu/hr (-1900)
2 / Bed 2	3800 btu/hr	3700 btu/hr (-100)
2 / Bed 3	1800 btu/hr	2200 btu/hr (+400)
2 / Bath	1800 btu/hr	1300 btu/hr (-500)

* Assumes 1 gpm and John Siegenthaler water temp vs. output chart, series loop begins in Bed 1 and continues in order shown in table

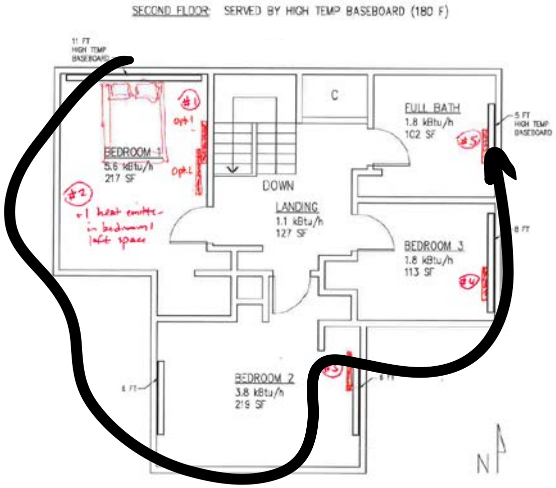


Sizing the distribution system

Critical: energy modeling

Zone / Room	Design heat load	Output of existing baseboard, 180F*	Output of existing baseboard, 120F*
2 / Bed 1	5600 btu/hr	3700 btu/hr (-1900)	1000 btu/hr **(-4600)**
2 / Bed 2	3800 btu/hr	3700 btu/hr (-100)	1000 btu/hr **(-2800)**
2 / Bed 3	1800 btu/hr	2200 btu/hr (+400)	700 btu/hr **(-1100)**
2 / Bath	1800 btu/hr	1300 btu/hr (-500)	900 btu/hr **(-900)**

* Assumes 1 gpm and John Siegenthaler water temp vs. output chart, series loop begins in Bed 1 and continues in order shown in table



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Sizing the distribution system

Radiator right-sizing

Zone / Room	Design heat load	180F (Match manufacturer literature)
2 / Bed 1	5600 btu/hr	12" x 71" (1-plate)
2 / Bed 2	3800 btu/hr	12" x 59" (1-plate)
2 / Bed 3	1800 btu/hr	12" x 24" (1-plate)
2 / Bath	1800 btu/hr	12" x 24" (1-plate)

* Assumes 1 gpm, each room is a homerun to the mechanical room supply manifold

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Sizing the distribution system

Radiator right-sizing

Zone / Room	Design heat load	180F (Match manufacturer literature)	120F
2 / Bed 1	5600 btu/hr	12″ x 71″ (1-plate)	20″ x 91″ (3-plate) 12″ x 24″ (2-plate)
2 / Bed 2	3800 btu/hr	12″ x 59″ (1-plate)	24″ x 64″ (3-plate)
2 / Bed 3	1800 btu/hr	12″ x 24″ (1-plate)	24″ x 36″ (2-plate)
2 / Bath	1800 btu/hr	12″ x 24″ (1-plate)	24″ x 36″ (2-plate)

* Assumes 1 gpm, each room is a homerun to the mechanical room supply manifold

If you did this, the system would be 3-4x undersized!

Sizing the distribution system

Radiator right-sizing

Zone / Room	Design heat load	180F (Match manufacturer literature)	120F
2 / Bed 1	5600 btu/hr		20″ x 91″ (3-plate) 12″ x 24″ (2-plate)
2 / Bed 2	3800 btu/hr		24″ x 64″ (3-plate)
2 / Bed 3	1800 btu/hr		24″ x 36″ (2-plate)
2 / Bath	1800 btu/hr		24″ x 36″ (2-plate)

* Assumes 1 gpm, each room is a homerun to the

Model 22 4" Deep

DIMENSIONS (H X W)	PART NUMBER	BTU @ 180° F*
12" x 16"	7750100604	1573
12" x 24"	7750100606	2359
12" x 36"	7750100609	2539
12" x 48"	7750100612	4719
12" x 59"	7750100615	6291
12" x 71"	7750100618	7078
20" x 16"	7750102604	2341
20" x 24"	7750102606	3511
20" x 36"	7750102609	5266
20" x 48"	7750102612	7022
20" x 59"	7750102615	8777
20" x 71"	7750102618	10,533
24" x 16"	7750103604	2713
24" x 24"	7750103606	4069
24" x 36"	7750103609	6104

Listed output = 6104
Adj. output = 1856
(30% of listed)

Installation

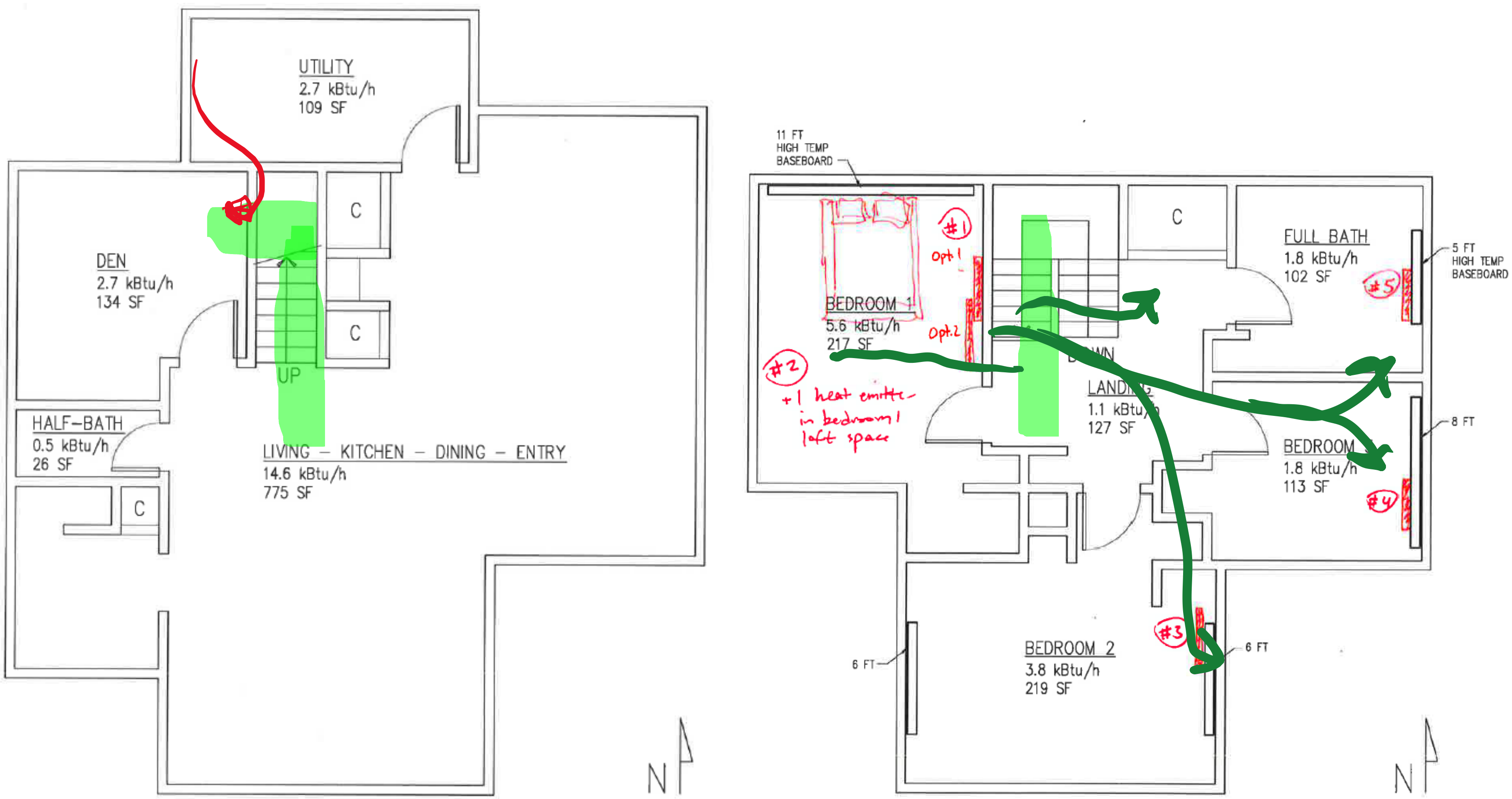
If there's one thing you take away today:

In 99% of existing homes, putting in a AWHP is NOT simply a boiler swap

Efficiency Vermont

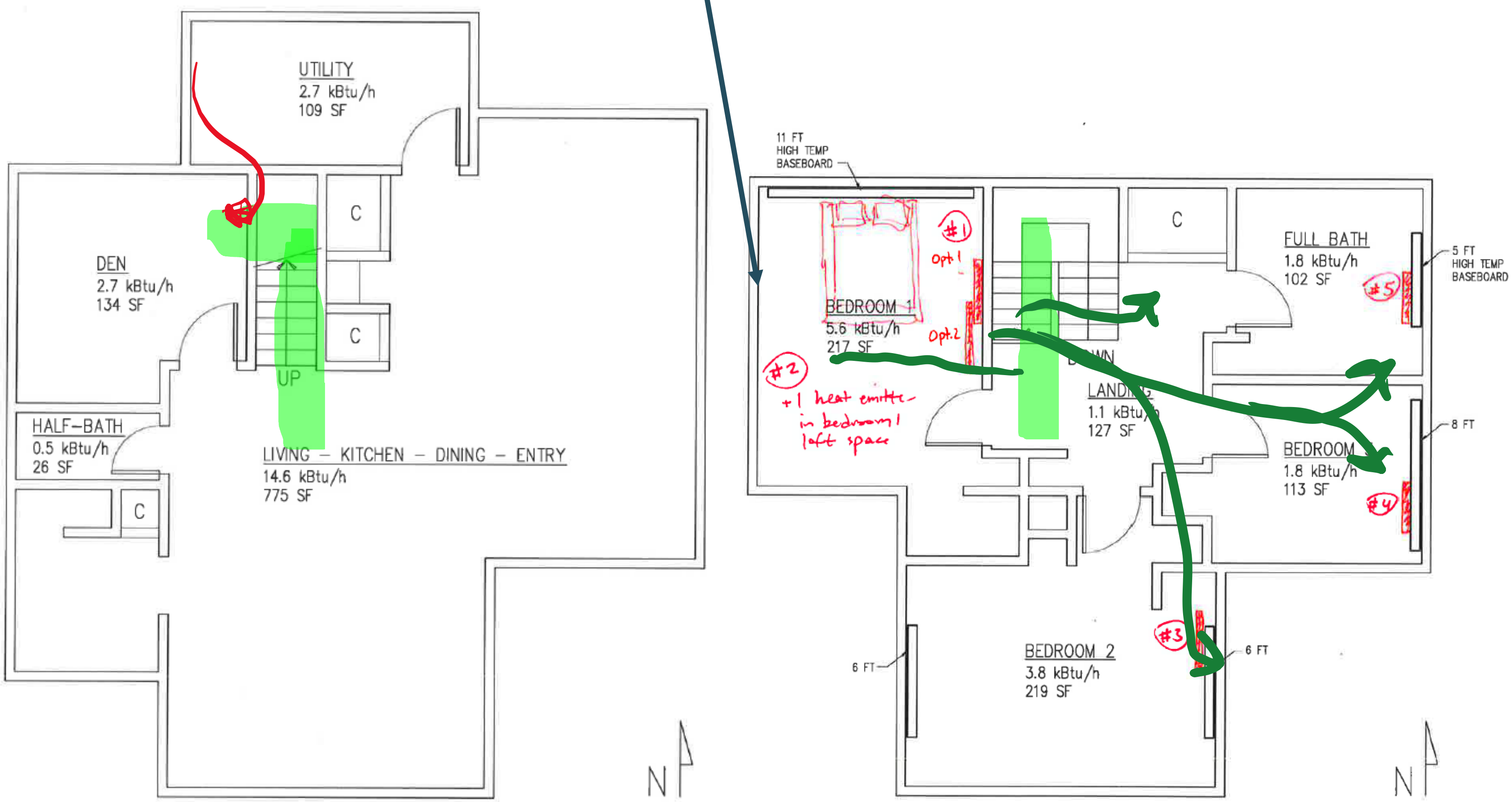
Routing

Need to get homeruns (1/2" PERT tubing pairs) from the mechanical room to EACH of 5 panel radiator locations



Routing

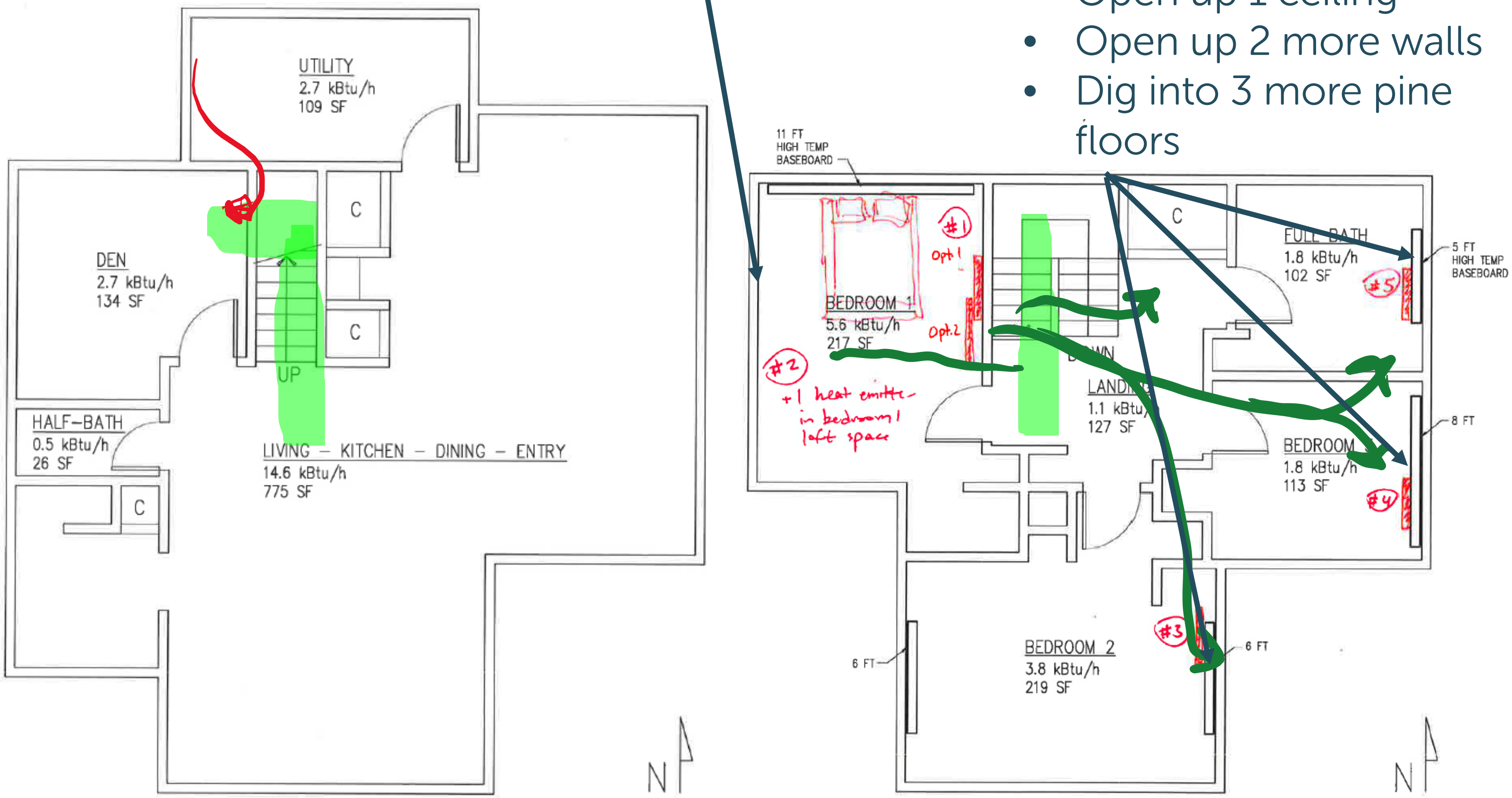
- Destroy 3 walls
- Close in 2 storage nooks
- Multiple holes through pine floor



Routing

- Destroy 3 walls
- Close in 2 storage nooks
- Multiple holes through pine floor

- Destroy complete finished floor
- Destroy attic floor
- Open up 1 ceiling
- Open up 2 more walls
- Dig into 3 more pine floors



Photos – Phase I (2018)

Office – 1st floor

Before…

The hope was to stop here…
Connection to mech. room

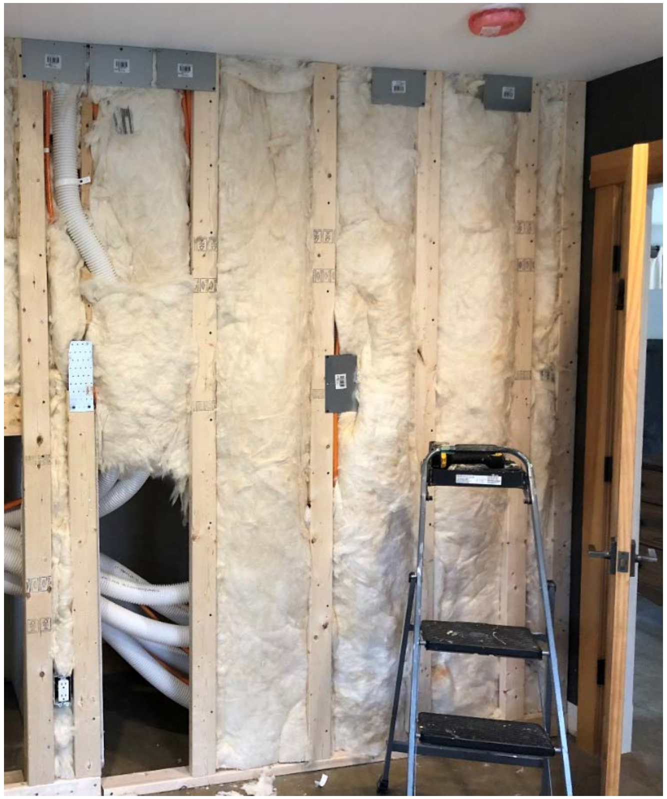
Efficiency Vermont

Office – 1st floor

White tube = ventilation system
Orange = PERT tubing for heating

Surprise! Whole wall needs to be padded out (due to structural beam above)

…and lost triangular storage area due to joist locations / real estate for tubing



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Office – 1st floor

Note the fresh air ventilation register (top left)

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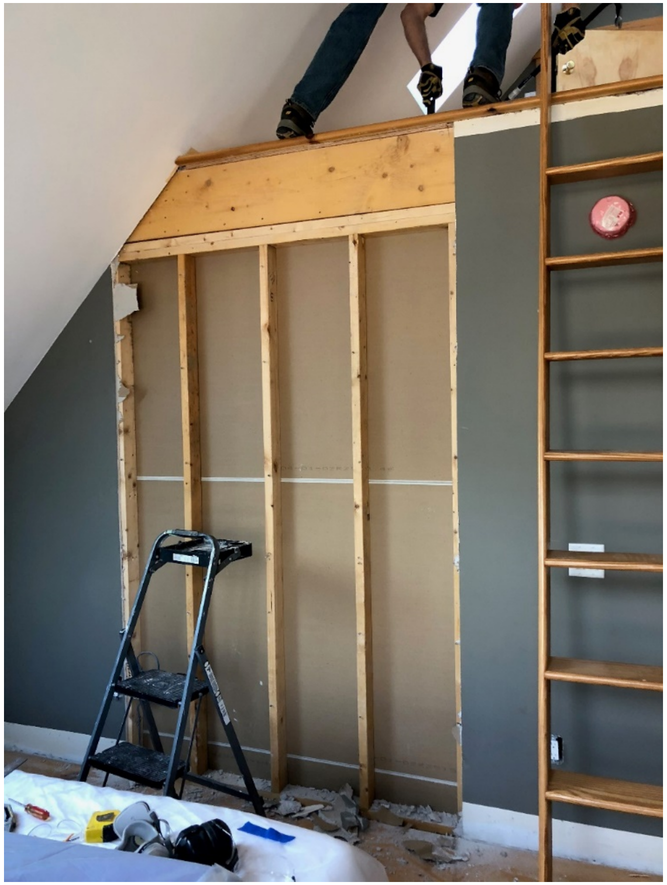
Master bedroom – 2nd floor

Old baseboard

Exploratory work

Master bedroom – 2^{nd} floor



Hope was to stop here…
(1^{st} floor office wall is below)

…but a structural beam is in the way…

Master bedroom – 2nd floor

Access holes to drilled through to office below

Entire wall needed to be padded out (loft space is above)

Master bedroom – 2nd floor

Insulation (sound, not thermal) and nailplates

Everything's in! (with PERT clips and tube strapping to keep as tidy as realistic)

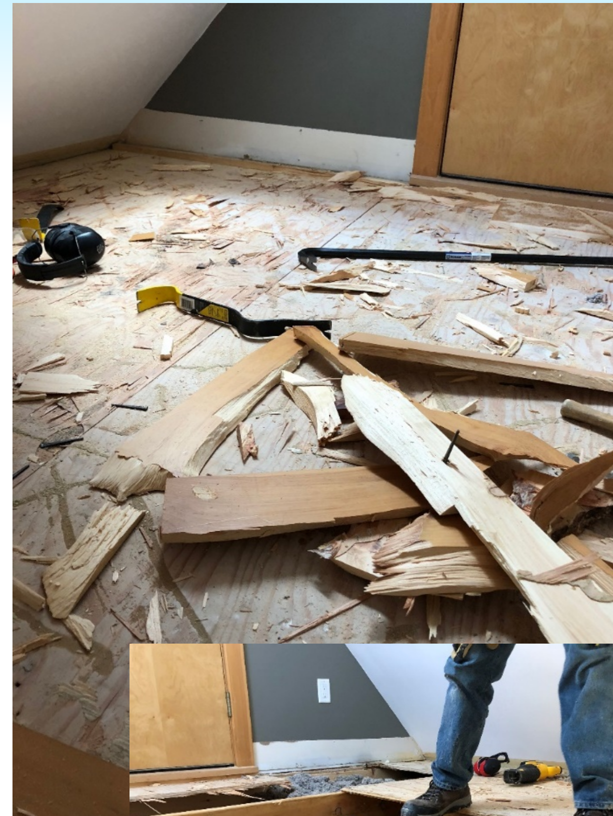
Master bedroom – 2nd floor

Floor joist direction meant getting to the window wall wasn't too bad…

Although blocking halfway across necessitated creativity and small hands

Master bedroom – 2nd floor

Loft



Glued-down pine flooring was a nightmare to remove

Loft

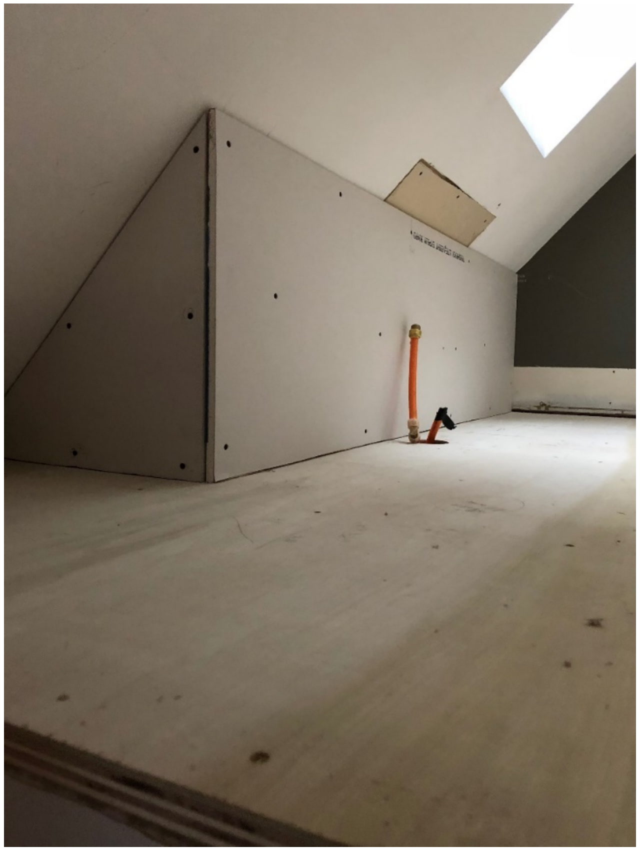
Holes to feed 2 bedrooms and bath (south bedroom at mid-right)

Loft

Discover reason for damaged always-frosty skylight: No insulation in this cavity!

Add blocking to minimize future cellulose spillage

Loft



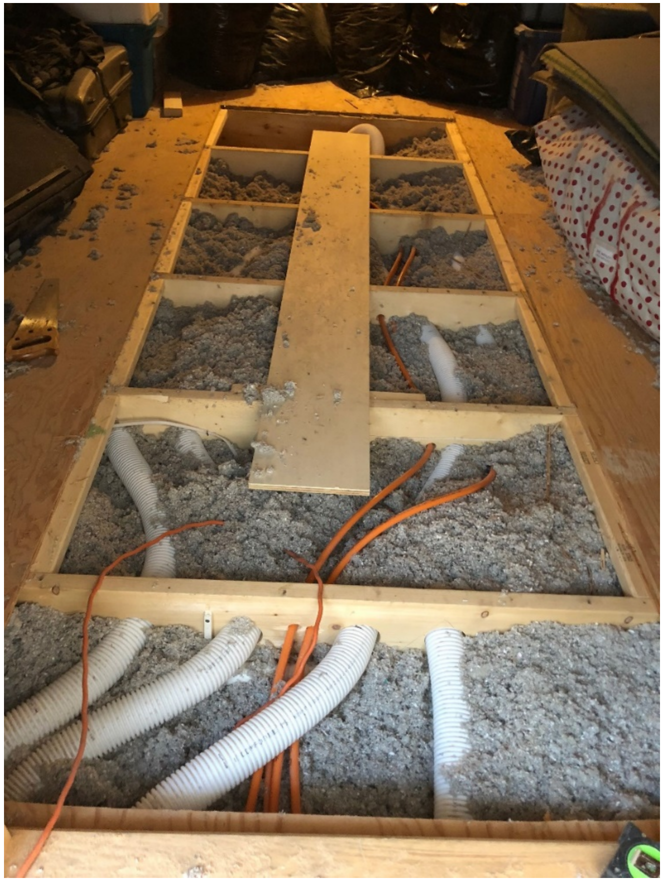
Kneewall to support panel radiator

New subfloor and locally-milled maple floor

Attic

Before…

Attic



All lines in!
Air sealed partitions and holes

90s installed for dropdowns to east bedroom and bathroom PERT

Ceiling ventilation return for bathroom below

Attic

Repack cellulose, add rockwool
Blocking plus 1.5" polyiso and plywood

R-23 of mineral wool + 1.5" polyiso (R-10) above all lines
New deck raised floor 1.5"

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South bedroom – 2nd floor

Before…

A tricky route

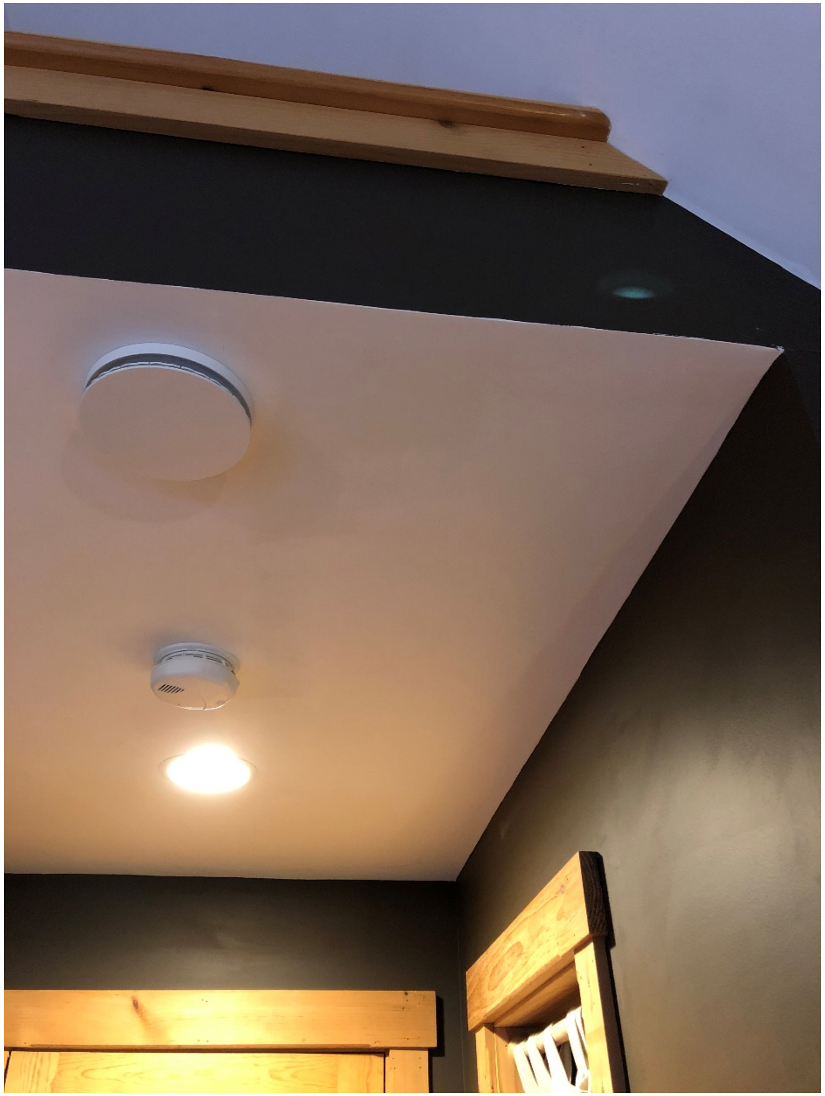
Efficiency Vermont

South bedroom – 2nd floor

Use ceiling and closet wall / floor to access exterior wall
Cut path for PERT tubing

Efficiency Vermont

South bedroom – 2nd floor



Bathroom – 2nd floor

Before…

Bathroom – 2nd floor

Common wall with adjacent bedroom

Creating a PERT pathway to exterior wall

Efficiency Vermont

Bathroom – 2nd floor

Putting it all together

Bathroom – 2nd floor

Reconstruction

East bedroom – 2nd floor

Baseboard out and access for
PERT in

East bedroom – 2nd floor

Mechanical room – 1st floor

Exploratory holes

Opening wall to office space

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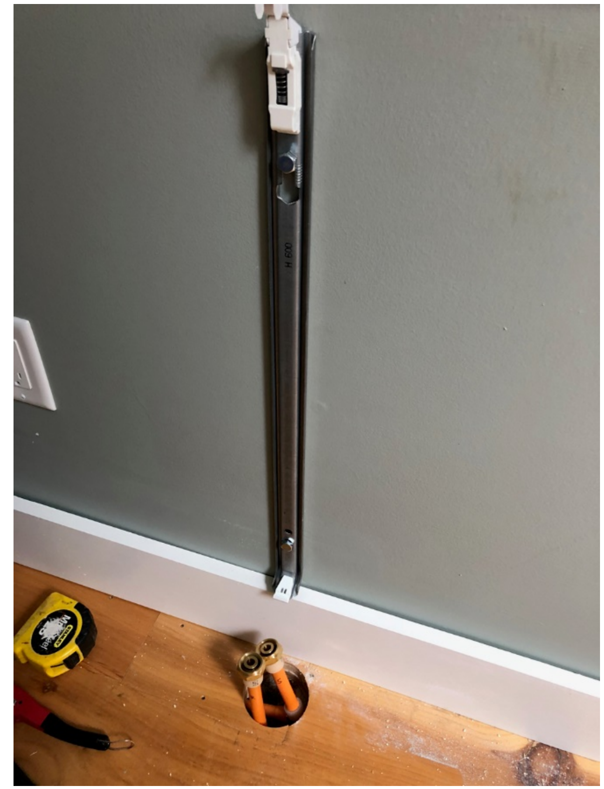
Mechanical room – 1st floor

End state 2018

A month later…



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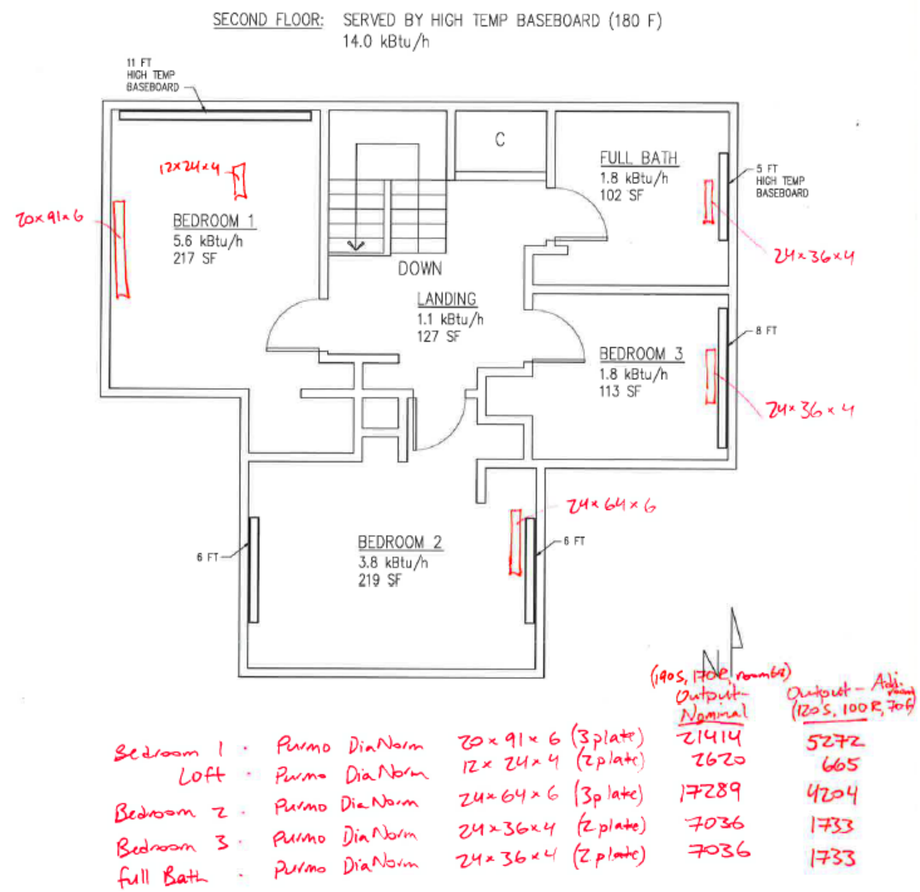
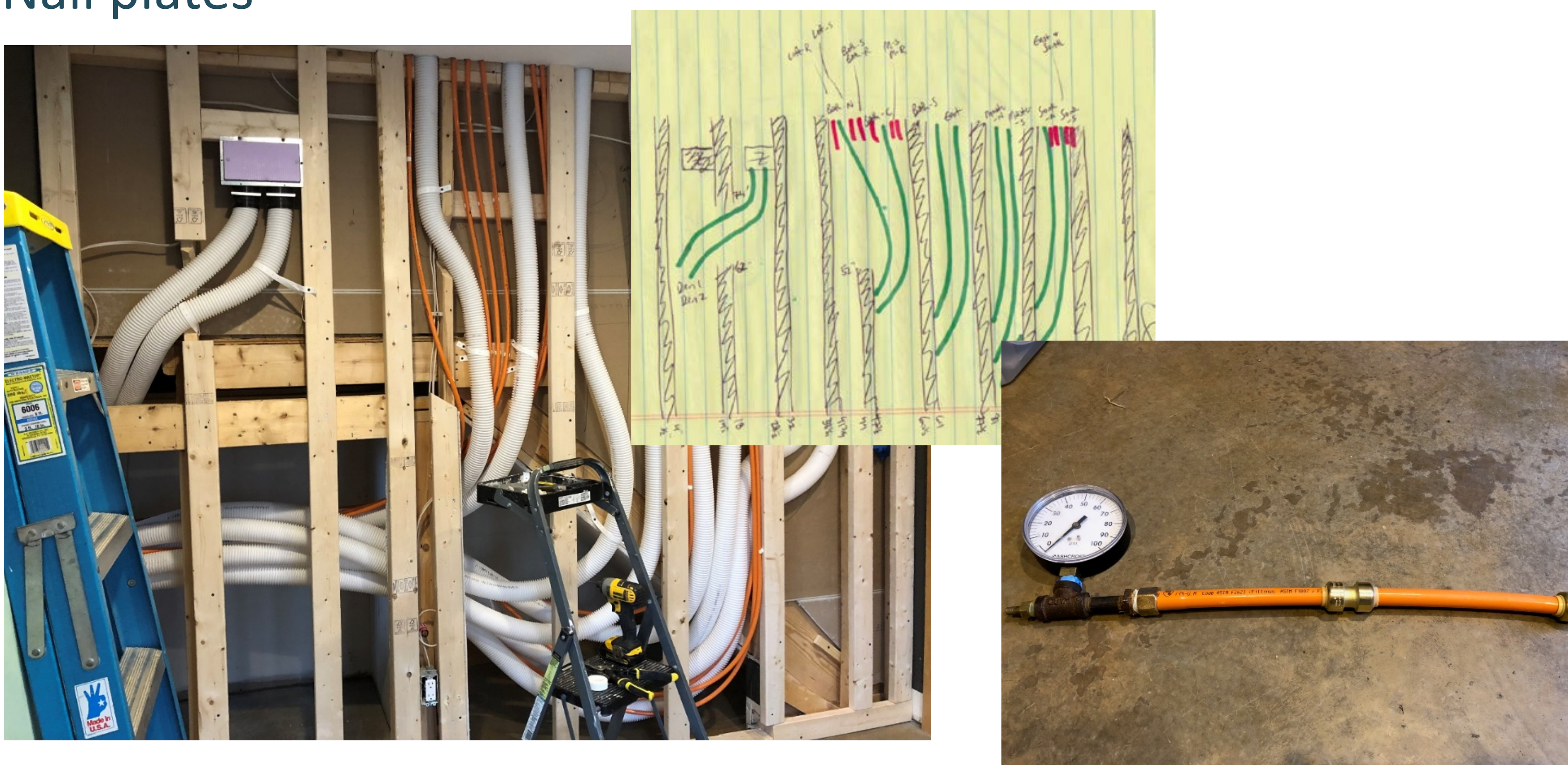
2018 summary

- 650’ of PERT
- 400’ of ComfoTube (for ventilation)
- Destruction tally:
  - 6 walls
  - 1 ceiling
  - 1 floor (complete), plus 4 that needed repair



2018 summary, cont.

- Lines pressure tested and mapped for future
- No upstairs heat for winter of 2018-19
- Nail plates



Photos – Phase II (2019)

Mechanical room

State, previous 10 months

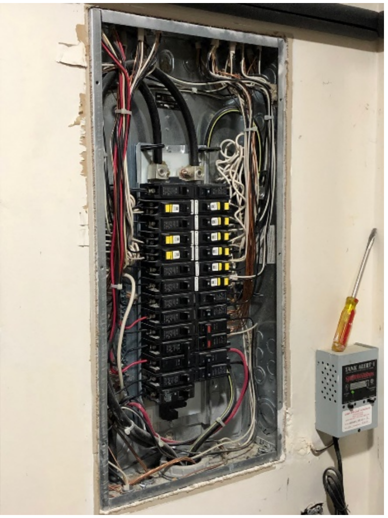
Mechanical room

Status, previous 10 months

Efficiency Vermont

Propane out

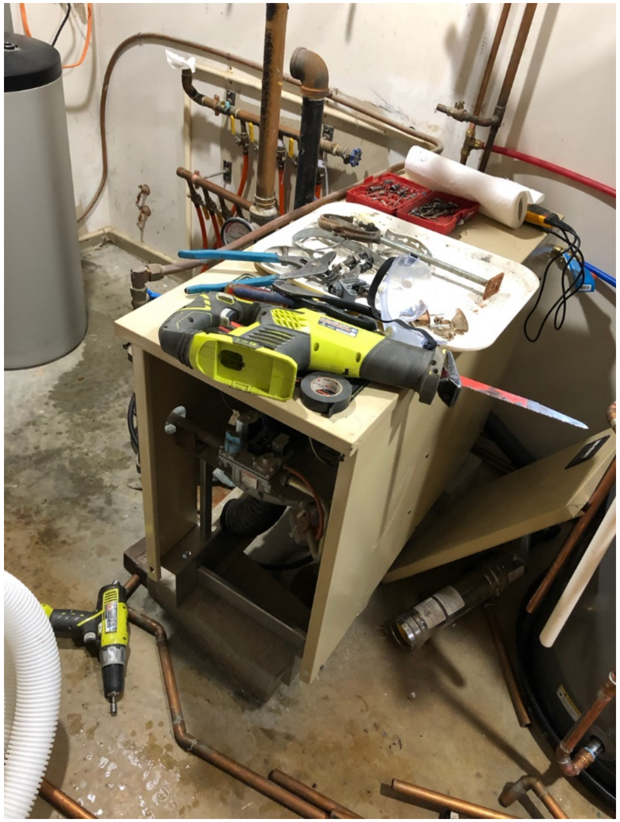
Heat pump water heater in



Electrical upgrades needed

Efficiency Vermont

Cleaning up the mess



Plug holes

Boiler venting

Old exhaust-only ventilation

Ventilation system

Outdoor
air intake

Kitchen exhaust

Mechanical room
exhaust

Efficiency Vermont

Ventilation system

Ventilator hung and initial tubing connections

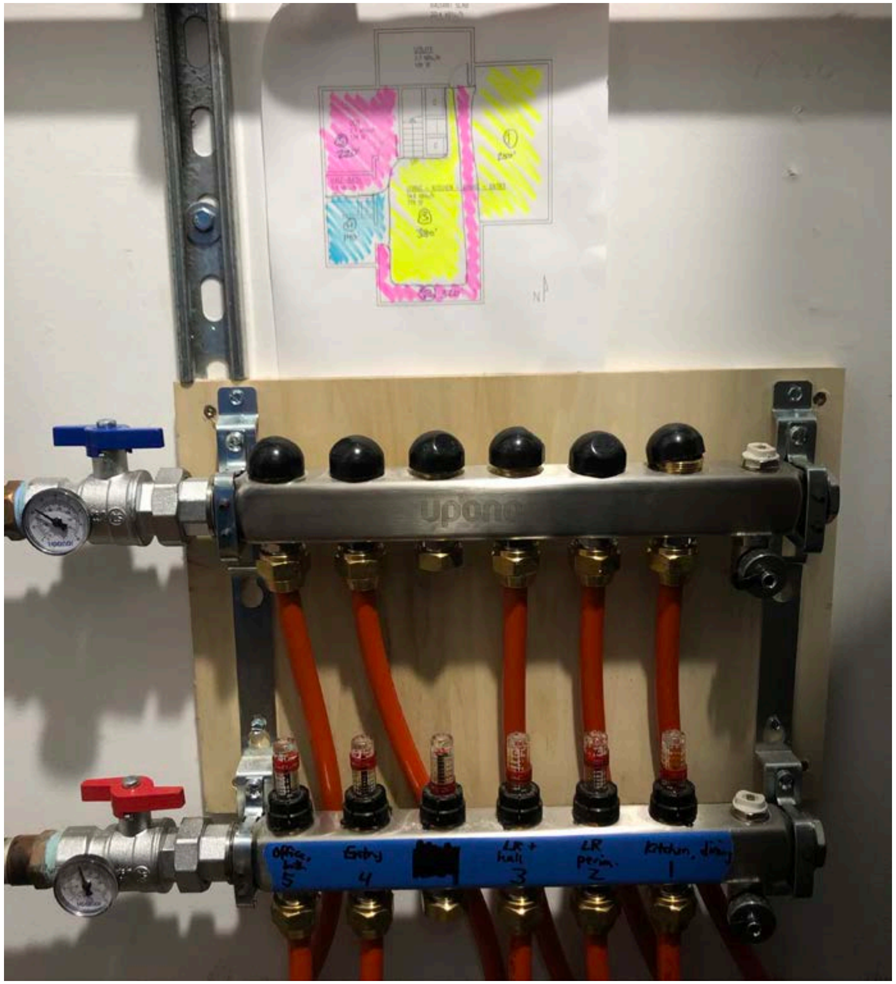
Operational

Fresh air intake

AWHP, buffer tank, and distribution

Floor zone manifold

Before…



After

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Upstairs manifold

Outdoors

Results

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Final product

Great swap!

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AWHP

Efficiency Vermont

Master / Loft

South bedroom

East bedroom / Bathroom

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House operation

Thermostats

Thermostatic radiator valves (TRVs)

Valve position	Reference temperature	Recommended setting for	
*	6°C	Frost protection	43 °F
0-1	12°C	Cellar, stairs	
1	15°C	Unoccupied room, laundry, recess	59 °F
2	17°C	Entrance hall, corridor	62.6 °F
2-3	18°C	Bedroom	64.4 °F
3	19-20°C	Kitchen	66-68 °F
3-4	20-21°C	Lounge, child's bedroom	68-70 °F
4	22°C	Bathroom	71.6 °F
5	max.	Valve completely open	

Ref: https://www.energuide.be/en/questions-answers/to-which-temperature-do-the-digits-or-scales-on-a-thermostatic-radiator-valve-correspond/1524/

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Thermostat controls (initial)

- Zone 1 (slab)
  - 68F daytime
  - 67F nighttime
- Zone 2 (upstairs)
  - TStat set to 80F (so circulator pump runs 24/7)
  - TRVs set very low in unused rooms; Grundfos ECM pump adapts to demand; daytime typ. 10-15W
  - Master bedroom has programmable TRV (AA battery) that heats the room to 68F from 6:30pm-6:30am
  - Low-mass system doesn’t take too long to warm

HPWH setting

Data: non-AWHP

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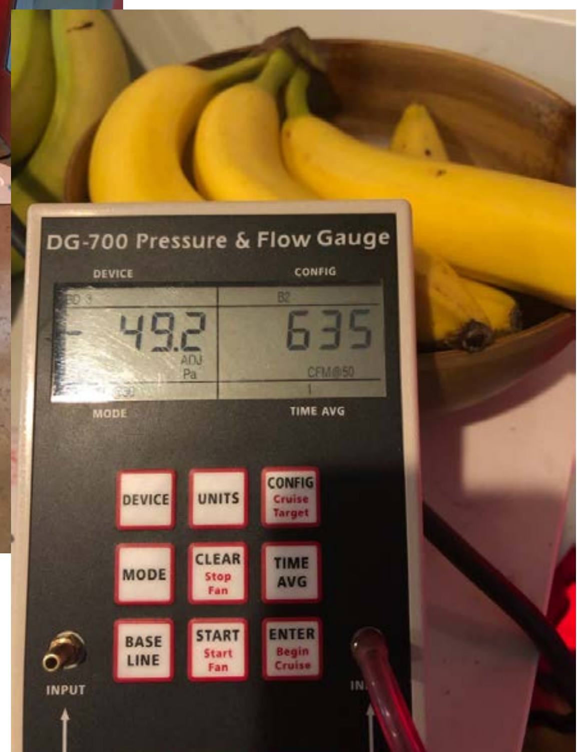
Air sealing = 100 cfm improvement



Efficiency Vermont

Energy models, before and after

	2015	2020
HERS	76	55
Airtightness	763 cfm50	628 cfm50
Design heat load	33.1 kbtu/hr	31.1 kbtu/hr
Heat $/yr	$1549	$1363 (-$186/yr)
Total $/yr	$3511	$2506 (-$1005/yr)

Per REM/Rate v15.7.1

This project:
- AWHP replaces propane boiler
- Heat pump water heater replaces propane indirect tank
- High efficiency balanced ventilation replaces exhaust-only system
- Air sealing

Other improvements:
- 100% LEDs
- ENERGY STAR appliances
- Low flow DHW fixtures
- EPA 2020-compliant woodstove
- Previous air sealing

Efficiency Vermont

Energy models, before and after

	2015	2019
HERS	76	55
Airtightness	763 cfm50	628 cfm50
Design heat load	33.1 kbtu/hr	31.1 kbtu/hr
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Per REM/Rate v15.7.1

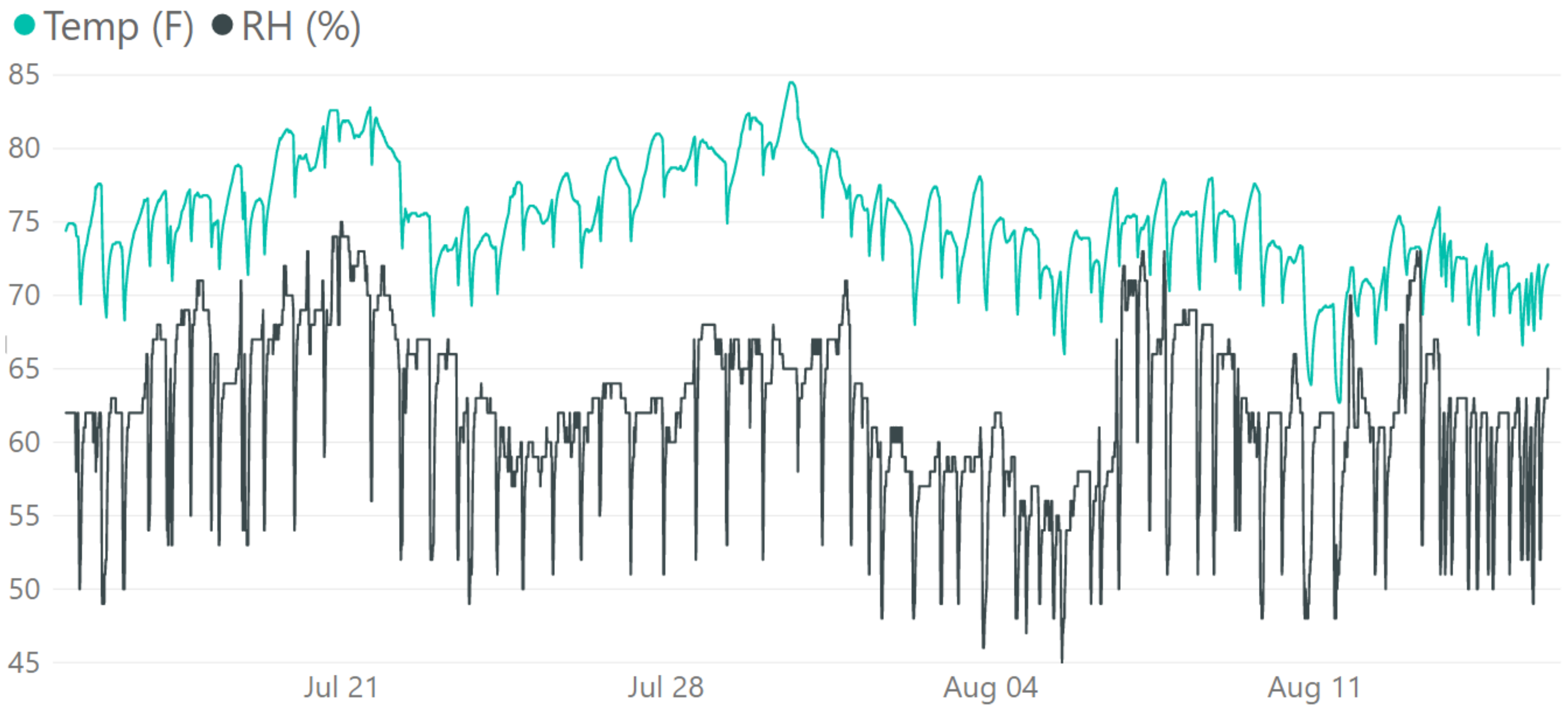
This project:
- AWHP replaces propa
- Heat pump water hea
- High efficiency balanc
- Air sealing

Other improvements:
- 100% LEDs
- ENERGY STAR appliances
- Low flow DHW fixtures
- EPA 2020-compliant woodstove
- Previous air sealing

AWHP upgrade only:
- 1 HERS point
- $260/year total energy

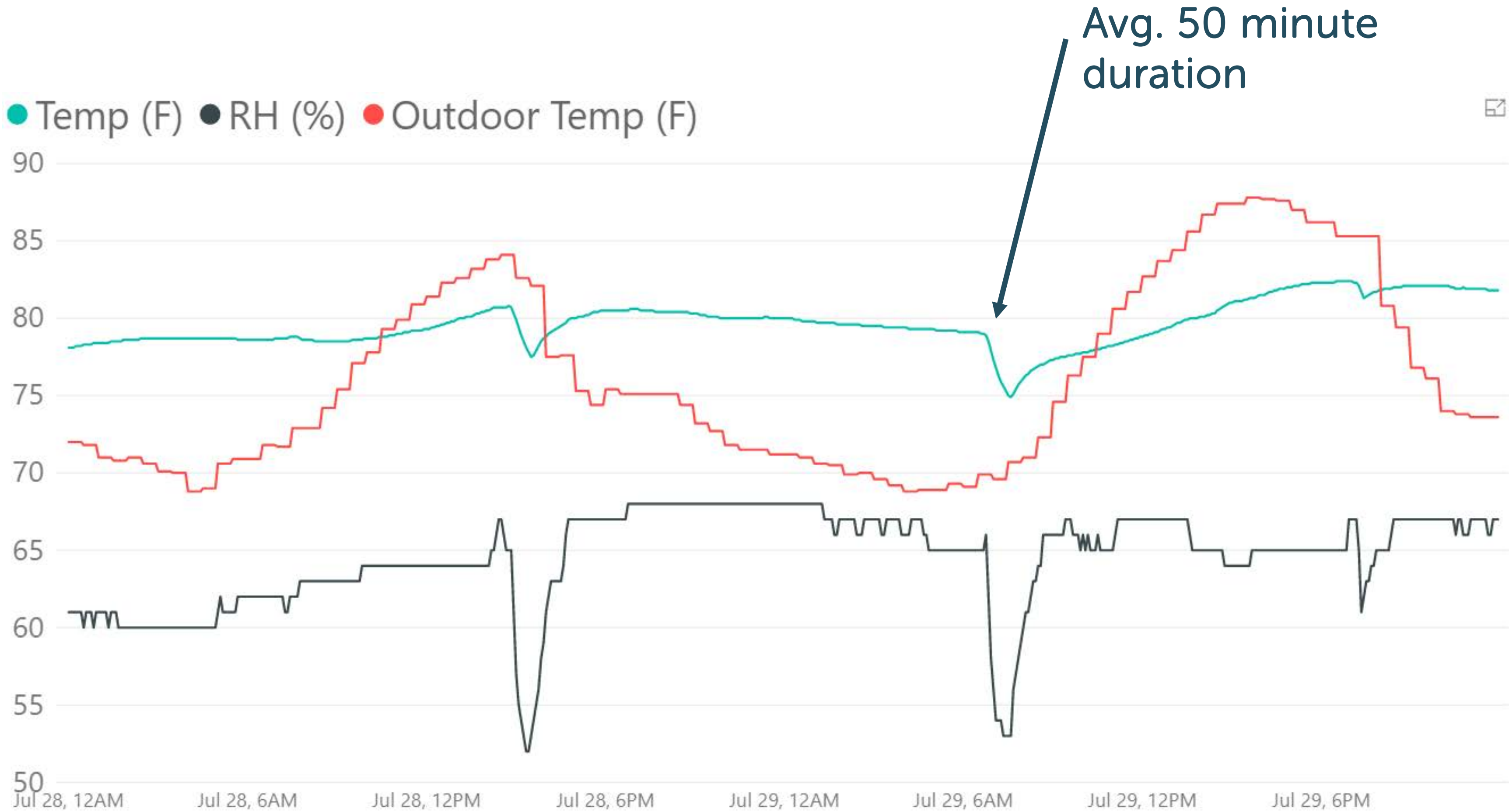
Mechanical room temperature

Summer, Jul 15 – Aug 15



Mechanical room temperature

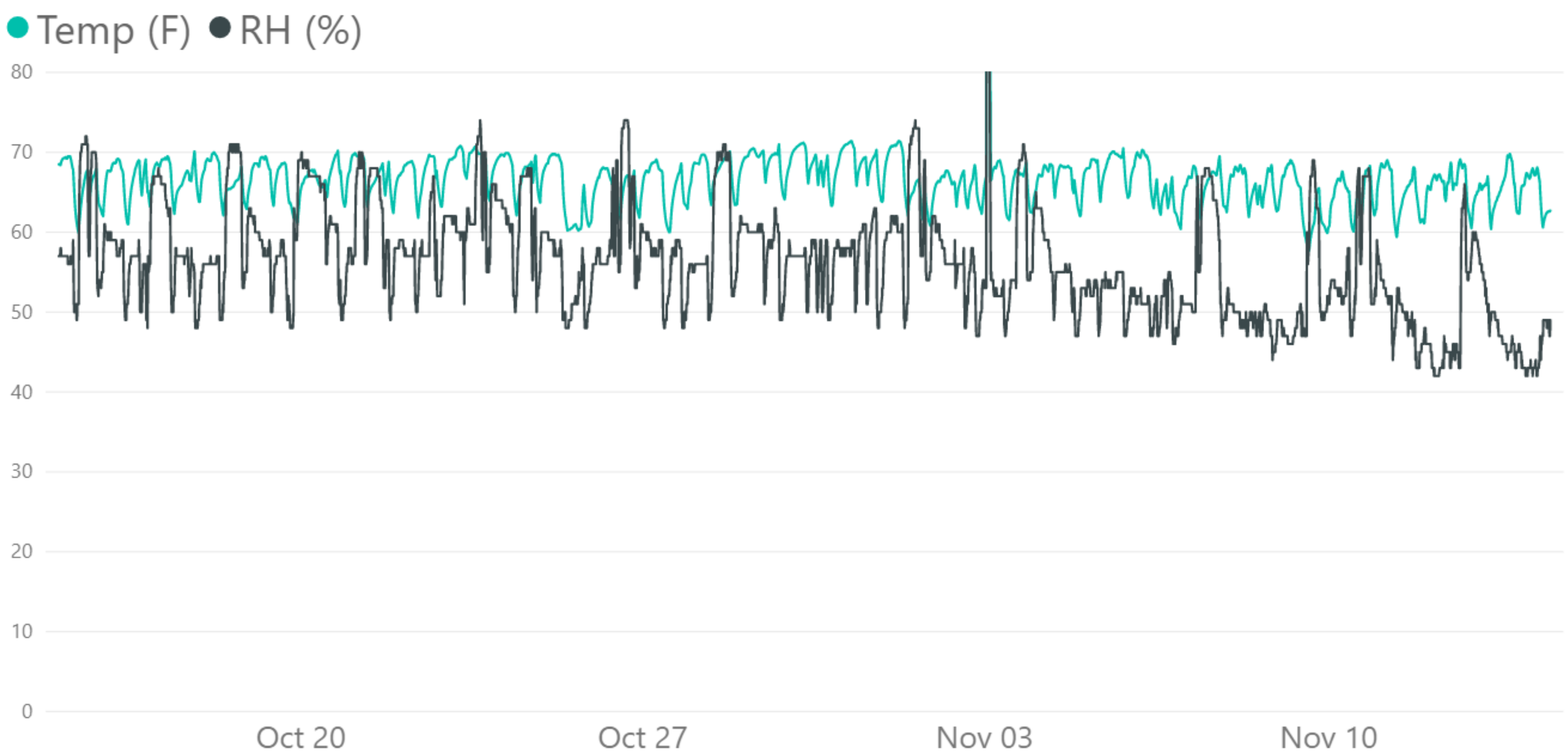
Summer, 1 day (Jul 28-29)



Efficiency Vermont

Mechanical room temperature

Autumn/Winter, Oct 14 – Nov 14



Temperatures, 1 week in January

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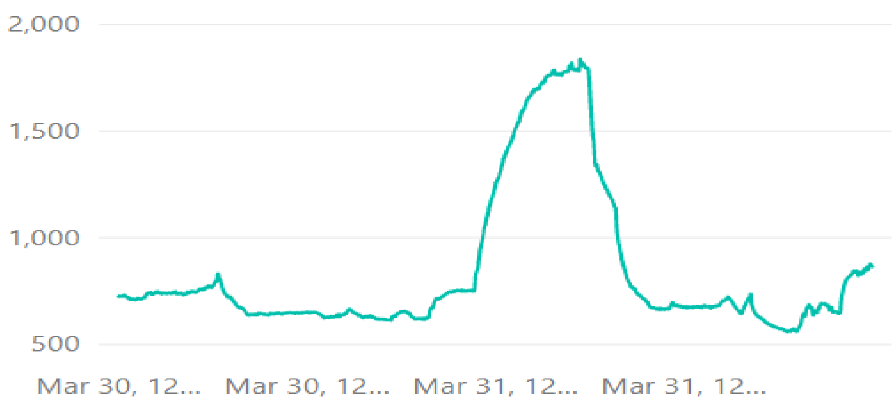
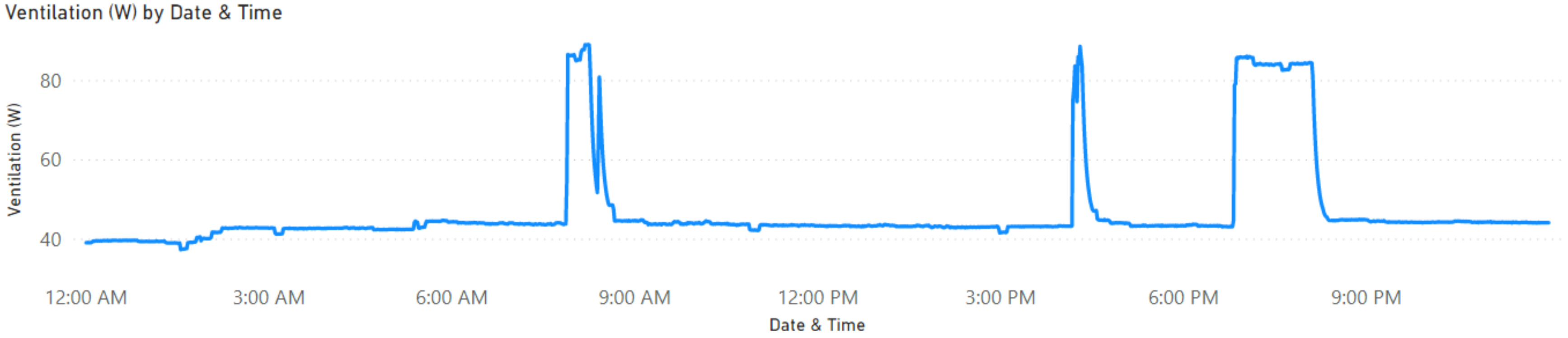
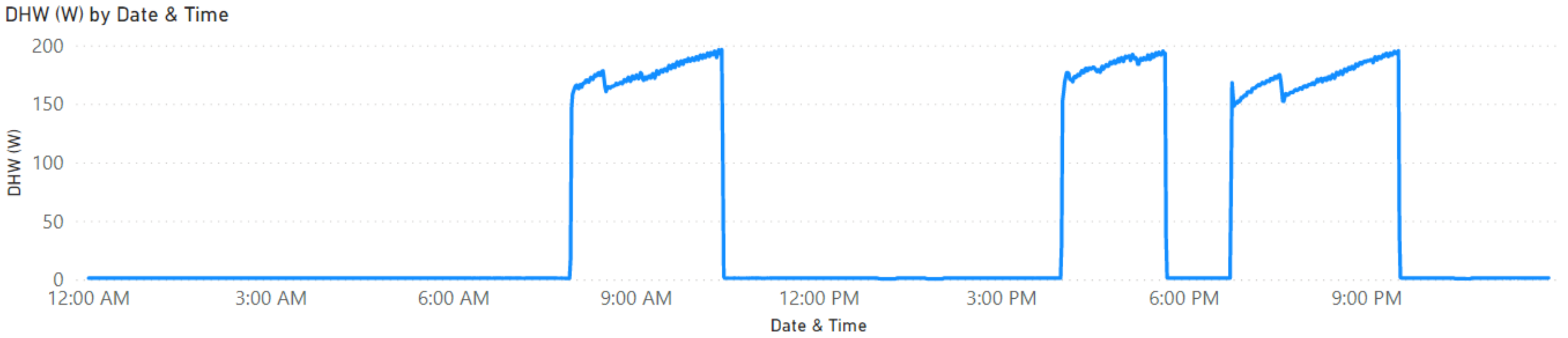
CO_2 in bedroom, before/after



Ventilation and HPWH electricity

Autumn/Winter, 1 day (Nov 1)





Efficiency Vermont

Data: AWHP output and temperatures

Notes and disclaimer

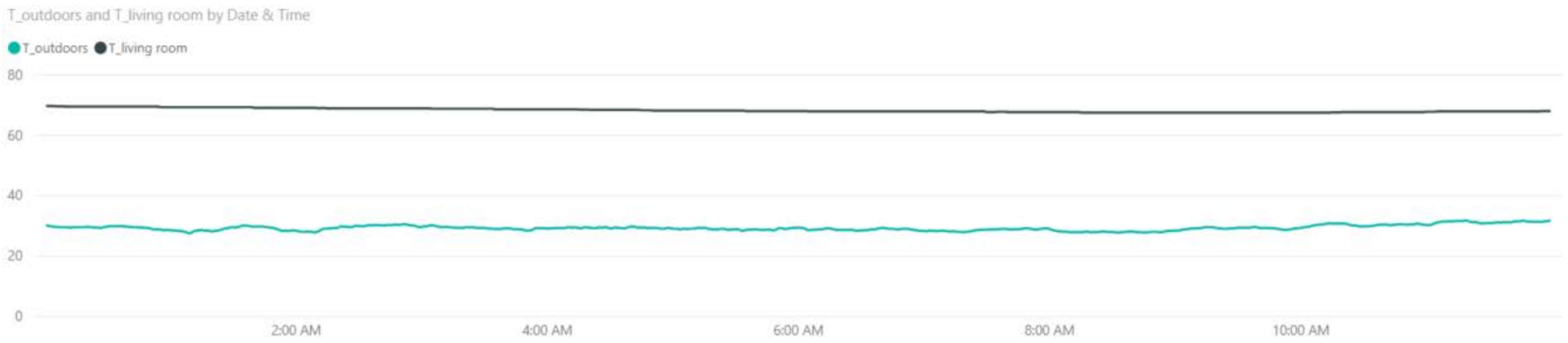
Home operation:

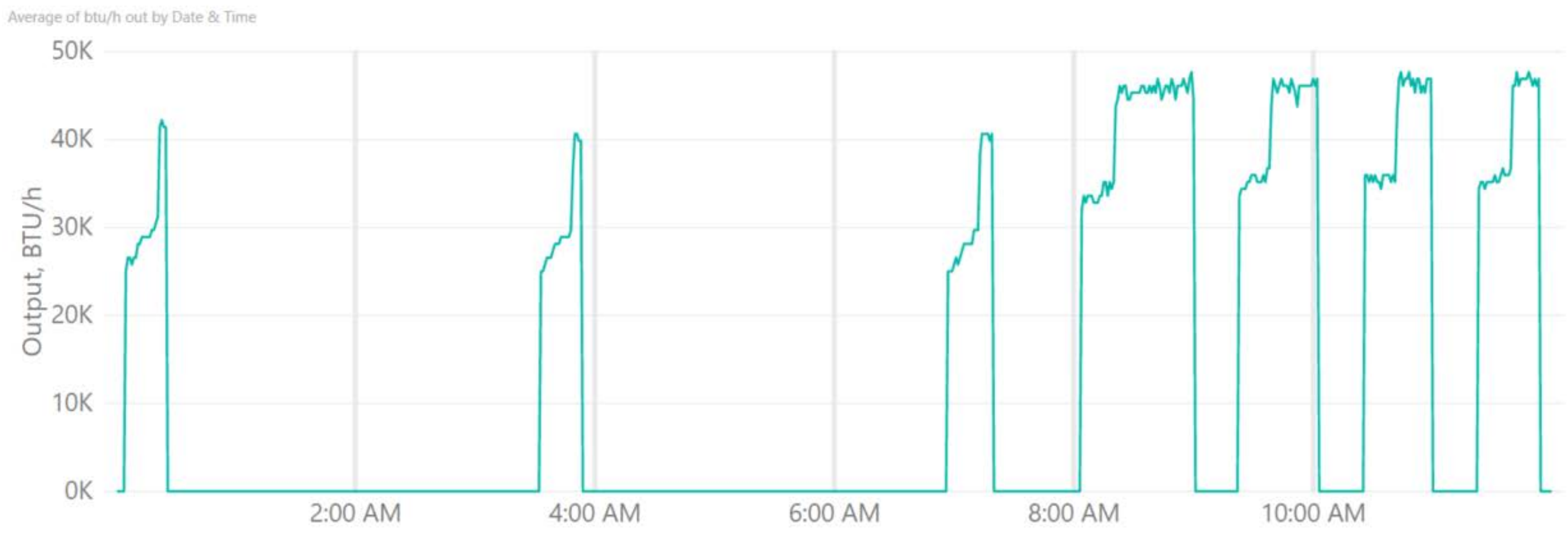
- Wood burning when temp drops to 10F or below, about ½ cord burned this winter
- Zone 2 (upstairs) still uses AWHP during wood burning
- Backup resistance heat (9 kW) has not fired up yet

Data notes:

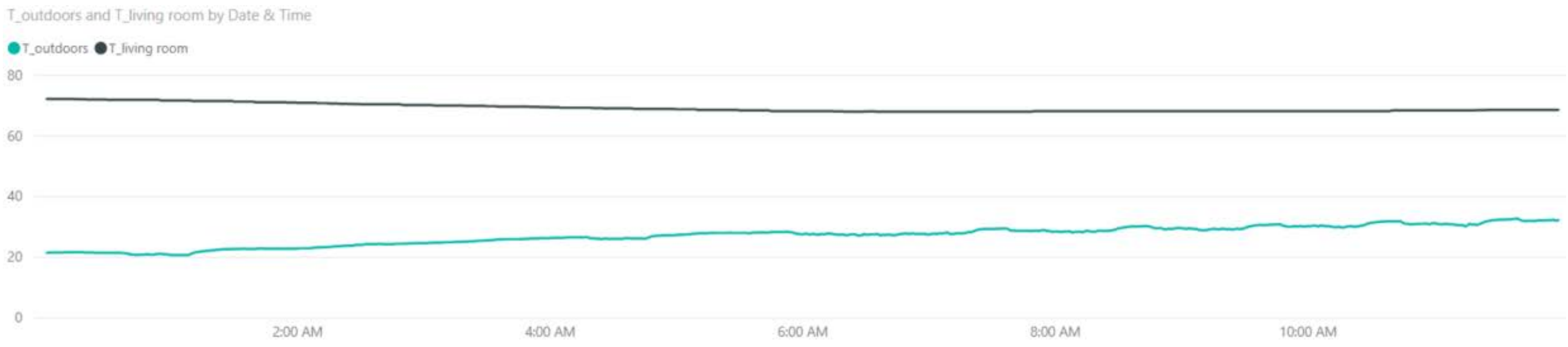
- Nov 1 2019 – Jan 22 2020
- Flow rate used is 15.55 gpm, based on averaged data (single speed)
- Slight misalignment in 1-minute eGauge and Nordic data means for some calculations, I've omitted first and last points in heat pump cycle (for instantaneous COP and output)
- For seasonal COP calculation uses cumulative data

Output (Jan 7, 12 hrs, AWHP only)



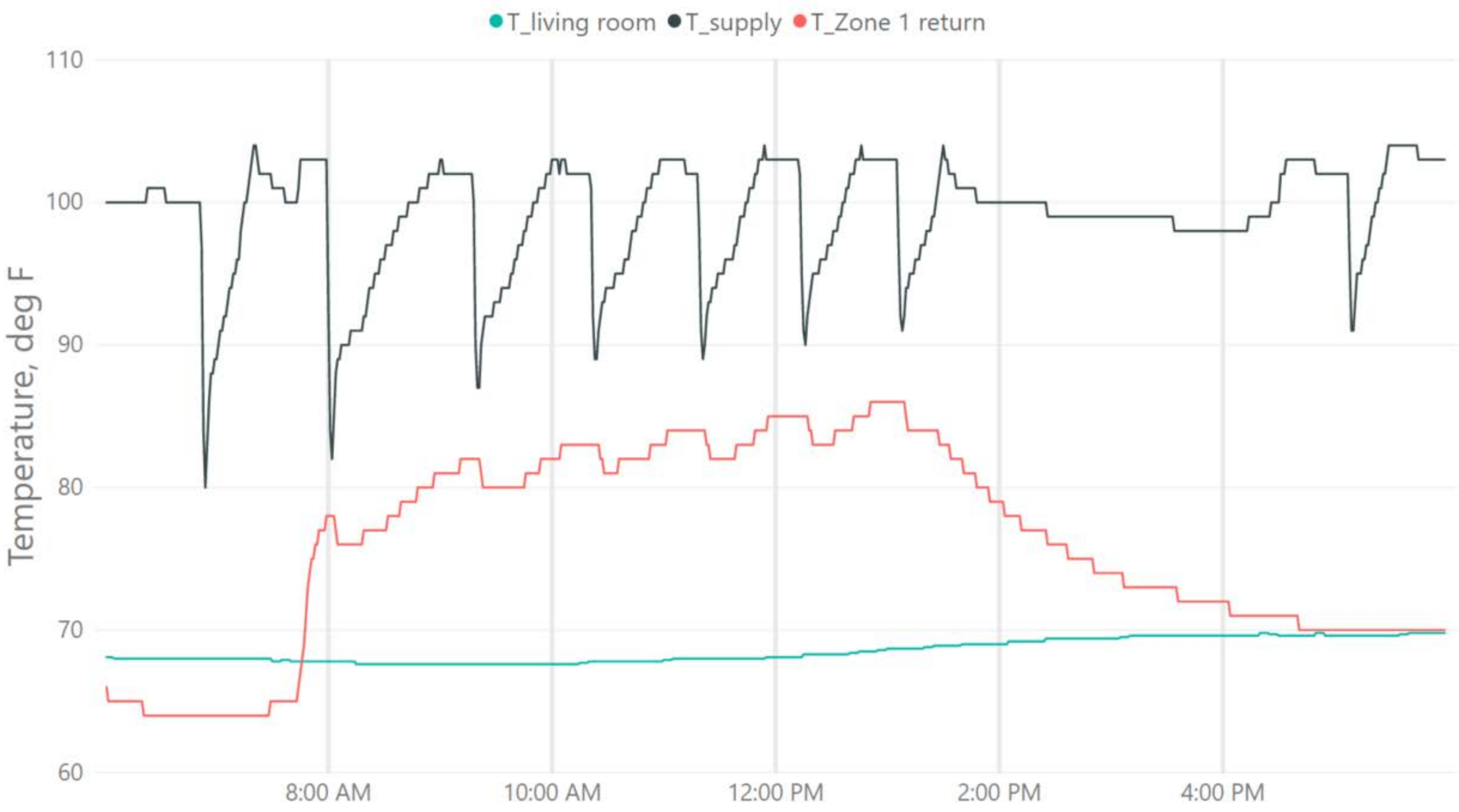


Output (Jan 10, cool slab after days of wood heat)



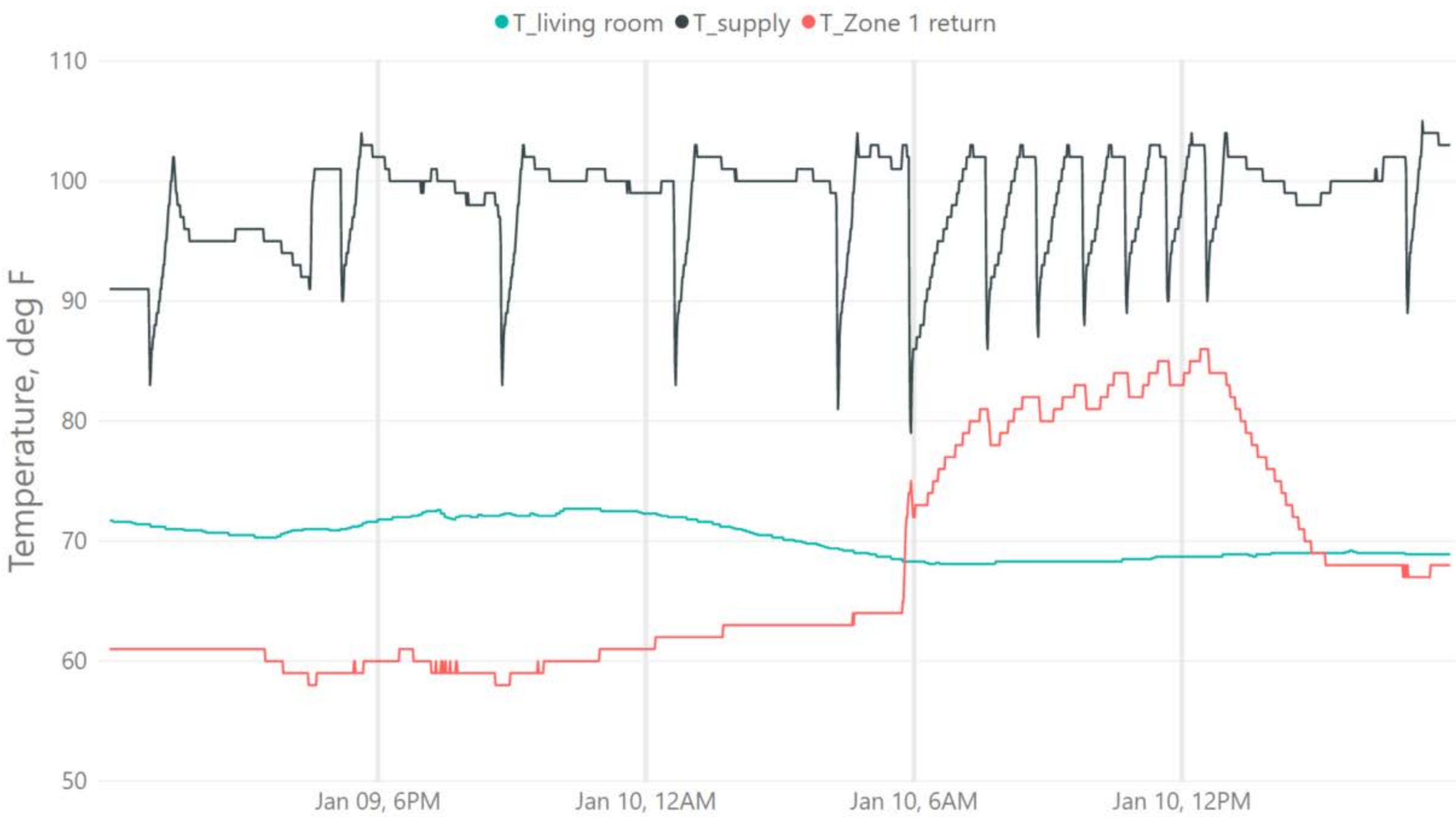
Efficiency Vermont

Zone 1 (slab) distribution



Efficiency Vermont

Zone 1 recovery after wood heat



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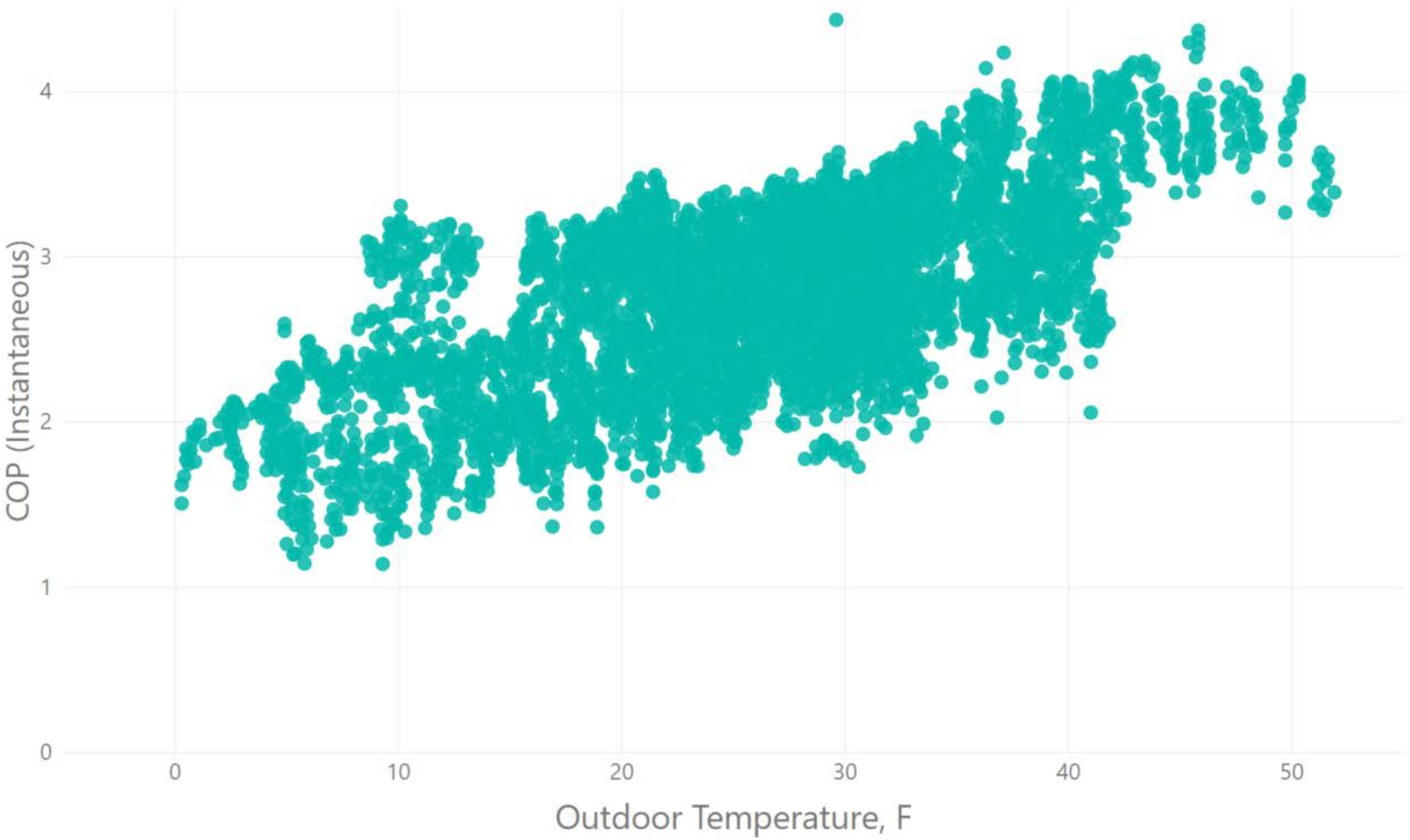
Zone 2 distribution

Efficiency Vermont

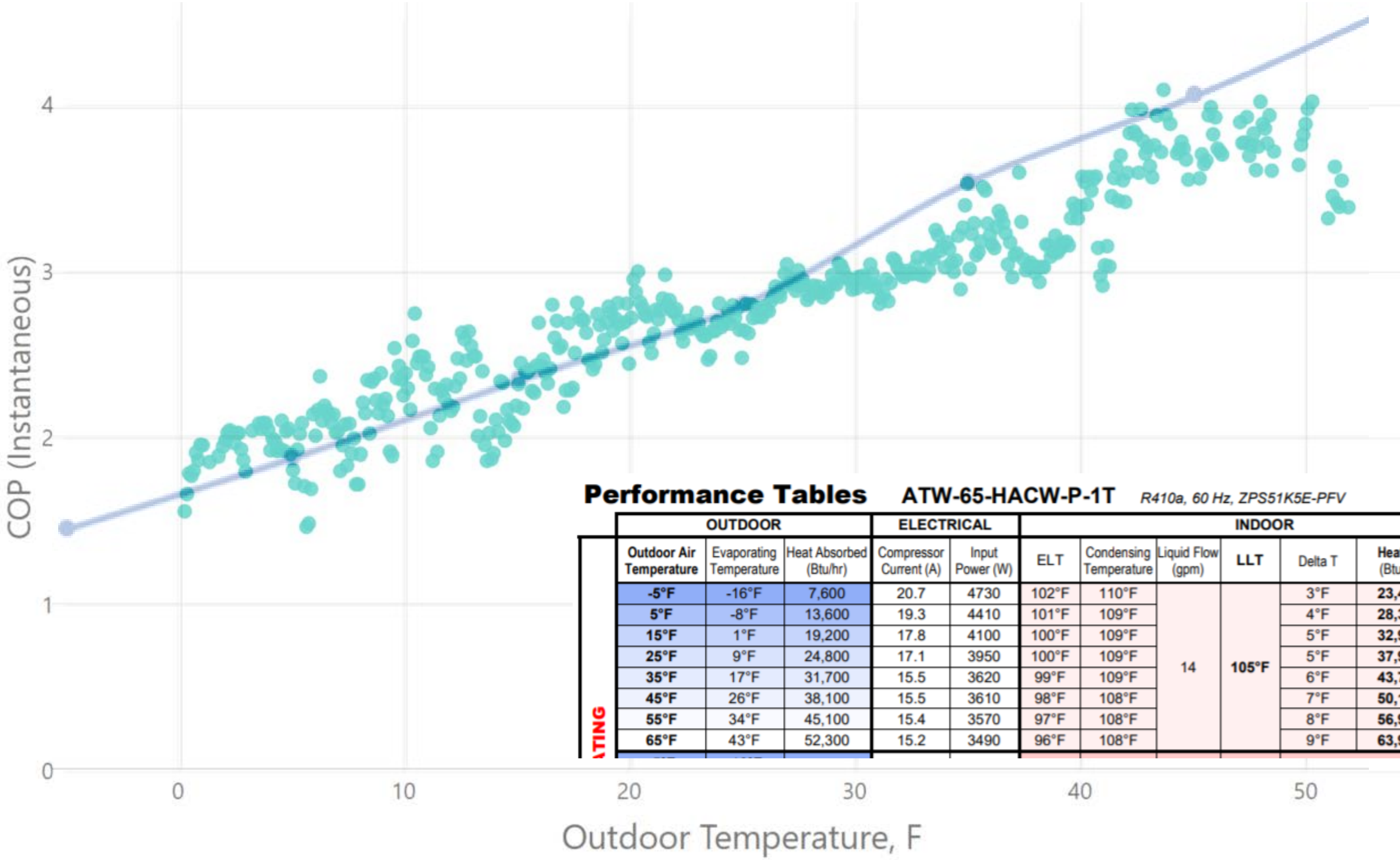
Data: AWHP COP

COP, instant. (Nov 2019-Jan 2020)



Efficiency Vermont

COP, vs. Manufacturer Specs

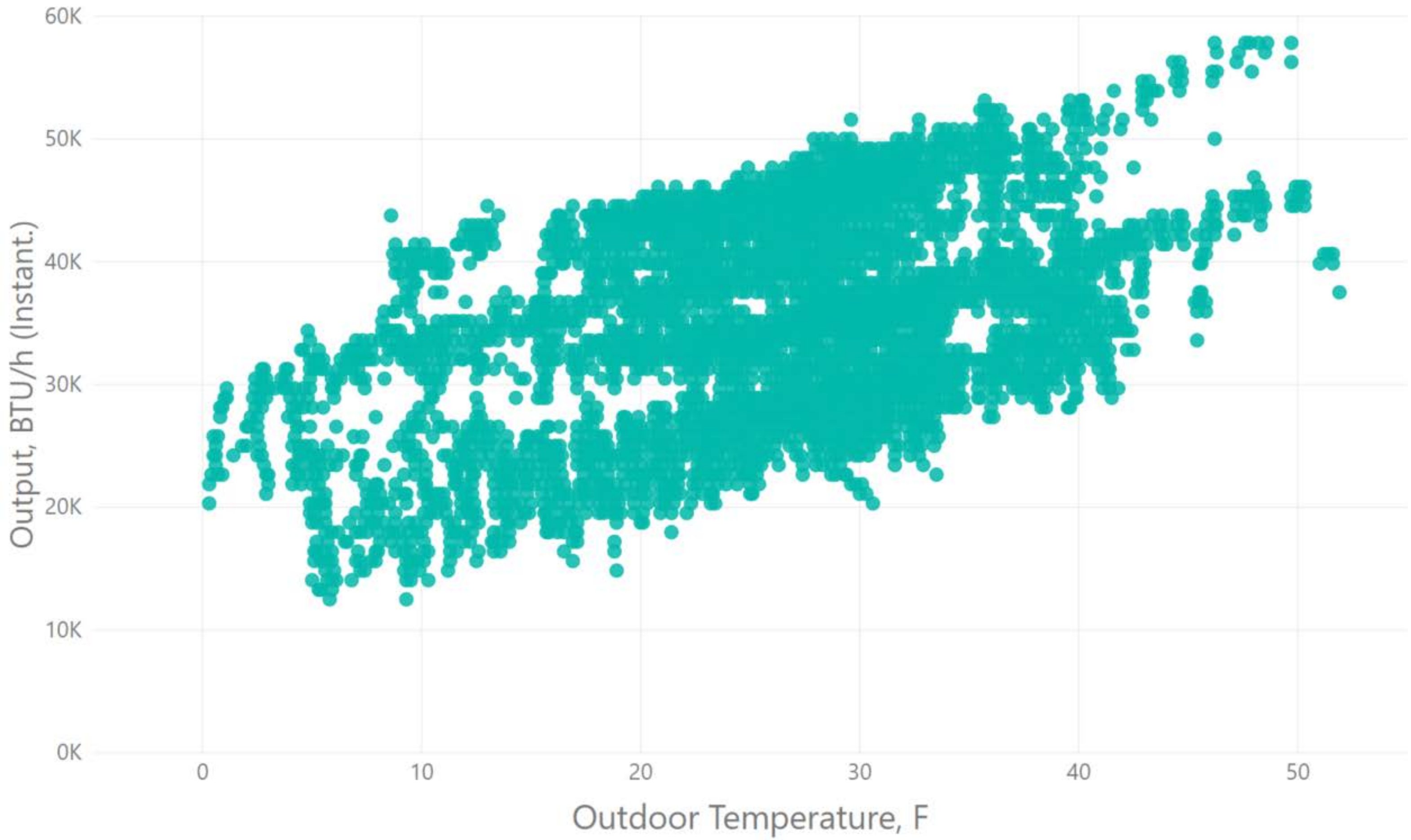


Performance Tables **ATW-65-HACW-P-1T** *R410a, 60 Hz, ZPS51K5E-PFV*

OUTDOOR			ELECTRICAL		INDOOR						
Outdoor Air Temperature	Evaporating Temperature	Heat Absorbed (Btu/hr)	Compressor Current (A)	Input Power (W)	ELT	Condensing Temperature	Liquid Flow (gpm)	LLT	Delta T	Heating (Btu/hr)	COP_H
-5°F	-16°F	7,600	20.7	4730	102°F	110°F	14	105°F	3°F	23,400	1.45
5°F	-8°F	13,600	19.3	4410	101°F	109°F			4°F	28,300	1.88
15°F	1°F	19,200	17.8	4100	100°F	109°F			5°F	32,900	2.35
25°F	9°F	24,800	17.1	3950	100°F	109°F			5°F	37,900	2.81
35°F	17°F	31,700	15.5	3620	99°F	109°F			6°F	43,700	3.55
45°F	26°F	38,100	15.5	3610	98°F	108°F			7°F	50,100	4.07
55°F	34°F	45,100	15.4	3570	97°F	108°F			8°F	56,900	4.68
65°F	43°F	52,300	15.2	3490	96°F	108°F			9°F	63,900	5.37

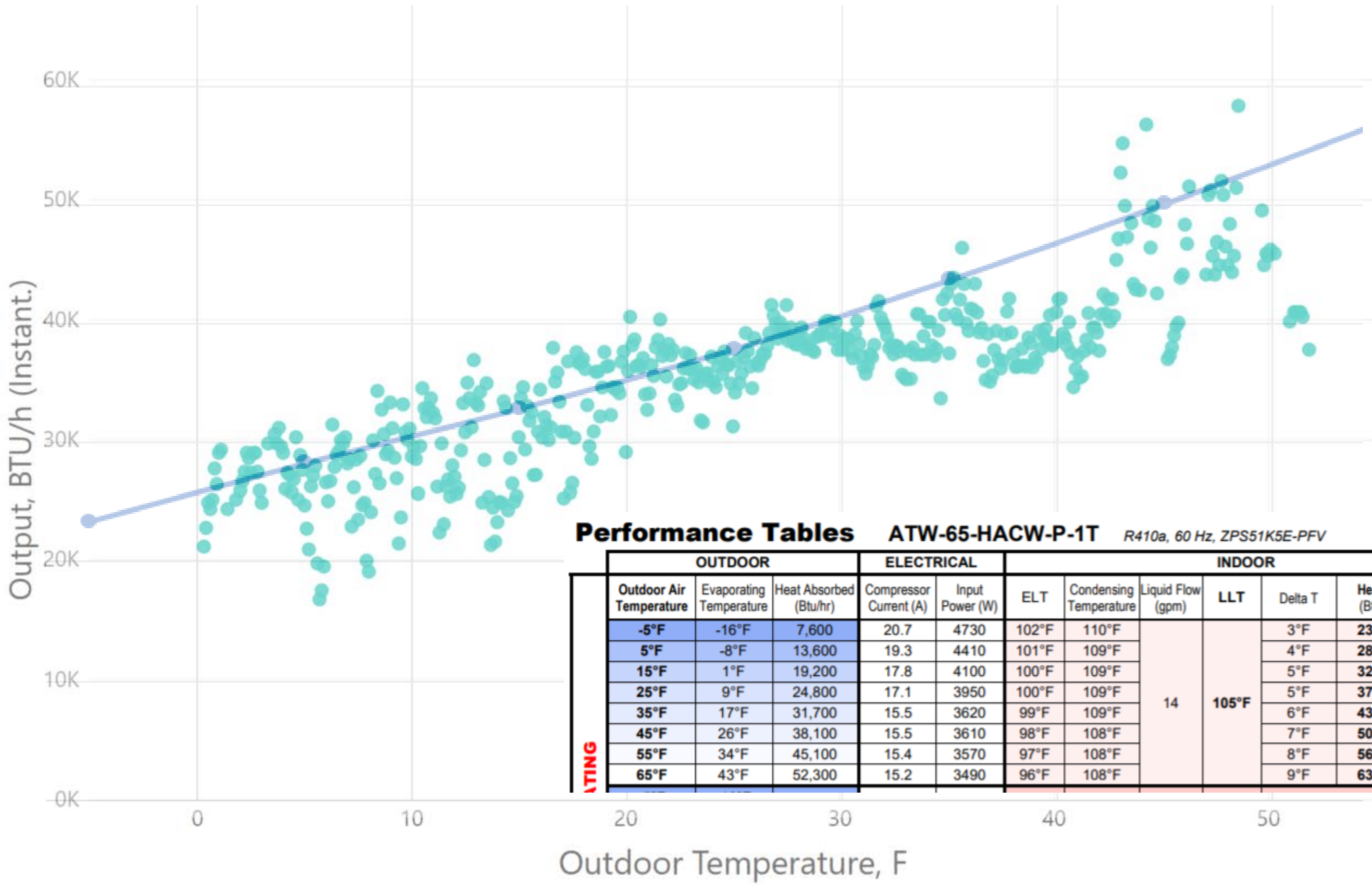
Efficiency Vermont

Output, instant. (Nov 2019-Jan 2020)



Efficiency Vermont

Output, vs. Manufacturer Specs



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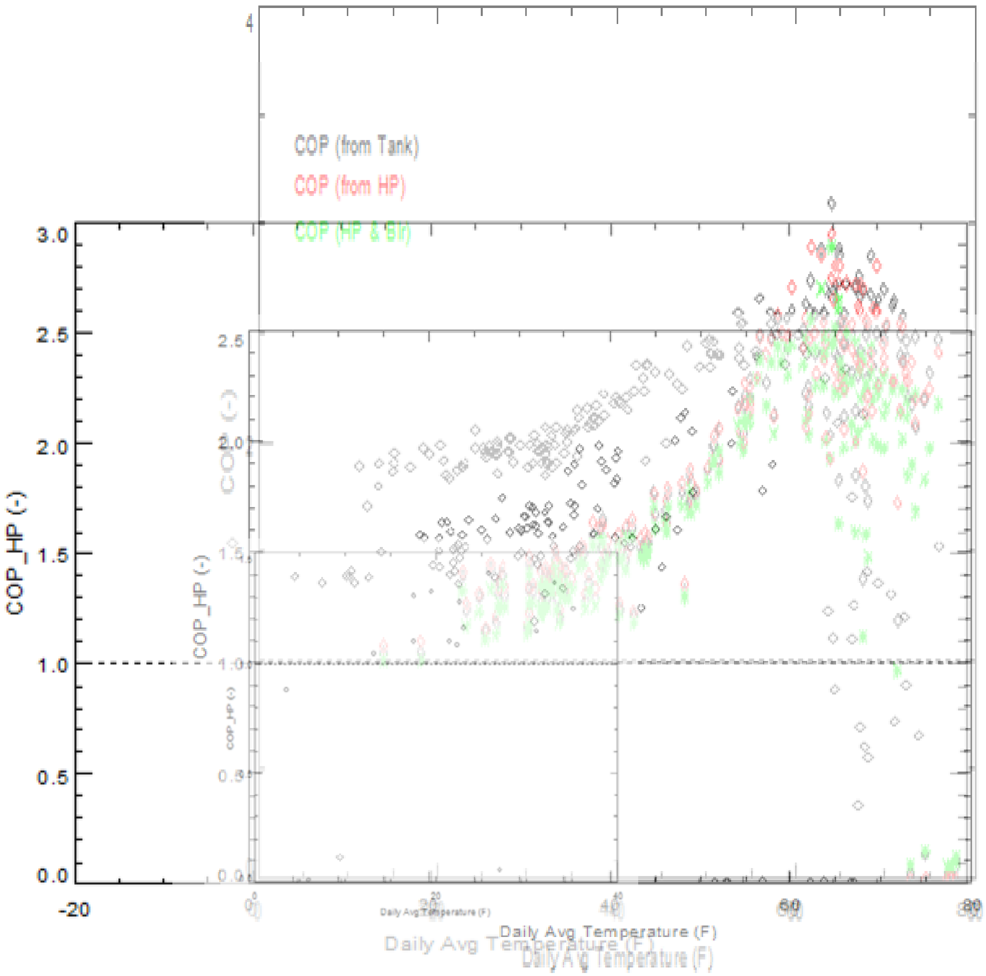
-5°F	-16°F	7,600	20.7	4730	102°F	110°F	14	105°F	3°F	23,400	1.45
5°F	-8°F	13,600	19.3	4410	101°F	109°F			4°F	28,300	1.88
15°F	1°F	19,200	17.8	4100	100°F	109°F			5°F	32,900	2.35
25°F	9°F	24,800	17.1	3950	100°F	109°F			5°F	37,900	2.81
35°F	17°F	31,700	15.5	3620	99°F	109°F			6°F	43,700	3.55
45°F	26°F	38,100	15.5	3610	98°F	108°F			7°F	50,100	4.07
55°F	34°F	45,100	15.4	3570	97°F	108°F			8°F	56,900	4.68
65°F	43°F	52,300	15.2	3490	96°F	108°F			9°F	63,900	5.37

ATING

Efficiency Vermont

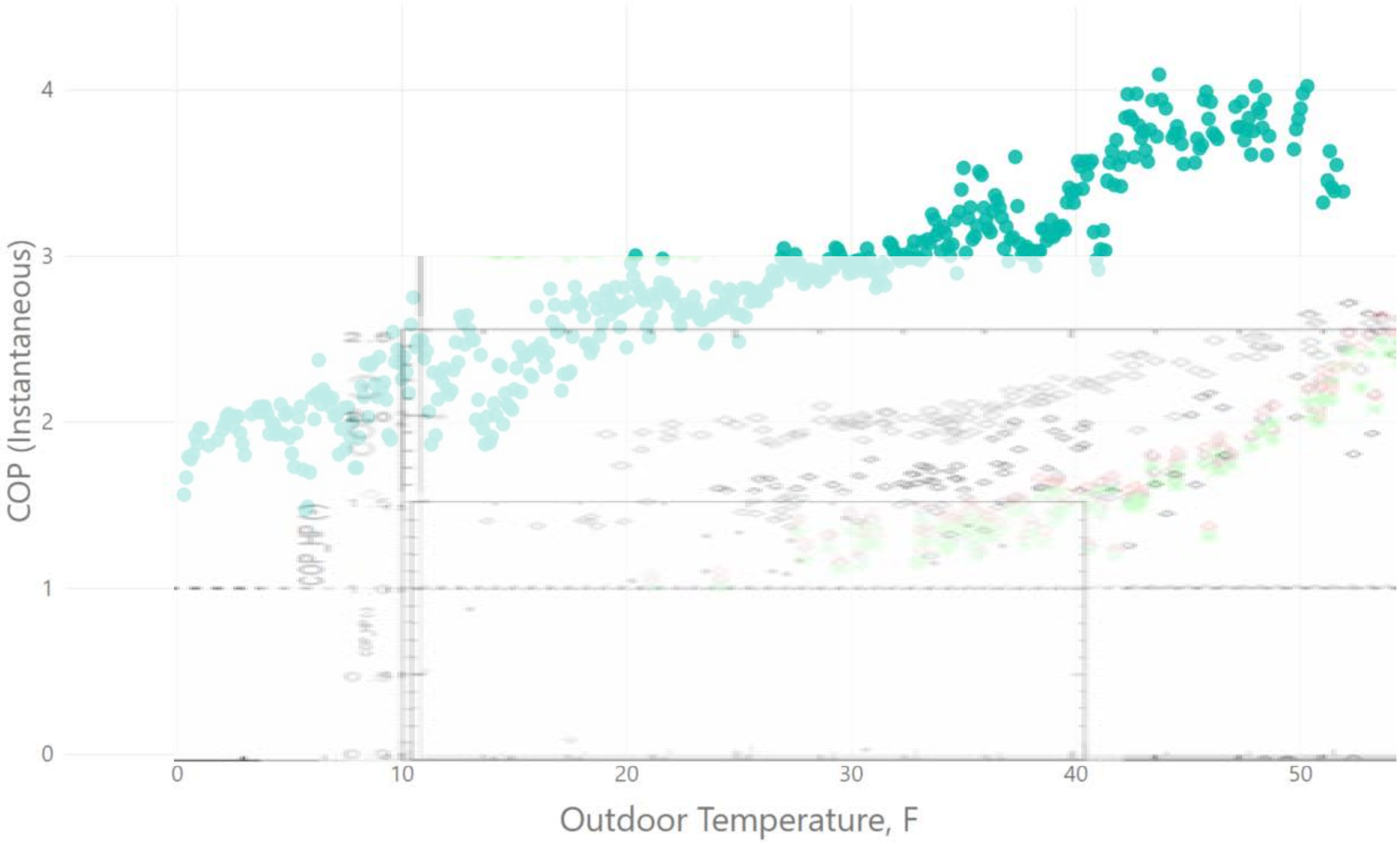
COP: NYSERDA study (4 SpacePak AWHPs)



4 plots overlaid (by me), from graphics within NYSERDA / Frontier Energy reports

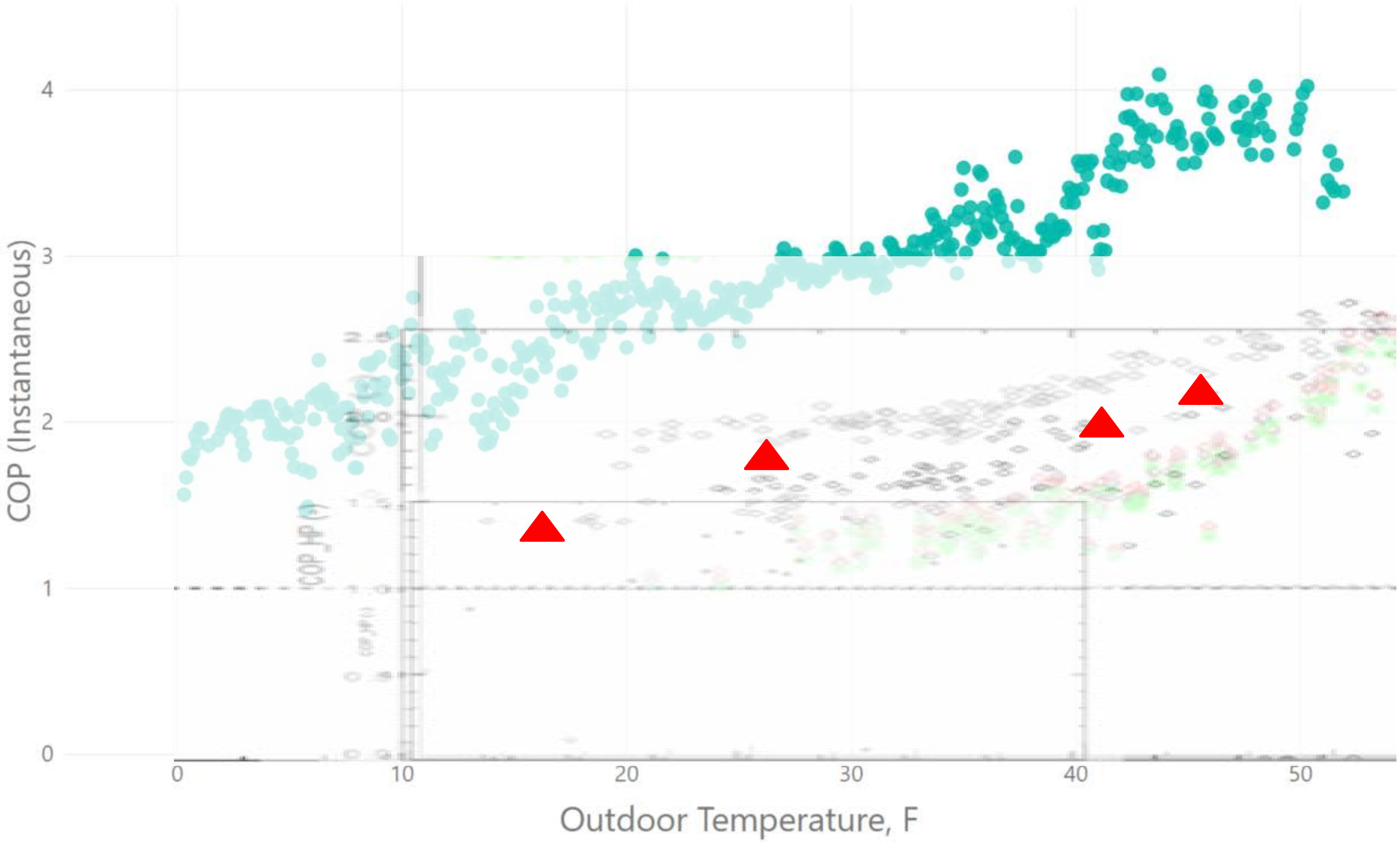
Efficiency Vermont

COP: System comp. to NYSERDA study



Efficiency Vermont

COP: System comp. to NYSERDA study + VT site



Efficiency Vermont

Performance

Fully monitored period:

- 8.21 MMBTU **heat produced** (2405 kWh)
- 967 kWh in (includes 108 kWh defrost)
  - Includes all auxiliaries except the two distribution system circulator pumps

➔ "Seasonal" COP 2.49*

*Assuming period is typical of the heating season
2.40 when adding in distribution system electricity

Efficiency Vermont

Operational cost

Based on current usage, projected 12-month cost of running AWHP

= $823

Comparison

= $1084 (replaced propane boiler)

= $745 (new gas boiler)

Costs

Prices incl. tax, shipping, etc.

Heating system costs

Category	Item	Cost
Distribution	PERT tubing	473
	Fittings and misc.	324
	Panel radiators	2182
	Panel radiator fittings, valves	243
	Manifolds – Uponor 6-loop (2)	700
	Circulator pump - Grundfos alpha2 26-99	446
	Circulator pumps - Grundfos alpha2 15-55F (2)	389
	EVT rebate – circulator pumps	-100
	Finishing work incl. non-HVAC contracted labor	2000
	Subtotal	**$6,657**
AWHP	AWHP - Nordic ATW-65 with accessories	7590
	EVT rebate – AWHP	-5000
	Buffer tank – ecoUltra 70g with 9 kW backup	1956
	Controls and thermostat	227
	Electrical – breaker upgrade, panel rewiring	1440
	Labor, fittings, mounting hardware, refrig.	3365
	Finishing work incl. non-HVAC contracted labor	315
	Subtotal	**$9,893**
	Total	**$16,550**

Prices incl. tax, shipping, etc.

Heating system costs

Category	Item	Cost	Cost, future-proof
Distribution	PERT tubing	473	
	Fittings and misc.	324	
	Panel radiators	2182	
	Panel radiator fittings, valves	243	
	Manifolds – Uponor 6-loop (2)	700	
	Circulator pump - Grundfos alpha2 26-99	446	
	Circulator pumps - Grundfos alpha2 15-55F (2)	389	
	EVT rebate – circulator pumps	-100	
	Finishing work incl. non-HVAC contracted labor	2000	
	Subtotal	**$6,657**	
AWHP	AWHP - Nordic ATW-65 with accessories	7590	7590
	EVT rebate – AWHP	-5000	-5000
	Buffer tank – ecoUltra 70g with 9 kW backup	1956	***
	Controls and thermostat	227	
	Electrical – breaker upgrade, panel rewiring	1440	500
	Labor, fittings, mounting hardware, refrig.	3365	1500
	Finishing work incl. non-HVAC contracted labor	315	
	Subtotal	**$9,893**	$4,590
	Total	**$16,550**	$4,590

Prices incl. tax, shipping, etc.

Rest of "system" costs

Category	Item	Cost
Ventilation	Distribution tubing and registers	1769
	Finishing work incl. non-HVAC contracted labor (Phase I)	2000
	Ventilator plus accessory parts, fittings, and filters	4709
	Electrical	150
	Finishing work incl. non-HVAC contracted labor (Phase I)	900
	Subtotal	**$9,528**
DHW	Heat pump water heater (HPWH)	1719
	EVT rebate – HPWH	-500
	Parts and labor	2246
	Electrical	300
	Finishing work incl. non-HVAC contracted labor	100
	Subtotal	**$3,865**

Prices incl. tax, shipping, etc.

Rest of “system” costs

Category	Item	Cost
Ventilation	Distribution tubing and registers	1769
	Finishing work incl. non-HVAC contracted labor (Phase I)	2000
	Ventilator plus accessory parts, fittings, and filters	4709
	Electrical	150
	Finishing work incl. non-HVAC contracted labor (Phase I)	900
	Subtotal	**$9,528**
DHW	Heat pump water heater (HPWH)	1719
	EVT rebate – HPWH	-500
	Parts and labor	2246
	Electrical	300
	Finishing work incl. non-HVAC contracted labor	100
	Subtotal	**$3,865**
Heating	**Subtotal**	**$16,550**

Total	$29,943

Notes:
- Includes $5600 in EVT rebates
- Retail or contractor pricing / no “free” or extra-discounted equipment

Radiator right-sizing, cost impacts

Zone / Room	Design heat load	180F (Match manufacturer literature)	120F design
2 / Bed 1	5600 btu/hr	12" x 71" (1-plate) $530	$619 + $172 = $791
2 / Bed 2	3800 btu/hr	12" x 59" (1-plate) $500	$511
2 / Bed 3	1800 btu/hr	12" x 24" (1-plate) $260	$247
2 / Bath	1800 btu/hr	12" x 24" (1-plate) $260	$247
Radiator cost (excl. freight, fittings, and valves)		**$1550**	**$1796** **(+$246 premium)**

* Assumes 1 gpm, each room is a homerun to the mechanical room supply manifold
Prices for "Match manufacturer literature" column are hyperlinked to product, via SupplyHouse.com; note that for true apples-to-apples comparison I could have had Purmo radiators priced
Prices for "Design for 120F supply water" are actuals paid, Purmo radiators ordered from VP Supply

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Prices incl. tax, shipping, etc.

Rest of "system" costs

Category	Item	Cost	Cost, future-proof
Ventilation	Distribution tubing and registers	1769	
	Finishing work incl. non-HVAC contracted labor (Phase I)	2000	
	Ventilator plus accessory parts, fittings, and filters	4709	
	Electrical	150	
	Finishing work incl. non-HVAC contracted labor (Phase I)	900	
	Subtotal	**$9,528**	$0
DHW	Heat pump water heater (HPWH)	1719	1719
	EVT rebate – HPWH	-500	-500
	Parts and labor	2246	2246
	Electrical	300	300
	Finishing work incl. non-HVAC contracted labor	100	100
	Subtotal	**$3,865**	$3,865
Heating	**Subtotal**	**$16,550**	$4,590

Total	$29,943	$8,455

Could have been worse!

- What's my labor worth? $10-15k?
- HVAC contractor willing to learn on his own time (and brainstormed ways to save cost)

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Payback

Simple payback

- Because existing design was *incompatible*:
  - Approx. 60 years (with $5100 EVT incentives)

Payback

Simple payback

- Because existing design was incompatible:
  - Approx. 60 years (with $5100 EVT incentives)
- If existing design was AWHP compatible and boiler did not need replacement:
  - Approx. 20 years

Payback

Simple payback

- Because existing design was incompatible:
  - Approx. 60 years (with $5100 EVT incentives)
- If existing design was AWHP compatible and boiler did not need replacement:
  - Approx. 20 years
- If existing design was AWHP compatible and boiler needed replacement:
  - Somewhere in the 0-5 year range

Closing thoughts

Benefits

Challenging payback as the lens

How do you attach a price to the following?

- No combustion / propane is gone

Challenging payback as the lens

How do you attach a price to the following?

- No combustion / propane is gone
- Room by room temperature control*
- Filtered fresh air ventilation
- Balanced slab heat
- Less window condensation
- Warm radiators / no possible burn surfaces
- House tightened and insulation gaps filled
- HPWH scavenges waste heat (slab, AWHP, buffer tank, pumps, electronics)
- Cool-dry zone (HPWH + no boiler)

Challenging payback as the lens

How do you attach a price to the following?

- No combusti
- Room by roo
- Filtered fresh
- Balanced slab
- Less window
- Warm radiato
- House tighter
- HPWH scaven
  tank, pumps,

- Cool-dry zone (HPWH + no boiler)

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Challenging payback as the lens

How do you attach a price to the following?

- No combustion / propane is gone
- Room by room temperature control*
- Filtered fresh air ventilation
- Balanc
- Less wi
- Warm r ... s
- House
- HPWH ... buffer tank, pumps, electronics)
- Cool-dry zone (HPWH + no boiler)

<u>If you're in this room:</u>

"We" have to use **creativity** to encourage people to see past the **$-only approach**

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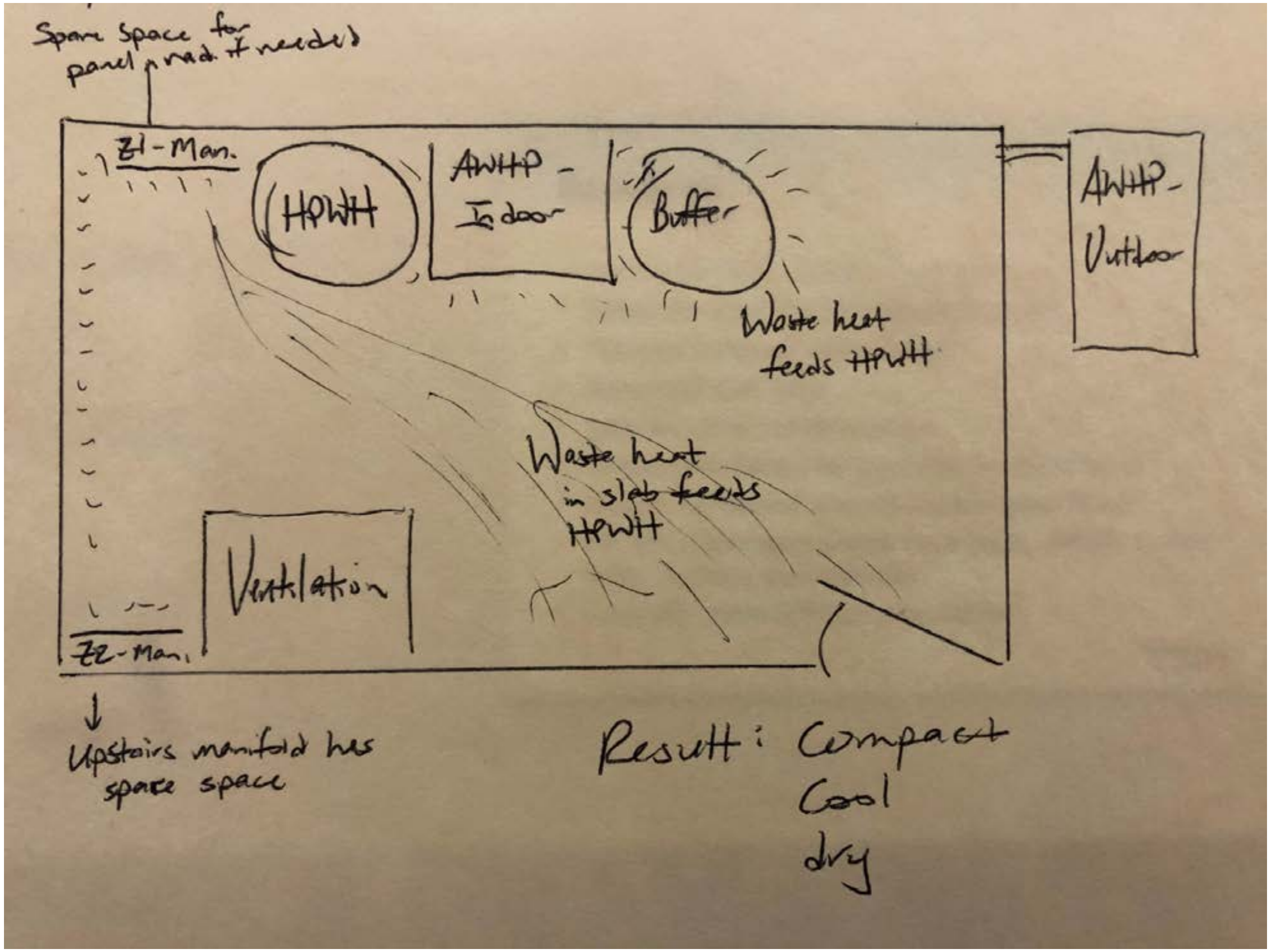
House as a "system"



Heating backup:

- Electric element
- Woodstove

Lessons learned

- Leg kit and sound insulation add-ons should be standard
- One size smaller might have been the better choice
- Haven’t found controller to prioritize Zone 2 necessary (could have saved $100)
- 2-wire to thermostats was a pain
- Emitters a bit oversized ➔ doing just fine down to zero degrees with 105F supply
- Started heating season with outdoor reset, but AWHP runtimes so short that moved to 105F all the time
- Split vs. mono-bloc has challenges

Closing thoughts

1. AWHP not right or easy for every <u>existing</u> home

Closing thoughts

1. AWHP not right or easy for every existing home
2. **100% of new homes** need to be built with **low temperature infrastructure** in place

➔ Beyond the tubing embedded in the concrete slab, very little was reused

➔ Like balanced (fresh air) ventilation—another important feature that requires advanced planning—this is a no-brainer

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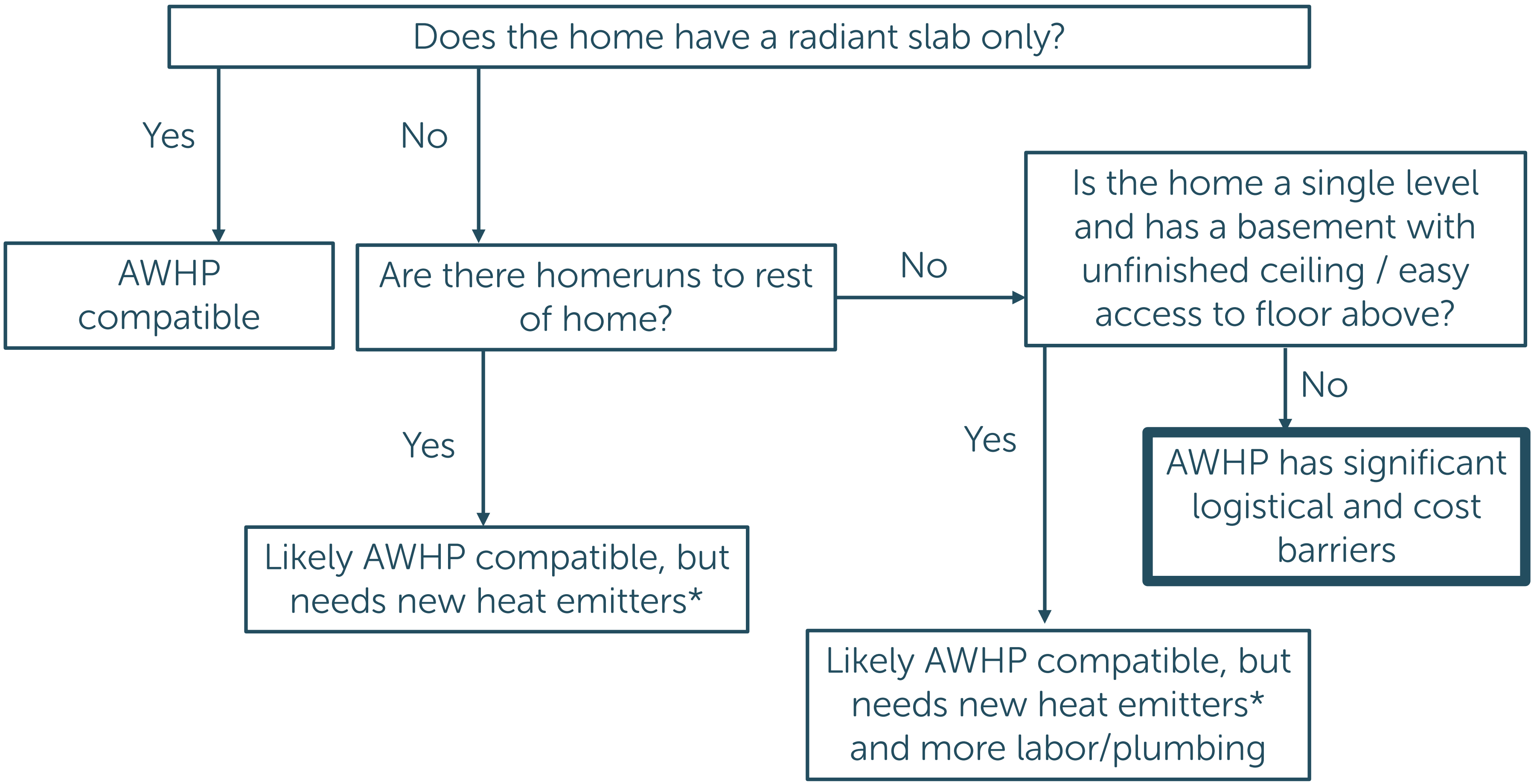
Suggested “decision tree”

Decision tree: Existing homes



* Properly sized (for 120F supply) panel radiators/high-output baseboards/other emitters designed for low temperature

Decision tree: Existing homes

Does the home have a radiant slab only?

Yes

No

Is the home a single level and has a basement with unfinished ceiling / easy access above?

In most cases, AWHPs should probably not be characterized as a straightforward boiler replacement option

Likely AWHP compatible, but needs new heat emitters*

Likely AWHP compatible, but needs new heat emitters* and more labor/plumbing

barriers

* Properly sized (for 120F supply) panel radiators/high-output baseboards/other emitters designed for low temperature

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Decision tree: New homes

Regardless of boiler type, is heating distribution sized for 120F or less output temperature, with homeruns to all heat emitters?*

Yes

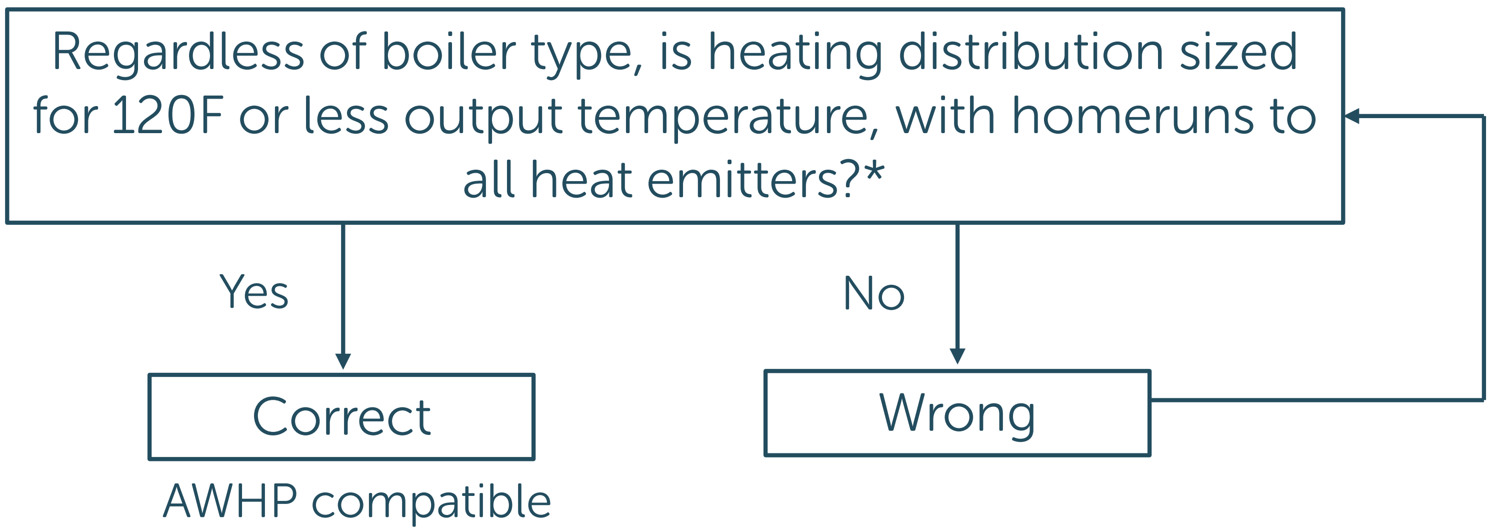
Correct

AWHP compatible

* Heat load calculation done, with buffer tank plus combination of radiant floors/surfaces and *homeruns* to any panel radiators/high-output baseboards/other emitters designed for low temperature. Alternative to homeruns is supply and return loop with zone valves at take-offs.

Don't install 2-wire to thermostat locations

Decision tree: <u>New</u> homes



* Heat load calculation done, with buffer tank plus combination of radiant floors/surfaces and *homeruns* to any panel radiators/high-output baseboards/other emitters designed for low temperature. Alternative to homeruns is supply and return loop with zone valves at take-offs.

Don't install 2-wire to thermostat locations

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Decision tree: New homes

Regardless of boiler type, is heating distribution sized for 120F or less output temperature, with homeruns to all he

Yes

Correct

AWHP compatible

John Siegenthaler:

If putting in fossil fuel system now,

I would advocate design for maximum of 120 ºF supply water temperature at design load conditions, and supply through a mixing valve if necessary.

Me:

Get 200-250A service to the house

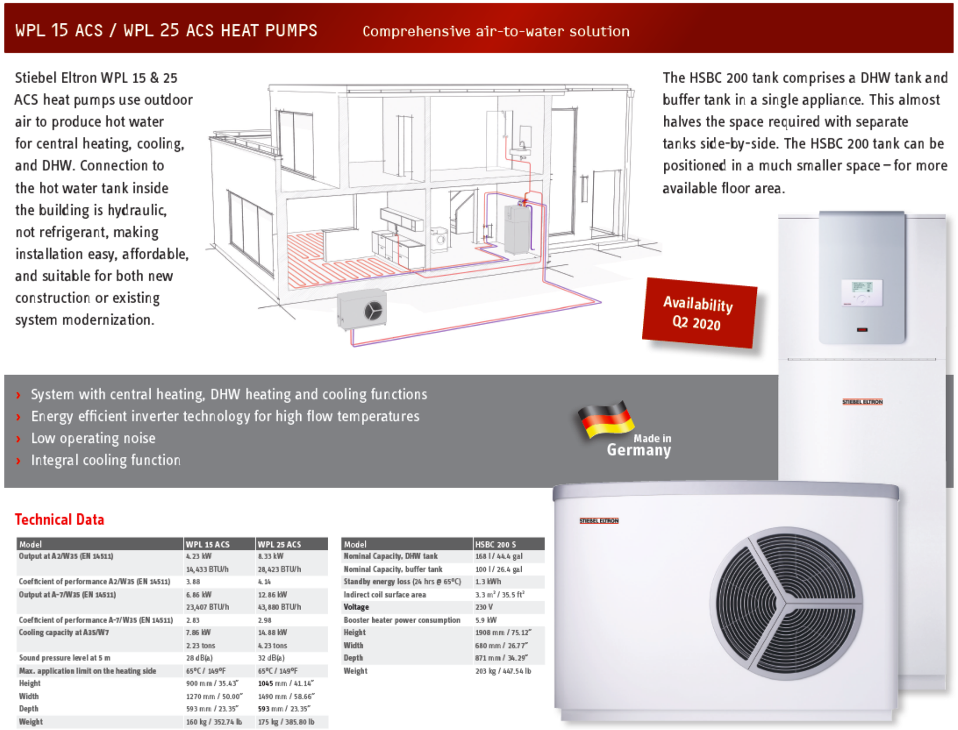
* Heat load calculation done, with b
homeruns to any panel radiators/hi
temperature. Alternative to homeru

Don't install 2-wire to thermostat locations

On the horizon…

Stiebel Eltron split system

- Split (hydraulic)
- 2 sizes (specs @ A-7/W35*)
  - 43.9 kbtu/h, 2.98 COP
  - 23.4 kbtu/h, 2.83 COP
- Inverter-driven
- DHW+buffer integrated
  - Buffer 26.4gal
  - DHW 44.4gal
- Built-in backup (5.9 kW)
- Field testing 10 units in September 2020



WPL 15 ACS / WPL 25 ACS HEAT PUMPS Comprehensive air-to-water solution

Stiebel Eltron WPL 15 & 25 ACS heat pumps use outdoor air to produce hot water for central heating, cooling, and DHW. Connection to the hot water tank inside the building is hydraulic, not refrigerant, making installation easy, affordable, and suitable for both new construction or existing system modernization.

The HSBC 200 tank comprises a DHW tank and buffer tank in a single appliance. This almost halves the space required with separate tanks side-by-side. The HSBC 200 tank can be positioned in a much smaller space – for more available floor area.

Availability Q2 2020

- System with central heating, DHW heating and cooling functions
- Energy efficient inverter technology for high flow temperatures
- Low operating noise
- Integral cooling function

Made in Germany

Technical Data

Model	WPL 15 ACS	WPL 25 ACS
Output at A2/W35 (EN 14511)	4.23 kW 14,433 BTU/h	8.33 kW 28,423 BTU/h
Coefficient of performance A2/W35 (EN 14511)	3.88	4.14
Output at A-7/W35 (EN 14511)	6.86 kW 23,407 BTU/h	12.86 kW 43,880 BTU/h
Coefficient of performance A-7/W35 (EN 14511)	2.83	2.98
Cooling capacity at A35/W7	7.86 kW 2.23 tons	14.88 kW 4.23 tons
Sound pressure level at 5 m	28 dB(a)	32 dB(a)
Max. application limit on the heating side	65°C / 149°F	65°C / 149°F
Height	900 mm / 35.43"	1045 mm / 41.14"
Width	1270 mm / 50.00"	1490 mm / 58.66"
Depth	593 mm / 23.35"	593 mm / 23.35"
Weight	160 kg / 352.74 lb	175 kg / 385.80 lb

Model	HSBC 200 S
Nominal Capacity, DHW tank	168 l / 44.4 gal
Nominal Capacity, buffer tank	100 l / 26.4 gal
Standby energy loss (24 hrs @ 65°C)	1.3 kWh
Indirect coil surface area	3.3 m^2 / 35.5 ft^2
Voltage	230 V
Booster heater power consumption	5.9 kW
Height	1908 mm / 75.12"
Width	680 mm / 26.77"
Depth	871 mm / 34.29"
Weight	203 kg / 447.54 lb

*Outside -7C (19.4F), supply water 35C (95F)

Enertech split system

- Details unknown
- Announced at AHR conference this week
- Based on NIBE (Sweden)

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Taco split system

- Split (hydraulic)
- Based on Dimplex (German)
- Size (specs @ A-7/W35*)
  – 30.5 kbtu/h, 2.8 COP
- Inverter-driven
- Buffer integrated
- One installed VT
- Available Q3 2020

*Outside -7C (19.4F), supply water 35C (95F)

SpacePak split system

- Split (refrigerant)
- Up to 68 kbtu/h
- Inverter-driven
- Operates to -22F
- Expected Q3 2020

*Outside -7C (19.4F), supply water 35C (95F)

Natural refrigerants?

1. Sanden Eco Runo
   - R-744 (CO_2)
   - Field trials in Pacific Northwest

2. Vaillant
   - R-290 (propane)
   - German system for sale in Europe Nov 2020

Wrap-up

I’ve heard:

“The technology isn’t there…”

I disagree.

- Good products are out there; and more are coming
- $1000/ton incentive in Vermont right now
- It’s taking off as we speak
- Modulation isn’t necessary with proper design

Takeaways

Pro:

- **Thermal comfort** and **ability to control** is fantastic – likely **far better than minisplits**
- Proper **ventilation** is great
- Separating **DHW** from the AWHP was a good move
- **Mechanical room** very full, but **useful** in a different if unconventional way than before
- No gas/propane hookups or combustion = **safety**

Takeaways

Pro:

- **Thermal comfort** and **ability to control** is fantastic – likely **far better than minisplits**
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- No gas/propane hookups or combustion = **safety**

Con:

- **Expensive**, **took longer** than hoped, and was **destructive**
- There is a **0% chance** we would have done this **if not for** the simultaneous ventilation system and bathroom remodel

Takeaways

Pro:

- **Thermal comfort** and **ability to control** is fantastic – likely **far better than minisplits**
- Proper **ventilation** is great
- Separating **DHW** from the AWHP was a good move
- **Mechanical room** very full, but **useful** in a different if unconventional way than before
- No gas/propane hookups or combustion = **safety**

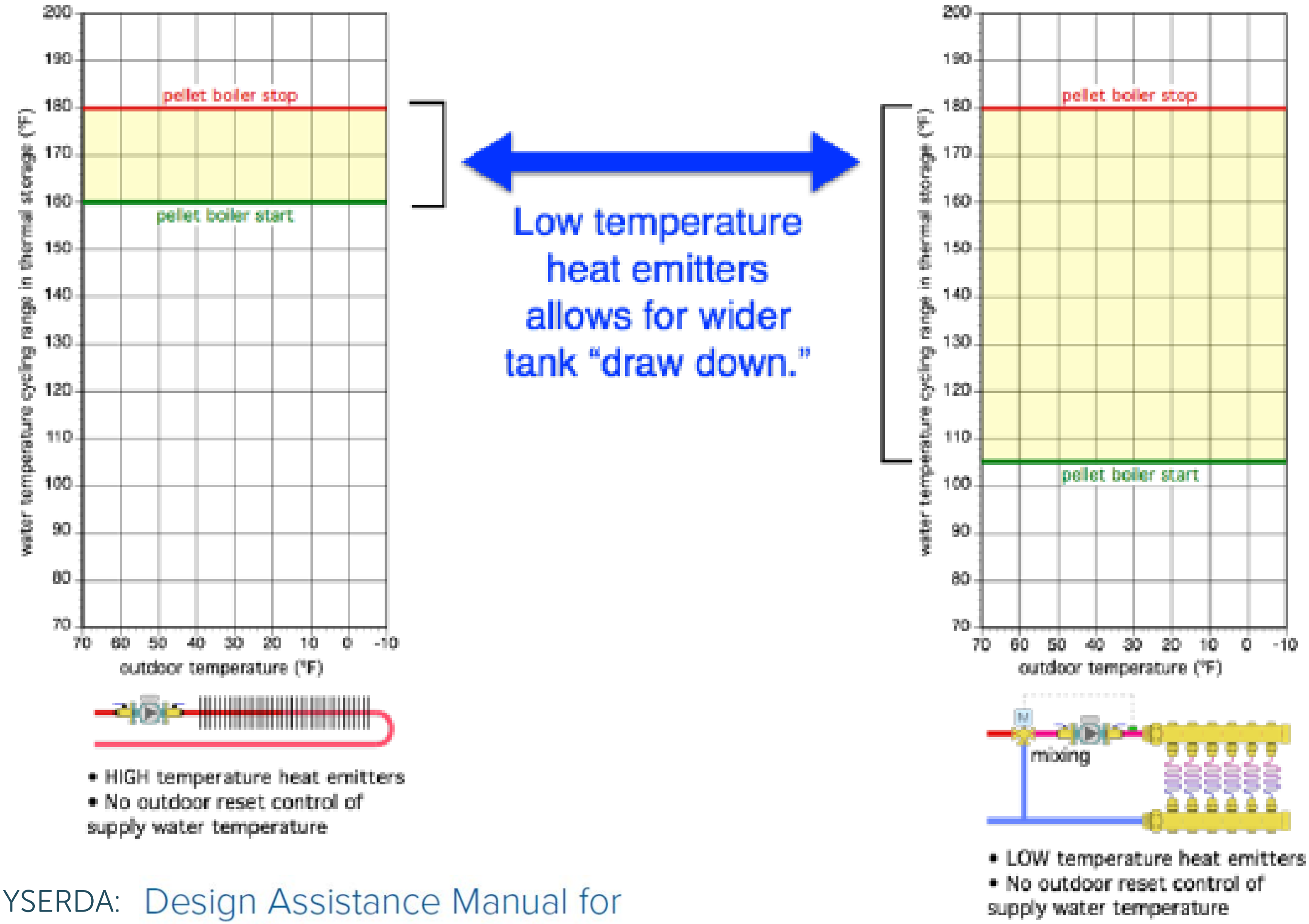
Combined with an induction cooktop and heat pump water heater, it's a fantastic **all-electric** package that people should be able to replicate

Would we do it again?

If any single person in this room designs or installs distribution that relies on 180F supply, in a new home, this presentation has been a failure


bjust@veic.org

Figure 3-4. Comparison of temperature cycling range for a thermal storage tank using high-temperature heat emitters versus low-temperature heat emitters



NYSERDA: Design Assistance Manual for High-Efficiency, Low-Emissions Biomass Boiler Systems

In Residential and Commercial Buildings

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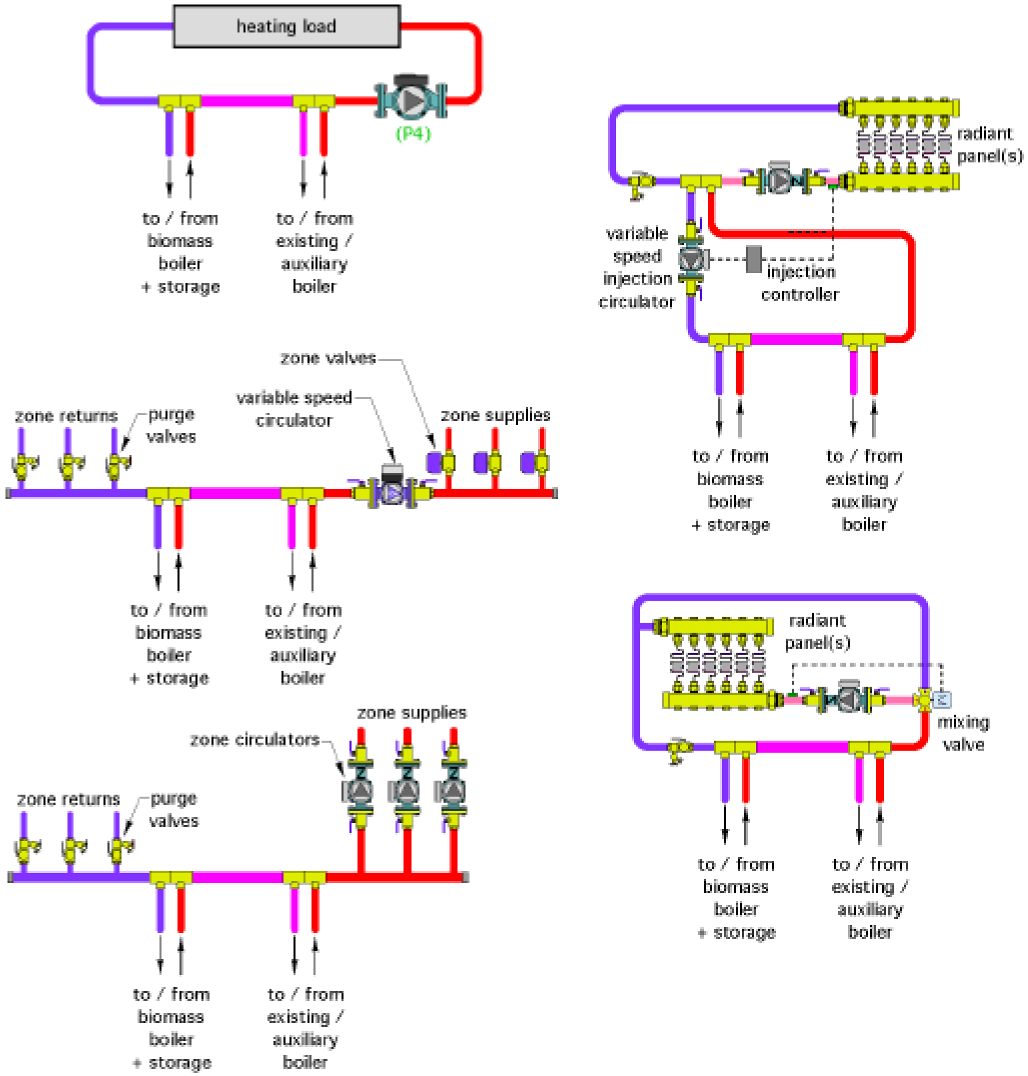
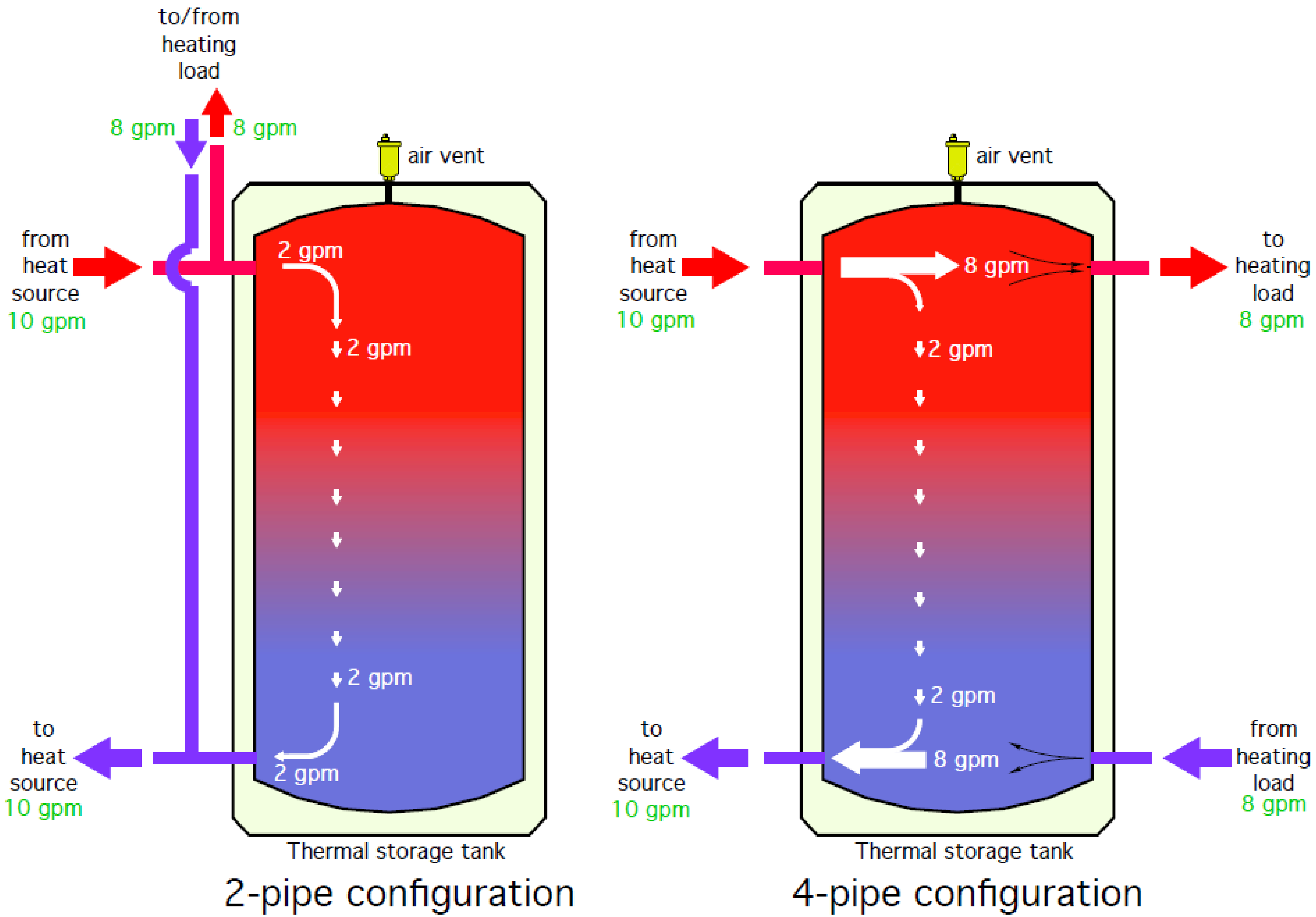
Figure 7-21. Possible configurations for distribution systems based on connecting heat sources as shown in figure 7-20



NYSERDA: Design Assistance Manual for High-Efficiency, Low-Emissions Biomass Boiler Systems

In Residential and Commercial Buildings

“2-pipe” versus “4-pipe buffer tank piping



Siegenthaler, BBD 2019