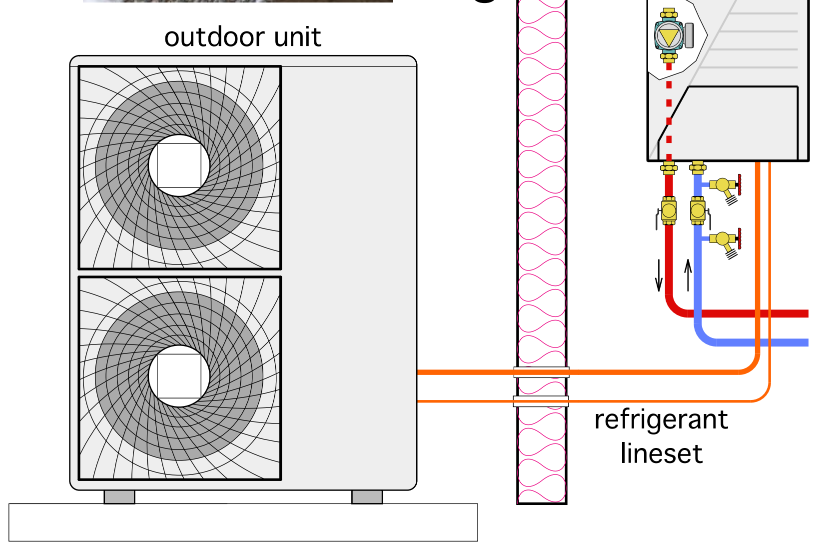
Air-to-Water Heat Pumps: *Emerging Market Opportunities*

Part 1



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HPAC HEATING PLUMBING AIR CONDITIONING

September 22, 2020

presented by:

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Appropriate Designs
Holland Patent, NY
www.hydronicpros.com

John Siegenthaler

HPAC WEBINAR

September 22nd at 3:00 EST

Anticipated length: 50 minutes with 10 minutes for Q&A

Why air-to-water heat pumps are a market opportunity for hydronic professionals.

There's a world wide trend underway that will undoubtedly affect the future of North American hydronics technology. That trend is away from fossil-fueled boilers and toward electrically powered heat pumps. This trend presents a significant opportunity for hydronic pros that are ready to take advantage of it using modern air-to-water heat pump systems.

This webinar will introduce the basics of air-to-water heat pumps, describe why they will be a new niche for hydronic professionals, and show some basic system configurations. Attendees will see how their current knowledge and skills in crafting modern hydronic systems can be leveraged around this new heating / cooling source.

LEARNING OBJECTIVE:

- Understand the basic operation & performance of air-to-water heat pumps
- Grasp global trends that will increase this market niche
- Understand the importance of low water temperatures in air-to-water heat pump systems
- Learn how to configure a basic system for heating and cooling

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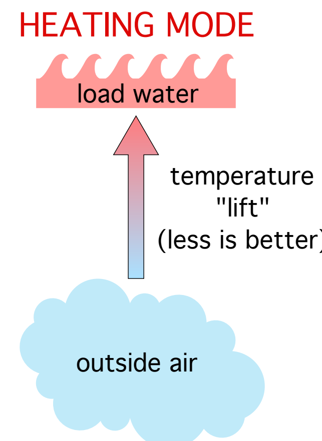
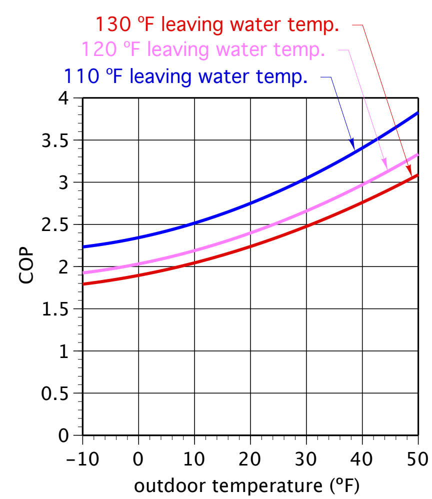
Air-to-Water Heat Pumps: *Emerging Market Opportunities*

First… I miss you folks in Canada…
(& hopefully will have an opportunity to return soon)



Today's topics:

- Why hydronics
- Air to water heat pump fundamentals
- Thermal performance of air to water heat pumps
- Why North American market will grow
- New concepts for AWHPs

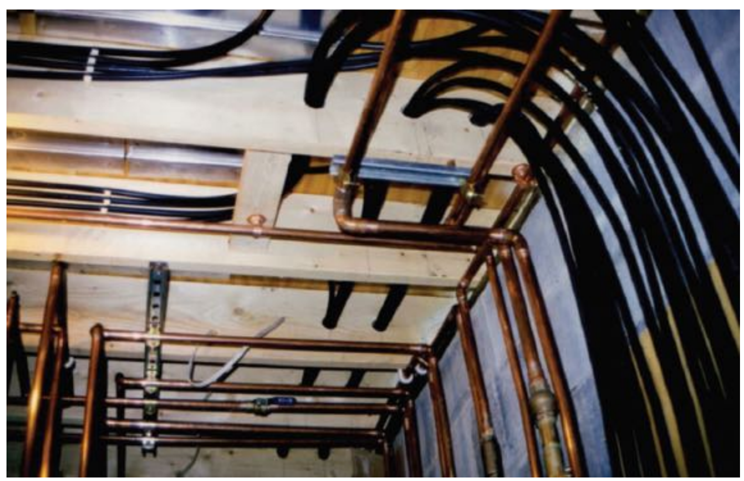


Why hydronics

+ heat pumps ?

Water vs. air: It’s hardly fair...

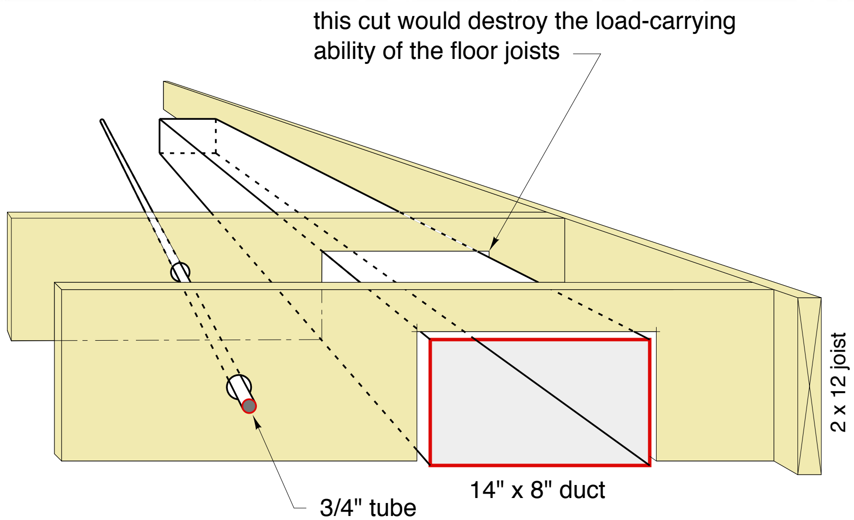
courtesy of Dan Foley



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	$\boxed{62.4}$
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	$\boxed{0.018}$
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

Defining DISTRIBUTION EFFICIENCY

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

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:

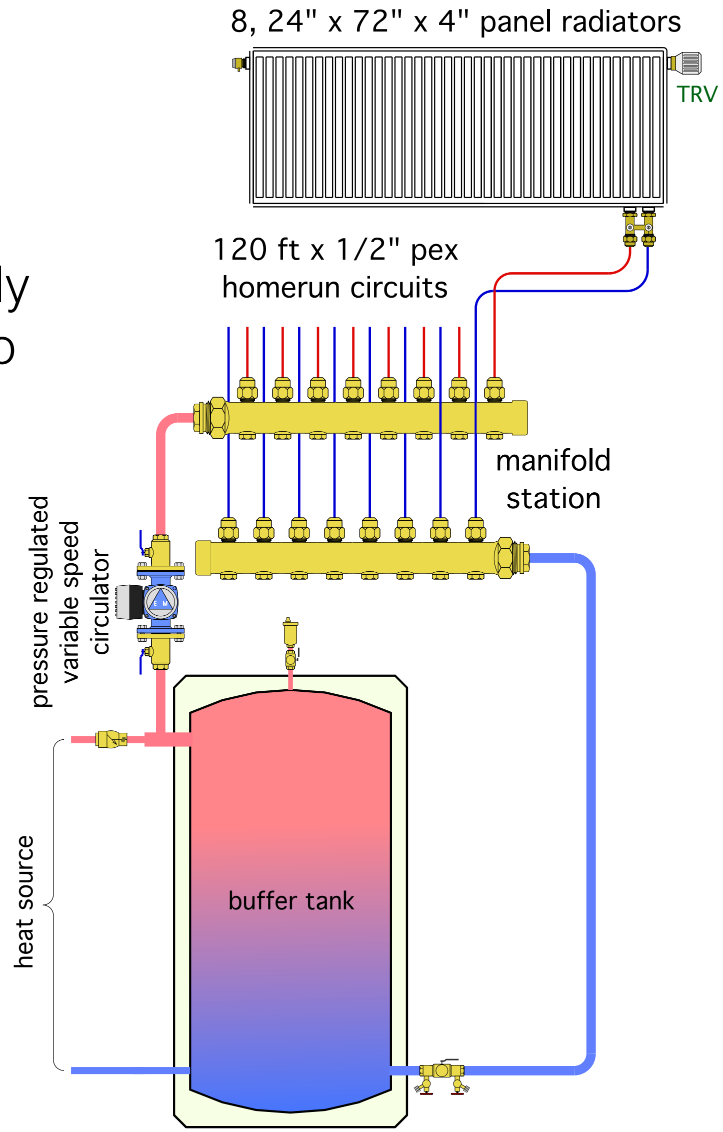
$$\text{distribution efficiency} = \frac{80{,}000 \text{ Btu/hr}}{850 \text{ watts}} = 94 \ \frac{\text{Btu/hr}}{\text{watt}}$$

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.

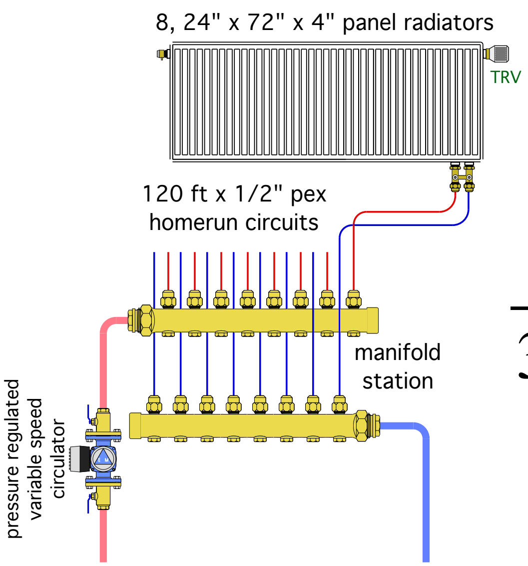
With good design and modern hardware it's possible to design a homerun distribution system for panel radiators that can supply 30,000 Btu/hr design load using only 8.6 watts of electrical power input to circulator!

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



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

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



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

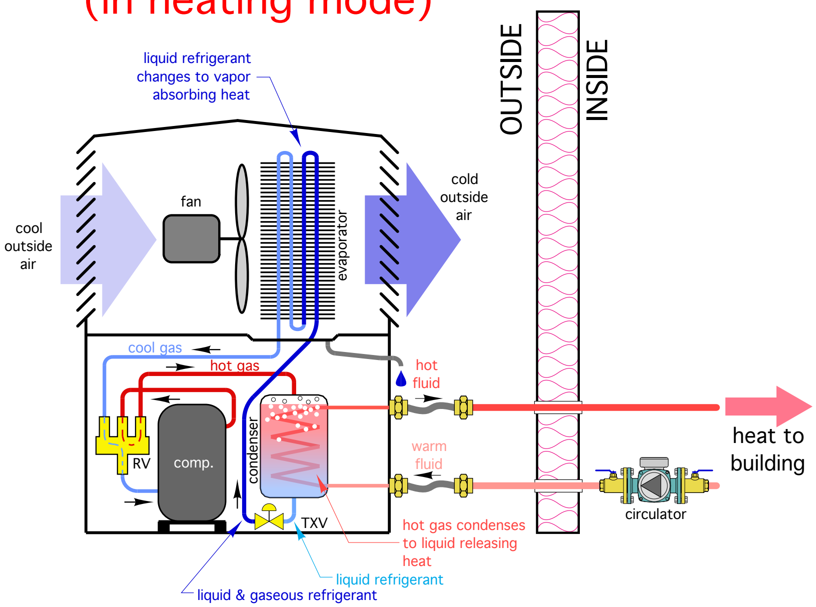
$$\frac{94}{3581} = 2.6\%$$

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).

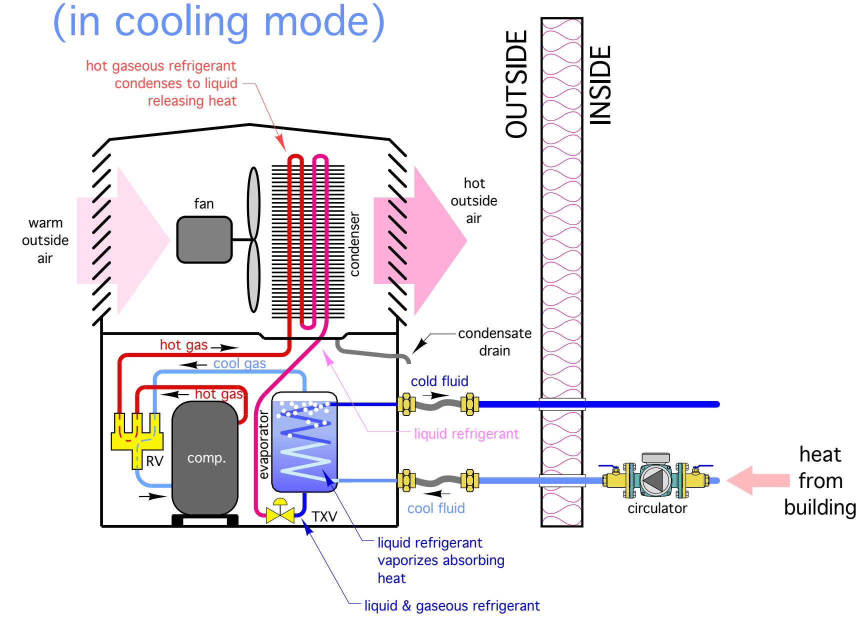
Fundamentals of air-to-water heat pumps

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

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



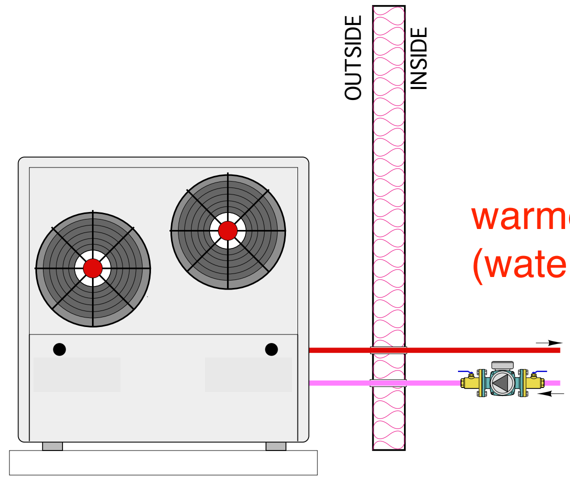
air-to-water heat pump
(in cooling mode)



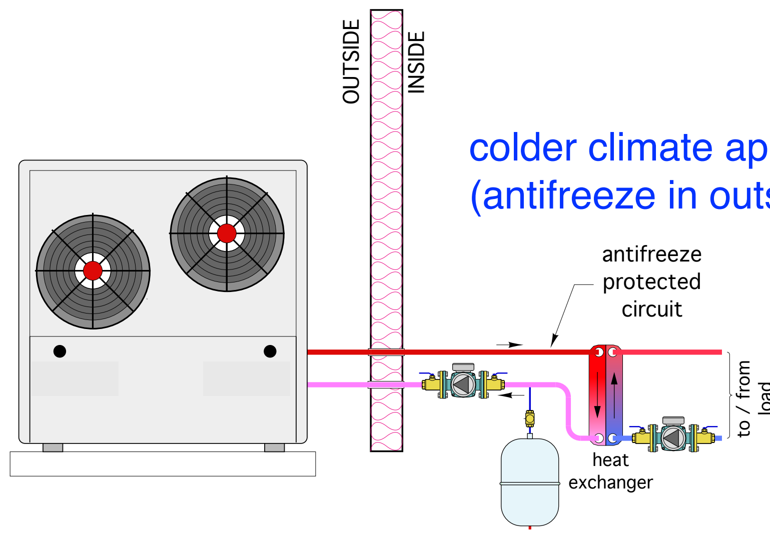
In heating mode: The heat pump extracts low temperature heat from outside air, and transfers it to a fluid stream (water or water & antifreeze) to be used by a hydronic distribution system.

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

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



warmer climate application
(water in outside unit)



colder climate application
(antifreeze in outside unit)

- Heating + cooling + DHW
- Pre-charged refrigeration system
- Some are 2-stage for better load matching

Self-contained (“monobloc”) air-to-water heat pumps

Split system air-to-water heat pump

Outdoor unit

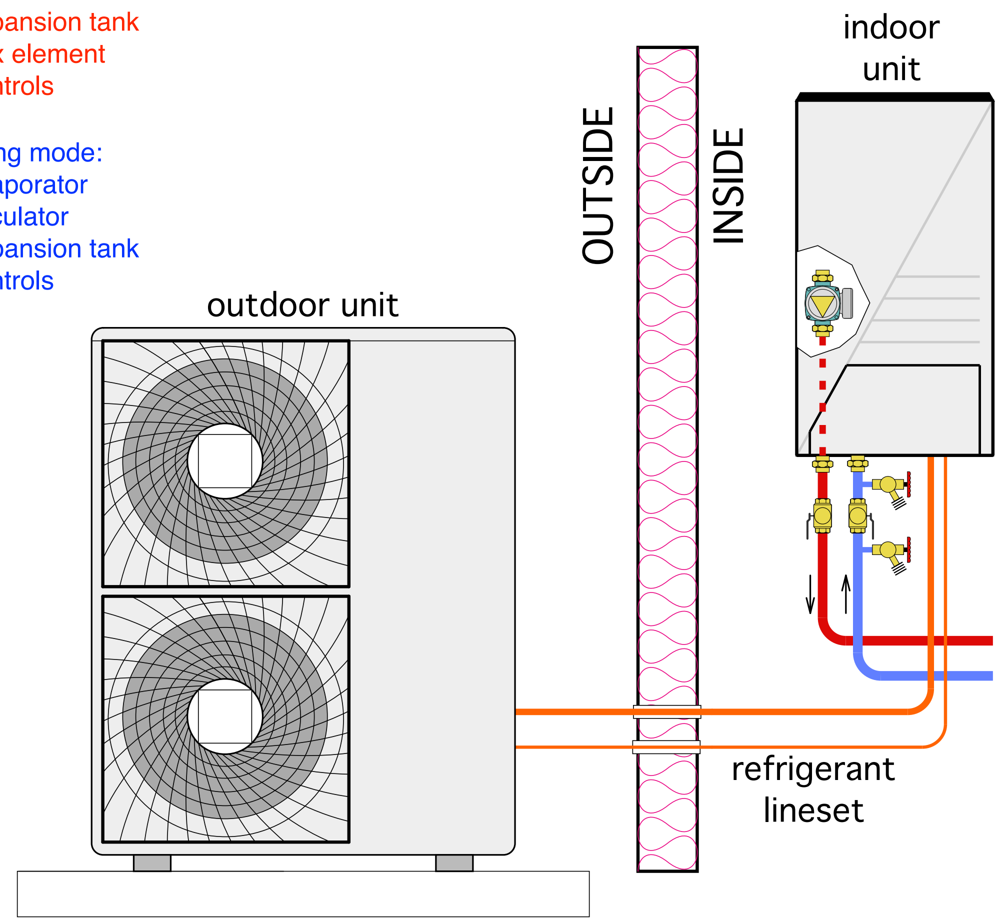
Heating mode:
1. compressor
2. evaporator
3. expansion device

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



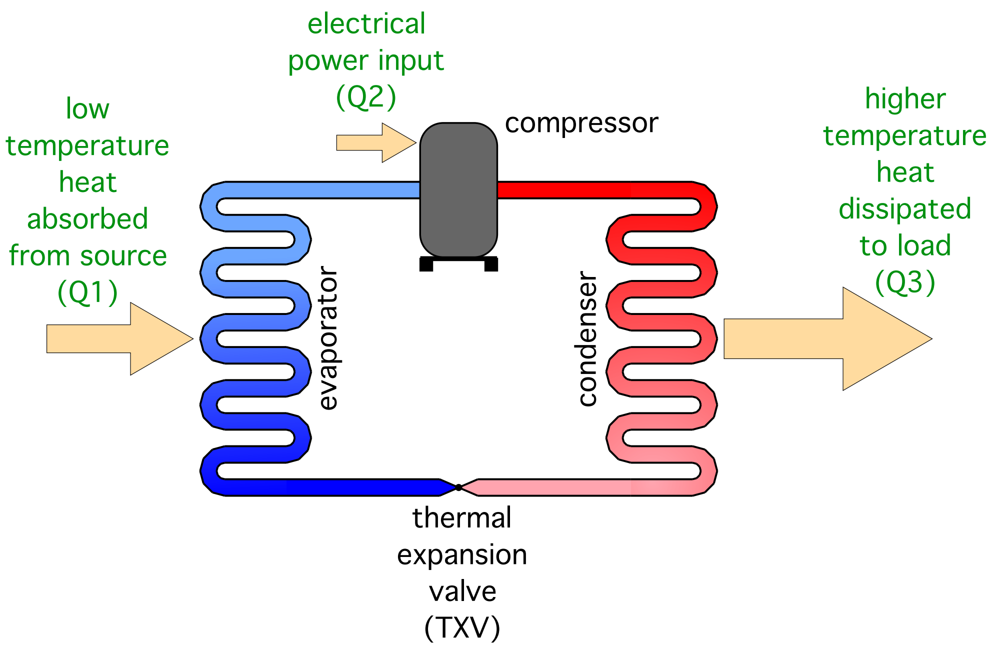
Split system air-to-water heat pump

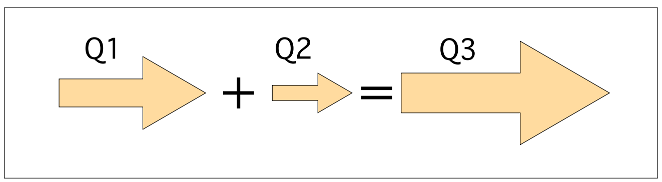
images from Nordic Heat Pumps

- 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

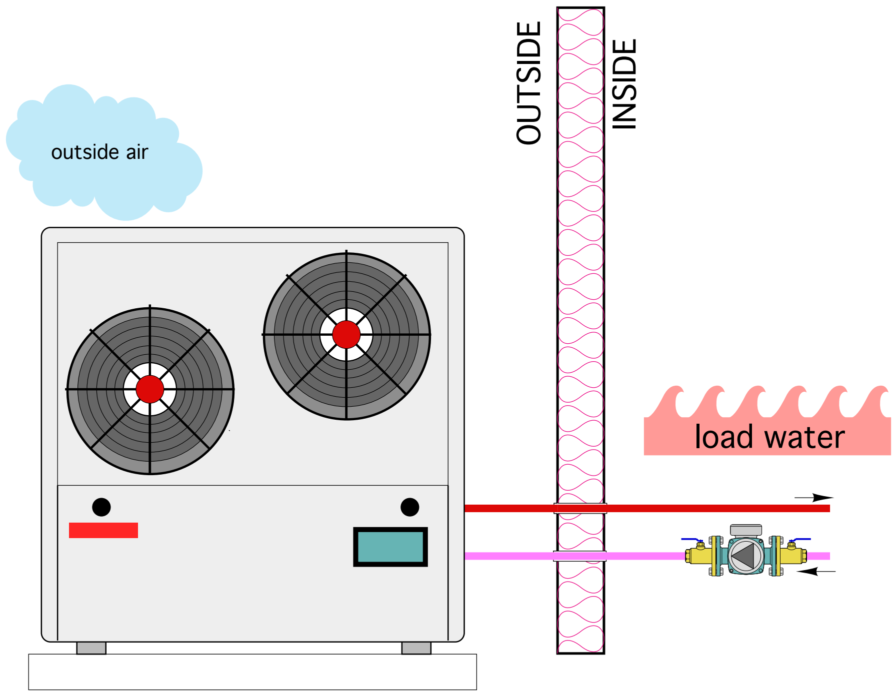


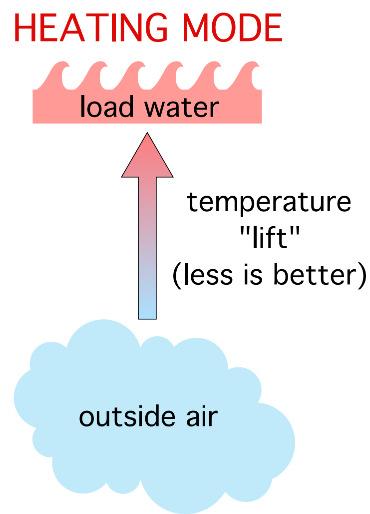


$$COP = \frac{Q3}{Q2}$$

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

Heating performance:



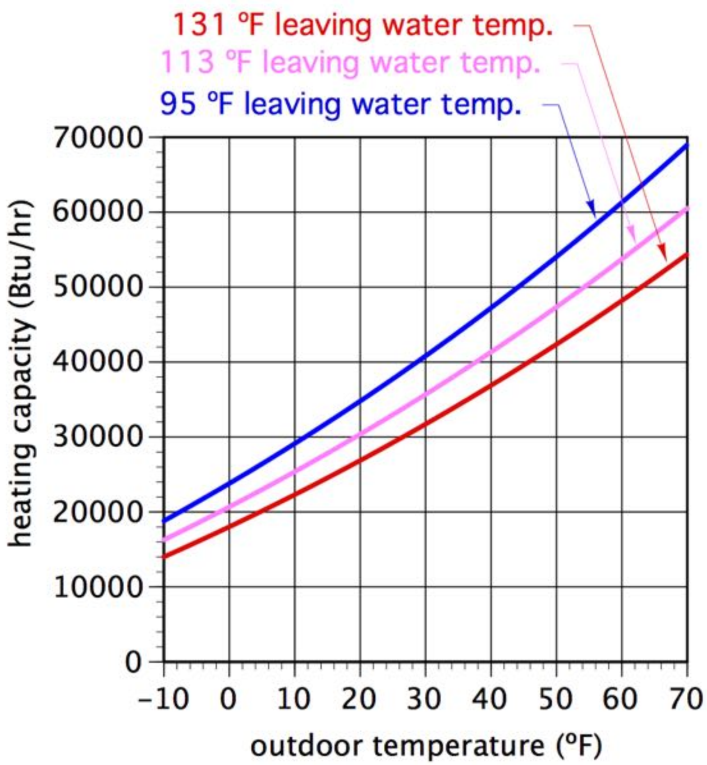


Anything that *reduces* the “temperature lift” *increases* both the heating capacity and COP of the heat pump.

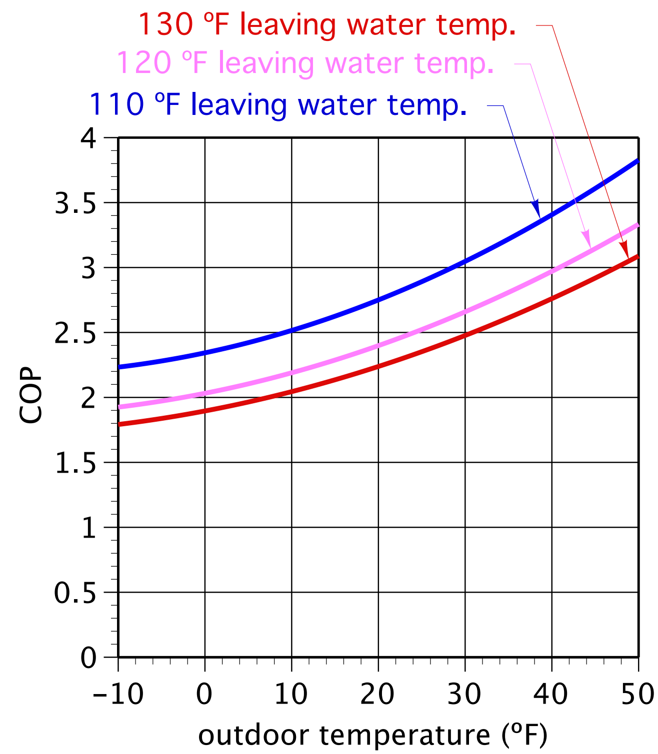
Low temperature distribution systems are critical to good performance.

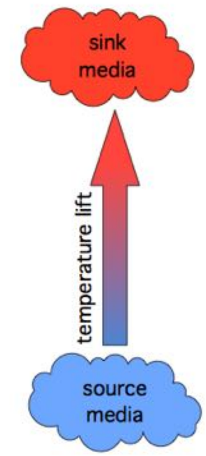
Heating Performance

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



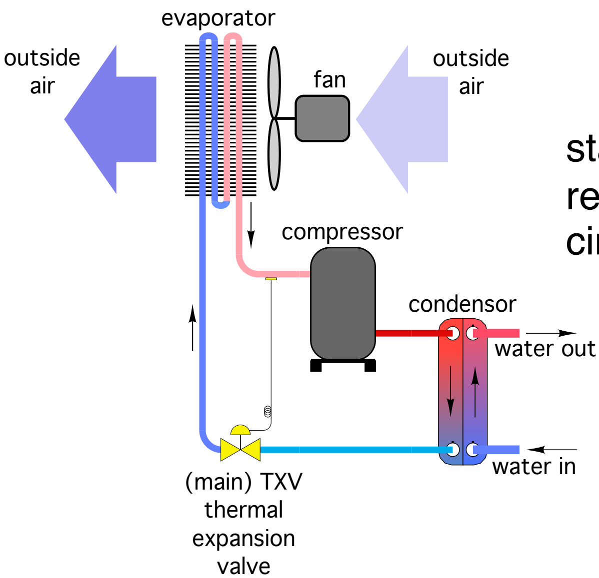
The COP also decreases with increasing condenser temperature.



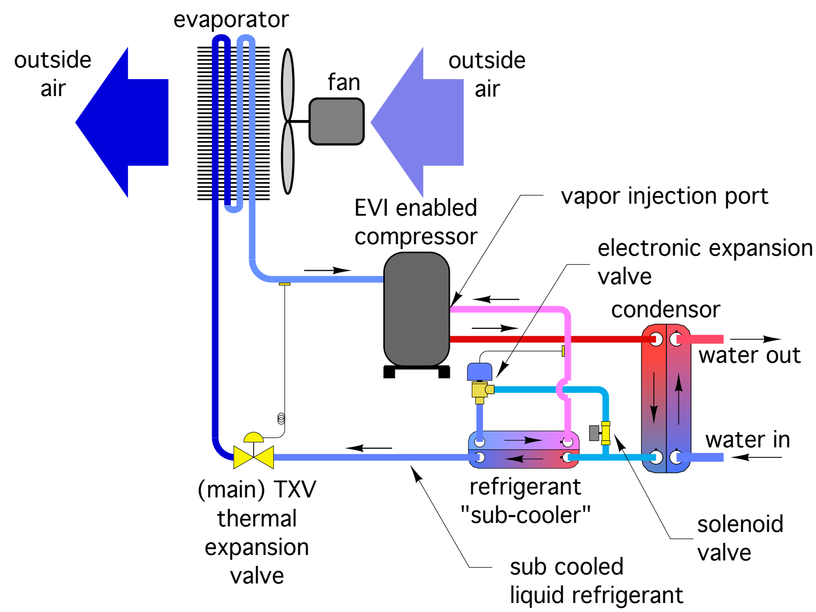


The smaller the "temperature lift" between evaporator and condenser, the higher the heating capacity and COP.

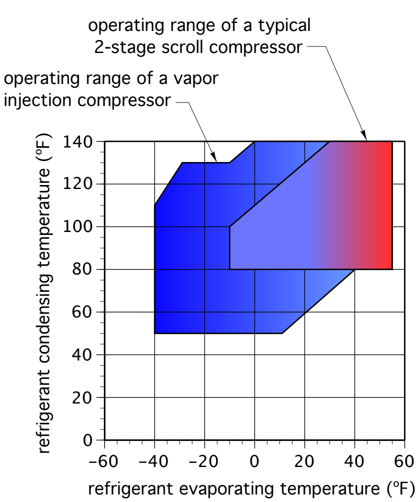
Enhanced Vapor Injection (EVI) Systems



standard refrigeration circuit

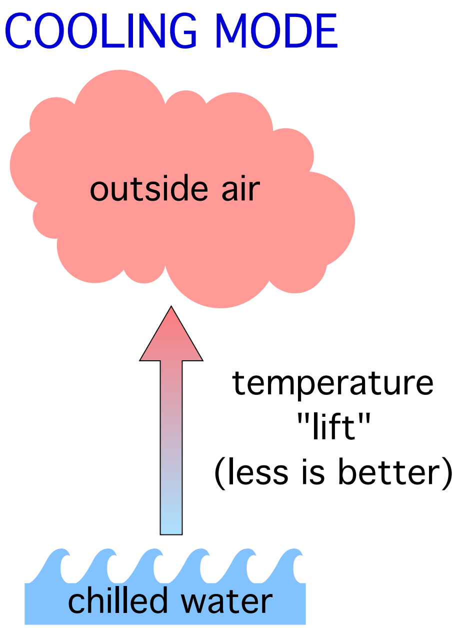


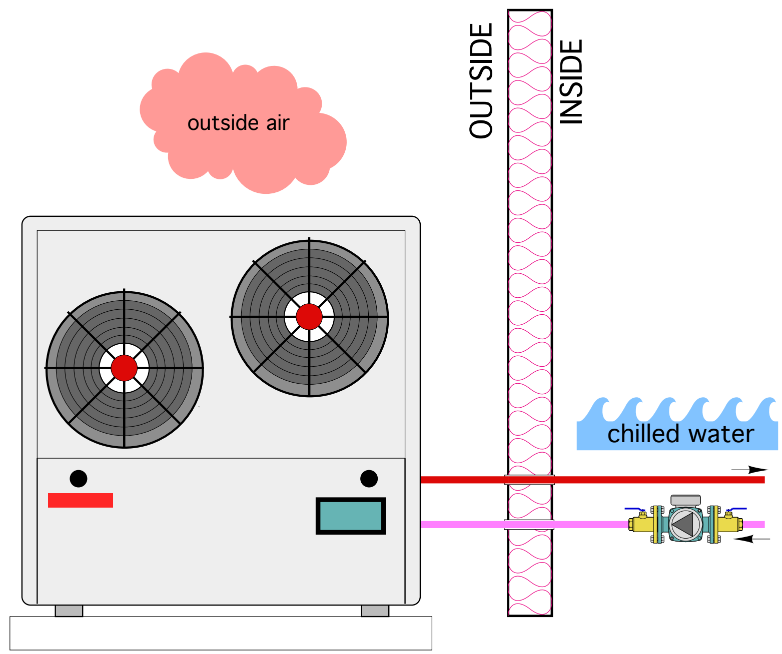
EVI refrigeration circuit



- 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:

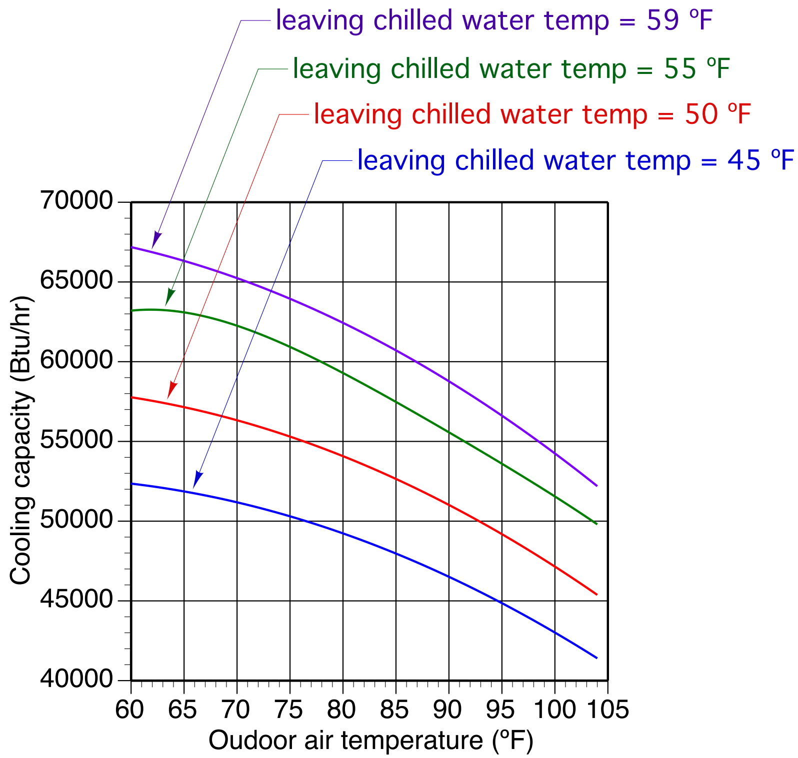




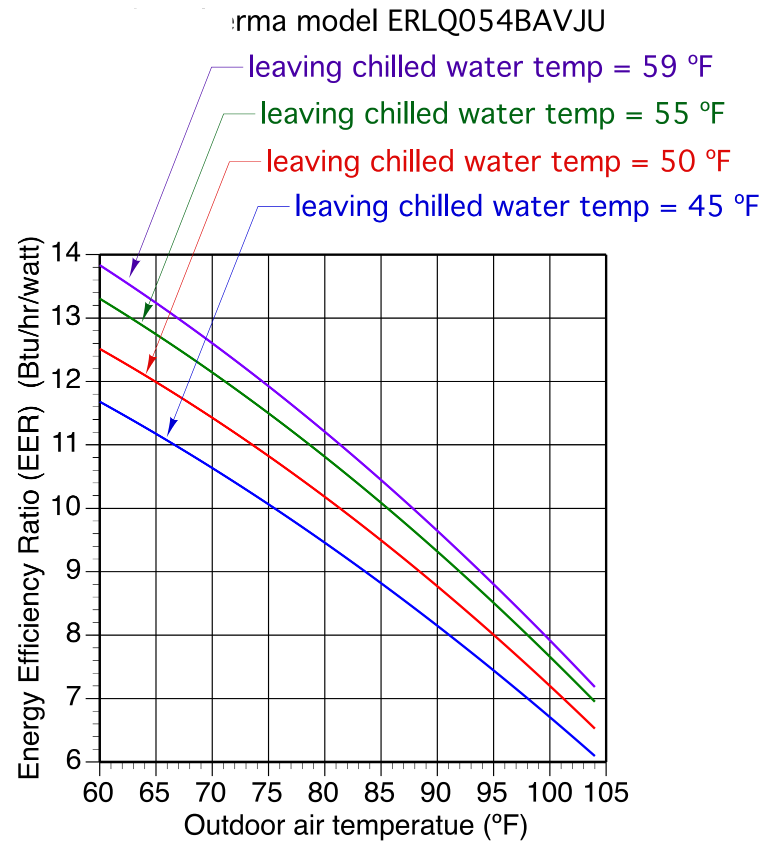
Anything that decreases the temperature lift' increases both the cooling capacity and EER of the heat pump.

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**.

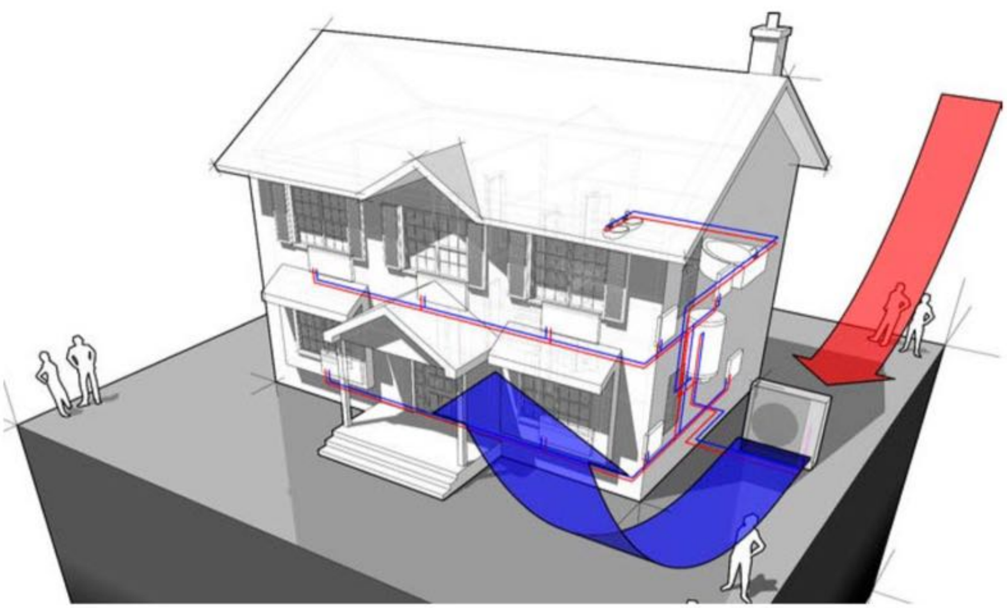
China accounted for just over 2 million of these units. Around 600,000 units were attributed to the European market, lead by France, Germany and Italy.

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]

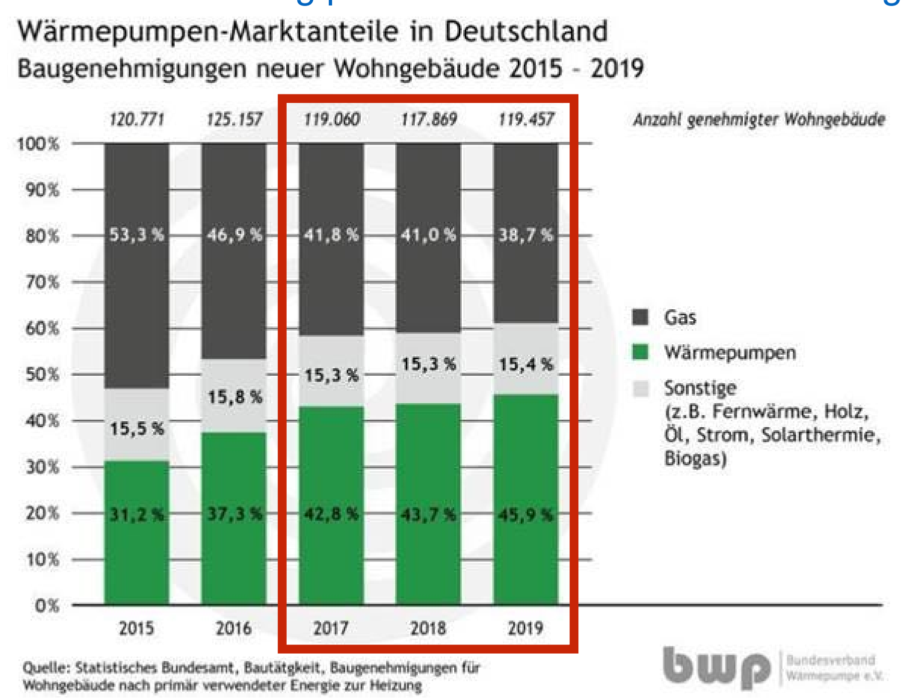
* Source: JARN July 2020,

Heat pumps overtake boilers in Germany



Heat pumps were installed in 43% of residential buildings in 2017. This was just ahead of gas heaters, which represented 42% of installations.

Heat pump market share in Germany
based on building permits for new residential buildings



Several trends suggest that a growing market will develop 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.

Thus, 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.

<u>*Space heat + DHW loads are so small it doesn't pay to put a gas meter on these houses.*</u>

<u>*AWHP could provide heating, cooling, & DHW*</u>

Source: Zerohomes.org

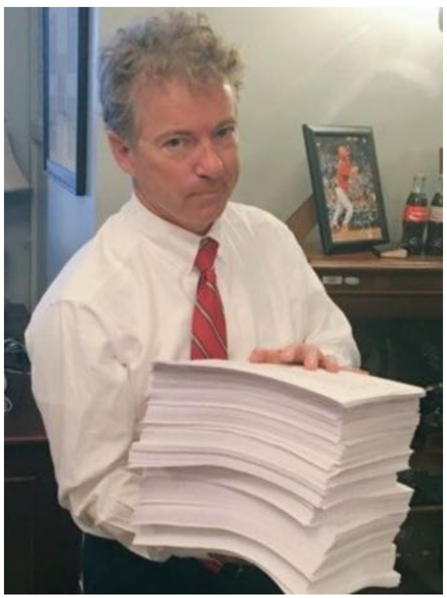
Several trends suggest that a growing market will develop for air-to-water heat pumps in North America

2. 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?

Several trends suggest that a growing market will develop for air-to-water heat pumps in North America

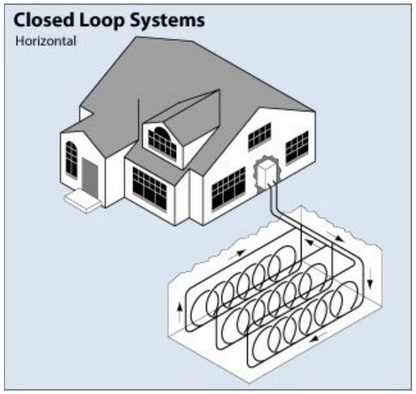
3. Air-to-water heat pumps are significantly less expensive to install compared to geothermal heat pumps:

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.

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

geothermal heat pump
typical installed cost = $X



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

Several trends suggest that a growing market will develop for air-to-water heat pumps in North America

4. Air-to-water heat pumps are significantly less disruptive to install 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.

Several trends suggest that a growing market will develop for air-to-water heat pumps in North America

5. 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.

Several trends suggest that a growing market will emerge for air-to-water heat pumps.

6. 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.

$$COP_{\text{HP only}} = \frac{27700\frac{Btu}{hr}}{(2.37kw)\left(\frac{3413\frac{Btu}{hr}}{kw}\right)} = 3.42 \qquad COP_{\text{HP +loop pump}} = \frac{27700\frac{Btu}{hr}}{(2.37kw + 0.287kw)\left(\frac{3413\frac{Btu}{hr}}{kw}\right)} = 3.05$$

Nominal 11% drop in "net" COP

Several trends suggest that a growing market will emerge for air-to-water heat pumps.

7. 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 °F, and the indoor temperature is 70 °F. The house is located in Syracuse, NY with 6,720 annual heating °F•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?

Several trends suggest that a growing market will emerge for air-to-water heat pumps.

8. 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….

I've discussed small scale chilled water cooling in several HPAC articles.

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

What about ductless mini-split heat pumps in low energy houses?

Why is the "net zero" housing market defaulting to mini-split heat pumps rather than hydronics?

Common suggestion for net zero houses….
Install a ductless mini-split air-to-air heat pump, with 1 or 2 indoor wall cassettes, and leave the interior doors open for heat distribution.

from www.greenbuildingadvisor.com

"Leave bedroom doors open during the day
If you want to heat your house with a ductless minisplit located in a living room or hallway, you'll need to leave your bedroom doors open during the day. When the bedroom doors are closed at night, bedroom temperatures may drop 5 F° between bedtime and morning."

"If family members don't want to abide by this approach, or don't want to accept occasional low bedroom temperatures during the winter, then supplemental electric resistance heaters should be installed in the bedrooms."

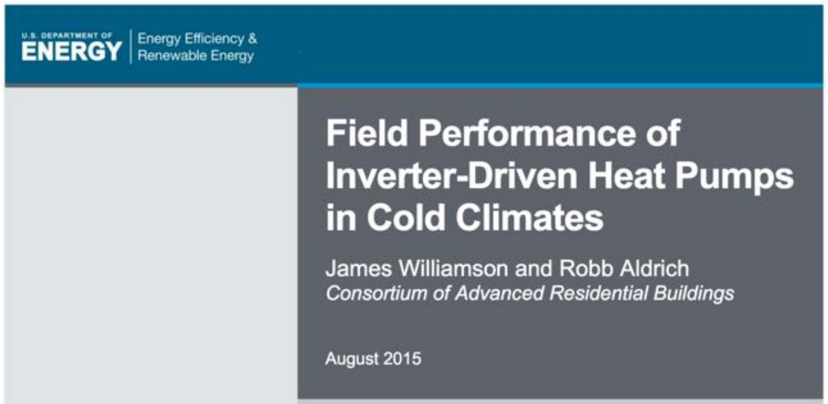
This is certainly a comfort "compromise"

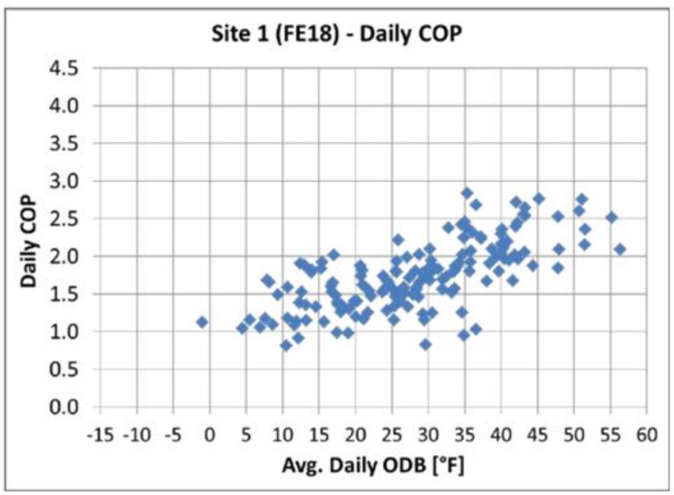
The "sub 0ºF" COPs of cold climate ductless mini-split heat pumps with inverter compressors, are not widely publicized.

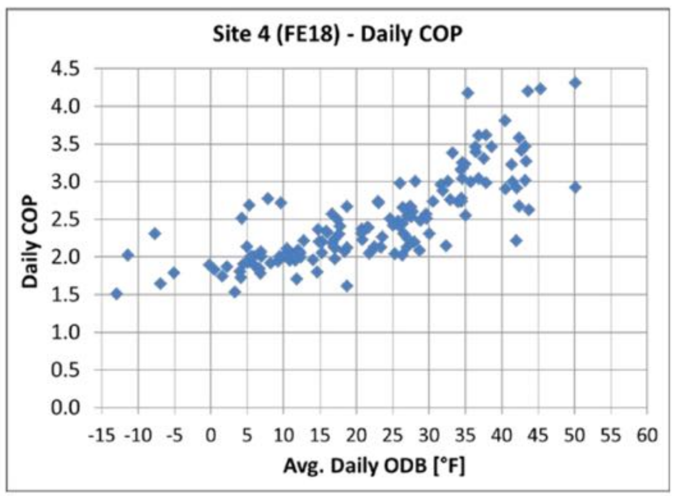

source: Revision Energy


historicshed.com

What happens to the COP of ductless mini splits at low ambient air temperatures?







Site 1 : COP = 1.1 at 0 °F

Site 4 : COP = 1.8 at 0 °F

It's not **just** about matching BTU delivery to load…
It's about providing <u>**COMFORT**</u>

Ductless mini-split heat pumps rely on forced air delivery.

While generally acceptable for cooling, forced air delivery doesn't provide optimal comfort for heating.

• There will be some temperature stratification from floor to ceiling.

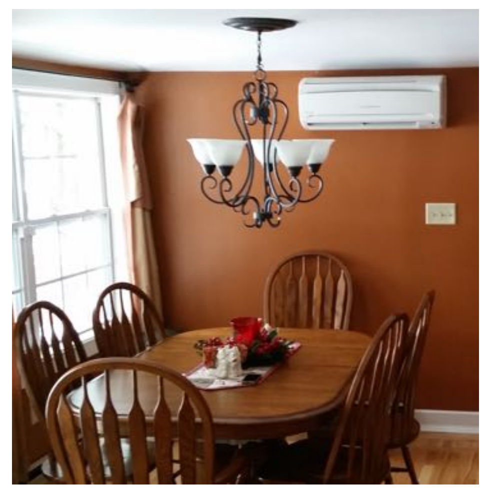
• Mini-splits blow cool air into spaces while defrosting outdoor unit.

• Cold floors are a common complaint with forced air heating.

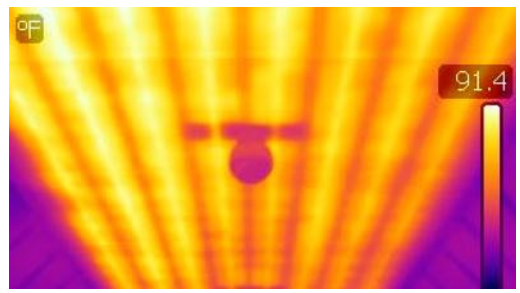
• High wall cassettes do little to counteract natural downdraft from large window surfaces.

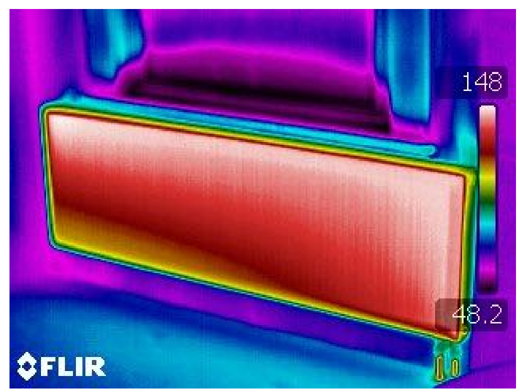
• Forced air heating may aggravate allergies or other respiratory symptoms.

• There will be some sound from forced air terminal units. Properly designed radiant floor, wall, and ceiling panels can operate with virtually no detectible sound.



Ductless mini-split heat pumps provide heating & cooling





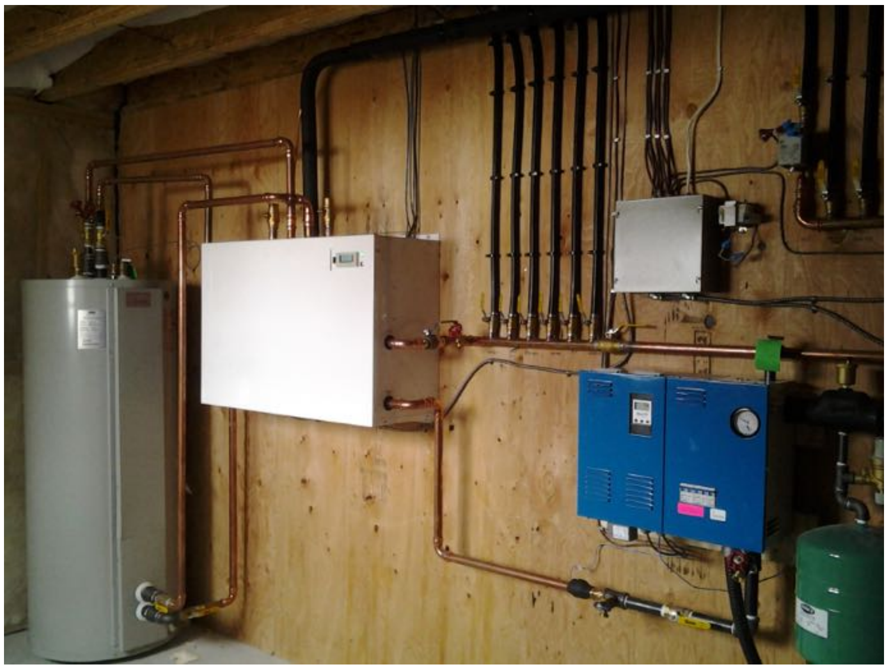
An air-to-water heat pump has the potential to provide…

- Room-by-room zoning
- Radiant & convective heat delivery
- Zoned cooling (air & radiant delivery)
- Domestic water heating
- Pool heating in summer
- Higher distribution efficiency
- Fewer (if any) interior refrigerant piping connections

New Concepts for air-to-water heat pumps

Bring your own condenser...

ThermAtlantic Energy Products, Inc.

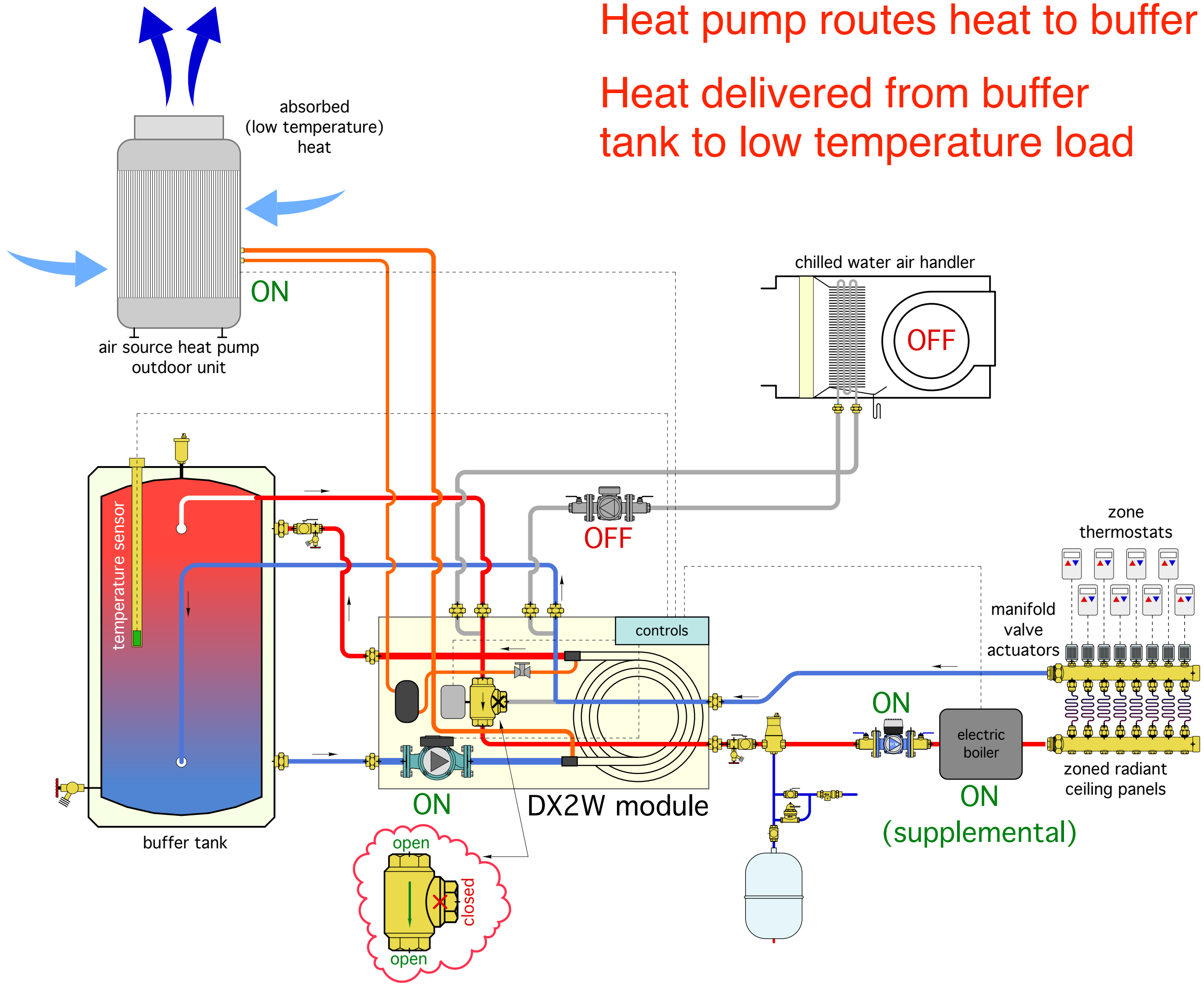


Bring your own condenser...

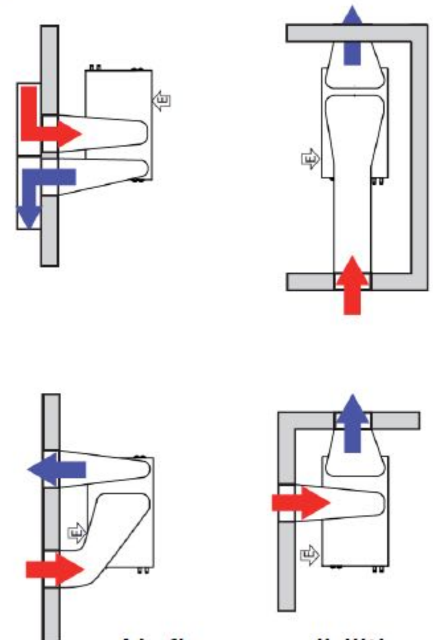
Heating mode

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:

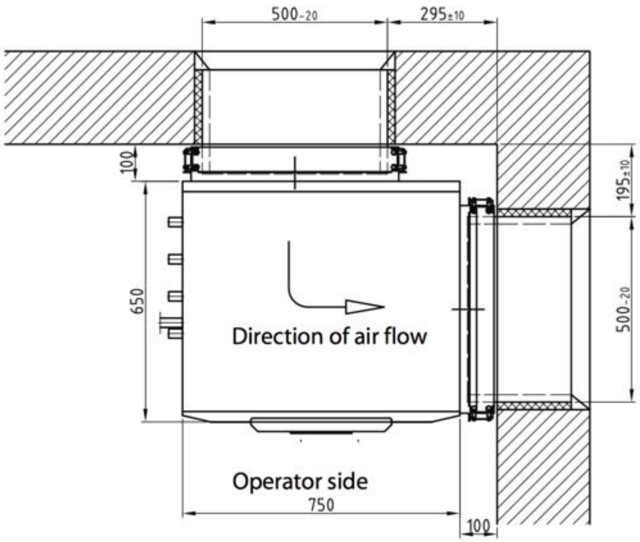
• No outdoor equipment beyond air intake and discharge grills
• Less potential to freeze water containing within the heat pump
• Less environmental weathering effect on equipment
• Reduced potential for debris on heat transfer coil surfaces

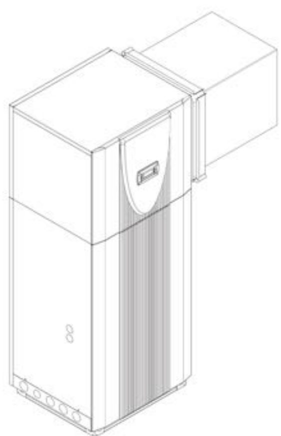
Disadvantages:

• 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.

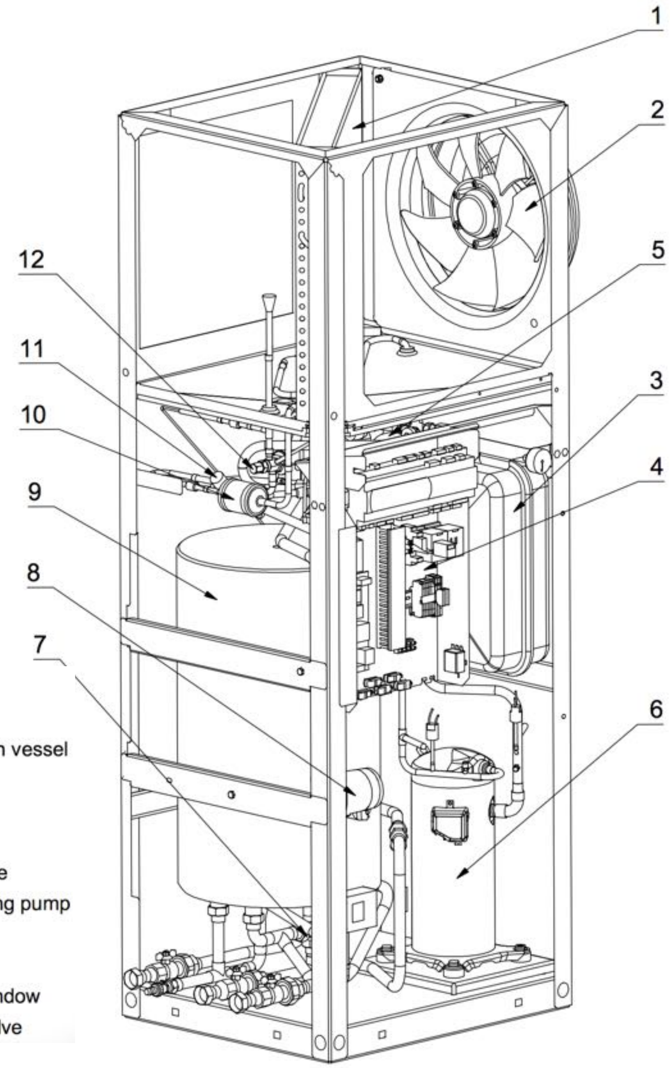
image courtesy of HotJet.cz

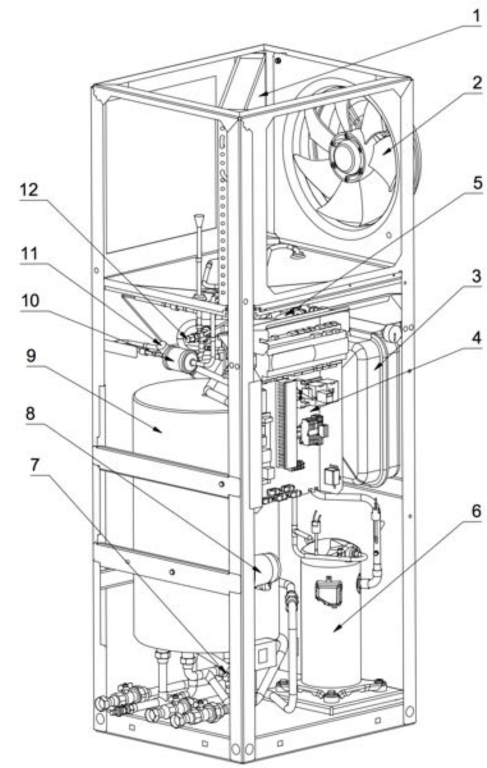
Interior *air-to-water heat pump (corner)*





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





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Additional information

Hot-off-the-press and today's topic of discussion.

idronics #27
Air-to-Water Heat Pump Systems

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

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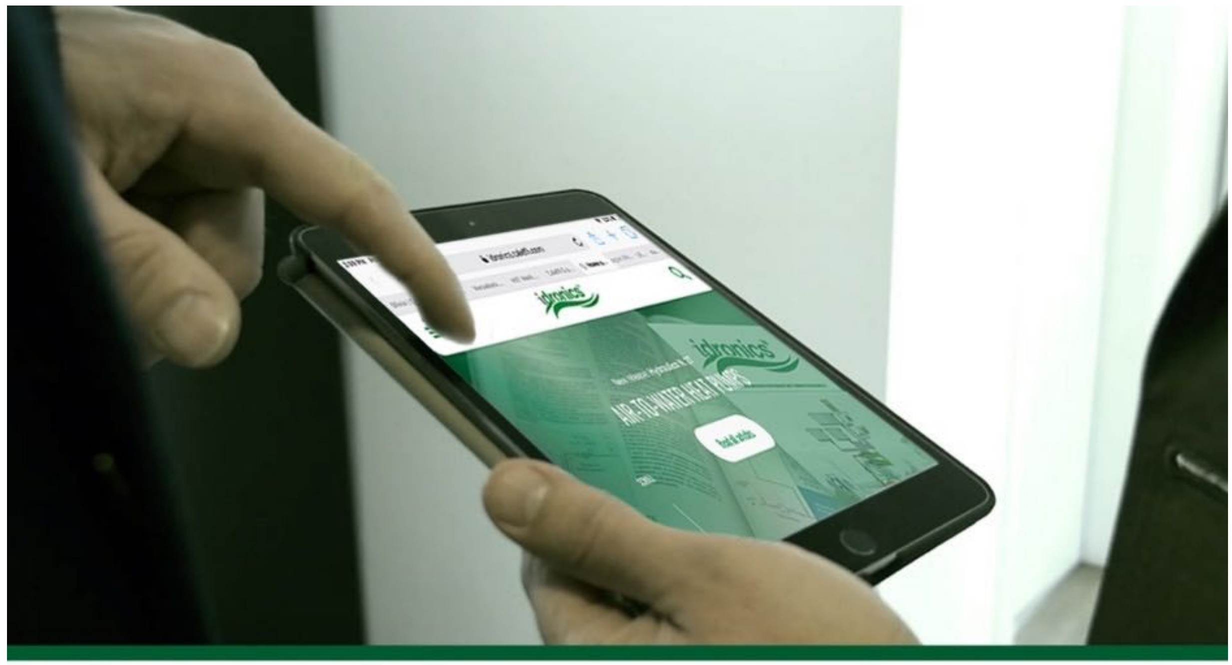

Air-to-Water Heat Pump Systems

CALEFFI Hydronic Solutions

More training assets.

Part 2 (of this webinar)…
Nov 20, 2020 @ 1 PM

Will focus on systems design and performance simulation.
Register at: HPACmag.com

QUESTIONS ?