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Making a case

Air-to-water heat pumps might be the right choice for light commercial applications.

The purpose of any heat pump is to move heat from some material at lower temperature to another material at higher temperature. The "material" that supplies the heat (e.g., the "source") can be just about anything from which heat can be reliably and repeatedly extracted through a heat exchanger to an evaporating (or absorbing) refrigerant.

The most common sources of low temperature heat are outdoor air and water. The most common type of heat pump for space heating and cooling extracts heat from outdoor air and is thus called an air-source heat pump. Heat pumps that extract heat from water appropriately are called water-source heat pumps. When the water comes from a well, pond, lake or passes through tubing buried in the earth, more specific names include geothermal, ground-source or even earth-linked heat pumps.

In thermodynamic parlance, the material into which the heat pump delivers higher temperature heat is called the "sink" of the heat pump. The most common sink materials again are air and water. The air typically is interior air circulated through a forced-air distribution system. When heat is delivered to water for space-heating purposes, the water circulates through a hydronic distribution system.

If you put the source and sink terms together, with the text (-to-) between them, a more complete description of the heat pump emerges. Examples include air-to-air, water-to-water, water-to-air and air-to-water.

A what?

Nearly all North American heating professionals are familiar with heat pumps. Also, most know what a geothermal heat pump does, even if they do not design, install or service them. But ask them about air-to-water heat pumps and you are likely to get a confused stare in return. Although most heating professionals likely could figure out what an air-to-water heat pump does, given its description, most have never dealt with this type of hardware.

Photo courtesy of John Siegenthaler

This is not the case in other markets such as Asia and Europe where a strong market exists. In 2014, the global market for air-to-water heat pumps totaled more than 1.7 million units! The Chinese market alone represented almost 1 million units sold in 2014. The European market was 232,000 units, with France as the No. 1 market, followed by Germany and the United Kingdom. The North American market was a tiny fraction of global sales.

Still, several indicators suggest the air-to-water heat pump market has significant growth potential for North America. Here's a list for your consideration.

1. Net zero: A net-zero energy home produces at least as much energy as it consumes during an average year. To reach this goal, a typical NZE house is well insulated. The heating energy used by such a house is often 1/3 or less than that used by a similar-size house constructed 30 years ago. NZE houses also need a sizable solar photovoltaic array on the roof or on a ground-mount frame to generate electrical energy.

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 can be "parked" on the electrical grid and reclaimed to run a heat pump on a cold winter night with no technical or economic penalty. This is an ideal scenario that can be leveraged through use of electrically-driven heat pumps.

One common approach to heating and cooling NZE homes is to install a ductless mini-split air-to-air heat pump system with two or three high-wall fan coils. These fan coils usually are located in central areas of the home, such as hallways, and occupants are told to leave interior doors open for proper distribution of heated or cooled air.

Proponents of this approach stress their belief that no interior comfort distribution system, such as ducting or piping, is needed. One blog on the subject states if all interior doors are left open in a well-insulated house, interior air temperatures will stabilize at not less than 2° F below the air temperature where the indoor fan coils are located. This reference also states if bedroom doors are closed at night, the bedroom temperature may drop 5° below the temperature where the indoor unit of the heat pump is located.

Should these constraints be accepted without hesitation?

Designers who only are concerned with matching heat input to space heat loss likely would say yes. However, those who appreciate

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the superior comfort that is possible using modern hydronics technology would view this approach as a significant compromise. They understand buildings can be both energy efficient and very comfortable – doors open or closed.

Imagine if one could retain the thermal performance advantages of modern "low ambient" air-source heat pumps, but switch to hydronics for the balance of system, and enjoy superior comfort, the potential for room-by-room zoning, design versatility, and the ability to handle several ancillary loads (other than space heating or cooling).

This all is possible using modern air-to-water heat pumps coupled to low-temperature hydronic distribution systems.

Cooling can be handled by chilled water flowing through a central air handler, multiple smaller air handlers distributed throughout a building, or a combination of radiant panel cooling and a relatively small air-handling system for humidity control and ventilation.

2. Reduced installation cost: Air-to-water heat pumps are significantly less expensive to install compared to geothermal heat pumps. This especially is true if vertical boreholes are required for the earth loop, which, in some areas, can cost more than $3,000 per ton of heat pump heating capacity for drilling, pipe insertion and grouting. Additional cost is incurred for connecting multiple vertical loops and routing them back to the mechanical room. Replacement of any affected pavements or landscaping also must be factored into the cost of installing a geothermal heat pump system. Thus, the cost of installing a 3-ton-rated vertical geothermal earth loop and piping it back into the building could easily exceed $10,000. The sizable portion of the system installation cost is eliminated when an air-to-water heat pump is used.

3. COPing out: The published coefficient of performance of some water-to-water heat pumps used in geothermal applications is higher than those of some air-source heat pumps. For example, one currently available water-to-water heat pump has a published COP of 3.0, based on 30° entering source fluid (water/antifreeze mixture) and a leaving load water temperature of 112°.

One currently available air-to-water heat pump has a listed COP of about 2.1 when operating under similar conditions (e.g., 30° ambient air temperature and a leaving load water temperature of 110°). If one directly compares the COPs of these two heat pumps, the water-to-water heat pump seemingly has a significant advantage.

However, before directly comparing these COPs it is prudent to examine how they are calculated.

Many water-to-water heat pumps used in closed-loop geothermal applications have listed COPs based on ANSI/AHRI/ASHRAE/ISO Standard 13256-2. This standard includes an estimated power demand for the earth loop circulator(s). That power demand can be calculated using Formula 1.

> Formula 1.

$$w_1 = 0.629(f)(H_{HP})$$

Where:

w_1 = assumed power requirer to create flow through the heat pump water-to-refrigerant heat exchanger (not the earth loop) (watts)

f = flow rate at which the heat pump is tested (gpm)

H_{HP} = head loss through heat pump due to flow (f)

Under ANSI/AHRI/ASHRAE/ISO Standard 13256-2, the heat pump is tested at a single flow rate. This flow rate and the resulting head loss through the heat pump are used in Formula 1 to estimate the power required to circulate the water through the heat pump. This power is added to the power demand of the heat pump's compressor when calculating the COP of the heat pump.

Here's an example using data from a commercially available 5-ton water-to-water heat pump.

At an 18-gpm flow rate, the head loss of the heat pump is 15.9 ft.

Using Formula 1:

$$w_1 = 0.629(f)(H_{HP}) = 0.629(18)(15.9) = 180\,watt$$

However, when the head loss of an earth loop consisting of three parallel 1,000-ft.-long circuits of 1-in. DR-11 HDPE tubing operating with a 20% solution of propylene glycol antifreeze and a short 1.25" header system is included, the total head loss of the complete earth loop circuit is 38 ft. of head at 13.3 gpm. The latter flow rate is the minimum at which turbulent flow can be maintained in the 1" nominal piping when conveying a 20% solution of propylene glycol at 30°. The pressure drop of the 20% propylene glycol solution corresponding to a head loss of 38 ft. is 16.63 psi.

The power consumption needed to maintain flow through the entire earth loop circuit (e.g., heat pump + earth loop) can be estimated using Formula 2.

> Formula 2.

$$w_2 = \frac{0.4344(f)(\Delta P)}{\eta_{w/w}}$$

Where:

w_2 = estimated power demand of earth loop circulator (watts)

f = flow rate (from earth loop) through heat pump (gpm)

ΔP = pressure drop of circuit (psi)

$n_{w/w}$ = wire-to-water efficiency of earth loop circulator (decimal %)

Many light commercial and residential geothermal heat pump systems use wet-rotor circulators with permanent-split capacitor motors. These circulators would have a peak wire-to-water efficiency in the range of 25%.

Putting these numbers into Formula 2 yields the estimated electrical power input required to maintain flow in the entire earth loop.

$$w_2 = \frac{0.4344(f)(\Delta P)}{\eta_{w/w}} = \frac{0.4344(13.3)(16.63)}{0.25} = 384\,watt$$

The estimated power demand for this particular earth loop circuit is more than twice the estimated power consumption associated with flow through the heat pump only based on the ANSI/AHRI/ASHRAE/ISO Standard 13256-2.

An effective COP for a closed-loop geothermal heat pump, which includes the electrical power required for circulating fluid through the earth loop and heat pump, can be calculated by correcting the COP based on the 13256-2 standard using Formula 3 (on page 18).

> **Formula 3.**

$$COP_e = COP_{13256}\left(\frac{w_c + w_1}{w_c + w_2}\right)$$

Where:
w_1 = estimated power from formula 1 (watts)
w_2 = estimated power formula 2 (watts)
w_c = power demand of heat pump compressor (watts)
COP_{13256} = published COP of heat pump based on ANSI/AHRI/ASHRAE/ISO Standard 13256-2

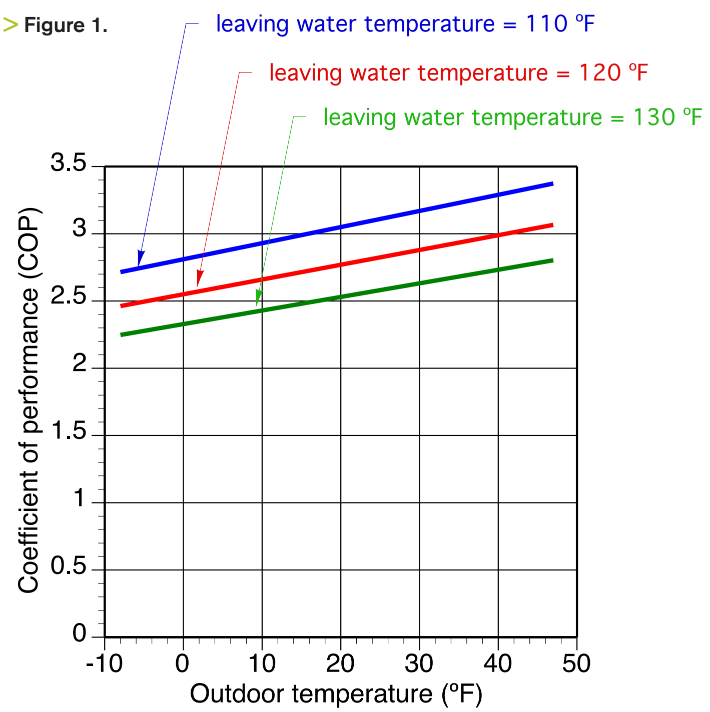
Here's an example: A nominal 5-ton water-to-water heat pump has a listed COP of 3.1 based on ANSI/AHRI/ASHRAE/ISO Standard 13256-2. At rated conditions, the compressor power input is 4,700 watts. The value of w_1 was calculated for the rated flow rate of 18 gpm at 180 watts. The value of w_2 was determined using Formula 2 as 384 watts. The effective COP of the heat pump plus earth loop circulator combination is:

$$COP_e = COP_{13256}\left(\frac{w_c + w_1}{w_c + w_2}\right) = 3.1\left(\frac{4700+180}{4700+384}\right) = 2.98$$

The greater the earth loop circulator(s) power consumption is relative to the compressor power, the lower the effective COP relative to the published COP.

The COPs of air-to-water heat pumps include the electrical power required to operate the fan(s) in the outdoor unit. Under similar conditions (e.g., outdoor temperature = 30° and leaving load water temperature = 110°), the COP of currently one available air-to-water heat pump is about 3.3. Figure 1 shows the range of COPs for this heat pump as a function of outdoor temperature and leaving load water temperature.

> **Figure 1.**



It's important to remember owners do not pay for COP. They pay for the kilowatt•hours of electrical energy used to operate the heat pump. As home heating loads decrease due to better thermal envelopes, the difference in annual heating cost between heat pumps operating at seasonal average COPs that differ by 1.0 or less decreases. The incrementally lower operating cost of the higher-performance heat pump may not amortize a significantly higher installation cost within the expected life of the system.

For example: A home with a design heat loss of 25,000 Btu/hr., based on an outdoor temperature of 0° and indoor temperature of 70°, and located in a 7,000° day climate, would have an estimated annual heating requirement of about 39 MMBtu/year. If this load was supplied using a geothermal heat pump with a seasonal average COP of 3.3 (which includes the power required to operate the earth loop circulators), in a location where electrical energy is priced at $0.12 per kWhr, the annual heating cost would be about $416.

If the same 39 MMBtu/year were supplied from a low-ambient air-to-water heat pump with a seasonal average COP of 2.5, the annual heating cost would be about $549. The difference, $133 per year, would not be able to amortize an installed cost that easily could be several thousands of dollars higher (even after factoring in the 30% federal income tax credit currently available in the U.S. for geothermal heat pumps) within the design life of the equipment.

4. Countdown: Given the status of federal politics it is impossible to say what might transpire in the final days leading up to Jan. 1, 2017. But, if the federal tax credits for geothermal heat pumps expire as currently scheduled, a major purchasing incentive will be gone, forcing geothermal heat pump systems to compete against far less costly alternatives in an unsubsidized market.

5. Don't forget DHW: In low-energy houses occupied by average people using 15 gal. of hot water per day per person, domestic water heating can account for up to 30% of the total annual energy usage.

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

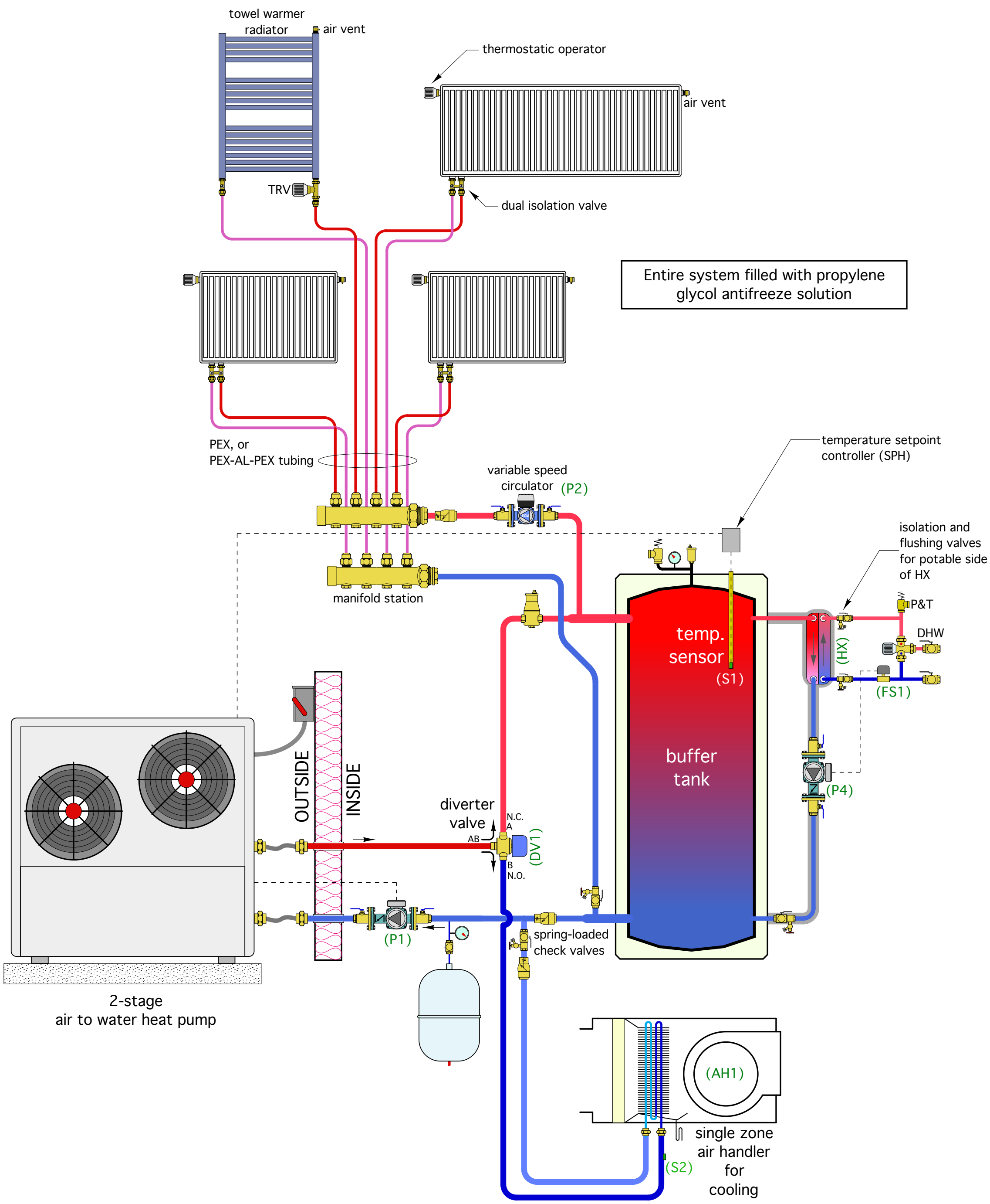
A standard electric water heater providing domestic water heating in a situation where an air-to-air heat pump cannot, delivers heat at a COP of 1.0. If that energy was instead attained through an air-to-water heat pump, it likely could be delivered at a COP averaging 2.5 throughout the year. For a family of four needing 60 gal. per day of water heated from 50-120°, and assuming electrical energy priced at $0.12 per kWhr, the savings in annual domestic water heating cost between these scenarios is $269 per year.

Figure 2 (on page 20) shows one example of a system which uses a two-stage air-to-water heat pump to maintain the temperature of a buffer tank in the range of 115 to 125°. This is sufficiently hot to heat domestic water through an "on-demand" external heat exchanger. It also is high enough to supply the design heating load through panel radiators that have been sized base on a supply water temperature of 120° at design load.

Aim low

The key to good space-heating performance is to integrate the air-to-water heat pump with a low-temperature hydronic distribution system. My suggestion is to design the heat emitter system so design loads can be provided using supply water temperatures no higher than 120°. Even lower supply water temperatures are possible with some types of radiant

> Figure 2.



floor, wall or ceiling panels. There also are panel radiators and even "enhanced" fin-tube baseboard that can operate at water temperatures no higher than 120°.

The lower the water temperature required by the distribution system, the higher the heating capacity and COP of the heat pump. This is evident in Figure 1 (on page 18).

I am confident modern air-to-water heat pumps coupled to a hydronic distribution system will play an increasingly important role in achieving NZE buildings.

They also will gain market share in buildings with somewhat less ambitious goals for reducing the cost of heating and cooling. They represent an important tool for designers looking to utilize renewable energy while also providing superior comfort. **pme**

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