Anatomy of a residential air-to-water heat pump system

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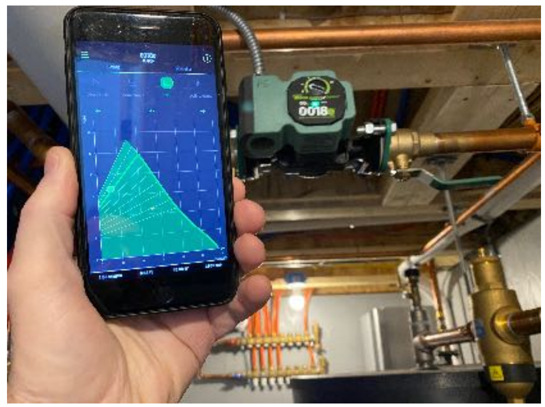

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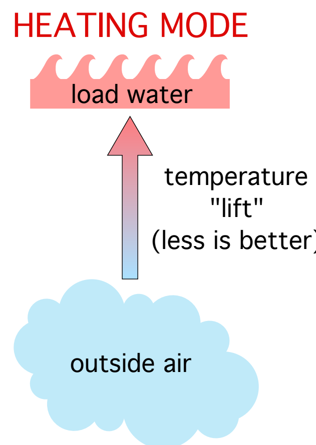
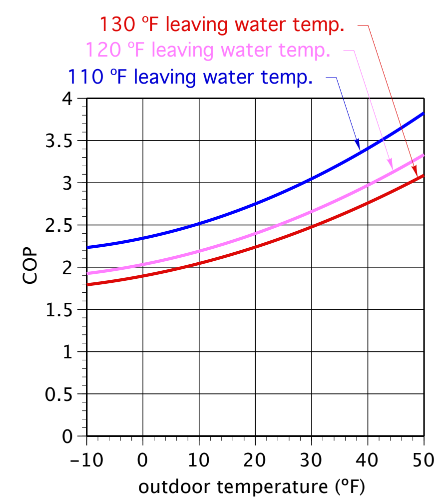


Today's topics:

- Why hydronics
- Fundamentals of air-to-water heat pumps
- Thermal performance of air-to-water heat pumps
- Enhanced Vapor Injection systems
- Why the North American air-to-water heat pump market will grow
- New concepts in air-to-water heat pumps
- Heating mode performance modeling
- Low temperature distribution systems
- Chilled water cooling
- An air-to-water heat pump system in a cold climate
- QUIZ

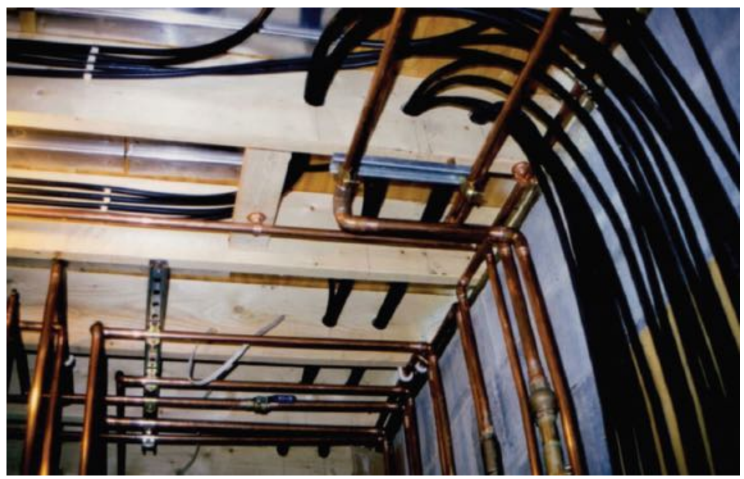


Why hydronics

+ heat pumps ?

Water vs. air: It's hardly fair...

courtesy of Dan Foley

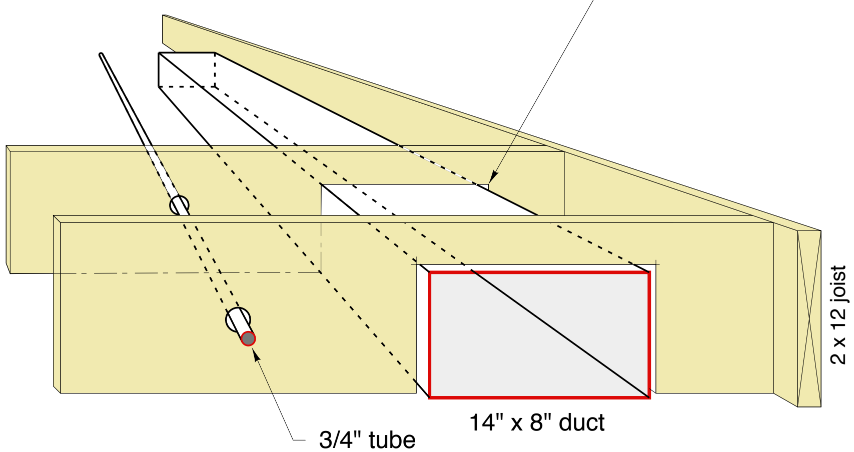


Why hydronics vs. forced air?

Water is vastly superior to air for conveying heat

Material	Specific heat (Btu/lb/°F)	Density* (lb/ft³)	Heat capacity (Btu/ft³/°F)
Water	1.00	62.4	62.4
Concrete	0.21	140	29.4
Steel	0.12	489	58.7
Wood (fir)	0.65	27	17.6
Ice	0.49	57.5	28.2
Air	0.24	0.074	0.018
Gypsum	0.26	78	20.3
Sand	0.1	94.6	9.5
Alcohol	0.68	49.3	33.5

$$\frac{62.4}{0.018} = 3467 \approx 3500$$



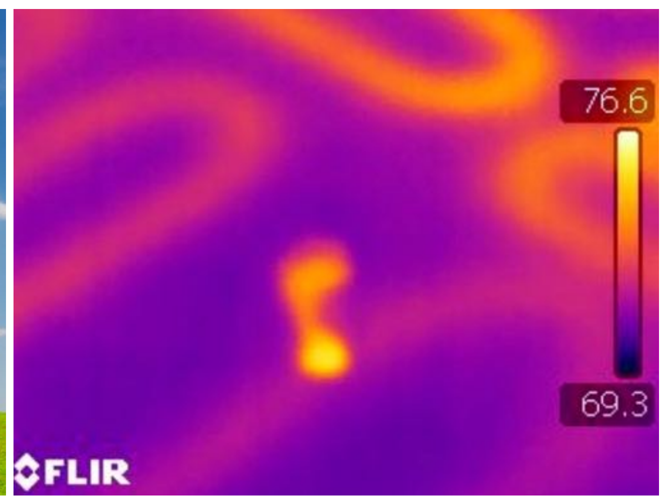
A given volume of water can absorb almost 3500 times as much heat as the same volume of air, when both undergo the same temperature change.

Modern hydronics is the “glue” holding together many thermally-based renewable energy systems.

Regardless of what renewable heat source is selected, if the distribution system, controls, and heat emitters are not properly matched, that system will not perform well.

Why hydronics enhances renewable heat sources

- **Unsurpassed comfort**
- Easy to adapt to wide range of renewable heat sources
- Low temp. operation (high heat source efficiency)
- Very high *distribution efficiency*
- Thermal storage potential
- No building filled with refrigerant tubing (e.g., no VRF)
- Easy integration with existing (now “auxiliary”) heat sources
- Very easy to zone to reduce loads
- Potential for thermal metering (ASTM E3137 now in place)



Hydronics provide superior DISTRIBUTION EFFICIENCY

$$\text{Efficiency} = \frac{\text{desired OUTPUT quantity}}{\text{necessary INPUT quantity}}$$

The concept of efficiency goes beyond the heat source…

Distribution efficiency for a space heating system.

$$\text{distribution efficiency} = \frac{\text{rate of heat delivery}}{\text{rate of energy use by distribution equipment}}$$

Consider a system that delivers 120,000 Btu/hr at design load conditions using four circulators operating at 85 watts each. The distribution efficiency of that system is:

$$\text{distribution efficiency} = \frac{120{,}000 \text{ Btu/hr}}{340 \text{ watts}} = 353 \ \frac{\text{Btu/hr}}{\text{watt}}$$

So is a distribution efficiency of 353 Btu/hr/watt good or bad?

To answer this you need something to compare it to.

Suppose a furnace blower operates at 850 watts while delivering 80,000 Btu/hr through a duct system. It delivery efficiency would be:

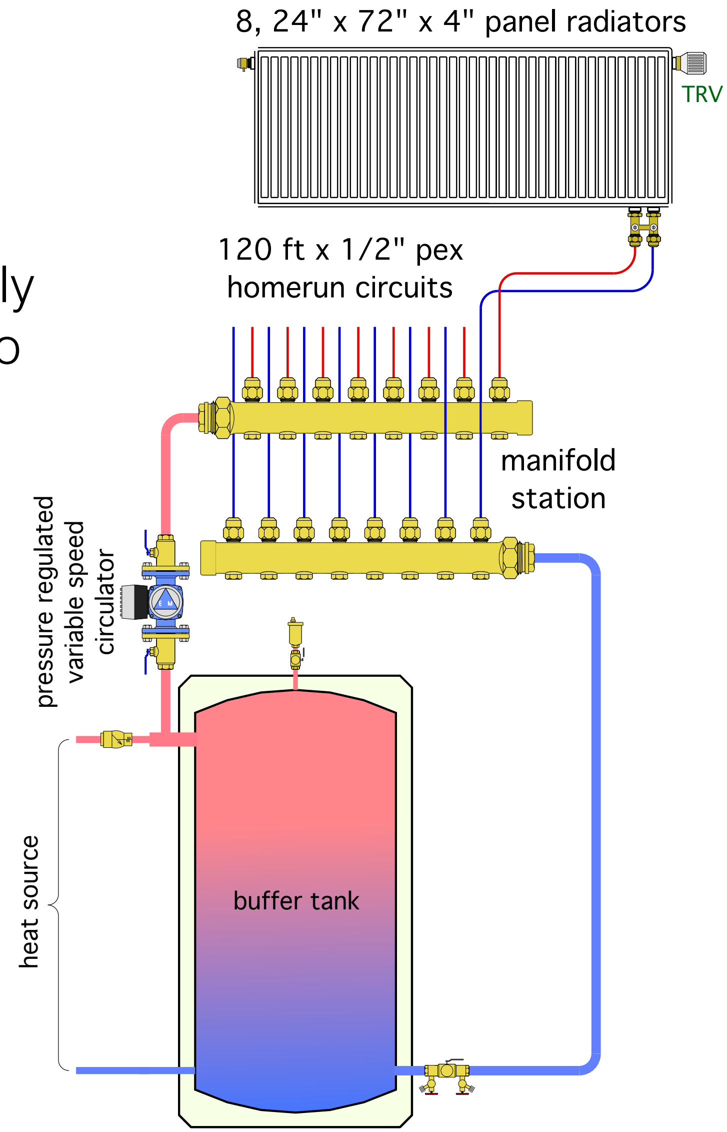
$$\text{distribution efficiency} = \frac{80{,}000 \text{ Btu/hr}}{850 \text{ watts}} = 94 \ \frac{\text{Btu/hr}}{\text{watt}}$$

The hydronic system in this comparison has a distribution efficiency almost four times higher than the forced air system.

Water is vastly superior to air as a conveyor belt for heat.

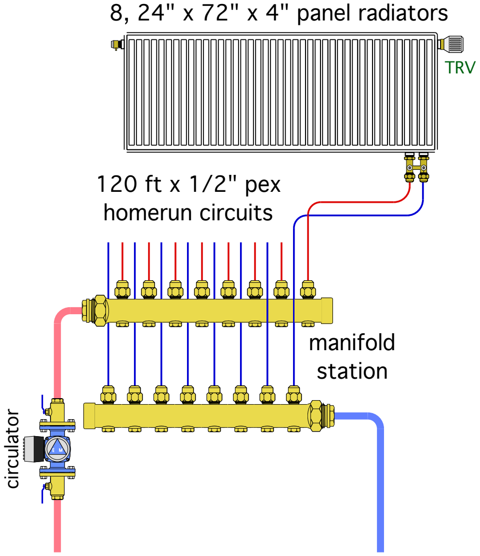
With good design and modern hardware it's possible to design a homerun distribution system for panel radiators that can supply 30,000 Btu/hr design load using only 8.6 watts of electrical power input to circulator!

$$\text{distribution efficiency} = \frac{30{,}800\frac{Btu}{hr}}{8.6watt} = 3581\frac{Btu/hr}{watt}$$



The distribution efficiency possible with a well designed hydronic system far exceeds that attainable with forced air systems

$$\text{distribution efficiency} = \frac{80{,}000 \text{ Btu/hr}}{850 \text{ watts}} = 94 \frac{\text{Btu/hr}}{\text{watt}}$$



$$\text{distribution efficiency} = \frac{30{,}800 \frac{Btu}{hr}}{8.6 watt} = 3581 \frac{Btu/hr}{watt}$$

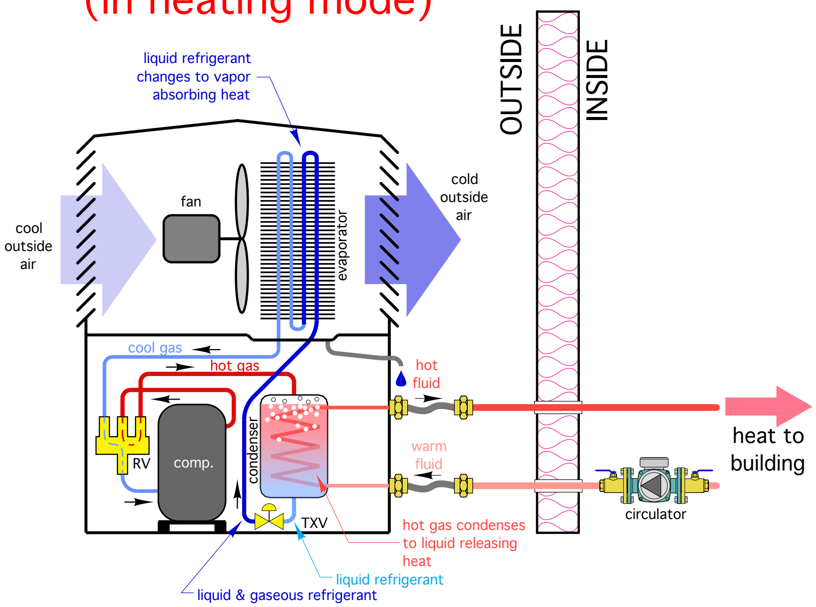
$$\frac{94}{3581} = 2.6\%$$

In this comparison the hydronic system uses only 2.6% of the electrical energy required by the forced air system for equal heat transport (source to load).

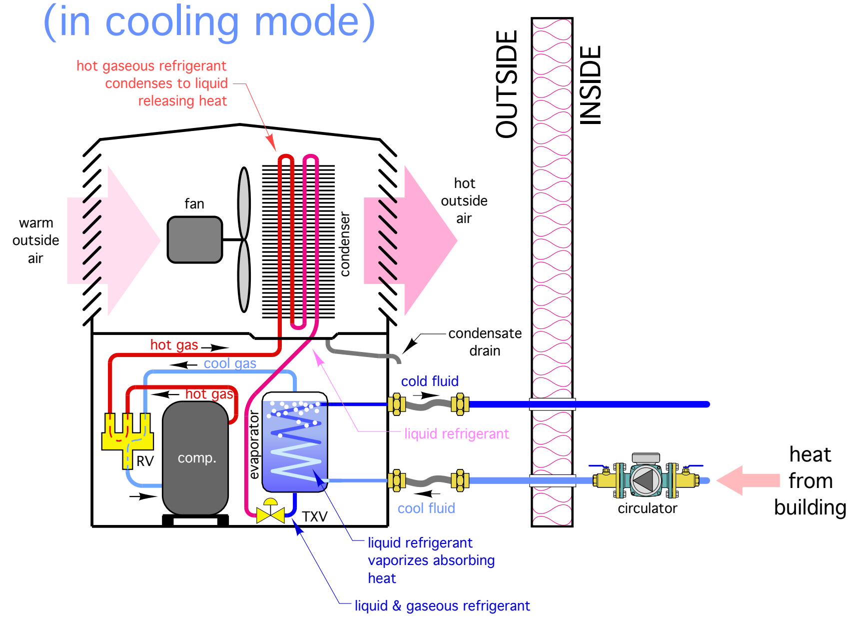
Fundamentals
of
air-to-water
heat pumps

So what is an air-to-water heat pump?

air-to-water heat pump
(in heating mode)



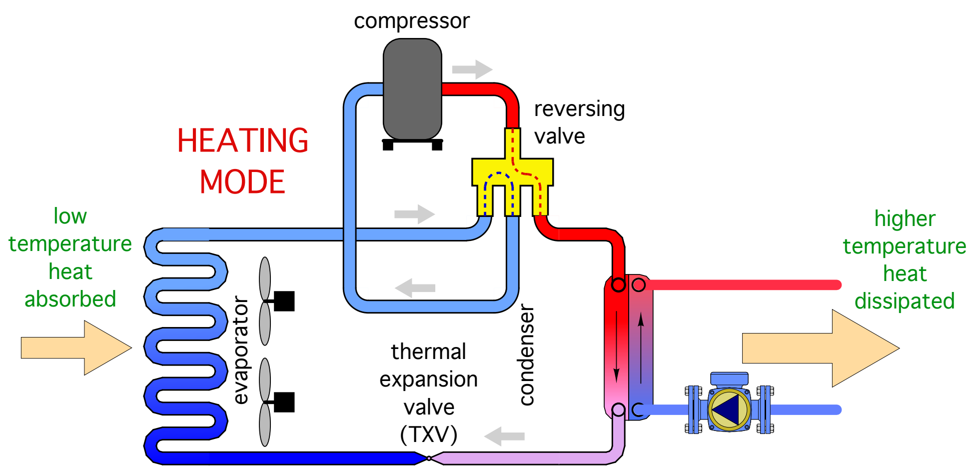
air-to-water heat pump
(in cooling mode)

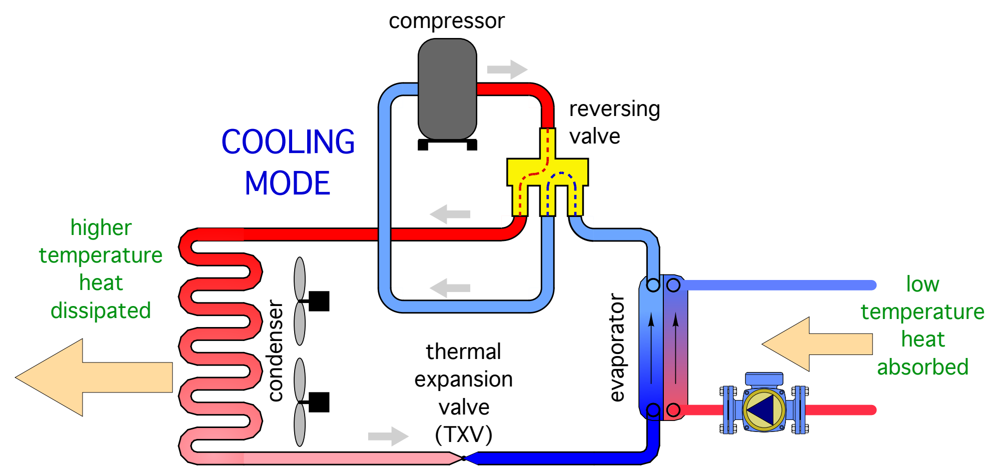


In heating mode: The heat pump extracts low temperature heat from outside air, and transfers it to a fluid stream (water or water & antifreeze) to be used by a hydronic distribution system.

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

Energy flows in a reversible air-to-water heat pump

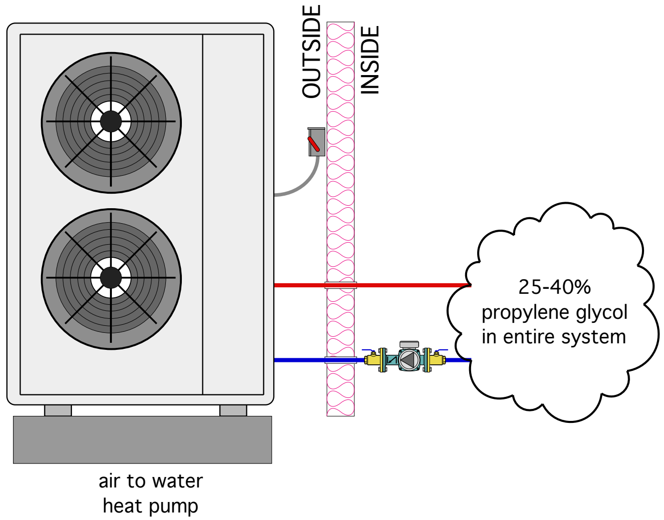




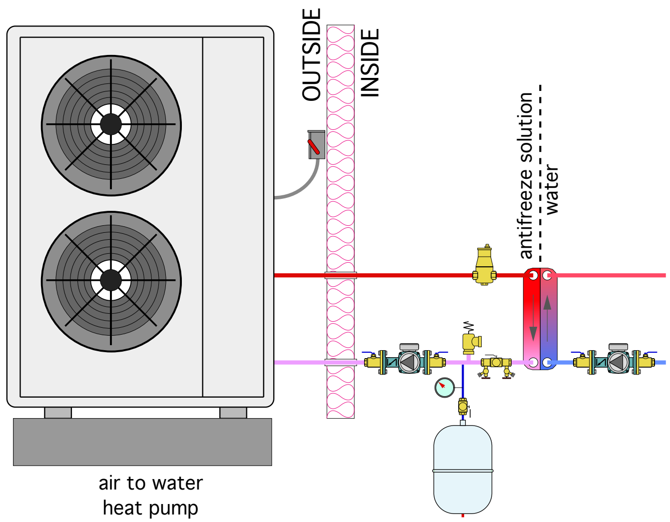
A brazed-plate stainless steel heat exchanger is the refrigerant-to-water heat exchanger (e.g., **condenser**) during heating mode.

A brazed-plate stainless steel heat exchanger is the refrigerant-to-water heat exchanger (e.g., **evaporator**) during cooling mode.

Self-contained ("monobloc") air-to-water heat pumps



Use 25-40% propylene glycol in the entire system



Use 25-40% propylene glycol in the heat pump loop, with water in remainder of system.

The use of a heat exchanger forces the HP to operate at higher condensing temperatures, and thus lower COP.

Requires 2 circulators & additional hardware / installation labor.

- Pre-charged refrigeration system
- Some have internal circulator, others don't
- Should have freeze protection in North American applications

Self-contained ("monobloc") air-to-water heat pumps

Enhanced Monobloc air-to-water heat pump

Indoor unit

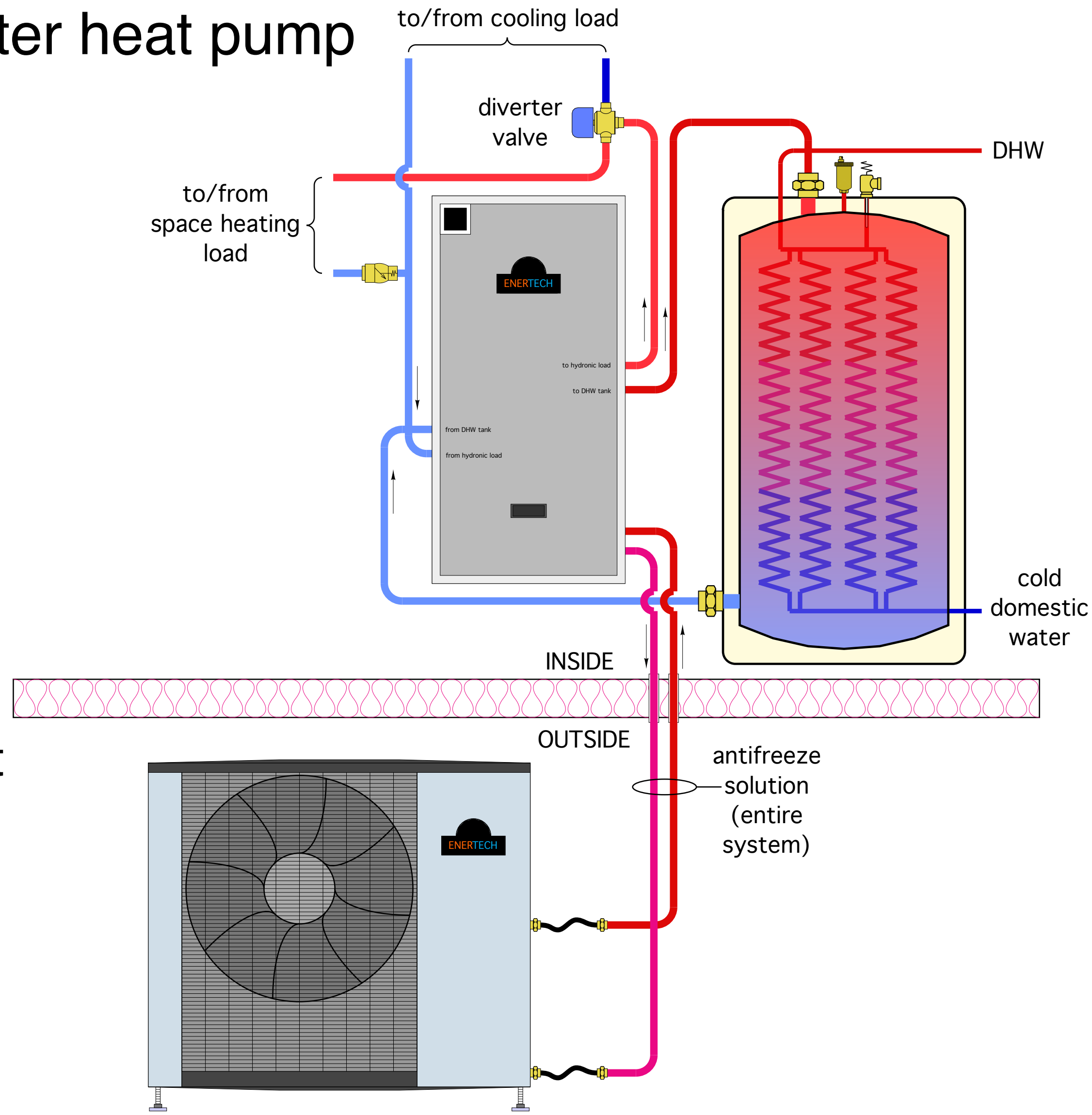
Heating mode:
1. condenser
2. circulator
3. expansion tank
4. aux element
5. controls

Cooling mode:
1. evaporator
2. circulator
3. expansion tank
4. controls

Outdoor unit

Heating mode:
1. compressor
2. evaporator
3. expansion device

Cooling mode:
1. compressor
2. condenser
3. expansion device



Split system air-to-water heat pump

Outdoor unit

Heating mode:
1. compressor
2. evaporator
3. expansion device

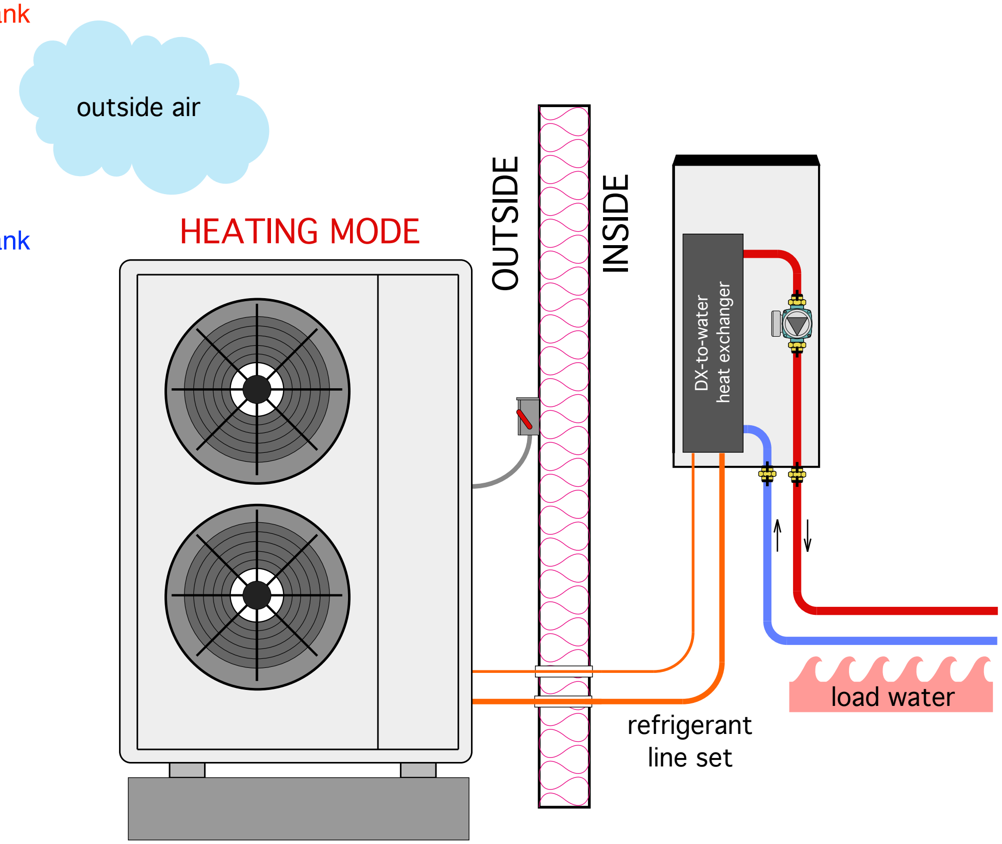
Cooling mode:
1. compressor
2. condenser
3. expansion device

Indoor unit

Heating mode:
1. condenser
2. circulator
3. expansion tank
4. aux element
5. controls

Cooling mode:
1. evaporator
2. circulator
3. expansion tank
4. controls

refrigerant line set



air to water heat pump
(split system)

Split system air-to-water heat pump

images from Nordic Heat Pumps

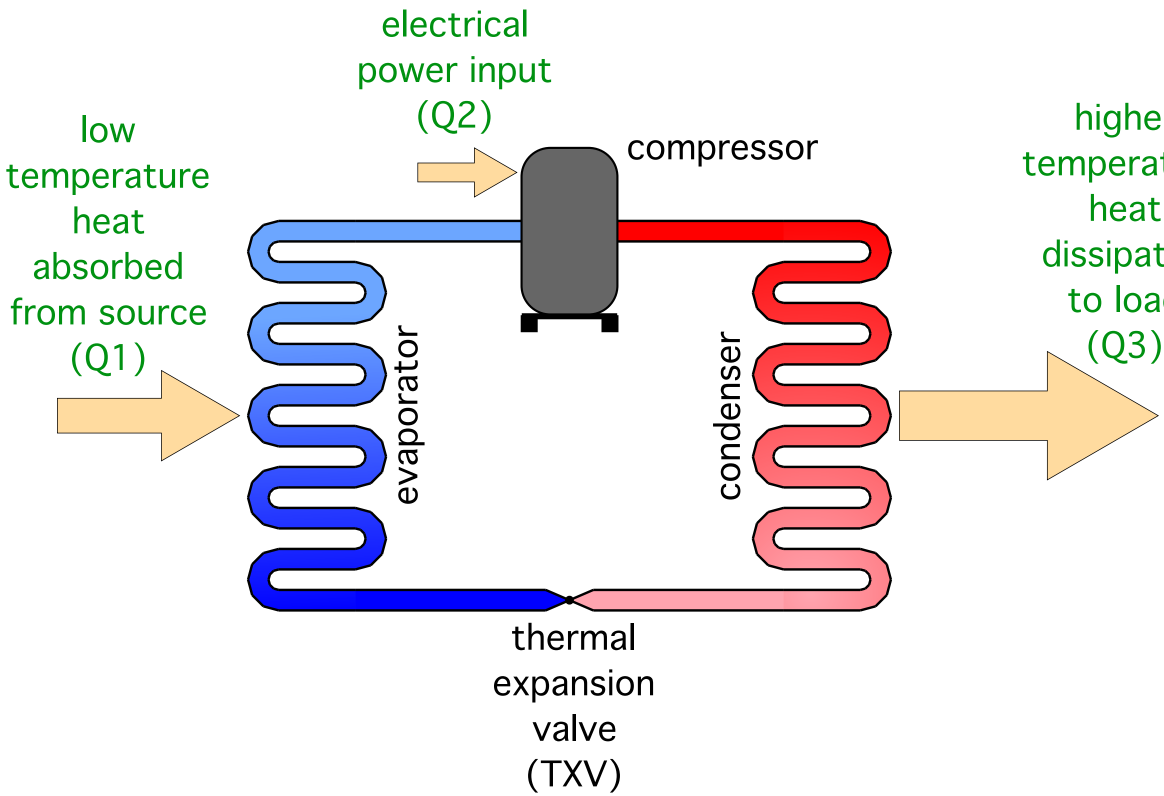
- Fan and coil are only exterior major components

- Compressor and electronics inside

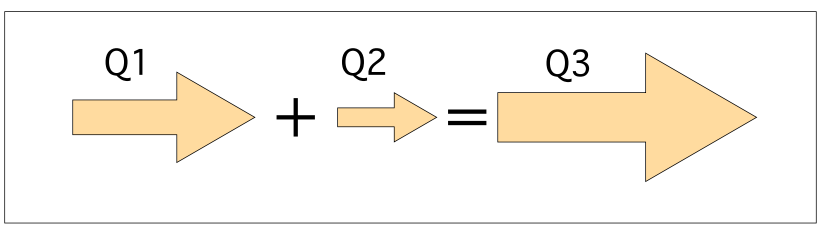
- Allows for domestic water heating via desuperheater

Thermal performance of air-to-water heat pumps

Basic heat pump operation

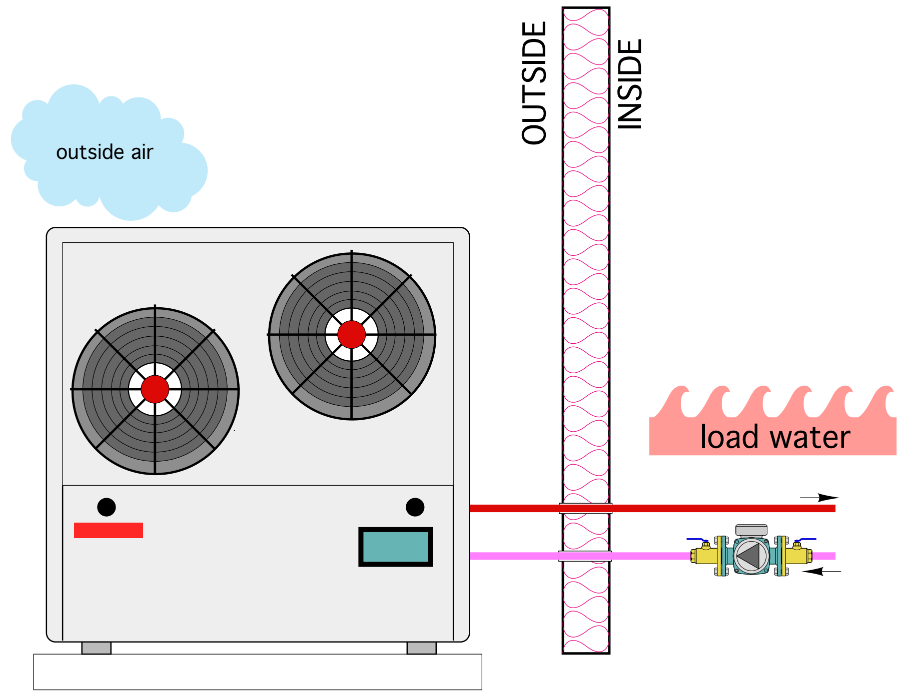


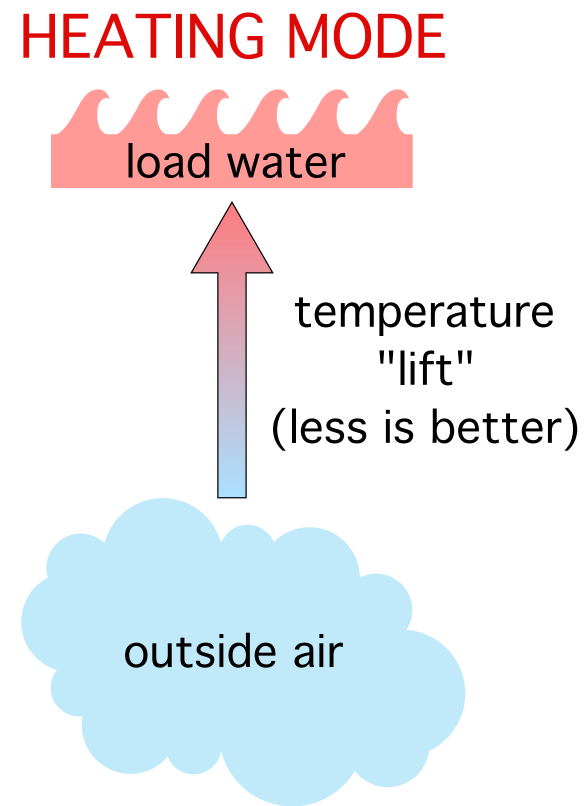
$$COP = \frac{Q3}{Q2}$$



$$COP = \frac{\text{heat output (Btu/hr)}}{\text{electrical input (watt)} \times 3.413}$$

Heating performance:



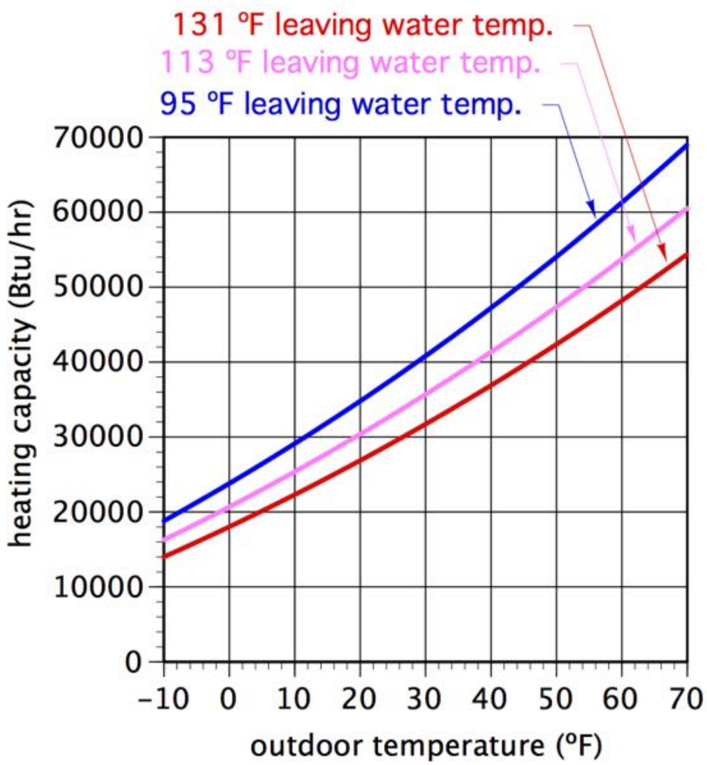


Anything that *reduces* the "temperature lift" *increases* both the heating capacity and COP of the heat pump.

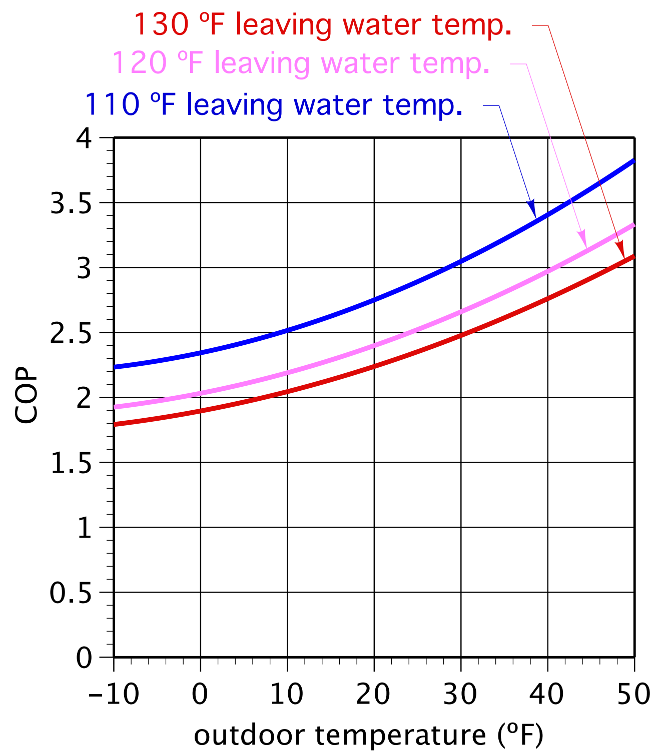
Low temperature distribution systems are critical to good performance.

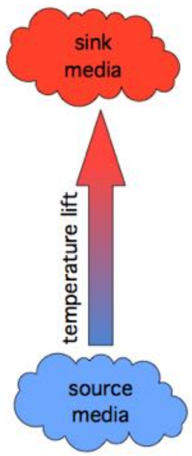
Heating Performance

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



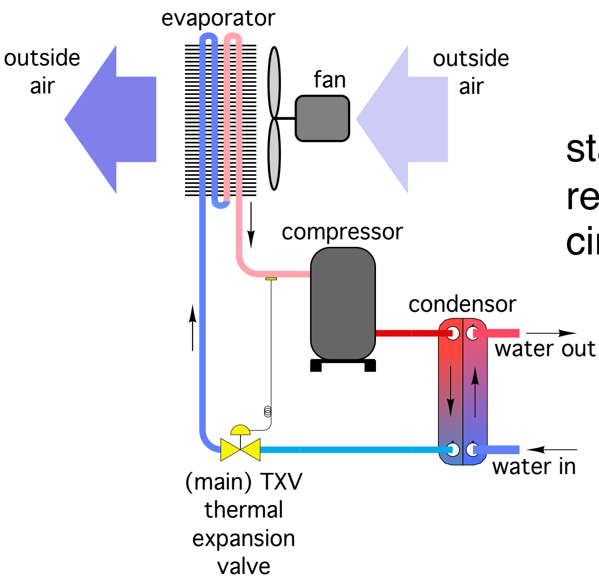
The COP also decreases with increasing condenser temperature.



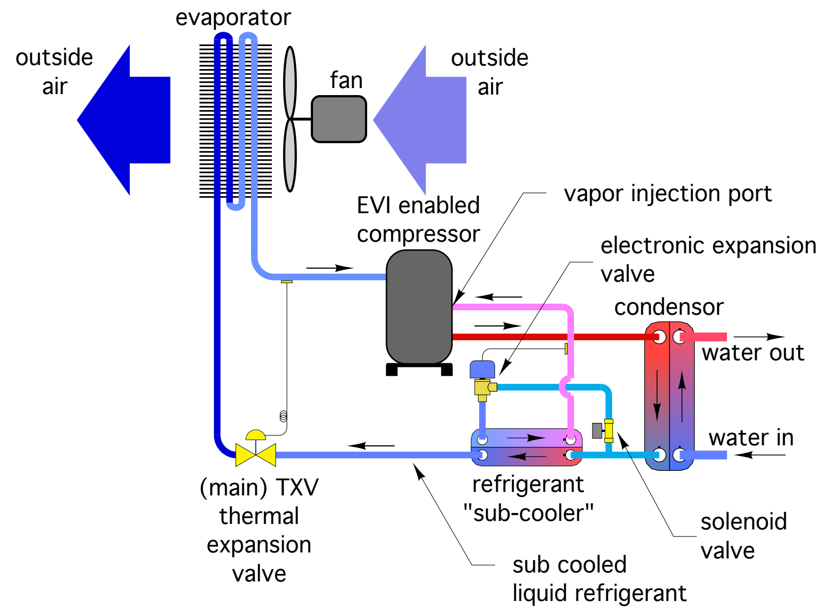


The smaller the "temperature lift" between evaporator and condenser, the higher the heating capacity and COP.

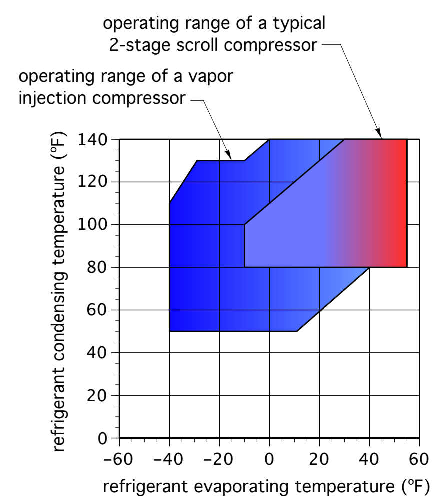
Enhanced
Vapor Injection (EVI)
Systems



standard refrigeration circuit

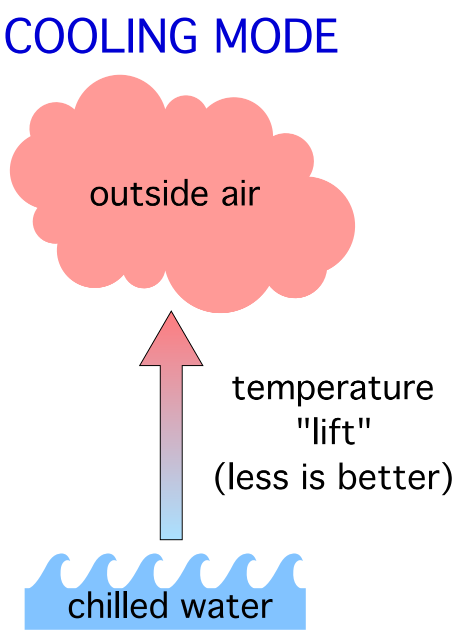


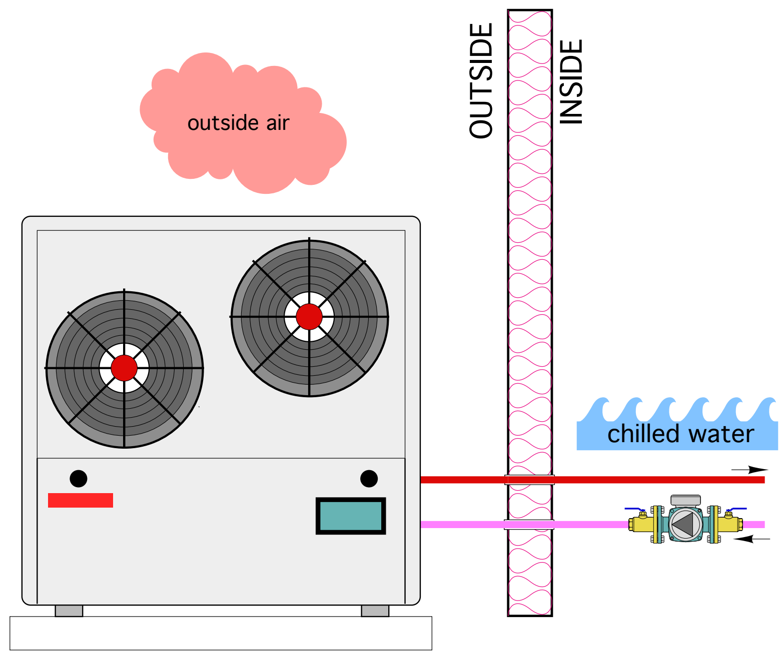
EVI refrigeration circuit



- EVI cools the liquid refrigerant to lower temperature prior to Evaporator (during heating mode)
- EVI increase refrigerant mass flow under lower temperature operation
- Some air to water heat pumps with EVI can operate at outdoor temperature down to -22 °F

Cooling performance:

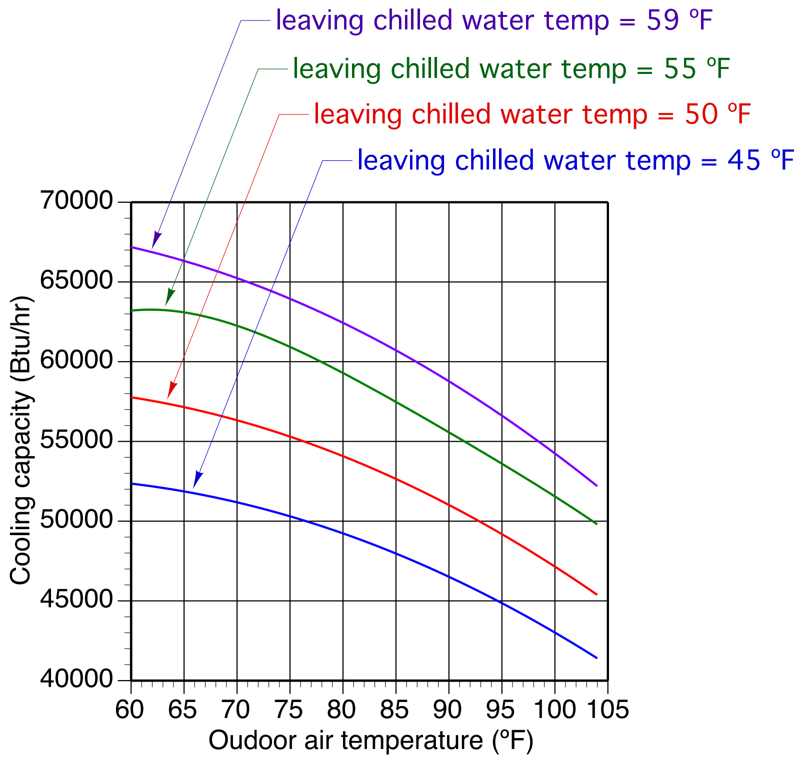


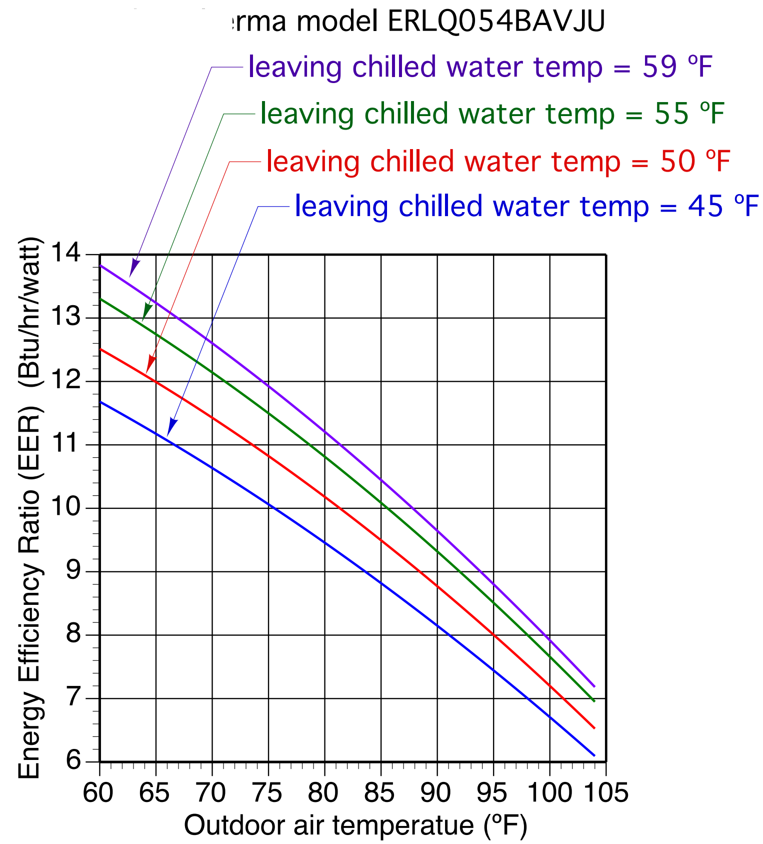


Anything that decreases the temperature lift' increases both the cooling capacity and EER of the heat pump.

Warmer chilled water temperatures improve performance.

Cooling performance of one AWHP:





Cooling capacity

Increases with:

a. lower outdoor temperature

b. Higher chilled water temperature

EER

Increases with:

a. lower outdoor temperature

b. higher chilled water temperature

Why the *North American* air-to-water heat pump market will grow

Global air-to-water heat pump market:

In July 2020, the Japanese HVAC publication JARN reported the pace of air-to-water heat pump adoption, globally, in 2019, increased at an annualized rate of **25.8%**, reaching a demand of **3.42 million units**.

China accounted for just over 2 million of these units. Around 600,000 units were attributed to the European market, lead by France, Germany and Italy.

Many of these heat pumps were installed as part of phase out plans for oil-fired boilers and low efficiency gas-fired boilers.

Asian manufacturers [Daikin, Mitsubishi, Fujitsu, Hitachi, Samsung, LG, Gree, Toshiba]
German manufacturers [Dimplex, Wolf, Viessmanm, Bosch,Vaillant]
Canadian manufacturers [ThermAtlantic, Nordic, Arctic, Aermec]

* Source: JARN July 2020,

Trends supporting an emerging market for air-to-water heat pumps in North America

1. Rapidly growing interest in Net Zero houses:

• The typical net zero house has a very low loss thermal envelop, and a sizable solar photovoltaic array on the roof.

• Net metering laws - where they exist - allow owners of photovoltaic systems to sell surplus electrical power back to the utility at full retail rate.

• Net zero housing units within the U.S. increased by 59% from 2017 to 2018. Over that same period, the increase in net zero housing units in Canada was 240%. Multi-family projects currently represent 71% of the total net zero housing stock. One market research firm anticipates that the global market for net zero buildings will increase at a compound annual growth rate of 39% by 2021.

Surplus kilowatt hours produced on a sunny summer day could conceivably be “parked” on the electrical grid, and reclaimed to run a heat pump on a cold winter night with no technical or economic penalty.


Source: Revision Energy


Source: Zerohomes.org

Trends supporting an emerging market for air-to-water heat pumps in North America

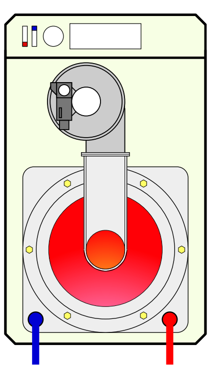
2. Decreasing heating loads:

- ***Pre-1990 houses design load where typically 25-40 Btu/hr/ft²***
- ***Modern low energy houses have typical design loads of 10-15 Btu/hr/ft²***

Consider a 1800 ft² house at 10 Btu/hr/ft² design load = 18000 Btu/hr (at design!)

Often difficult to find a boiler small enough to avoid oversizing, and short cycling under partial loads.

gas-fired modulating / condensing boiler



boiler model	MAXIMUM HEAT OUTPUT (Btu/hr)	MINIMUM HEAT OUTPUT (Btu/hr)
model 55	51,000	7,700
model 85	79,000	7,900
model 110	102,000	10,200
model 155	144,000	14,400
model 200	185,000	18,400
model 285	264,000	26,400
model 399	377,000	75,600

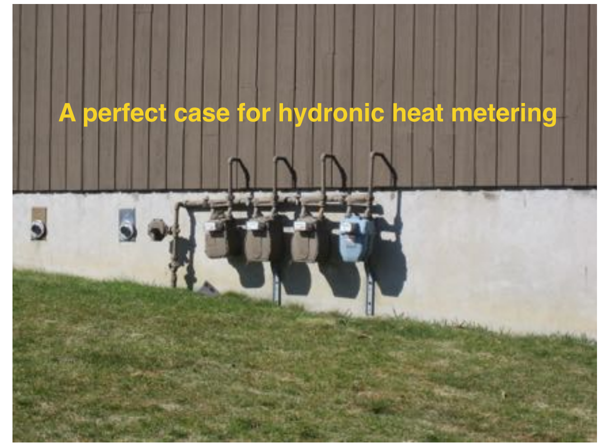
Trends supporting an emerging market for air-to-water heat pumps in North America

3. Eliminating gas eliminates the basic service charge for a gas meter

GAS RESIDENTIAL

Meter Number: [redacted]

Dec 19 reading (Actual)		9524	
Nov 17 reading (Actual)		-9349	
Total Usage CCF 32 days		175	
Delivery Charges			
Basic Service Charge			$20.00
Includes	3CCF	@ 0.000¢ each	$00.00
Next	47 CCF	@ 65.285¢ each	$30.68
Next	125 CCF	@ 62.835¢ each	$78.54
Month Gas Adj		@ 12.22455¢ each	$21.39
NY Assessment	175 CCF	@ 0.96528¢	$1.69
RDM Adjustment	175 CCF	@ 0.72803¢	$1.27
SBC Charge	175 CCF	@ 0.51500¢	$0.90
Government surcharges - Delivery			$5.22
Total Delivery Charges			**$159.69**
Merchant Function Chg	175 CCF @ 2.9453¢		$5.15
Government surcharges - Delivery			$0.17
Merchant Function Charges			**$5.32**
Gas Supply Chg	**175 CCF @ 33.00655¢**		**$57.75**
Government surcharges - Commodity			$0.75
Total Supply Charges			$58.51
CURRENT GAS CHARGES			**$223.52**

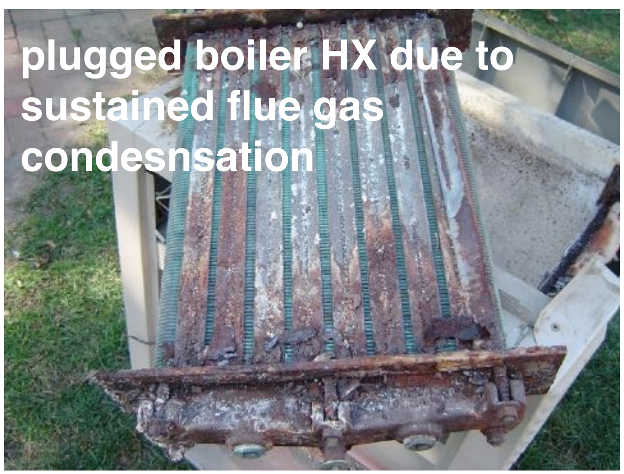


In some low energy houses the basic service charge could exceed the cost of purchased natural gas.

Trends supporting an emerging market for air-to-water heat pumps in North America

4. *Safety / liability issues associated with fossil fuels*

CO leaks inside bldg.


plugged boiler HX due to sustained flue gas condesnsation


fuel leaking from buried tanks


corroded vent piping

Trends supporting an emerging market for air-to-water heat pumps in North America

5. *Moratorium on natural gas service expansion*

National Grid has said it will not approve requests for new or upgraded gas service in its territory in New York City and Long Island until the state approves a $1 billion natural gas pipeline, arguing there will be a lack of adequate gas supply until it's built. The move has roiled developers and business owners who say their inability to get gas has threatened projects and jeopardized their operations.

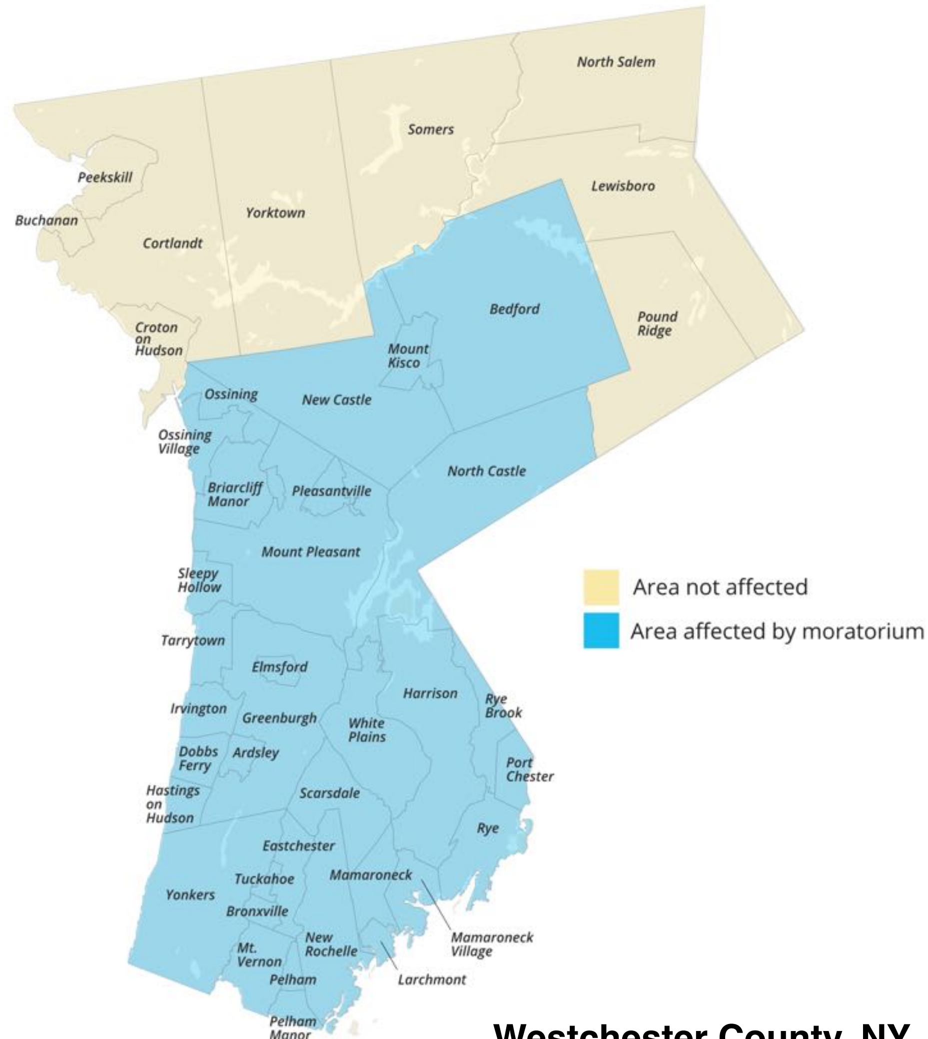
Source: Aug 23, 2019, POLITICO

Holyoke Gas and Electric imposes moratorium on new natural gas service

Updated Feb 14, 2019; Posted Feb 14, 2019

HOLYOKE -- Holyoke Gas and Electric (HG&E) has imposed a moratorium on new natural gas connections for residential and business customers, citing no increases in pipeline capacity by Berkshire Gas and Columbia Gas of Massachusetts.
In a statement, HG&E said the "load has grown significantly and is now operating at capacity during peak periods," which triggered the moratorium on new gas connections. A Tennessee Gas pipeline, known as the Northampton Lateral, became "severely constrained" as a result of high demand in the last 20 years.

Source: MASSlive.com



Westchester County, NY

Trends supporting an emerging market for air-to-water heat pumps in North America

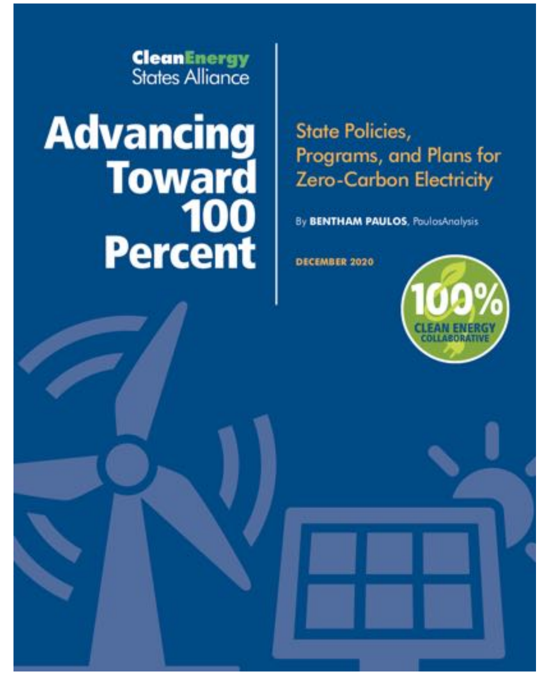
6. *State clean energy goals:*

States with 100 Percent Clean Energy Goals

State	The Goal	Comments
Arizona	100% carbon-free electricity by 2050	Adopted by order of the Arizona Commerce Commission in November 2020, extending and expanding the existing state RPS. Docket number RU-00000A-18-0284.
California	100% carbon-free electricity by 2045	2018 legislation (SB 100) extended and expanded the existing state RPS. State agencies are required to submit implementation plans by January 1, 2021. Also in 2018, Gov. Jerry Brown's Executive Order B-55-18 set a goal of statewide carbon neutrality by no later than 2045, with net negative GHG emissions thereafter.
Colorado	100% carbon-free electricity by 2050 for Xcel Energy	A 2019 law (SB 19-236) codified a pledge previously made by Xcel, whose service territory covers approximately 60% of the state's load. It is mandatory "so long as it is technically and economically feasible."
Connecticut	100% carbon-free electricity by 2040	Governor Ned Lamont's 2019 Executive Order (Number 3) set a 2040 goal for carbon-free electricity and asked the Department of Energy and Environmental Protection to develop a decarbonization plan for the power sector, in line with previous legislation to cut economy-wide carbon emissions by 80% below 2001 levels by 2050.
District of Columbia	100% renewable electricity by 2032 through the RPS	The *Clean Energy DC Omnibus Amendment Act of 2018* (DC Act 22-583) amended the existing RPS to mandate 100% renewable electricity by the year 2032.
Hawaii	100% renewable energy by 2045 through the RPS	2015 legislation (HB623) made Hawaii the first state to set a 100% RPS for the electricity sector.
Louisiana	Net zero greenhouse gas emissions by 2050	Governor John Bel Edwards' 2020 Executive Order (JBE 2020-18) established a Climate Initiatives Task Force to develop a roadmap and make recommendations.

The "operative" word in these energy targets is ELECTRICITY…

State	The Goal	Comments
Maine	100% clean energy by 2050	2019 legislation (LD 1494) increased Maine's RPS to 80% by 2030, and set a goal of 100% by 2050. Also LD1679 sets an economy-wide goal of 80% cuts to greenhouse gases by 2050.
Massachusetts	Net-zero greenhouse gas emissions by 2050	In April 2020, the Executive Office of Energy and Environmental Affairs set a 2050 net-zero goal under the authority of 2008 legislation, and is developing a roadmap by the end of 2020.
Michigan	Economy-wide carbon neutrality by 2050	Governor Gretchen Whitmer's order in 2020 (Executive Directive 2020-10) set a goal "to achieve economy-wide carbon neutrality no later than 2050." It directed the Department of Environment, Great Lakes, and Energy to develop a plan by the end of 2021.
Nevada	100% carbon-free electricity by 2050	2019 legislation (SB 358) raised the RPS to 50% by 2030, and set a goal of a net-zero emission power sector by 2050.
New Jersey	100% carbon-free electricity by 2050	Governor Phil Murphy's Executive Order 28 in 2018 set a carbon free goal for the power sector and directed the BPU to develop an Energy Master Plan, which was released in 2020.
New Mexico	100% carbon-free electricity by 2045	2019 legislation (SB 489) requires a zero-carbon power supply by 2050, with at least 80% from renewables.
New York	100% zero-emission electricity by 2040	2019 legislation (S6599) requires zero-emissions electricity by 2040 and sets a goal of cutting all state GHGs 85% by 2050. A Climate Action Council will develop a plan.
Puerto Rico	100% renewable energy for electricity by 2050	2019 legislation (SB1121), the Public Energy Policy Law of Puerto Rico, set a timeline for reaching 100% renewable electricity by the year 2050.
Rhode Island	100% renewable energy electricity by 2030	Governor Gina Raimondo's 2020 Executive Order (20-01) requires the Office of Energy Resources to "conduct economic and energy market analysis and develop viable policy and programmatic pathways" to meet 100% of statewide electricity deliveries with renewables by 2030.
Virginia	100% carbon-free electricity by 2045 for Dominion Energy and 2050 for Appalachian Power Company	The 2020 *Virginia Clean Economy Act* (House Bill 1526 and Senate Bill 851) requires zero-carbon utilities by 2050 at the latest.
Washington	100% zero-emissions electricity by 2045	2019's *Clean Energy Transformation Act* (SB5116) applies to all utilities. The state Commerce Department started a rulemaking process in August 2019. Utilities must file implementation plans by January 2022.
Wisconsin	100% carbon-free electricity by 2050	Governor Tony Evers' Executive Order (EO38) in 2019 directed a new Office of Sustainability and Clean Energy to "achieve a goal" of all carbon-free power by 2050.



https://www.cesa.org/wp-content/uploads/Advancing-Toward-100.pdf

Trends supporting an emerging market for air-to-water heat pumps in North America

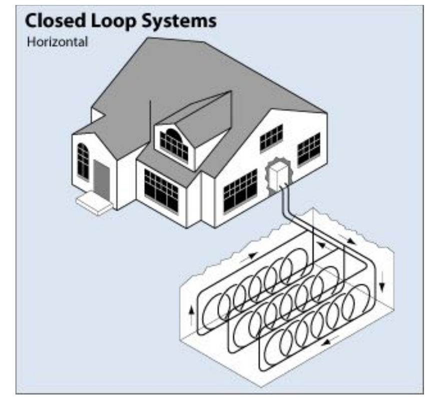
7. Air-to-water heat pumps are significantly less expensive to install compared to geothermal heat pumps:

This is especially true if vertical boreholes are required for the earth loop.

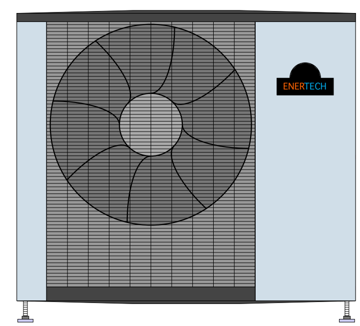
In my area, these holes cost about $3,000+ per ton for drilling, pipe insertion, and grouting. Additional cost is incurred for connecting multiple vertical piping loops, and routing piping back to the location of the heat pump.

In simplest terms: Air-to-water heat pumps eliminate the geothermal loop

geothermal heat pump
typical installed cost = $X



air-to-water heat pump
typical installed cost
= $(30% to 50%)X



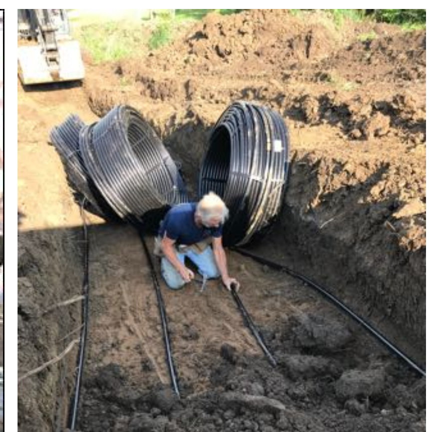
Trends supporting an emerging market for air-to-water heat pumps in North America

8. Air-to-water heat pumps are <u>significantly less disruptive to install</u> compared to geothermal heat pumps:

Horizontal earth loops require large land areas and major excavation.

In my area, vertical earth loops cost about $3,000+ per ton for drilling, pipe insertion, and grouting. Additional cost is incurred for connecting multiple vertical piping loops, and routing piping back to the location of the heat pump. The drill "tailings" usually have to be removed from the site.

Replacement of any affected pavements or landscaping also needs to be factored into the cost of installing a geothermal heat pump system.



Trends supporting an emerging market for air-to-water heat pumps in North America

9. The high COP cited for some geothermal heat pumps doesn’t include the power required to move flow through the earth loop.

Example of a commercially available earth loop flow center.
4, UP26-150 circulators (370 watts each) = 1,480 watts pumping power input.

The ANSI 13256-2 standard for geo heat pump COP includes an estimate for the power required to move flow through the heat pump - BUT DOESN’T INCLUDE ANY ALLOWANCE FOR THE EARTH LOOP PUMPING POWER.

The high flow and head required in some geothermal earth loops requires substantial circulator power.

Example: A specific water-to-water geothermal heat pump has the follow listed performance information:
Earth loop entering temperature = 30ºF
Entering load water temperature = 100 ºF
Flow rate (both evaporator and condenser) = 9 gpm
Heating capacity = 27,700 Btu/hr
Electrical power input = 2370 watts

Based on a typical earth loop, the pumping requirement is 10.5 gpm at 35.5 feet of head. This equates to an estimated pump input of 287 watts.

$$COP_{\text{HP only}} = \frac{27700\frac{Btu}{hr}}{(2.37kw)\left(\frac{3413\frac{Btu}{hr}}{kw}\right)} = 3.42$$

$$COP_{\text{HP +loop pump}} = \frac{27700\frac{Btu}{hr}}{(2.37kw + 0.287kw)\left(\frac{3413\frac{Btu}{hr}}{kw}\right)} = 3.05$$

Nominal 11% drop in “net” COP

Trends supporting an emerging market for air-to-water heat pumps in North America

10. The "COP gap" between geothermal and low ambient air source heat pumps is closing.

You don't pay for COP! (you pay for kilowatt•hours)

Example: A house has a design heating load of 36,000 Btu/hr when the outdoor temperature is 0 ºF, and the indoor temperature is 70 ºF. The house is located in Syracuse, NY with 6,720 annual heating ºF•days. The estimated annual space heating energy use is 49.7 MMBtu. Assume that one heat pump option has a seasonal average COP of 3.28. The other heat pump has a seasonal COP of 2.8.

$$S = load\left[\frac{1}{COP_L} - \frac{1}{COP_H}\right] = 49.7\left[\frac{1}{2.8} - \frac{1}{3.28}\right] = 2.6\,MMBtu\,/\,year$$

The cost savings associated with an energy savings of 2.6 MMBtu/hr depends on the cost of electricity. For example, if electricity sells at a flat rate of $0.13 / KWHR, the cost savings would be:

$$\text{Cost savings} = \frac{2.6\,MMBtu}{year}\left(\frac{292.997\,KWHR}{1\,MMBtu}\right)\left(\frac{\$0.13}{KWHR}\right) = \$99\,/\,year$$

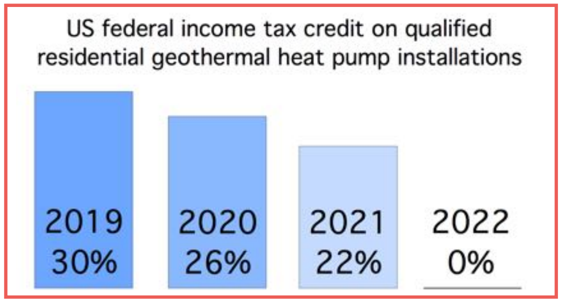
Can the added cost of the higher COP heat pump be recovered in a reasonable time?

Trends supporting an emerging market for air-to-water heat pumps in North America

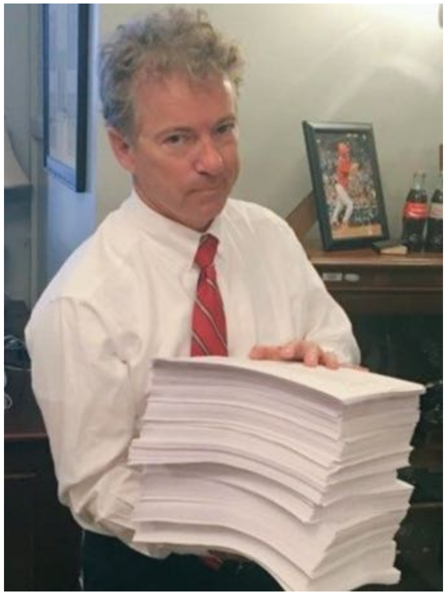
11. The geothermal heat pump industry is highly dependent on subsidies:

https://www.geoexchange.org/news/

50% decline in US residential GHP shipments during 2017, after federal tax credit expired 12/31/16.



This tax credit was reinstated in Feb 2018, retroactive to its 12/13/16 expiration.



Do you want to build your business model on the assumption that subsidies will always be there?

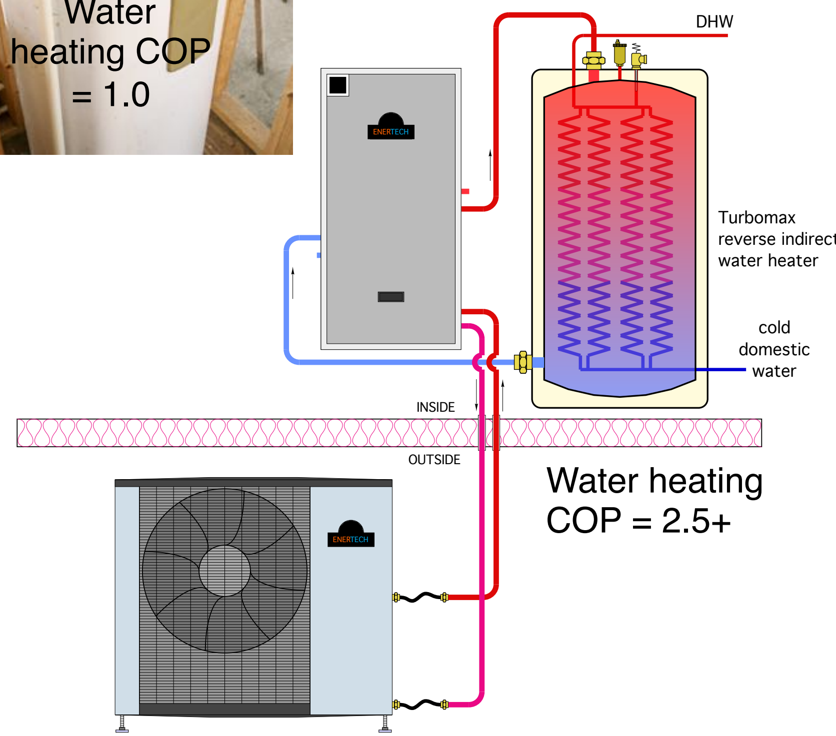
Trends supporting an emerging market for air-to-water heat pumps in North America

12. As home space heating loads get smaller, the domestic water heating load becomes an increasingly higher percentage of the total annual heating energy requirement.

Some estimates put the DHW load at 25-30 percent of the total annual energy requirement in a well insulated modern home.

Most ductless mini-split heat pumps cannot provide domestic water heating, but a properly configured air-to-water heat pump can.

A standard electric water heater providing domestic water heating in a situation where the heat pump can not, delivers heat at a COP of 1.0. If that energy was instead attained through an air-to-water heat pump, it could be delivered at a COP averaging perhaps 2.5 over the year. For a family of 4, needing 60 gallons per day of water heated from 50 to 120 ºF, and assuming electrical energy priced at $0.12 per KWHR, the *difference* in annual domestic water heating cost between these scenarios is $270.



Trends supporting an emerging market for air-to-water heat pumps in North America

13. Boilers don't offering cooling.

This has long been an "Achilles heel" for hydronics

Rather than tell prospective "heating" customers that they need an entirely separate system if the want cooling, heat pumps offer the opportunity to it in a single system.

Don't give this potential profit to another sub-contractor….

Several approaches:

- *single zone cooling / multi-zone heating*
- *zoned air handlers*
- *zoned wall consoles / cassettes*
- *single coil with zoned fans*
- *radiant panel cooling*

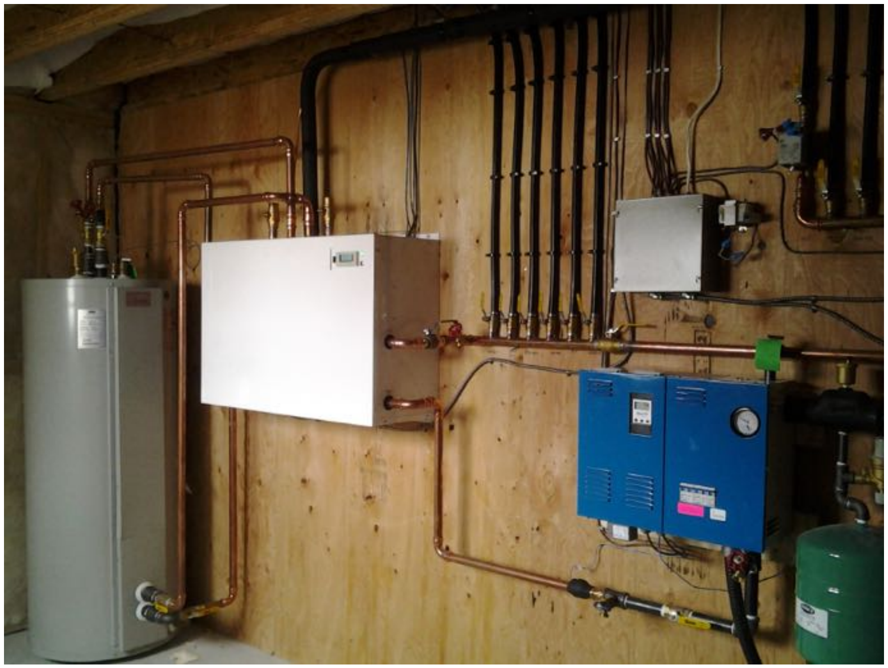
30 minute break…

will resume at 3:00 PM sharp

New Concepts for air-to-water heat pumps

Bring your own condenser...

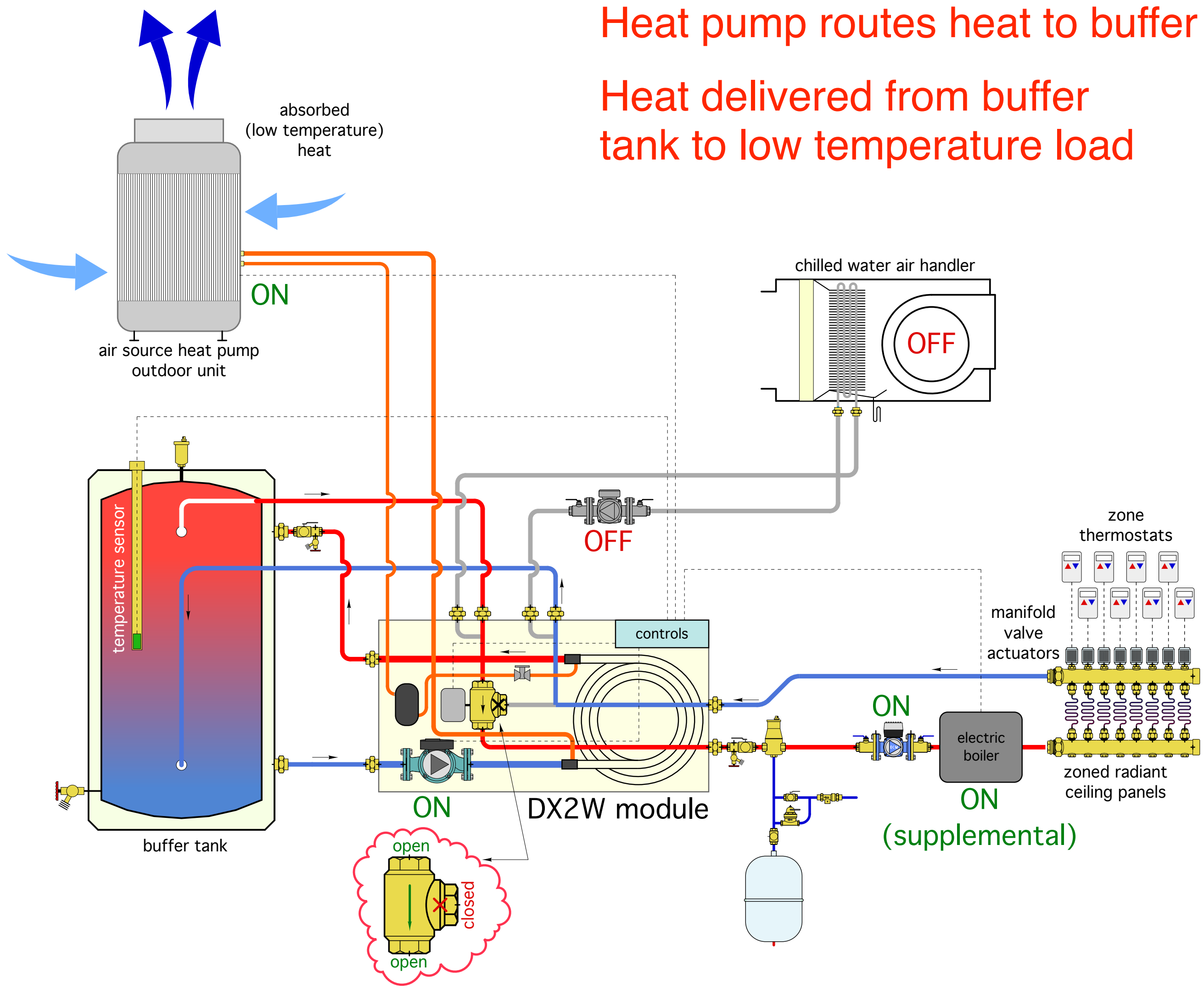
ThermAtlantic Energy Products, Inc.



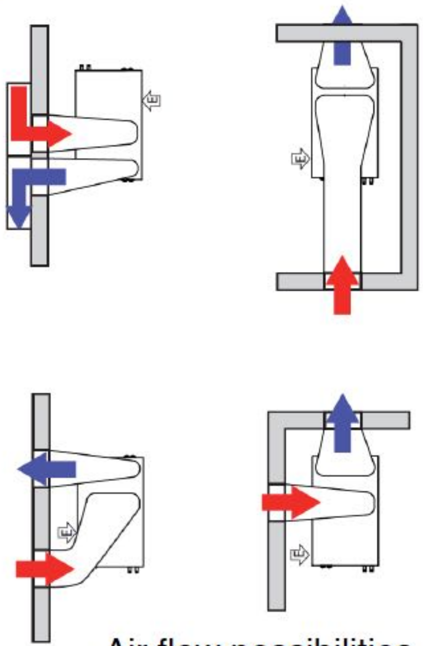
Bring your own condenser... **Heating mode**

Heat pump routes heat to buffer tank

Heat delivered from buffer tank to low temperature load



Interior air-to-water heat pump



Air flow possibilities

Advantages:

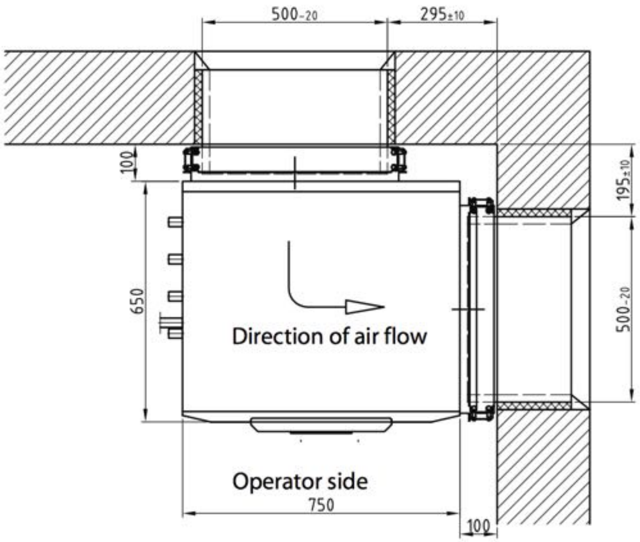
- No outdoor equipment beyond air intake and discharge grills
- Less potential to freeze water containing within the heat pump
- Less environmental weathering effect on equipment
- Reduced potential for debris on heat transfer coil surfaces

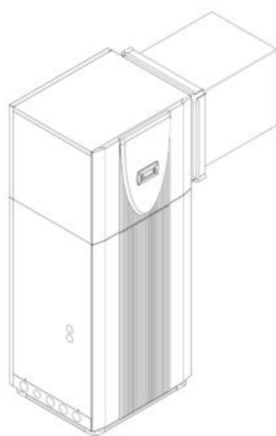
Disadvantages:

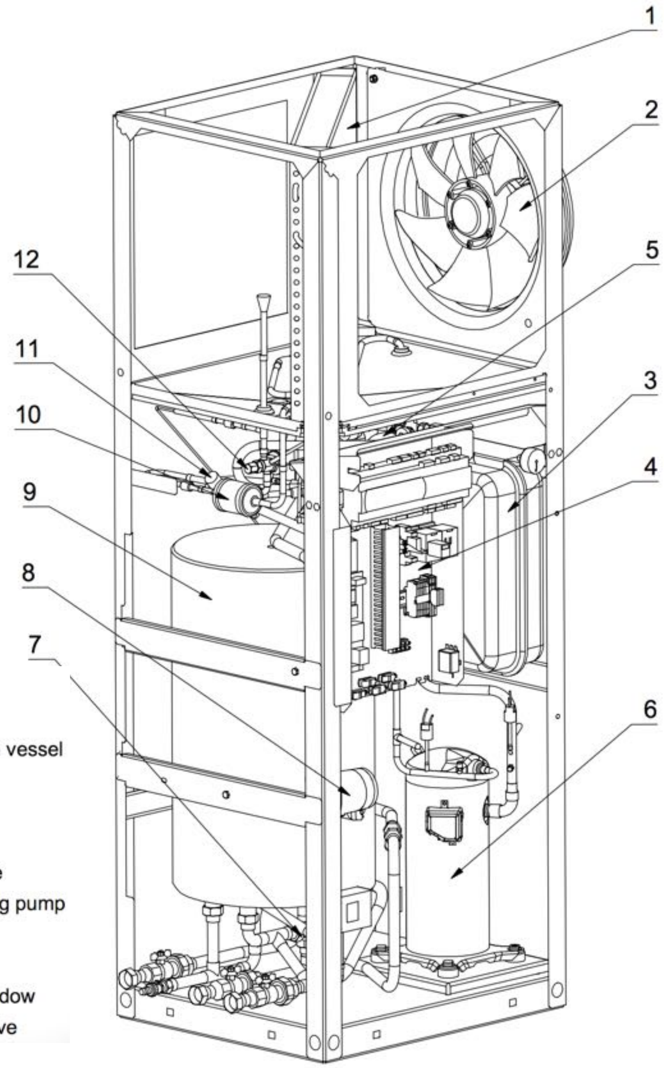
- Require more interior space
- Brings compressor sound within the structure
- Requires careful coordination with building design to ensure that adequately sized ducting can be accommodated, and terminated above snow level.

image courtesy of HotJet.cz

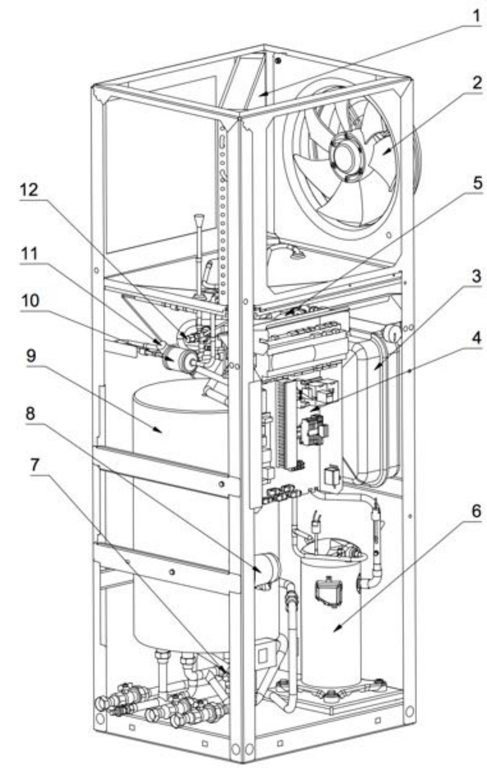
Interior *air-to-water heat pump (corner)*







1) Evaporator
2) Ventilator
3) 24 l expansion vessel
4) Switch box
5) Liquifier
6) Compressor
7) Overflow valve
8) Heat circulating pump
9) Buffer tank
10) Filter dryer
11) Inspection window
12) Expansion valve



1) Evaporator
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8) Heat circulating pump
9) Buffer tank
10) Filter dryer

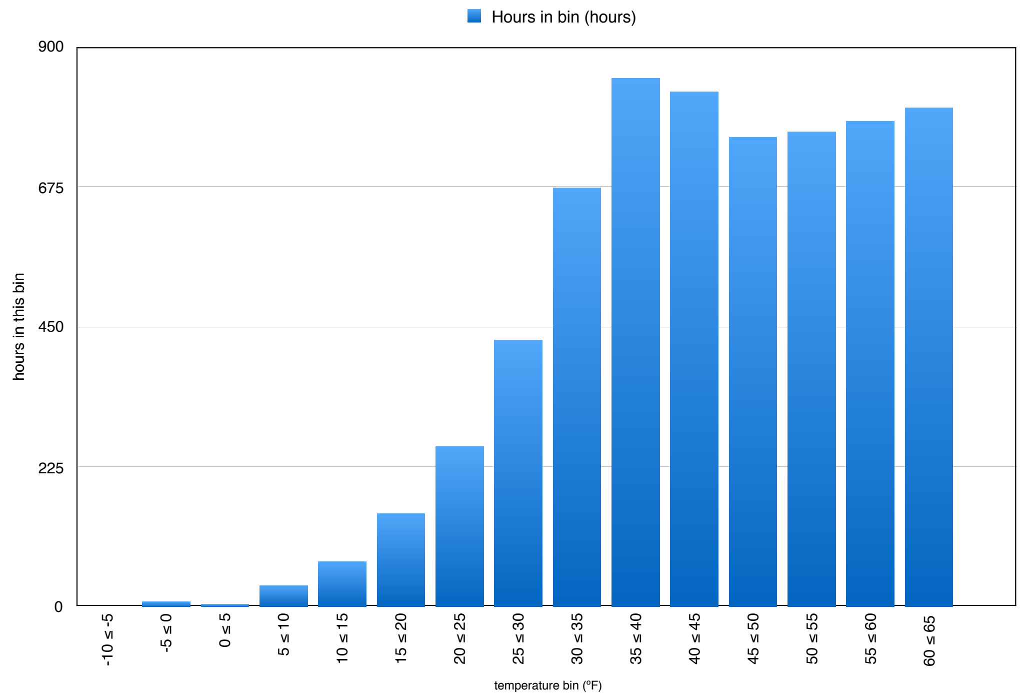
Heating mode Performance Modeling

Heating Performance

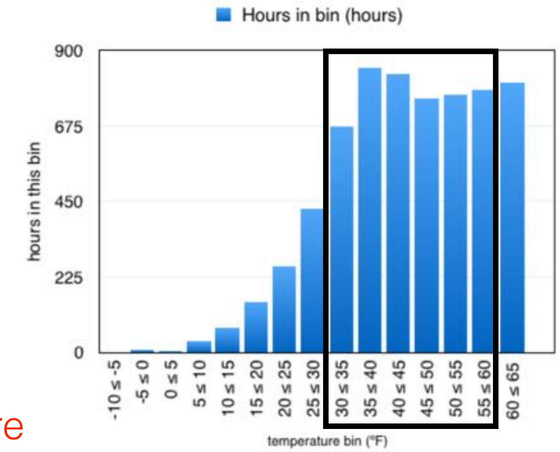
How does a specific heat pump match up with a building load and local weather?

Bin temperature data for Boston

Bin range (ºF)	Hours in bin (hours)	Average outdoor temp of bin (ºF)	% of design load	Hours during which load ≥ this % of design load
-10 ≤ -5	1	-7.5	127	1
-5 ≤ 0	9	-2.5	118.9	10
0 ≤ 5	4	2.5	110.7	14
5 ≤ 10	35	7.5	**100**	49
10 ≤ 15	74	12.5	94	123
15 ≤ 20	151	17.5	86	274
20 ≤ 25	256	22.5	78	530
25 ≤ 30	429	27.5	70	959
30 ≤ 35	674	32.5	62	1633
35 ≤ 40	848	37.5	53	2481
40 ≤ 45	828	42.5	45	3309
45 ≤ 50	757	47.5	37	4066
50 ≤ 55	766	52.5	29	4832
55 ≤ 60	781	57.5	20.5	5613
60 ≤ 65	804	62.5	12.3	6417



Performance estimating using spreadsheet simulations



BUILDING:
75,000 Btu/hr design load (9°F outdoor design temp)

HEAT PUMP: nominal 5-ton low ambient EVI

EXISTING HYDRONIC DISTRIBUTION SYSTEM requires 175 ° F water at design load.

CLIMATE: Boston bin temperature data

CONSTRAINTS:

- Heat pump limited to approximately 130°F leaving water temperature
- Heat pump limited to 60,000 Btu/hr & COP≤4.5
- No heating load above 60 °F outdoor temperature

c	ave outdoor temperature for bin (°F)	hours in bin for BOSTON	Supply based on reset ratio (0.897) and 67.5F room	house load (Btu/hr)	bo for heating capacity of SSI	b1 for heating capacity of SSI	heating capacity (SSI) (Btu/hr)	bo for COP of SSI	b1 for COP of SSI	b2 for COP of SSI	COP of SSI	total Btus consumed by house in this bin	run hours of heat pump	run hours * COP for this bin	auxiliary energy required (Btu)
-10 to -5	-7.5	1	205.35	96,153.8	35850.884025	449.9817315	32,476.02	-0.5190999999999	-0.0053407743	0.0000372929231	0	96,153.8	1.00	0.00	63,677.83
-5 to 0	-2.5	9	196.16	89,743.6	36775.75184	461.5878744	35,621.78	-0.28016	-0.00295966368	0.000030943699	0	807,692.3	9.00	0.00	487,096.27
0 to 5	2.5	4	186.97	83,333.3	37700.619655	473.1940173	38,883.60	-0.0412199999999	-0.0005785530600	0.0000252638577	0	333,333.3	4.00	0.00	177,798.91
5 to 10	7.5	35	177.78	76,923.1	38625.48747	484.8001602	42,261.49	0.19772	0.00180255756	0.0000202533982	0	2,692,307.7	35.00	0.00	1,213,155.59
10 to 15	12.5	74	168.59	70,512.8	39550.355285	496.4063031	45,755.43	0.43666000000000	0.00418366818	0.0000159123209	0	5,217,948.7	74.00	0.00	1,832,046.60
15 to 20	17.5	151	159.4	64,102.6	40475.2231	508.012446	49,365.44	0.6756	0.0065647788	0.0000122406258	0	9,679,487.2	151.00	0.00	2,225,305.60
20 to 25	22.5	256	150.21	57,692.3	41400.090915	519.6185889	53,091.51	0.91454	0.00894588942	0.0000092383128	0	14,769,230.8	278.18	0.00	14,769,230.8
25 to 30	27.5	429	141.02	51,282.1	42324.95873	531.2247318	56,933.64	1.15348	0.01132700004	0.0000069053820	0	22,000,000.0	386.41	0.00	22,000,000
30 to 35	32.5	674	131.83	44,871.8	43249.826545	542.8308747	60,000.00	1.39242	0.01370811066	0.0000052418333	**1.843**	30,243,589.7	504.06	929.22	0.00
35 to 40	37.5	848	122.64	38,461.5	44174.69436	554.4370176	60,000.00	1.63136	0.01608922128	0.0000042476668	**2.241**	32,615,384.6	543.59	1218.01	-0.00
40 to 45	42.5	828	113.45	32,051.3	45099.562175	566.0431605	60,000.00	1.8703	0.0184703319	0.0000039228825	**2.662**	26,538,461.5	442.31	1177.59	0
45 to 50	47.5	757	104.26	25,641.0	46024.42999	577.6493034	60,000.00	2.10924	0.02085144252	0.0000042674803	**3.109**	19,410,256.4	323.50	1005.88	0
50 to 55	52.5	766	95.07	19,230.8	46949.297805	589.2554463	60,000.00	2.34818	0.02323255314	0.0000052814602	**3.582**	14,730,769.2	245.51	879.54	0
55 to 60	57.5	781	85.88	12,820.5	47874.16562	600.8615892	60,000.00	2.58712	0.02561366376	0.0000069648224	4.500	10,012,820.5	166.88	750.96	0
60 to 65	62.5	804	76.69	0.0	48799.033435	612.4677321	60,000.00	2.82606	0.02799477438	0.0000093175666	4.500	0.0	0.00	0.00	0
65 to 70	67.5	819	67.5	0.0	49723.90125	624.073875	60,000.00	3.065	0.030375885	0.0000123396931	4.500	0.0	0	0.00	0.00
TOTALS												**189,147,435.9**	**3164.45**	**5961.19**	**42,768,312**
														seasonal average COP	% of total energy supplied by heat pump
														1.88	0.774

PREDICTIONS:

77.4% of total space heating energy supplied by heat pump.

Seasonal average COP = 1.88

Performance estimating using spreadsheet simulations

BUILDING:
75,000 Btu/hr design load
(9°F outdoor design temp)

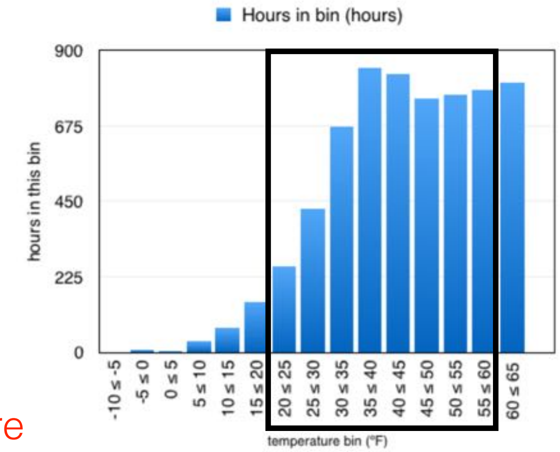
HEAT PUMP: nominal 5-ton low ambient EVI

EXISTING HYDRONIC DISTRIBUTION SYSTEM requires 150 ° F water at design load.

CLIMATE: Boston bin temperature data

CONSTRAITS:

- Heat pump limited to approximately 130°F leaving water temperature
- Heat pump limited to 60,000 Btu/hr & COP≤4.5
- No heating load above 60 °F outdoor temperature



bin temperature range	ave outdoor temperature for bin (°F)	hours in bin for BOSTON	Supply based on reset ratio (0.897) and 67.5F room	house load (Btu/hr)	bo for heating capacity of SSI	b1 for heating capacity of SSI	heating capacity (SSI) (Btu/hr)	bo for COP of SSI	b1 for COP of SSI	b2 for COP of SSI	COP of SSI	total Btus consumed by house in this bin	run hours of heat pump	run hours * COP for this bin	auxiliary energy required (Btu)
-10 to -5	-7.5	1	173.25	96,153.8	39081.379875	490.5211425	35,402.47	0.3155	0.0029762715	0.00001802990763	0	96,153.8	1.00	0.00	60,751.37
-5 to 0	-2.5	9	166.2	89,743.6	39790.8813	499.424658	38,542.32	0.498800000000000	0.0048029124	0.0000148930354	0	807,692.3	9.00	0.00	460,811.43
0 to 5	2.5	4	159.15	83,333.3	40500.382725	508.3281735	41,771.20	0.682100000000000	0.006629553300000	0.0000121500953	0	333,333.3	4.00	0.00	166,248.52
5 to 10	7.5	35	152.1	76,923.1	41209.88415	517.231689	45,089.12	0.865400000000000	0.0084561942	0.0000098010873	0	2,692,307.7	35.00	0.00	1,114,188.43
10 to 15	12.5	74	145.05	70,512.8	41919.385575	526.1352045	48,496.08	1.0487	0.0102828351	0.00000784601145	0	5,217,948.7	74.00	0.00	1,629,239.12
15 to 20	17.5	151	138	64,102.6	42628.887	535.03872	51,992.06	1.232	0.012109476	0.0000062848675	0	9,679,487.2	151.00	0.00	1,828,685.42
20 to 25	22.5	256	130.95	57,692.3	43338.388425	543.9422355	55,577.09	1.4153	0.0139361169	0.00000511765581	1.731	14,769,230.8	256.00	443.25	541,496.06
25 to 30	27.5	429	123.9	51,282.1	44047.88985	552.845751	59,251.15	1.5986	0.0157627578	0.0000043444376	2.035	22,000,000.0	371.30	755.73	0.00
30 to 35	32.5	674	116.85	44,871.8	44757.391275	561.7492665	60,000.00	1.7819	0.0175893987	0.0000039650284	2.358	30,243,589.7	504.06	1188.44	0.00
35 to 40	37.5	848	109.8	38,461.5	45466.8927	570.652782	60,000.00	1.9652	0.0194160396	0.00000397961291	2.699	32,615,384.6	543.59	1467.09	-0.00
40 to 45	42.5	828	102.75	32,051.3	46176.394125	579.5562975	60,000.00	2.1485	0.0212426805	0.0000043881294	3.059	26,538,461.5	442.31	1353.13	0
45 to 50	47.5	757	95.7	25,641.0	46885.89555	588.459813	60,000.00	2.3318	0.0230693214	0.0000051905780	3.439	19,410,256.4	323.50	1112.63	0
50 to 55	52.5	766	88.65	19,230.8	47595.396975	597.3633285	60,000.00	2.5151	0.0248959623	0.0000063869586	3.840	14,730,769.2	245.51	942.71	0
55 to 60	57.5	781	81.6	12,820.5	48304.8984	606.266844	60,000.00	2.6984	0.0267226032	0.0000079772714	4.500	10,012,820.5	166.88	750.96	0
60 to 65	62.5	804	74.55	0.0	49014.399825	615.1703595	60,000.00	2.8817	0.0285492441	0.0000099615162	4.500	0.0	0.00	0.00	0
65 to 70	67.5	819	67.5	0.0	49723.90125	624.073875	60,000.00	3.065	0.030375885	0.0000123396931	4.500	0.0	0.00	0.00	0.00
TOTALS												189,147,435.9	3127.16	8013.94	5,801,420
														seasonal average COP	% of total energy supplied by heat pump
based on 150°F water at design load														2.56	0.969

PREDICTIONS:

96.9% of total space heating energy supplied by heat pump.

Seasonal average COP = 2.56

Performance estimating using spreadsheet simulations

BUILDING:
75,000 Btu/hr design load
(9°F outdoor design temp)

HEAT PUMP: Enertech AV060

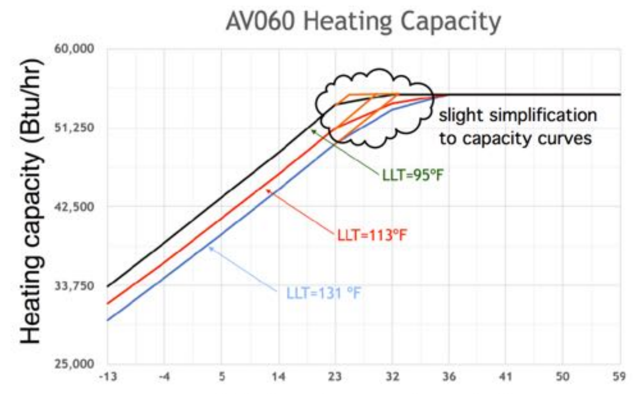
HYDRONIC DISTRIBUTION SYSTEM requires 130 ° F water at design load.

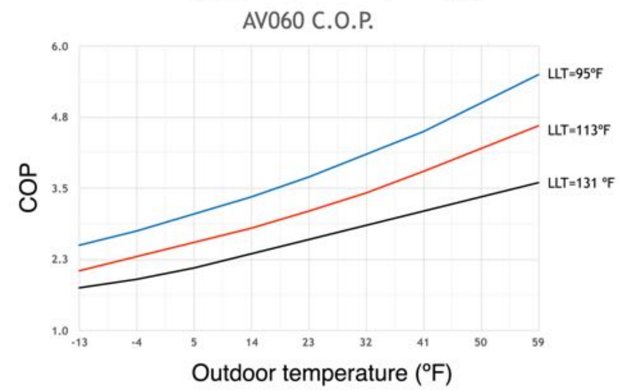
CLIMATE: Boston bin temperature data

CONSTRAITS:

- Heat pump limited to approximately 130°F leaving water temperature
- Heat pump limited to 55,000 Btu/hr & COP≤5.0
- No heating load above 60 °F outdoor temperature
- *3% capacity deduction for defrost*

bin temperature range	ave outdoor temperature for bin (°F)	hours in bin for BOSTON	Supply based on reset ratio (1.08) and 67.5F start	house load at ave bin temp (Btu/hr)	heat pump capacity (Btu/hr)	heat pump COP	total BTUs consumed by house in bin	total run hours of heat pump in bin	COP x run hours	aux energy require
-10 to -5	-7.5	1	147.75	96,154	0.00	0.00	96,154	0.00	0.00	96,153.8
-5 to 0	-2.5	9	142.4	89,744	0.00	0.00	807,692	0.00	0.00	807,692.3
0 to 5	2.5	4	137.05	83,333	0.00	0.00	333,333	0.00	0.00	333,333.3
5 to 10	7.5	35	131.7	76,923	0.00	0.00	2,692,308	0.00	0.00	2,692,307.7
10 to 15	12.5	74	126.35	70,513	42,713	2.53	5,217,949	74.00	186.92	2,057,175.4
15 to 20	17.5	151	121	64,103	45,908	2.84	9,679,487	151.00	429.23	2,747,383.5
20 to 25	22.5	256	115.65	57,692	49,146	3.17	14,769,231	256.00	812.76	2,187,861.5
25 to 30	27.5	429	110.3	51,282	52,427	3.52	22,000,000	419.63	1,478.25	0.0
30 to 35	32.5	674	104.95	44,872	53,350	3.89	30,243,590	566.89	2,203.08	-0.0
35 to 40	37.5	848	99.6	38,462	53,350	4.27	32,615,385	611.35	2,607.63	0.0
40 to 45	42.5	828	94.25	32,051	53,350	4.66	26,538,462	497.44	2,318.14	0.0
45 to 50	47.5	757	88.9	25,641	53,350	5.00	19,410,256	363.83	1,819.14	0.0
50 to 55	52.5	766	83.55	19,231	53,350	5.00	14,730,769	276.12	1,380.58	0.0
55 to 60	57.5	781	78.2	12,821	53,350	5.00	10,012,821	187.68	938.41	0.0
60 to 65	62.5	804	72.85	0	0	0.00	0	0.00	0.00	0.0
65 to 70	67.5	819	67.5	0	0	0.00	0	0.00	0.00	0.0
TOTALS							189,147,436	3403.93	14174.15	10,921,907.5
								COP_{ave} =	4.16	
		heat pump water temperature limited to about 130 °F	**based on 130°F water at design load**					seasonal heat supplied by HP (decimal %)	0.94	





PREDICTIONS:

94% of total space heating energy supplied by heat pump.

Seasonal average COP = 4.16

Low Temperature Distribution Systems

What kind of heat emitters should be used in buildings with air to water heat pumps?

• They should operate at **low supply water temperatures** to enhance the thermal efficiency of the heat source.

Select heat emitters, and design hydronic distribution systems so that they can supply design load output using supply water temperatures no higher than 120 ºF.

Even lower design load supply temperatures are preferred when possible.

• They should not be subject to future changes that could reduce performance
(no carpet / rugs added over heated floors)

• They should not create noticeable drafts or other discomfort
(avoid operating conventional fan coils or air handlers at supply air temperatures lower than 100 ºF)

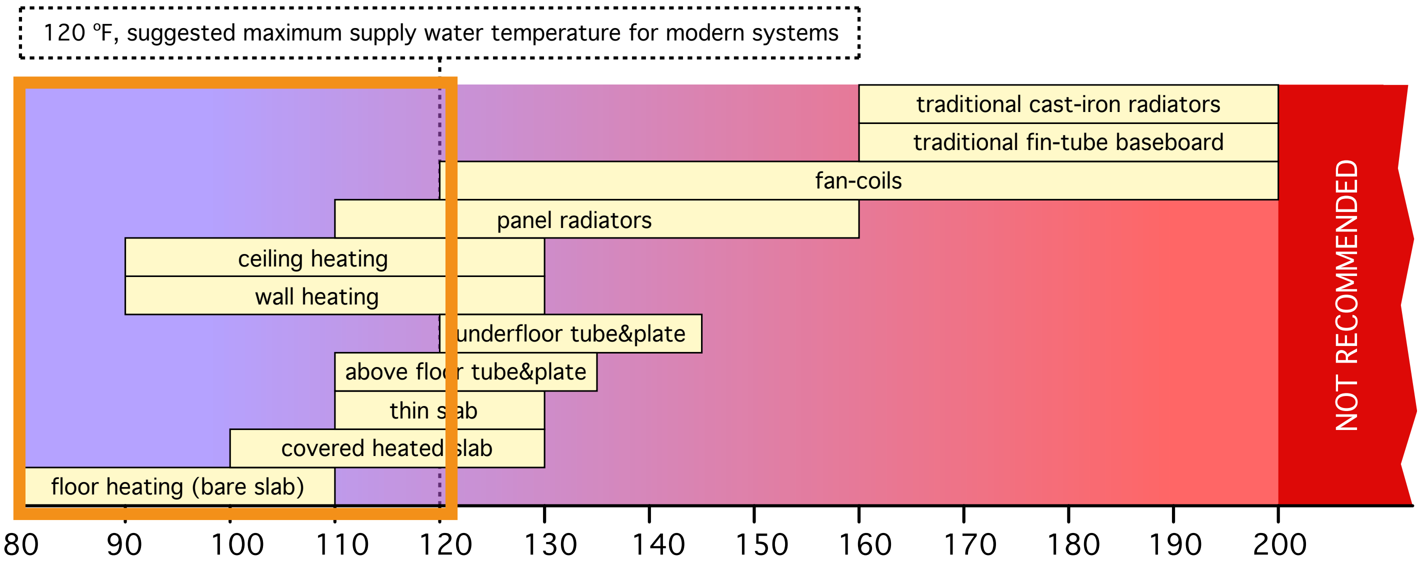
Low temperature heat emitters are essential to good AWHP performance

- The heat output of ***any*** heat emitter always drops with decreasing water temperature.

- There is always ***some*** output provided the supply water temperature is above the room air temperature.

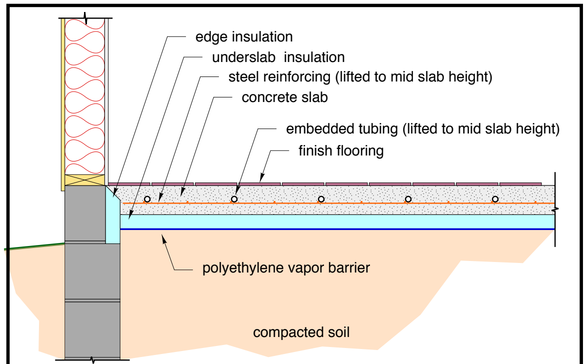
- There is always a trade off between the *total surface area of the heat emitters* in the system, and the *supply water temperature* required to meet the heating load.

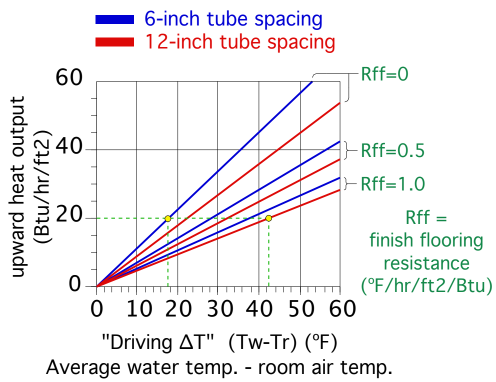
- ***More heat emitter area always lowers the required supply water temperature.***

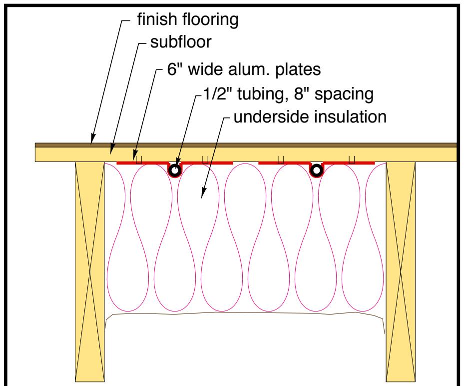


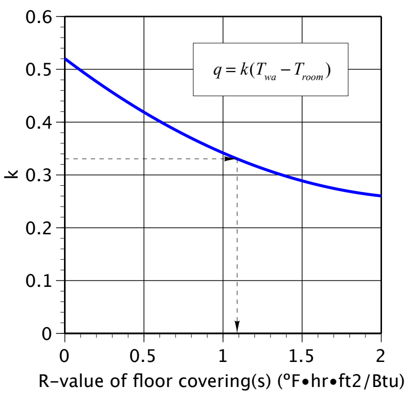
- Don't feel constrained to select heat emitters based on traditional supply water temperatures…

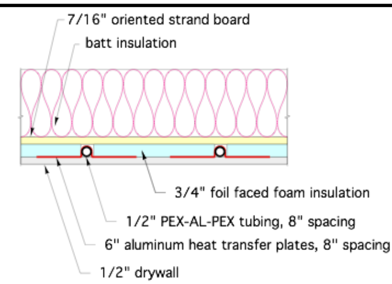
Low temperature heat emitter options

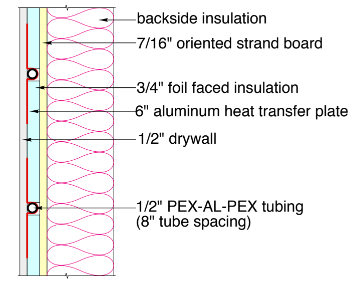












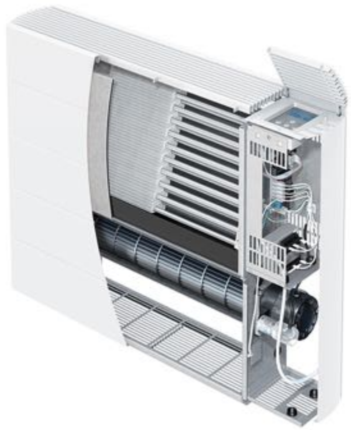
fan-assisted panel radiators (Myson / Rettig)

Chilled Water Cooling

Terminal units for chilled water cooling

Be sure that all chilled water fan-coils or air handlers are equipped with condensate drain pans, and rated for chilled water use.

Myson iVector wall console



SpacePak high wall cassette

GeoComfort 3-ton rated air handler

pre-insulated 3/4” PEX

secondary drain pan

float switch - turns off air handler if condensate drain is flooded

It’s critically important to insulate and vapor seal all piping and components conveying chilled water!

• Don’t insulate zone valve actuators or circulator motors (they need to dissipate heat)

Uninsulated volute after a few weeks chilled water operation

Suggested wall thickness of elastomeric foam insulation to prevent surface condensation (R-value of approximately 7.0 °F•hr•ft2/Btu per inch of wall thickness).

	fluid temperature in pipe ➡	50 °F	35 °F
normal conditions 85°F / 70% RH	3/8" ≤ d ≤ 1.25"	3/8"	1/2"
	1.25" < d ≤ 2"	3/8"	1/2"
	2" < d ≤ 2.5"	3/8"	1/2"
	2.5" < d ≤ 6"	1/2"	3/4"
mild conditions 80°F / 50% RH	3/8" ≤ d ≤ 2.5"	3/8"	3/8"
	2.5" < d ≤ 6"	1/2"	1/2"
severe conditions 90°F / 80% RH	3/8" ≤ d ≤ 1.25"	3/4"	1"
	1.25" < d ≤ 3.5"	3/4"	1"
	3.55" < d ≤ 6"	3/4"	1"

relative humidity — dry bulb air temperature — nominal pipe size

• Use piping supports that don’t compress insulation

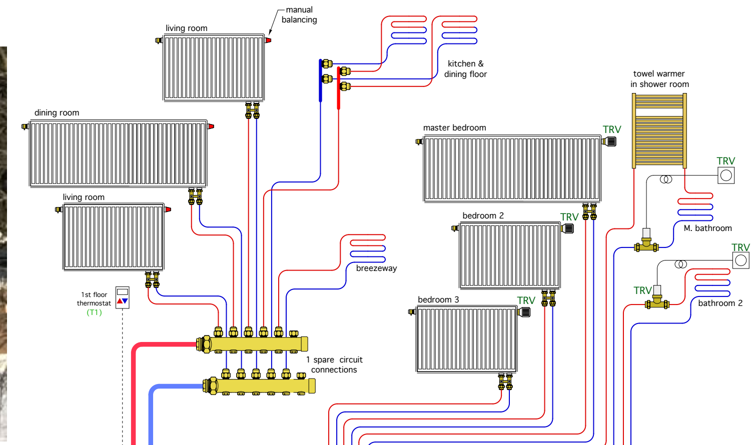
• Glue all joints and close all seams

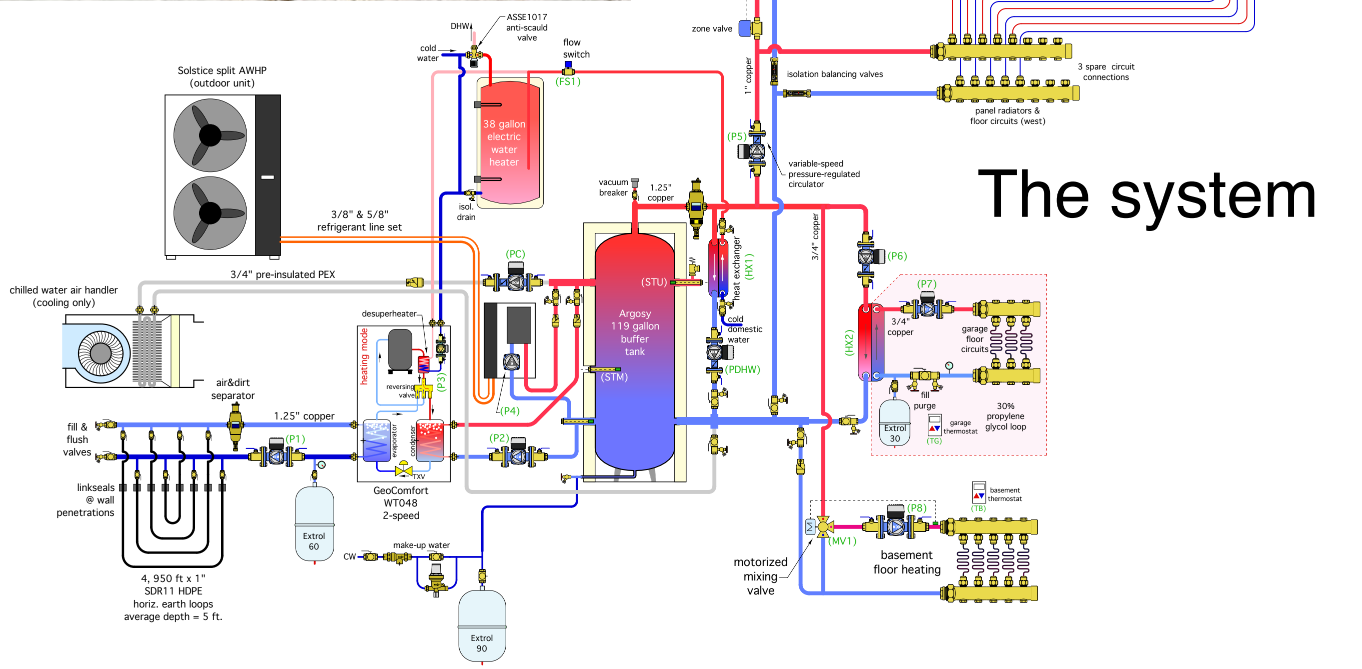
A unique system

The clients

The house

The system





Design considerations for heating & cooling

Client wants:

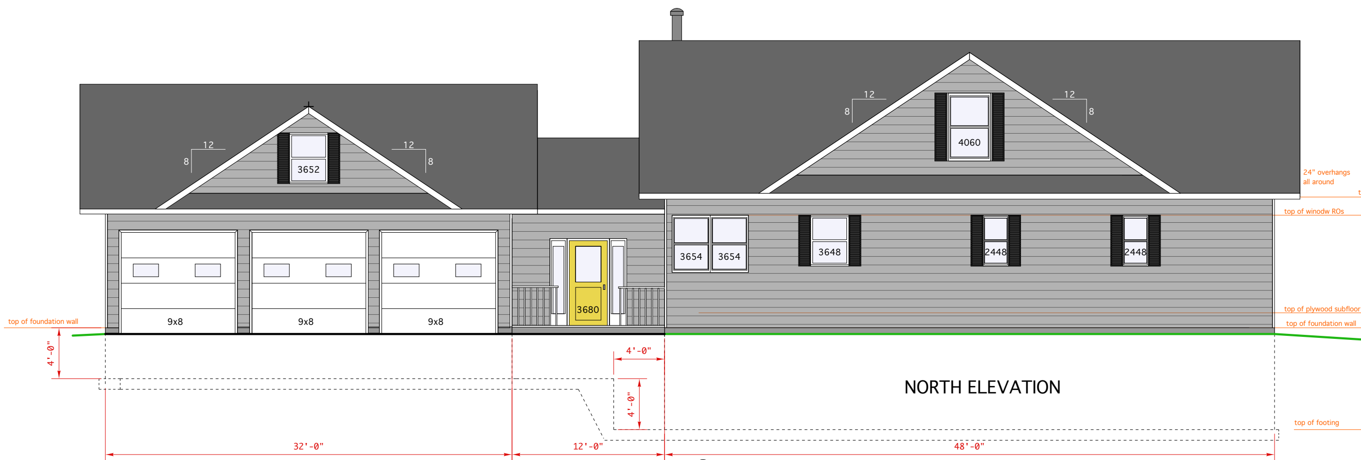
- Geothermal heat pump
- Simple heat/off/cool master switch
- Panel radiators good for areas without floor heating
- Central (single zone) cooling
- Wood stove for backup heating during power outage
- Thermostat controls heating & cooling in main living area (kitchen / dining / living room)
- Thermostat valves allow individual room temperature control in bedrooms and bathrooms

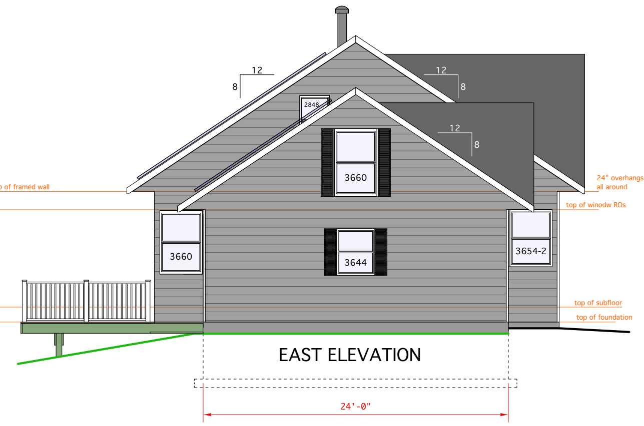
Floor coverings:

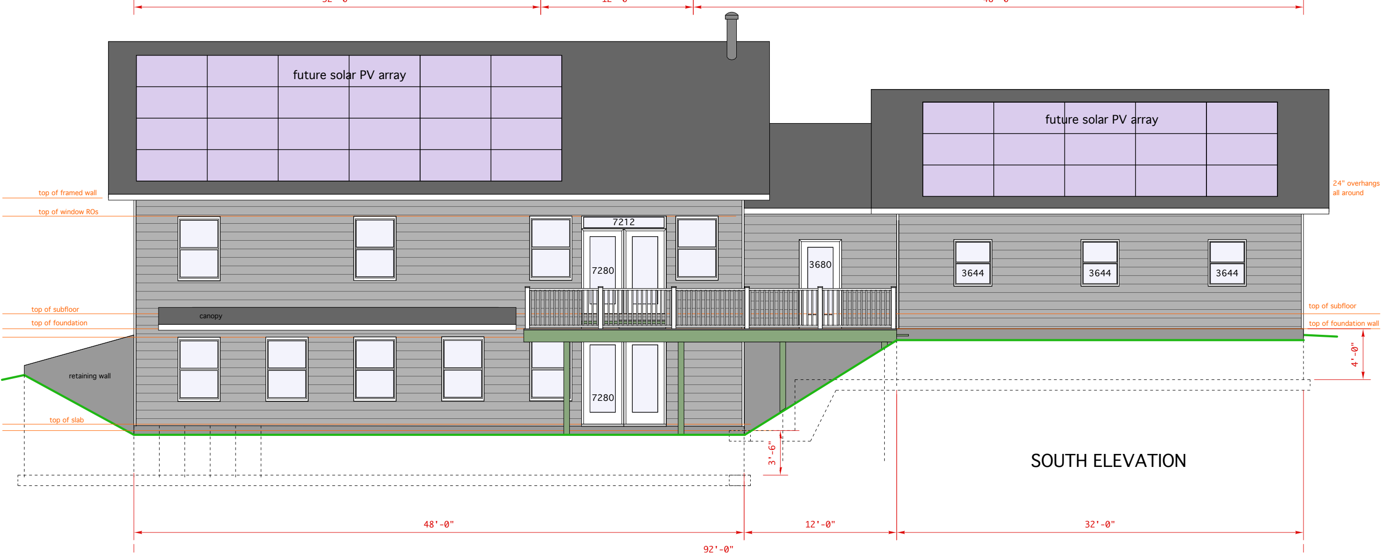
- Kitchen: engineered hardwood (moderate R-value allows floor heating)
- Living room: Engineered hardwood w/ large area rug (R-value too high for floor heating)
- Bathrooms: ceramic tile (low R-value good for floor heating)
- Bedrooms: carpet and padding (R-value too high for floor heating)

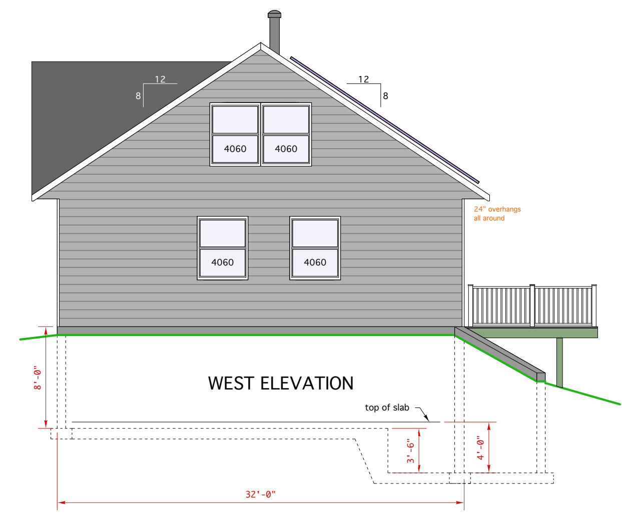
2.5 acres in upstate NY

Building elevations









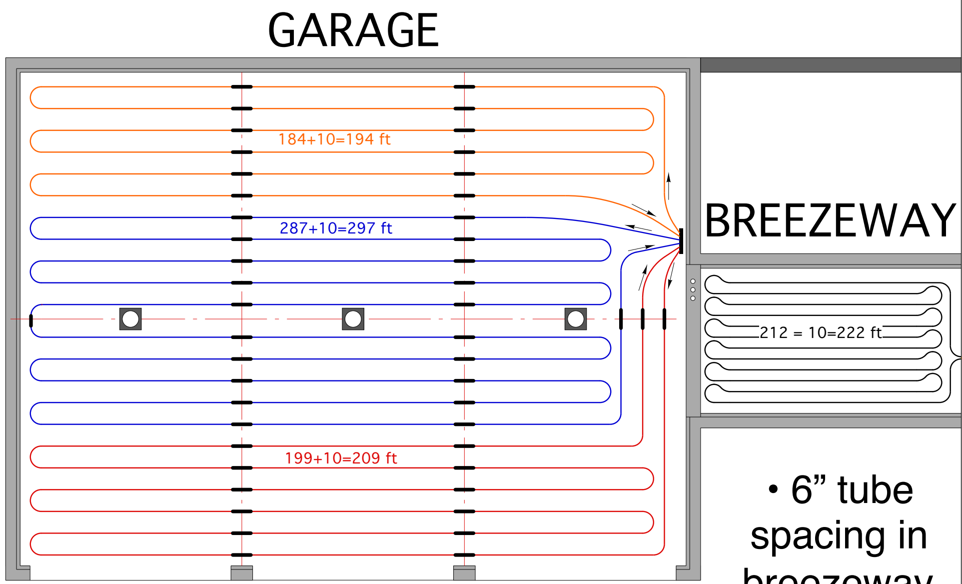
North & South elevations

- 3300 sq. ft. finished space

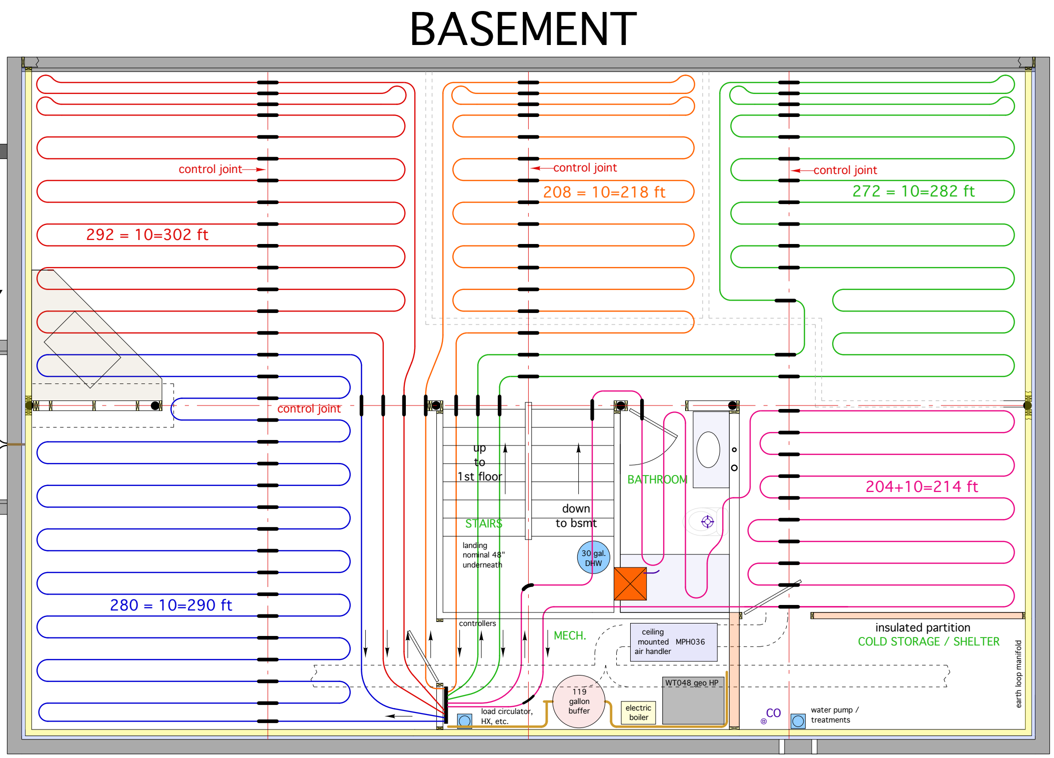
R29 above grade walls
R24 basement walls
R51 roofs (in upper truss cords)
R3.8 triple glass/low-E windows

- 35,000 Btu/hr design load (excluding garage)
- 10.6 Btu/hr/ft^2 design load
- 7.8 KW solar PV system w/ micro inverters, net metered to grid
- Design requirement - all electric house
- Long duration power outage - start the small wood stove in basement.

Basement & garage slab heating circuits



• 6” tube spacing in breezeway



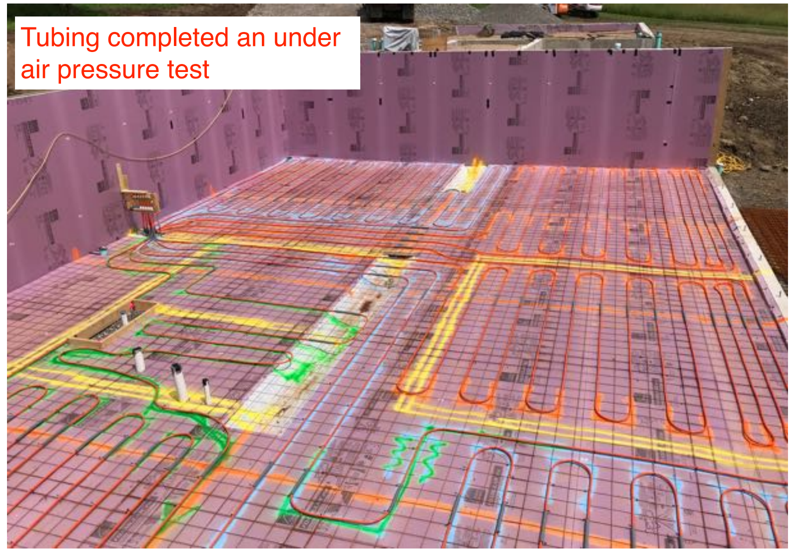
- 3 circuits of 1/2” PEX-AL-PEX in garage operating with 30% solution of propylene glycol

- 5 circuits of 1/2” PEX-AL-PEX in basement
- 12” spacing in most area, 6” spacing by south wall
- Circuit layout to accommodate possible future partitions
- Sleeves under all sawn control joint locations
- Basement circuits operate at 98 °F average circuit temperature under design load

Basement & garage slab heating circuits


Harvey ties down tubing


Manifold attached to plywood supported by rebar


Tubing completed an under air pressure test

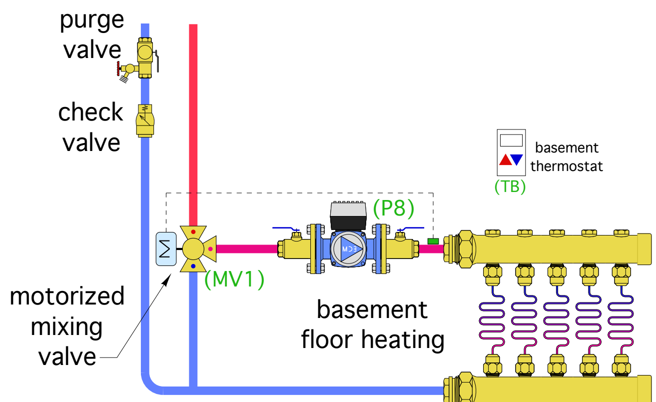

6” tube spacing in breezeway

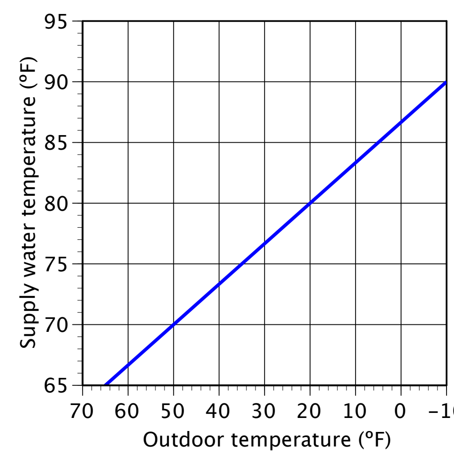

Harvey attaches tubing to manifold station


19 yards concrete on the way

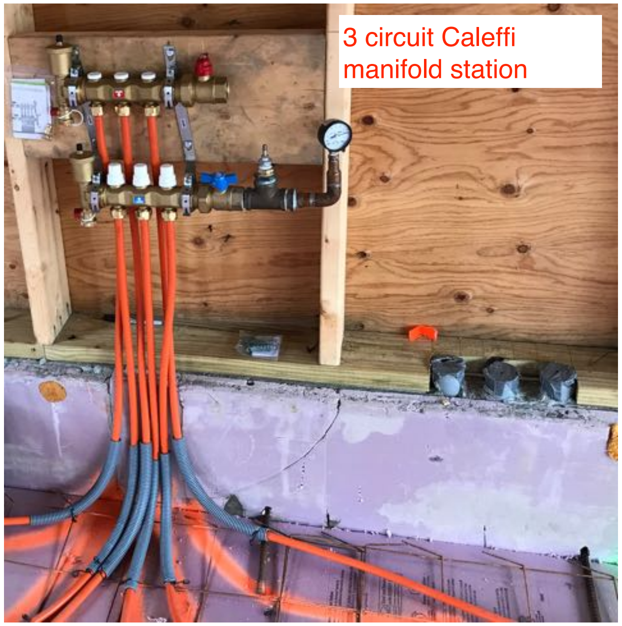
• 2” Extruded polystyrene underslab insulation -other than @ structural footings.

• All circuit paths marked prior to uncoiling tubing

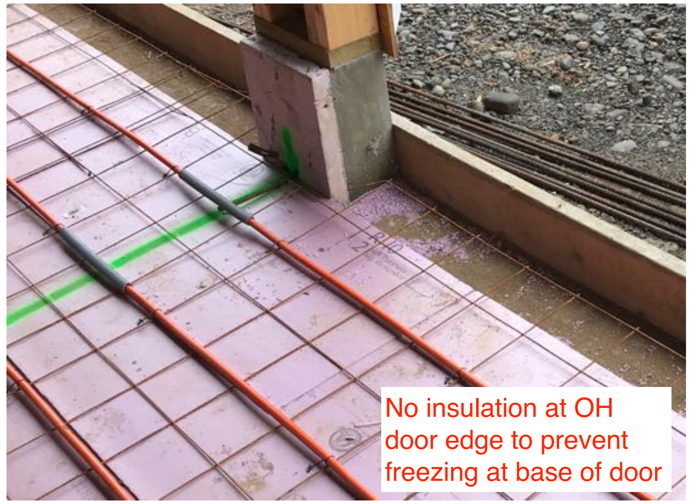




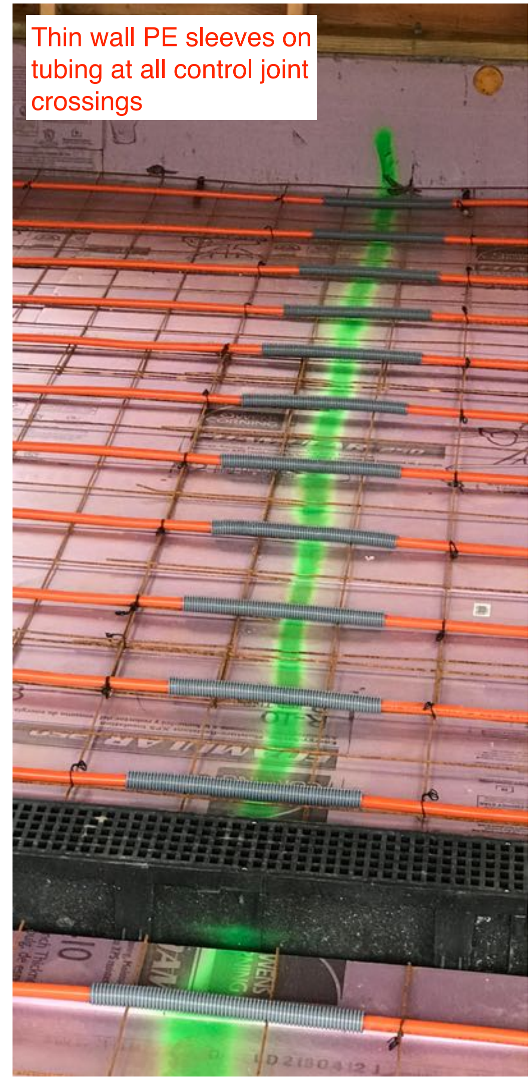
Garage slab heating circuits



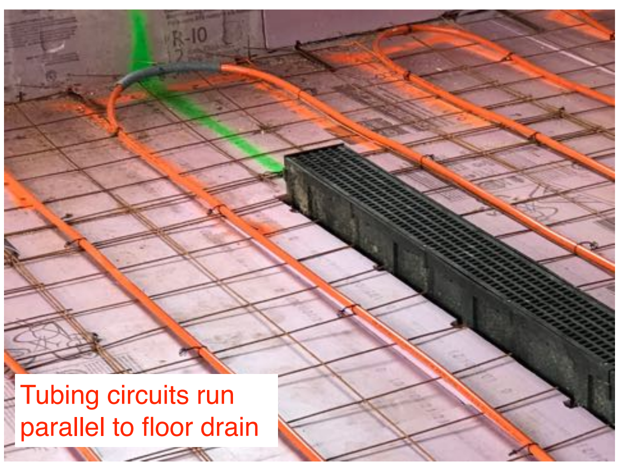
3 circuit Caleffi manifold station



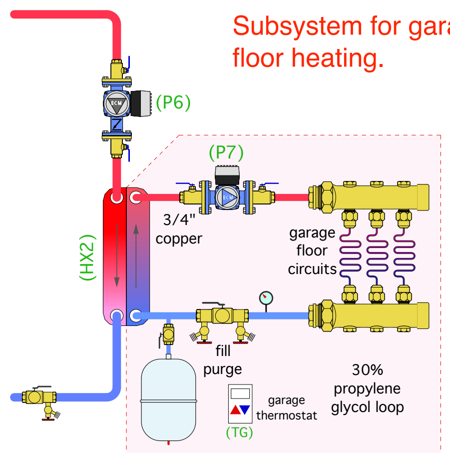
No insulation at OH door edge to prevent freezing at base of door



Thin wall PE sleeves on tubing at all control joint crossings

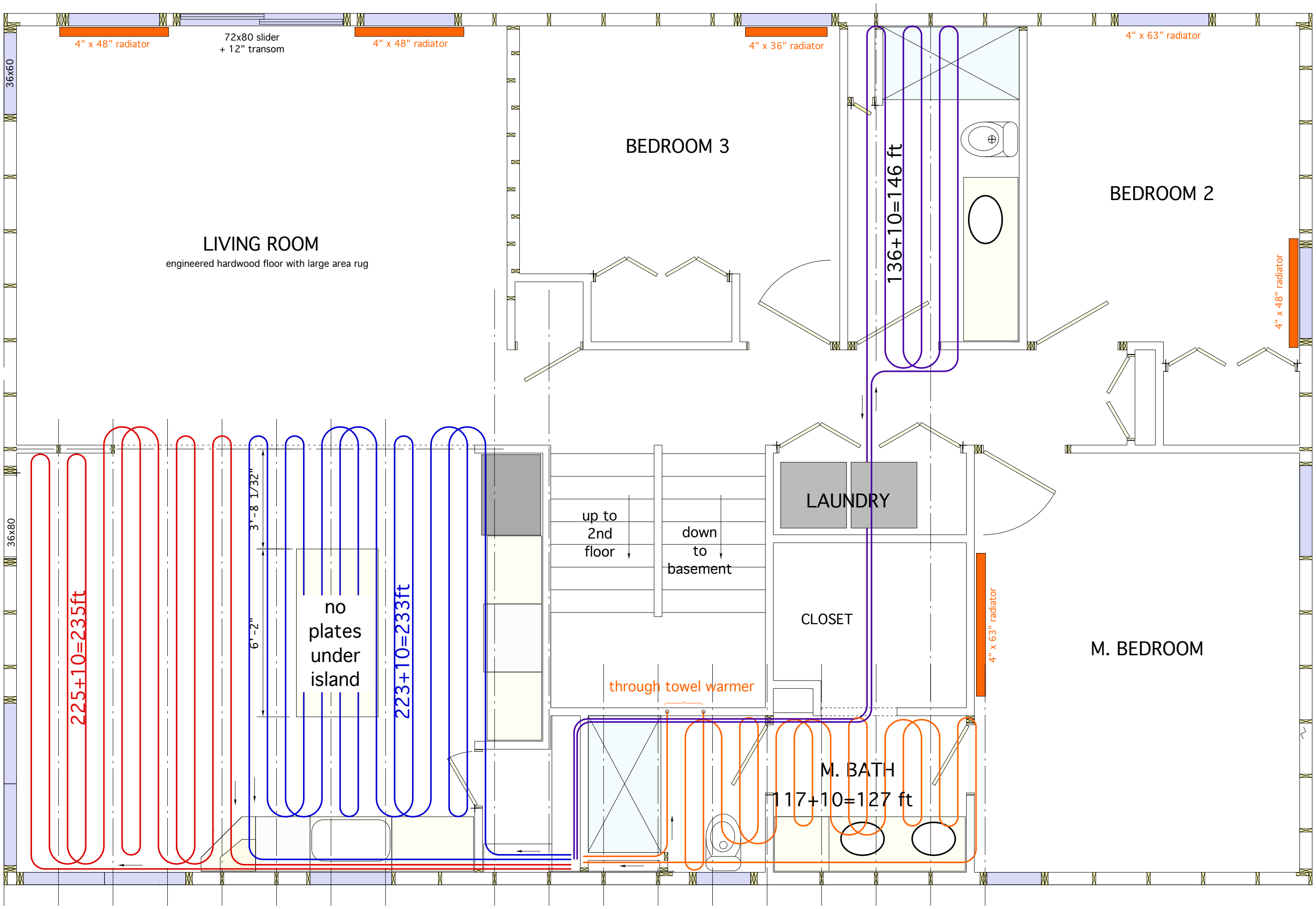


Tubing circuits run parallel to floor drain

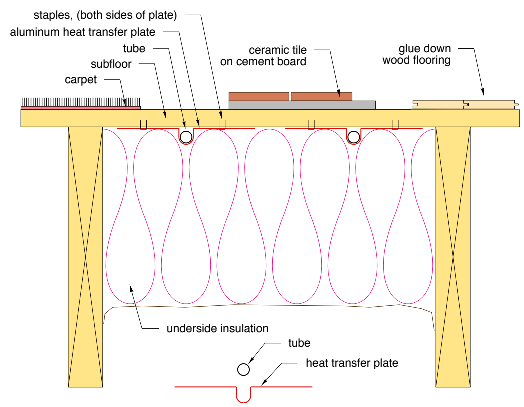


Subsystem for garage floor heating.

Main floor heat emitters

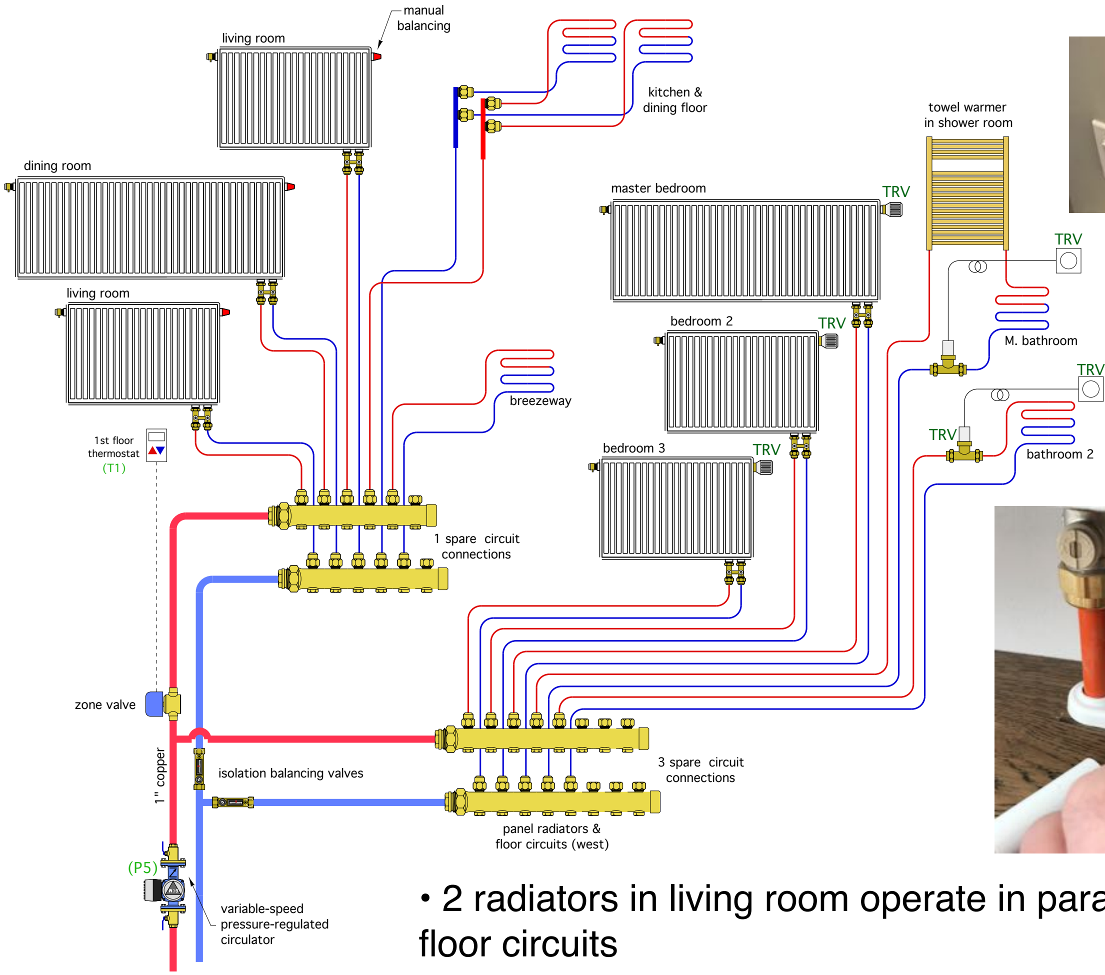


- Underfloor tube & plate
- 8" tube spacing
- 5" x 24" aluminum sheet plates
- 6" fiberglass underside insulation
- All panel radiators and floor circuit operate at same supply water temperature



Main floor heat emitters

- Several panel radiators used in bedrooms, and 2 in living room
- 3 radiators in bedrooms all have TRVs



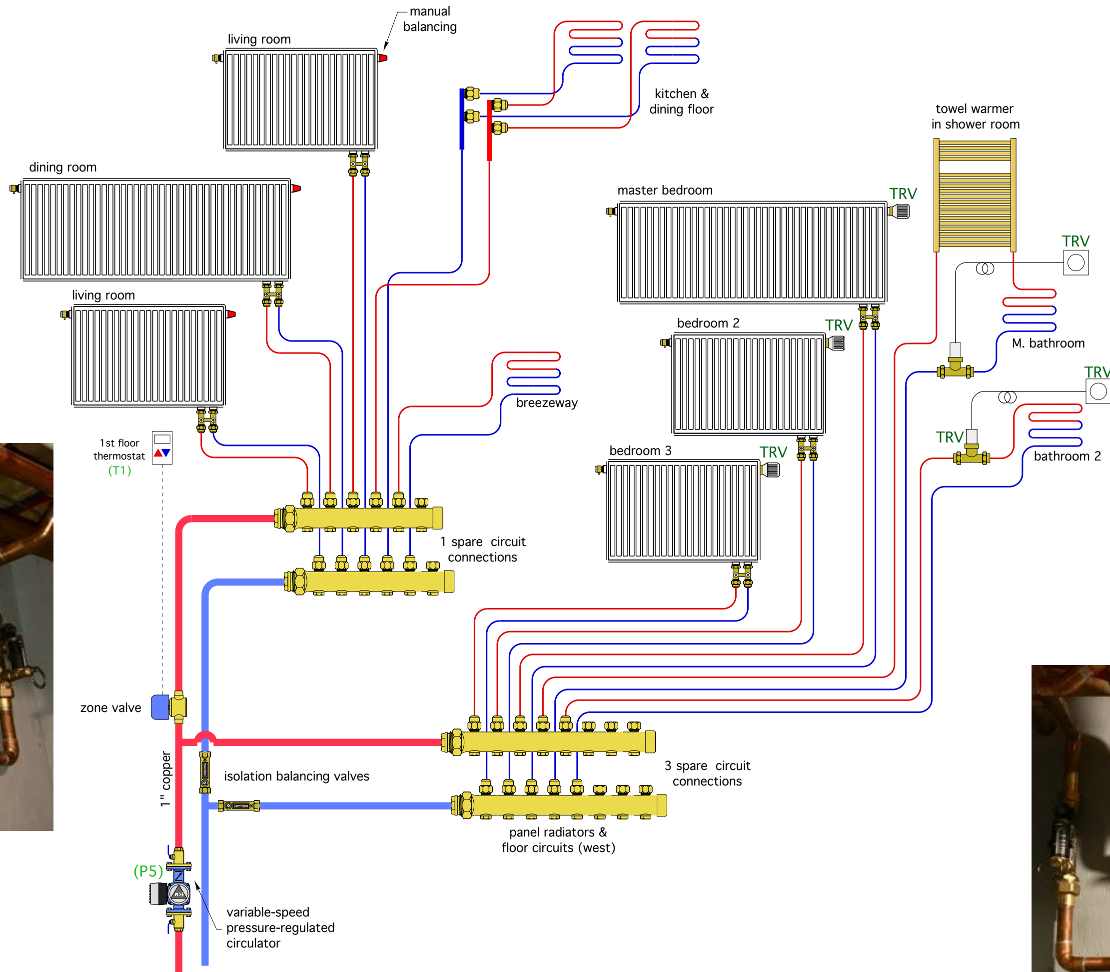
- 2 radiators in living room operate in parallel with floor circuits
- 2 “remote” TRVs used in bathrooms

Main floor heat emitters

- Several panel radiators used in bedrooms, and 2 in living room
- 3 radiators in bedrooms all have TRVs

Manifold station for living/ kitchen/dining room controlled through zone valve wiring to thermostat.

1 spare connection



- 2 radiators in living room operate in parallel with floor circuits

Manifold station for bedrooms and both bathrooms receives flow whenever system is in heating mode - TRVs regulated all heat output to rooms.

Routing 1/2” underfloor tubing

Routing PEX-AL-PEX through framing

String up through hole in floor to get capillary tube from setting knob down to “radiator” valve. Access panel in finish ceiling.

Setting knob for TRV, w/ capillary tube down through stud cavety.

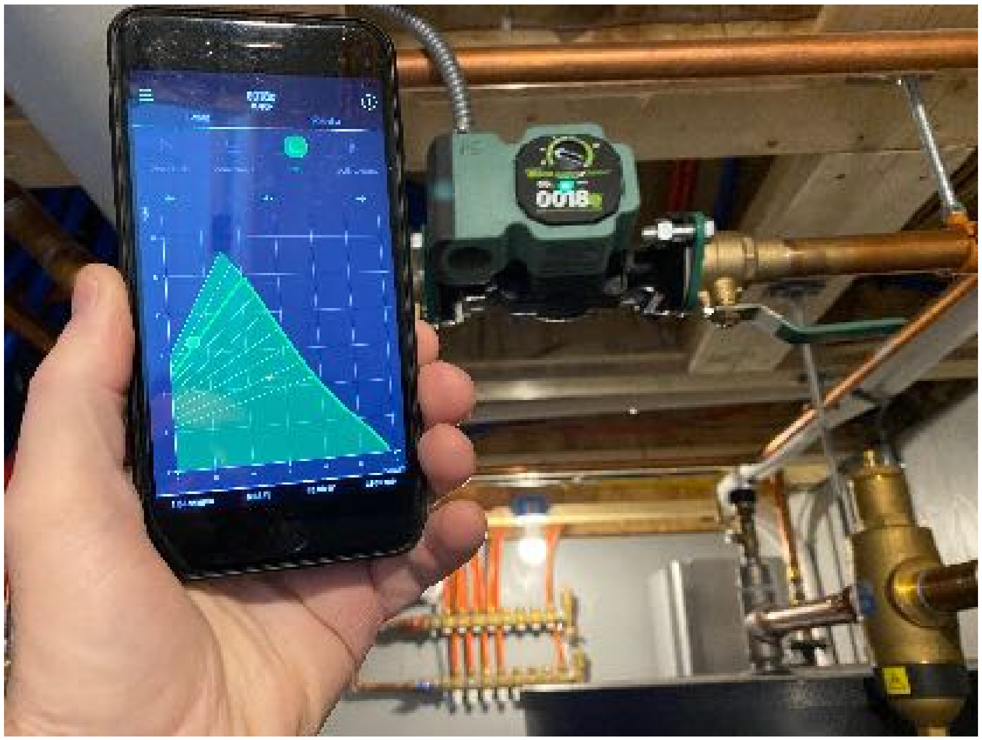
Be sure tubing is on “warm side” of spray foam insulation at rim joists

Keep domestic plumbing and DWV below insulation pressed against underfloor tube and plate

Slightly oversized holes for 1/2” PEX-AL-PEX up to isolation valves on panel radiators

Controls

The system used several Taco0018e circulators with Bluetooth communication to smartphone APP.



The Taco0018e circulator serving main floor operates continuously whenever system master switch is set to heating. It can operate in either proportional or constant differential pressure mode.

With all main floor zones on, and set for proportional ΔP mode, circulator operates at 4.3 gpm on 27 watts input power.

Assuming a 20 °F design ΔT on distribution system…

Q = 500 x gpm x ΔT

Q = 500 x 4.3 x 20 = 43,000 Btu/hr

$$\text{Distribution efficiency} = \frac{43{,}000\frac{Btu}{hr}}{27\,watt} = 1593\frac{Btu/hr}{watt}$$

Compare this to a 4-ton rated **geothermal water-to-air heat pump** delivering 48,000 Btu/hr (using a 1 HP/ ECM blower) operating on published 746 watts. The distribution efficiency of this delivery system is:

$$\text{Distribution efficiency} = \frac{48{,}000\,Btu/hr}{746\,watt} = 64.3\frac{Btu/hr}{watt}$$

The hydronic system, at full load, is delivering heat on about 4% of the electrical input power required by the water-to-air heat pump system.

Spreadsheet system simulation

SpacePak SIS-060A4 heat pump in upstate NY house with 36,000 Btu/hr design load @ -10ºF

Table 1

SYR bin averages	hours in bin for SYR	Supply based on reset ratio (0.484) and 67.5F room	house load (Btu/hr)	bo for heating capacity	b1 for capacity	q(SSI) (Btu/hr)	bo for COP	b1 for COP	b2 for COP	COP	total Btus consumed by house in this bin	run hours of heat pump	run hours * COP for this bin
-17.5	1	105	38,387.1	45949.9575	576.71475	**35,857.45**	2.09	020659710	0.0000042150	**1.730**	38,387.1	0705473323754	1.852
-12.5	1	105	36,129.0	45949.9575	576.71475	**38,741.02**	2.09	020659710	0.0000042150	**1.832**	36,129.0	325781650498	1.709
-7.5	7	105	33,871.0	45949.9575	576.71475	**41,624.60**	2.09	020659710	0.0000042150	**1.935**	237,096.8	6960737639227	11.024
-2.5	10	105	31,612.9	45949.9575	576.71475	**44,508.17**	2.09	020659710	0.0000042150	**2.038**	316,129.0	1027190697542	14.478
2.5	59	105	29,354.8	45949.9575	576.71475	**47,391.74**	2.09	020659710	0.0000042150	**2.142**	1,731,935.5	.545088321007	78.268
7.5	79	105	27,096.8	45949.9575	576.71475	**50,275.32**	2.09	020659710	0.0000042150	**2.245**	2,140,645.2	.578450840788	95.596
12.5	141	105	24,838.7	45949.9575	576.71475	**53,158.89**	2.09	020659710	0.0000042150	**2.349**	3,502,258.1	.882826766808	154.752
17.5	241	105	22,580.6	45949.9575	576.71475	**56,042.47**	2.09	020659710	0.0000042150	**2.453**	5,441,935.5	.103784124790	238.180
22.5	370	105	20,322.6	45949.9575	576.71475	**58,926.04**	2.09	020659710	0.0000042150	**2.557**	7,519,354.8	7.60665604652	326.287
27.5	564	105	18,064.5	45949.9575	576.71475	**61,809.61**	2.09	020659710	0.0000042150	**2.661**	10,188,387.1	4.83499219077	438.680
32.5	800	105	15,806.5	45949.9575	576.71475	**64,693.19**	2.09	020659710	0.0000042150	**2.766**	12,645,161.3	5.46357044916	540.631
37.5	752	105	13,548.4	45949.9575	576.71475	**68,000.00**	2.09	020659710	0.0000042150	**2.871**	10,188,387.1	49.82922201138	430.110
42.5	708	105	11,290.3	45949.9575	576.71475	**68,000.00**	2.09	020659710	0.0000042150	**2.976**	7,993,548.4	17.55218216318	349.794
47.5	669	105	9,032.3	45949.9575	576.71475	**68,000.00**	2.09	020659710	0.0000042150	**3.081**	6,042,580.6	.861480075901	273.769
52.5	709	105	6,774.2	45949.9575	576.71475	**68,000.00**	2.09	020659710	0.0000042150	**3.186**	4,802,903.2	.630929791271	225.048
57.5	753	105	4,516.1	45949.9575	576.71475	**68,000.00**	2.09	020659710	0.0000042150	**3.292**	3,400,645.2	.009487666034	164.625
62.5	742	105	2,258.1	45949.9575	576.71475	**68,000.00**	2.09	020659710	0.0000042150	**3.398**	1,675,483.9	.639468690702	83.717
67.5	752	105	0.0	45949.9575	576.71475	**68,000.00**	2.09	020659710	0.0000042150	**3.504**	0.0	0	0.000
												246.340057469	**3428.520**
												seasonal ave COP=	2.75

- Simulated COP limited to 4.5
- Simulated heating capacity limited to 68,000 Btu/hr
- If buffer tank maintained b/w 100 and 110 ºF, then seasonal **COP = 2.75**
- If buffer tank maintained b/w 95 and 105 ºF, then seasonal **COP = 2.92**
- If buffer tank maintained based on outdoor reset control, then seasonal **COP = 3.47**

These seasonal COPs are close to those attainable by geothermal water-to-water heat pumps

SpacePak SIS-060A4 heat pump

Spring 2020 energy prices in rural central NY

Propane: $2.459/gal
@ 92%AFUE = $29.13/MMBtu

#2 fuel oil: $2.23/gal
@ 86%AFUE = $18.59/MMBtu

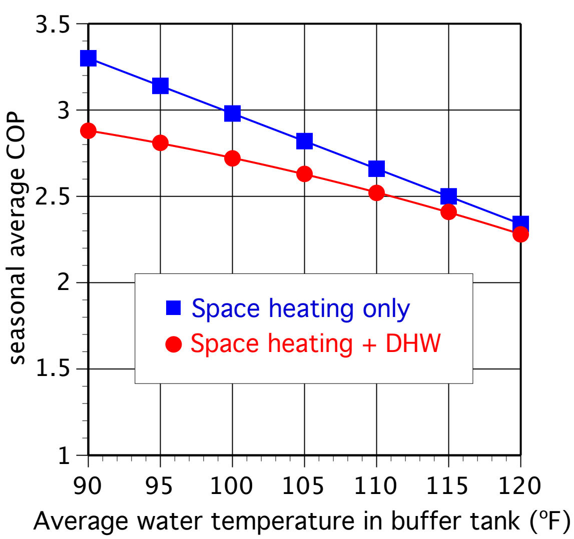
electricity: $0.0907/kwhr
@ COP=2.75 = $9.66/MMBtu

electricity: $0.0907/kwhr
@ COP=3.47 = $7.66/MMBtu

Seasonal average COPs space heating + DHW load (Syracuse, NY location)

DHW load = 60 Gal/day from 50°F to120°F
AWHP assumed to maintain buffer tank at average temperature of 105°F

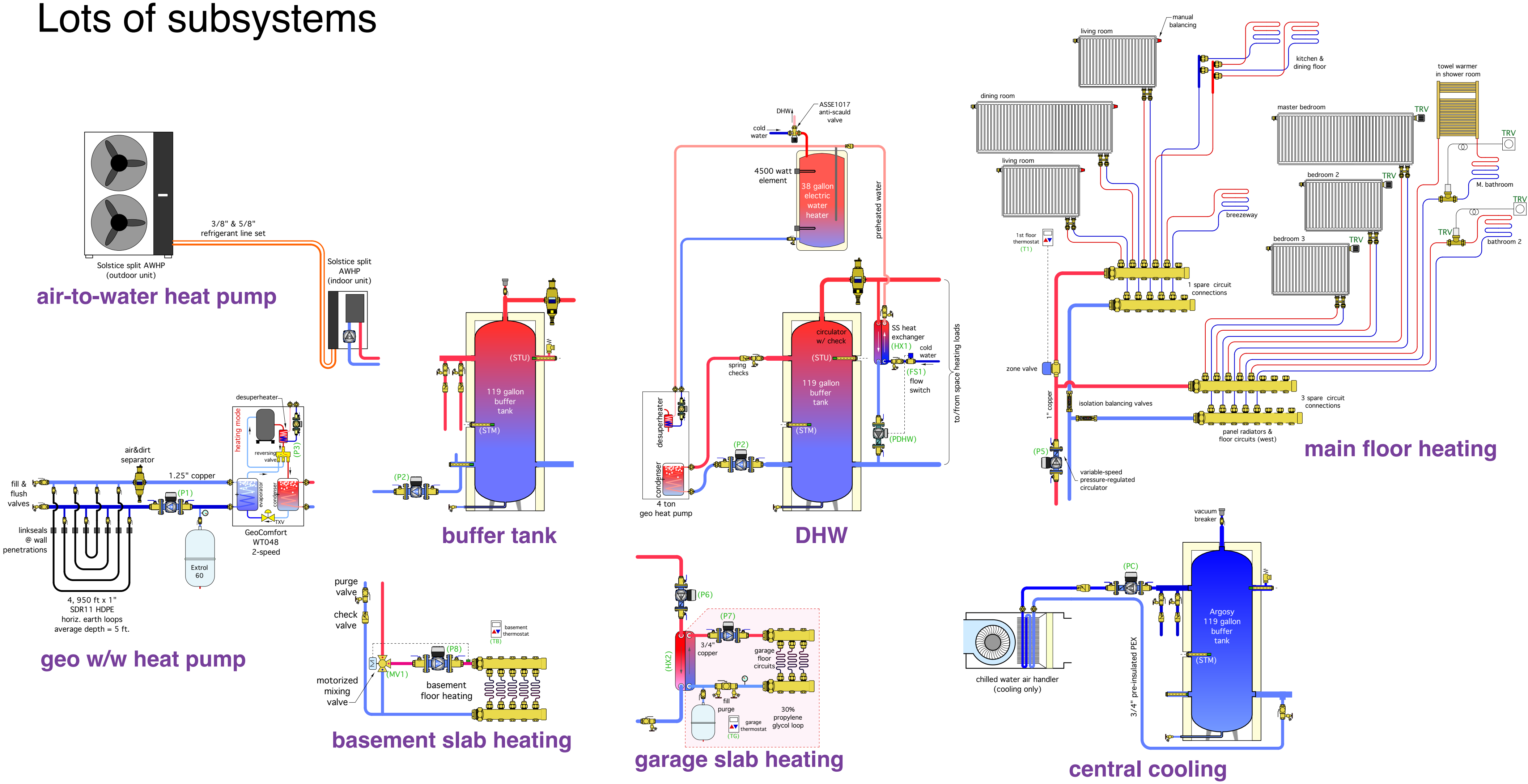
With setpoint temperature control of tank temperature + electric resistance supplemental heat for DHW



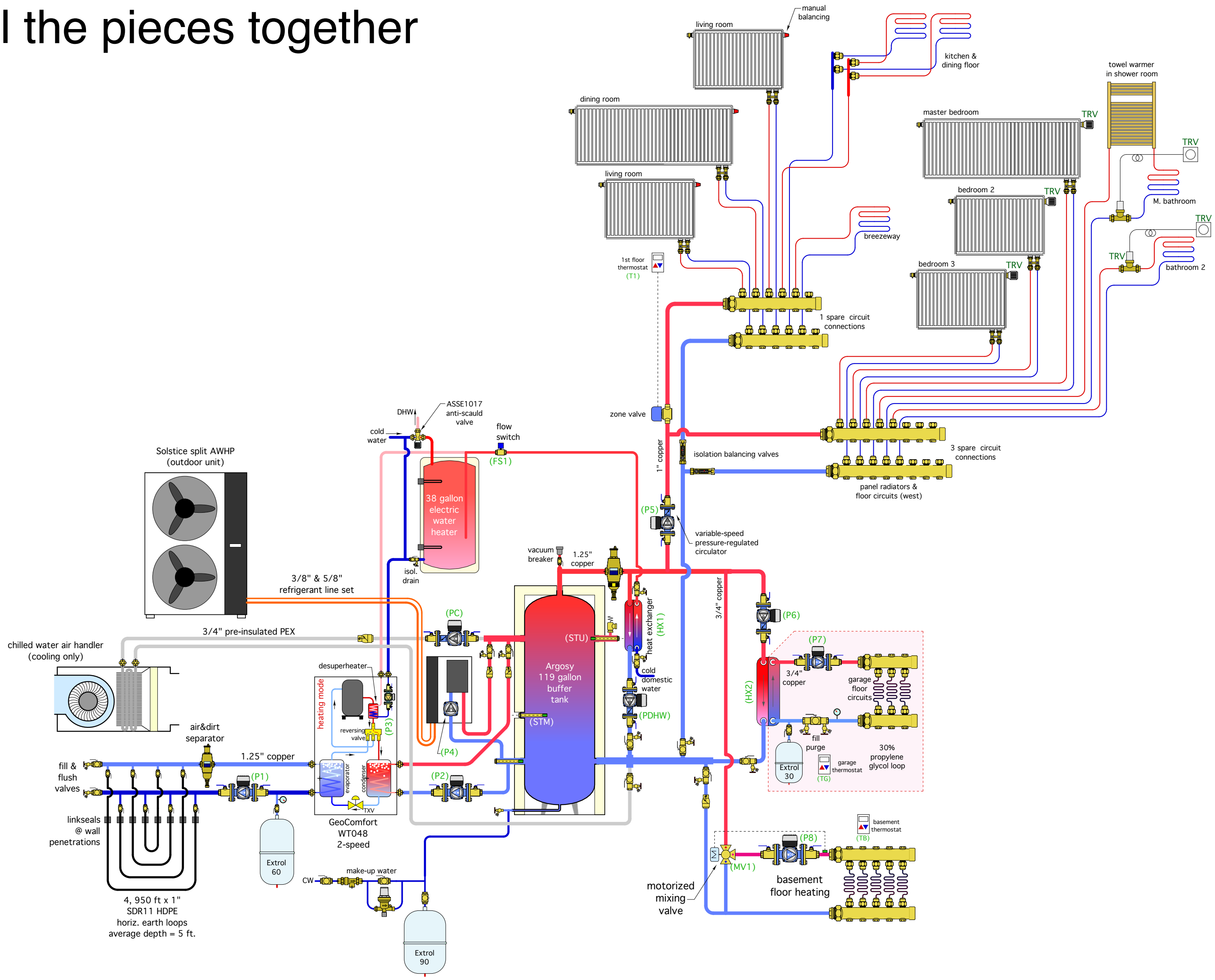
With full outdoor reset of tank temperature + electric resistance **supplemental** heat for DHW
COP_{ave}=2.82

With full outdoor reset of tank temperature + **all electric resistance heat for DHW**
COP_{ave}=2.57 *(11% of total energy supplied at COP=1.0)*

Lots of subsystems



Putting all the pieces together



Quiz:

1. T/F: Monobloc air to water heat pumps have refrigerant circulating between the outdoor and indoor units?
(False. All refrigerant is contained in the outdoor unit)

2. T/F: All air to water heat pumps have outdoor units?
(False. There are interior monobloc heat pumps in Europe)

3. T/F: All split system air to water heat pumps have a compressor in the outdoor unit?
(False. One of the split systems we looked at today has the compressor located indoors)

4. The highest *suggested* supply water temperature, to a hydronic space heating distribution system, under design load conditions is:
a. 110 ºF, b. 120 ºF, c. 125 ºF
(120 ºF was the suggested highest supply water temperature at design load for all new hydronic distribution systems)

5. T/F: The heat pump with the highest COP will always provide the best return on investment?
(False. In some cases a HP with lower COP and lower installed cost provides best ROI)

Quiz:

6. T/F: All air to water heat pumps can operate at sub 0ºF outdoor temperatures?
(False: Many do, but some are limited to approximately 15 ºF outdoor temperatures)

7. T/F: Using outdoor reset control to regulated buffer tank temperature will improve the amount of domestic hot water provided by the air to water heat pump.
(False: Lower buffer tank temperatures will require more supplemental heat input to bring DHW to final 120 ºF temperature)

8. lowering the water temperature required from the condenser of a heat pump will…
a. decrease COP
b. increase heating capacity
c. increase COP
d. reduce capacity but increase COP
e. increase COP but decrease capacity
f. increase both COP and capacity
(f. increase both COP and capacity)

9. T/F: All terminal units used for chilled water sensible and latent cooling require drip pans?
(True. Latent cooling is moisture removal. Without a drip pan there will be a mess!)

10.T/F: Air to water heat pumps with inverter compressor can operate down to 10% of their rated heating capacity?
(False. Most can reduce to approximately 30% of rated capacity)

Thanks for attending this session.

I hope to see some of you “face-to-face” at future Energy Design Conferences

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FREE Additional information

idronics #27
Air-to-Water Heat Pump Systems

https://www.caleffi.com/sites/default/files/file/idronics_27_na.pdf

QUESTIONS ?