SPACE PAK HYDRONICS
waterworks
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April 2020 Edition

An Air-to-Water Heat Pump Solution

Imagine that you're planning to build a new home. What should you be considering to stay warm in winter, cool in summer and always supplied with domestic hot water?

It's a question that tens of thousands of prospective homeowners face every year.

Today, most people turn to Internet searches for help, and some will spend hours looking at almost endless possibilities.

During their searches, they are likely to encounter information on building an energy-efficient or "net zero" home. The latter is an especially popular topic. The net zero housing market in the U.S. is currently experiencing an annual growth rate of over 30 percent.

Although there are multiple definitions for "net zero," the one that most consumers understand is a house that produces as much energy as it needs over the course of an average year. The only practical way to achieve net zero status is to produce some of the energy needed by the home on site. This is typically done by installing a solar photovoltaic system, or by participating in a "community" solar cooperative.

Lowered Losses

A somewhat self-evident requirement in achieving net zero status is to minimize energy use. Most net zero homes are very well-insulated and air-sealed. Design heat losses in the range of 10 to 15 Btu/hr per square foot of floor area are typical. Thus, a 2,000-square-foot net zero home could have a design load of only 20,000 to 30,000 Btu/hr. That's about 1/3 the rate of heat loss of a typical home constructed in the 1980s.

These reduced heating loads can be significantly smaller than the output of the smallest available gas-fired boilers, which typically have rated outputs of about 50,000 Btu/hr. Even the smallest modulating boiler will have a minimum output that often exceeds the heating needs of a modest well-insulated home. Installing a 50,000 Btu/hr boiler in a home with a design heat loss of 20,000 Btu/hr will lead to short cycling and reduced efficiency.

There's also the monthly meter charge associated with having natural gas service at the home. At $20 per month, this charge might even exceed the cost of the natural gas consumed in a highly efficient home.

Is "geo" the ultimate solution?

As consumers surf the Internet looking for way to reduce heating and cooling costs, they will also likely encounter information on geothermal heat pump systems. The advertised benefits of these systems will probably be appealing, since they operate on electricity, can be very efficient and can provide cooling. Some can even provide a portion of the home's domestic hot water requirements.

As of 2020, there's also a 26 percent federal income tax credit on qualified geothermal heat pump systems installed in the U.S. This all sounds very appealing, until they begin looking into the installation cost and complexity of a geothermal heat pump, thousands of feet of tubing buried in trenches or multiple boreholes, along with specialized equipment required for installation. The clock is also counting down on those U.S. federal income tax credits. In 2021, they will drop to 22 percent before expiring at the end of that year. Without these incentives, the return on investment for high-cost geothermal heat pump systems will be hard to justify.

Simulations of a home with a 36,000 Btu/hr design heating load, located in upstate New York (6100ºF•day climate), have shown annual cost savings of about $100 per year associated with a geothermal heat pump when compared to a low-ambient air-heat pump. The estimated additional cost of the geothermal heat pump system, without tax credits or other subsidies, is about $10,000. You do the math.

Consumers who further refine their search to comfort, rather than just heating and cooling, will probably come across information on low-temperature hydronic radiant floor heating — the "gold standard" of comfort and energy efficiency.

By this point, the typical web-surfing consumer has lots of information, ranging from building insulation options, tax credits, heat pumps, net zero options, forced air versus hydronic distribution systems and more. It's difficult for most consumers, who have little background in HVAC systems, to piece this information together into an overall plan for their upcoming mechanical system needs.

What they didn't find…

After hours of searching, there's a "hidden gem" that most consumers probably didn't come across. It's called an air-to-water heat pump. A device that can pull together the appealing concepts of net zero, heating, cooling, domestic hot water production and perhaps most importantly — comfort.

Air-to-water heat pumps extract low-temperature heat from outside air, concentrate that heat and deliver it to buildings through low-temperature hydronic distribution systems. They are widely used in Asia and Europe. In 2018, there were over 368,000 air-to-water heat pumps sold in Europe, with France and Germany leading the way. That same year, the Chinese market for air-to-water heat pumps was approximately 1.28 million units. The Japanese market was about 475,000 units. They have established a reputation for good performance in a variety of climates. This technology is now poised to capture an increasing share of the North American heat pump market.

SpacePak is a leader in air-to-water heat pump technology. It's current generation SIS-060A4 model can extract heat from outside air at temperatures down to -22ºF. making it viable for most locations in North America. The SIS-060A4 heat pump can also deliver water at temperatures up to 130ºF, making it compatible with a wide variety of modern hydronic heating systems.

This issue of Waterworks will describe one installation that uses a SpacePak SIS-060A4 heat pump to tie together many of the concepts mentioned above. The resulting system supplies comfort heating, central cooling and a significant percentage of the home's domestic hot water needs.

The Requirements

The clients for the system to be described wanted their new home in rural upstate New York to be energy efficient, have superior comfort without the "compromises" of forced-air heating and remain cool in summer.

The home they designed has about 3,300 square feet of finished/heated space, and a 3-stall garage. The home was constructed with R-29 above-grade walls, R-24 basement walls, R-51 ceilings, and triple-glazed low-E argon-filled windows. Part of the insulation system was sprayed polyurethane foam, resulting in minimal air leakage. The design heating load, excluding the garage, was 35,000 Btu/hr, or about 11 Btu/hr per square foot of living space. The outdoor design temperature at the home's location is -10ºF.

The rear of the house was oriented directly south to take advantage of passive solar gain. This orientation was also ideal for installation of a roof-mounted 7.8-kilowatt solar photovoltaic system. The home's North and South elevations are shown in Figures 1 and 2.

Figure 1

Figure 2

The clients had done their research and wanted hydronic heating as well as central cooling. They also wanted an all-electric house to maximize use of their net-metered solar electric system. They also wanted a small wood stove to provide backup heating, just in case a prolonged power outage occurred during cold weather.

This combination of hydronic heating and cooling, supplied through electricity, points to a heat pump as the main heat source, as well as a chiller. ***A SpacePak SIS-060A4 split-system air-to-water heat pump was selected.*** Its variable-speed inverter compressor provides a heating output range from 21,000 to 68,000 Btu/hr, and a cooling output range of 1.7 to 4.3 tons (20,400 to 51,600 Btu/hr). This unit, which can operate at outdoor temperatures as low as -22ºF, could handle the design heating load for the house at 35,000 Btu/hr, with reserve capacity for occasionally warming the garage.

The outdoor portion of the SIS-060A4 heat pump was mounted on the north side of the building, just outside the basement mechanical room, as shown in Figure 3.

Figure 3

The outdoor unit is bolted to an adjustable steel stand that supports it about 15 inches above finished grade. This is high enough to keep the unit above snow. It also reduces debris such as grass clippings or leaves from accumulating on the air-to-refrigerant heat exchanger coil. The legs of the stand are bolted to pressure-treated 2x8 pads that are leveled just below finish grade. The area under the stand is covered with landscape fabric to prevent weed growth. A layer of crushed stone was placed over this fabric. Short steel angle brackets were connected between the rear legs of the stand and the concrete foundation to better stabilize the unit against the strong wind gusts common to the area.

A 15-foot insulated refrigerant line set (5/8" suction line/3/8" liquid line) connects the outdoor unit to the indoor unit, as seen in Figure 4.

Figure 4

The indoor unit contains a refrigerant-to-water heat exchanger, 1" FPT connections for water piping, and a touchscreen user interface. It's about the same size as a small wall-hung boiler and has a fully hinged front access panel.

Emitter Ensemble

The clients wanted a variety of floor coverings in their new home, ranging from ceramic tile, to engineered hardwood, a large throw rug in the living room, and wall-to-wall carpet in the bedrooms. The latter was specified as moderately plush with polyurethane padding. The high thermal resistance of the carpet plus padding ruled out floor heating in the bedroom areas. The modern hydronics solution — size up a panel radiator for each bedroom. One of those radiators is shown in Figure 5.

The bathrooms were specified with ceramic tile and floor heating. One additional request — a towel warmer in the master bathroom.

The great room space includes a living room, kitchen and dining area. The kitchen and dining areas would have engineered wood floors and floor heating. The living room would also have wood floors, but they would be mostly covered with a large area rug, which created too much thermal resistance for floor heating. Two panel radiators, operating in parallel with the floor heating in the kitchen and dining areas, would keep the living room comfortable.

Each of the three bedrooms and two bathrooms would be operated as a separate zone. Although this sounds complicated, it's easy to accomplish using homerun piping circuits of 1/2" PEX, PE-RT or PEX-AL-PEX tubing to each radiator, along with nonelectric thermostatic radiator valves. These valves are integrated into the upper corner of each radiator. They continually sense room air temperature and adjust the warm water flow rate through the radiator to maintain each room at the set comfort level. Figure 6 shows a close-up of one thermostatic valve.

Figure 5

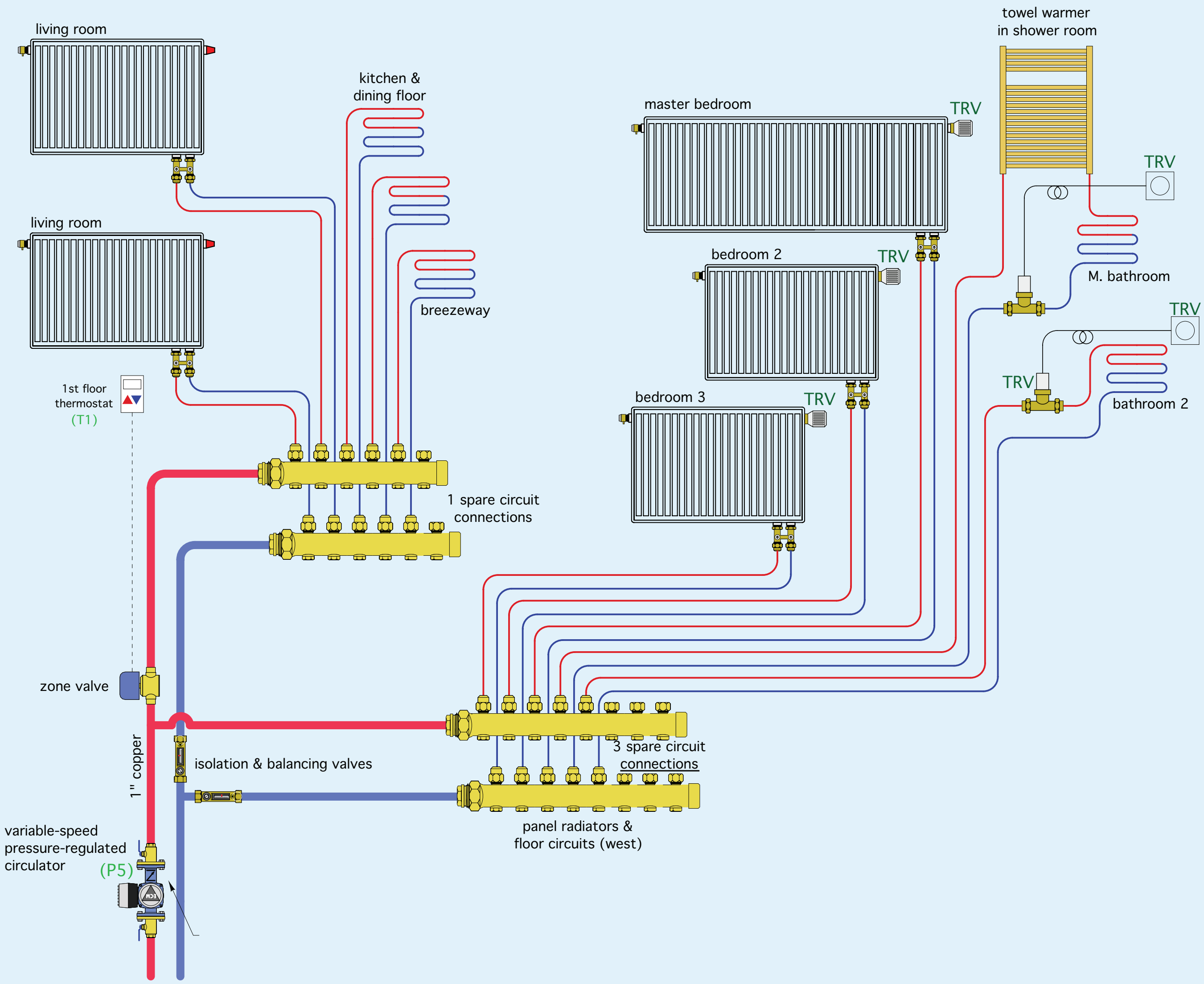
Figure 6

The system has a simple "mode switch" which can be set for heating, cooling or off. Whenever this switch is set to heating, water at a temperature of 100 to 110ºF, created by the SIS-060A4 heat pump, flows to any room with an open (or partially open) radiator valve. A low-power/high-efficiency circulator creates that flow and automatically adjusts its speed as the various thermostatic valves open, close or modulate.

The panel radiators and floor-heating circuits were all sized to operate at a supply water temperature of 120ºF at design load conditions. However, experience gained with the system over its first heating season proved that supply water temperatures no higher than 110ºF can meet all heating loads.

Figure 7 shows how the heat emitters were supplied from two manifold stations.

Figure 7



The upper manifold station serves the 3 floor-heating circuits, one each in the kitchen and dining room, and another in the breezeway. This manifold station also serves the two panel radiators in the living room. Flow to all 5 circuits on this manifold passes through a zone valve operated by a room thermostat. This manifold also had one "spare" connection to allow another panel radiator, or other heat emitter, to be easily added in the future.

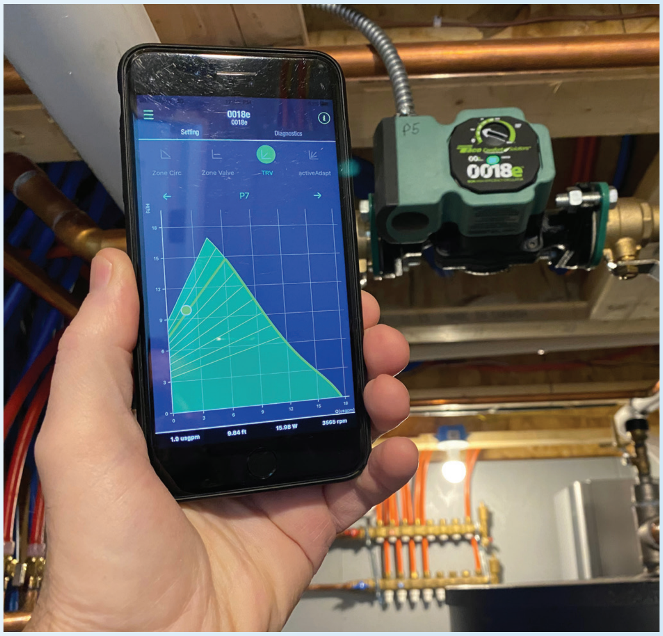
The lower manifold serves the three panel radiators in the bedrooms, and the two floor-heating circuits in the bathrooms. The master bathroom also has a towel warmer piped in series with the short floor-heating circuit. Each panel radiator has an integral thermostatic valve. The two floor-heating circuits are also regulated by thermostatic valves, which are mounted in accessible areas under the floor. These valves are connected to setting dials by capillary tubes. Each setting dial is mounted at normal thermostat height, as seen in Figure 8. The lower manifold station has three spare connectors to allow the possibility of adding radiators in a future finished attic.

Figure 8

Because they are piped in parallel and supplied by the same circulator, each manifold station has a flow balancing valve with integral flowmeter.

Flow to both manifold stations is provided by a small variable-speed circulator operating under proportional differential pressure control. That circulator, a Taco 0018, can communicate with a smart phone or tablet using Bluetooth protocol. Its power demand, flow rate and head can be monitored in real time, as shown in Figure 9.

Figure 9

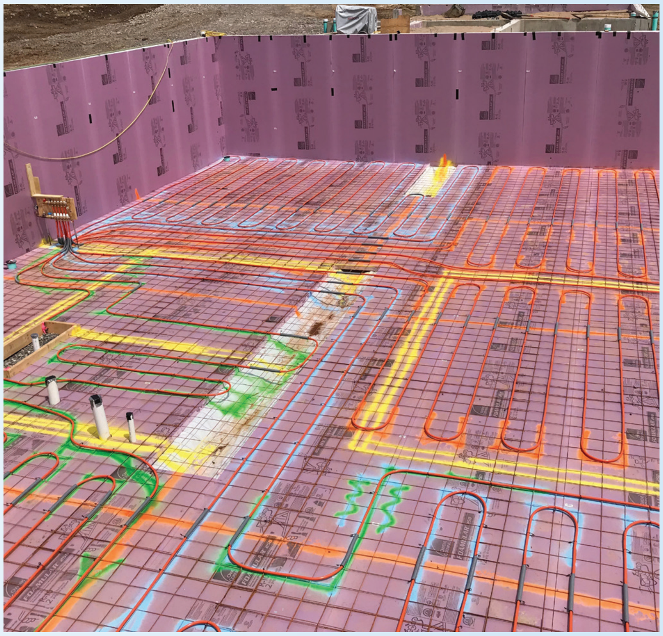


When all zones are operating at full flow, supplying heat to the entire main floor and breezeway, this circulator only requires about 28 watts of electrical power input. This is far less power than would be required by a forced-air distribution system of equal heating capacity.

Barefoot Basement

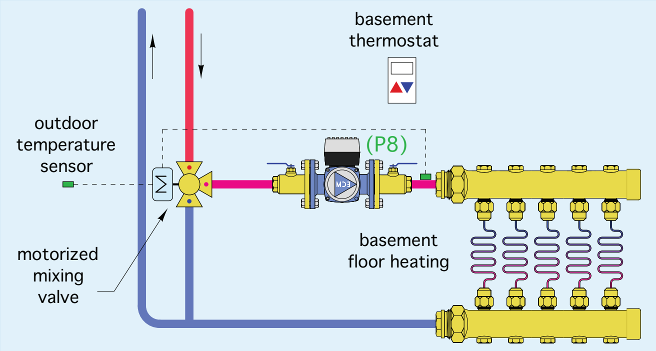
The walk-out basement has in-slab heating. The tubing was carefully laid out to minimize control joint crossings and to allow for possible future partitions, as shown in Figure 10.

Figure 10



The basement is operated as a separate zone. Because of its large floor area and low heat loss, the required water temperature at design load is only about 95ºF. This is significantly lower than the supply water temperature required for the panel radiator and underfloor tube & plate floor heating on the main floor. The reduction in supply water temperature is handled by a motorized 3-way mixing valve operating based on outdoor reset logic. The warmer the outdoor temperature, the lower the supply water temperature to the basement floor circuits. The piping for this zone is shown in Figure 11.

Figure 11



The home's garage is also equipped with slab heating and set up as a separate zone. This portion of the system operates with a 30 percent solution of propylene glycol antifreeze, which provides burst protection down to -10ºF, allowing it to remain off in cold weather if the owner chooses. It is separated from the balance of the system by a 5" x 12" x 30 plate stainless steel brazed plate heat exchanger. This portion of the piping is shown in Figure 12.

Figure 12

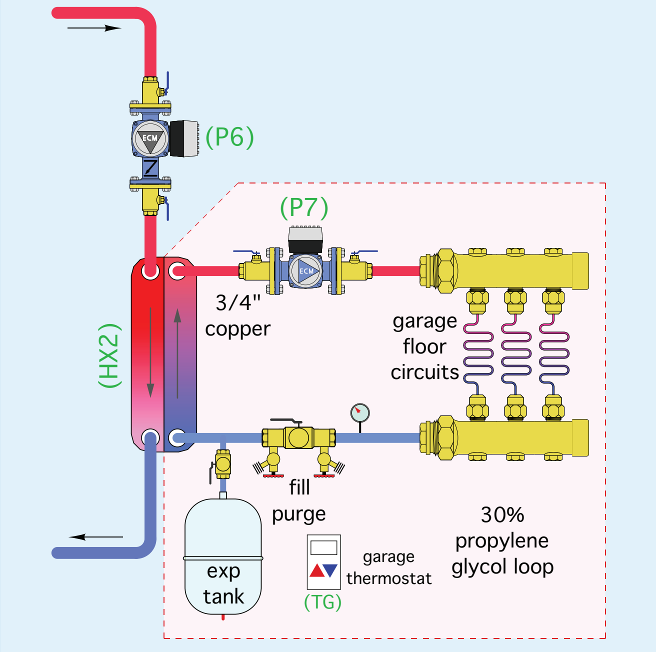
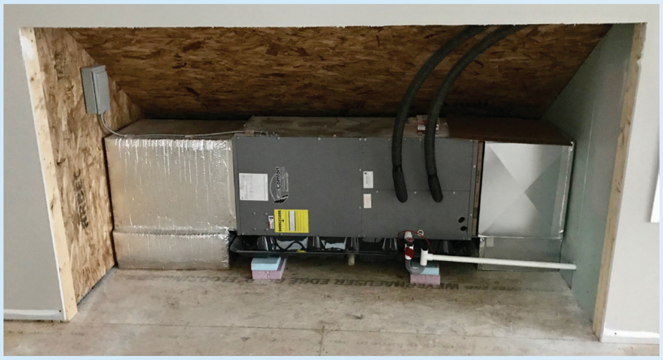


Figure 13



The air handler has an internal drip pan mounted beneath its chilled-water coil to collect condensate as it forms and drops from the coil. Because it is installed over a finished ceiling, a secondary drip pan was installed under the air handler. This pan would capture any water leaking from the unit should the internal drip pan ever fail. All captured condensate is routed to an outside drain through a 3/4" PVC tube. The coil in the air handler is supplied with chilled water through 3/4" pre-insulated PEX tubing, which runs seamlessly from the air handler to the basement mechanical room. The air handler can be accessed by pulling out a shelf frame mounted on rollers.

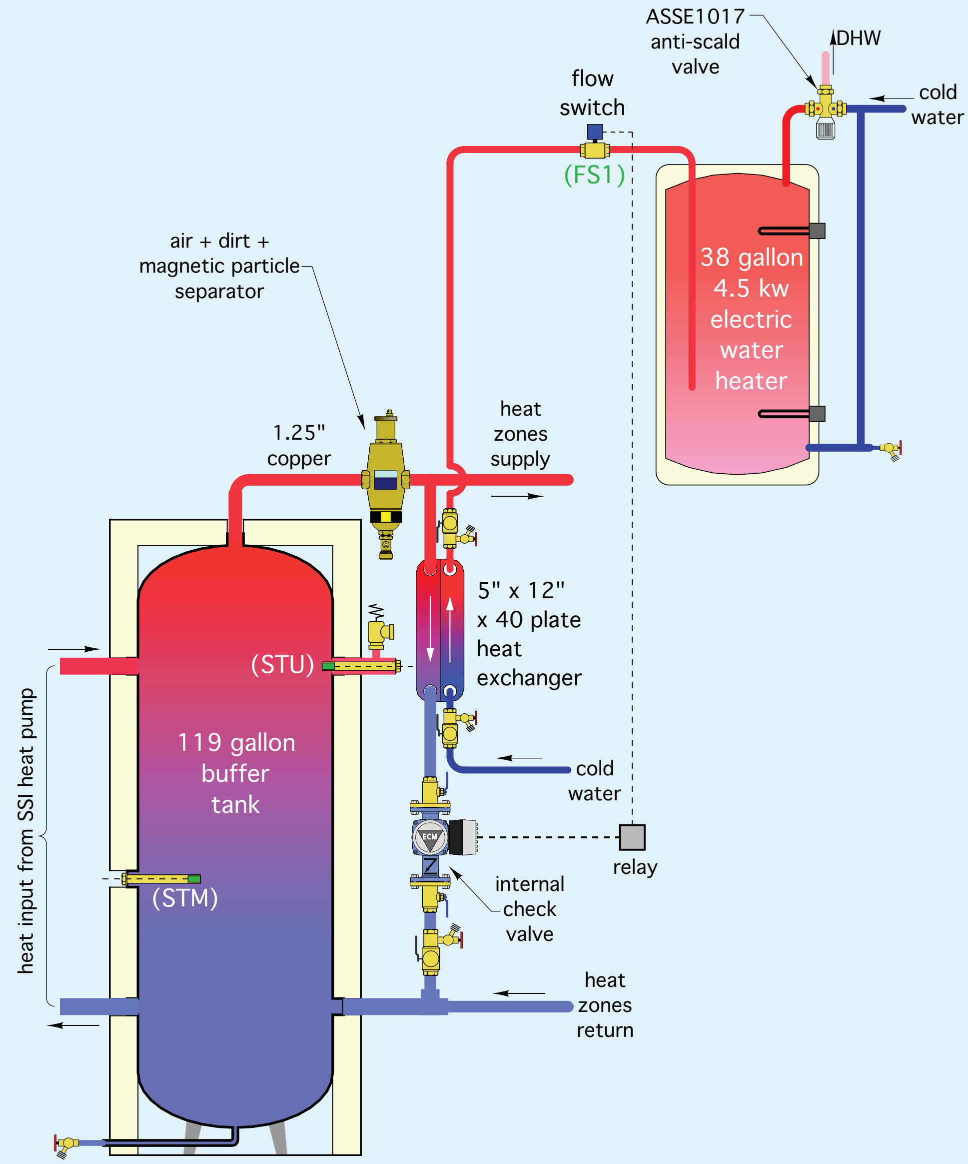
All ducting is contained within the building's thermal envelope. The three bedrooms have individual supply diffusers and return air grills. The main living area and finished attic space are supplied by several registers with a common return near the air handler. Control provisions allow the air handler's blower to be turned on whenever the owners want to circulate air within the house, such as dispersing warm air from solar heat gains.

Domestic Details

Raising the temperature of well water from about 45ºF to about 110ºF is an ideal load for a low-temperature hydronic system. However, there are situations where heating domestic water to a final temperature higher than 130ºF is necessary. These higher temperatures may not be attainable by the heat pump, especially under very low outdoor temperatures. The solution? Use the heat pump to "preheat" the domestic water through the majority of its temperature rise, and "top off" the water's temperature with a conventional electric water heater.

There are several hardware configurations that will accomplish this. One of the most versatile and serviceable is using a stainless steel brazed plate heat exchanger to extract heat from a buffer tank whenever domestic hot water is flowing to a fixture. The component assembly for this is shown in Figure 14.

Figure 14



Whenever the system is in heating mode, the SIS-060A4 heat pump maintains the water in the buffer tank between 100 and 110ºF. When domestic hot water is drawn from a fixture, cold domestic water flows into the secondary side of a 5" x 12" x 40 plate stainless steel heat exchanger. When the domestic water flow rate reaches 0.7 gallons per minute, which occurs almost instantly on most hot water draws, a flow switch closes its contacts. This signals a relay to operate a small 45-watt circulator that draws hot water from the top of the buffer tank and routes it through the primary side of the heat exchanger. Heat transfers from the tank water to the domestic water, which is typically heated to within 5ºF of the upper tank temperature by the time it exits the heat exchanger. This preheated water then flows into a 38-gallon/4,500-watt electric water heater for a final temperature boost to 120ºF (or higher if the owner chooses). Under average conditions, heat from the SIS-060A4 heat pump supplies about 80 percent of the energy required for delivery of 120ºF domestic water.

During cooling mode operation, when the tank contains chilled water, the circulator for the domestic water preheating assembly is automatically disabled.

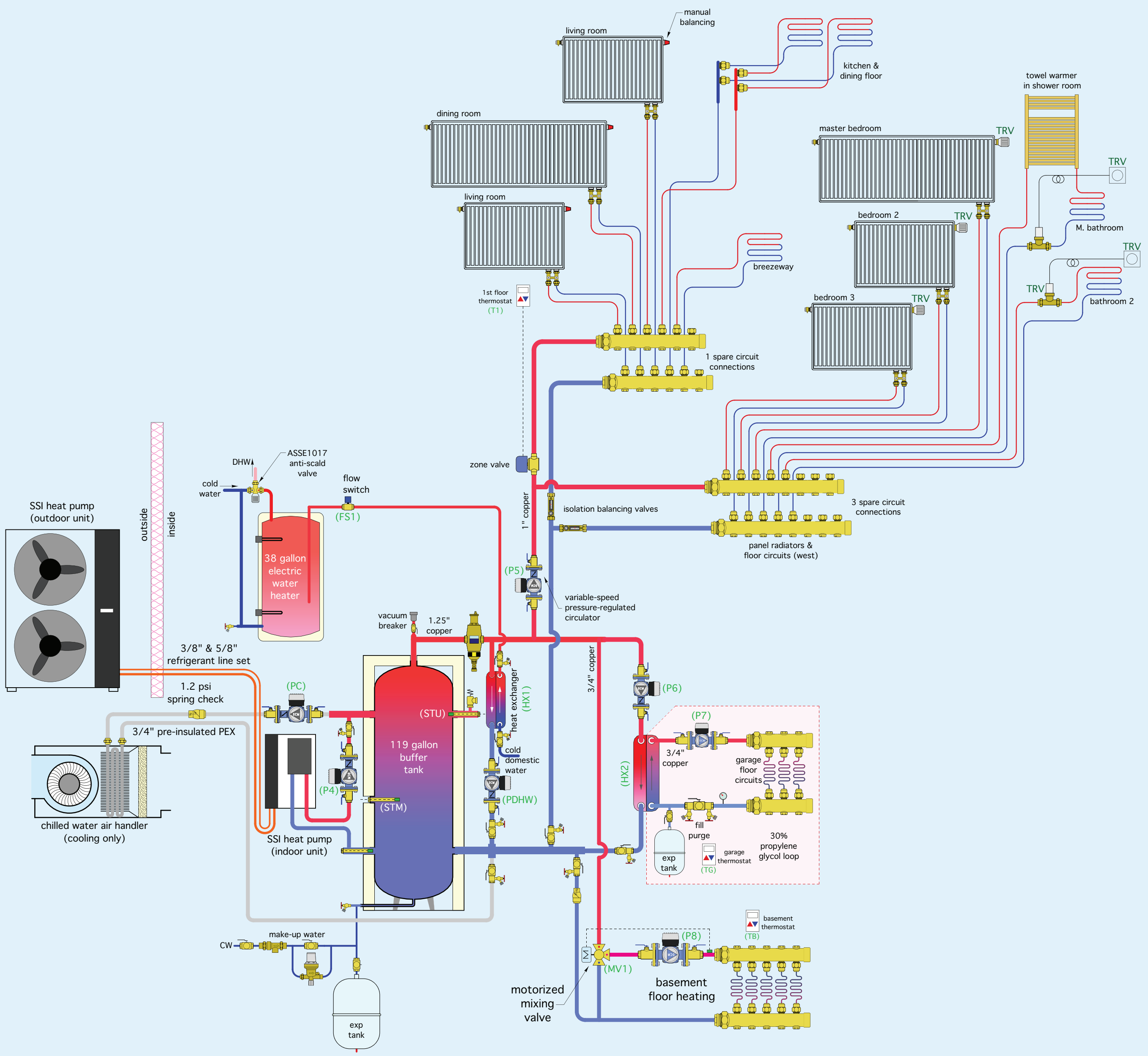
The domestic water side of the heat exchanger is equipped with isolation/flushing valves at the inlet and outlet connections. These allow the domestic water side of the heat exchanger to be isolated from the remainder of the plumbing system and flushed with a mild acid solution to remove any accumulated scale.

This "on-demand" domestic water preheating assembly could also be paired with a tankless electric water heater for the final temperature boost. This would minimize standby heat loss. It would also minimize the amount of heated domestic water stored in the system. The latter would reduce the possibility of Legionella bacteria growth.

Putting It All Together

A piping schematic for the overall system is shown in Figure 15.

Figure 15



During heating mode operation, the temperature of the 119-gallon buffer tank is monitored by a setpoint controller. The SIS-060A4 heat pump turns on when the temperature in the upper portion of the tank drops to 100°F and continues to run until the tank temperature reaches 110°F. *This control action is completely independent of calls for heat from any room thermostat or the DHW flow switch.* Circulator (P5) operates continuously during heating mode. It's speed automatically ramps up and down based on the status of the five thermostatic radiator valves and the single zone valve. The circulators for the other heating loads turn on and off based on thermostat calls or draws of domestic hot water.

When the system's mode switch is set to cooling, all heating loads and the domestic water preheating assembly are disabled. Another setpoint controller monitors the temperature of the buffer tank and operates the SIS-060A4 heat pump to maintain the tank between 45 and 60ºF. *This control action is independent of a call for cooling from the room thermostat in the great room area.*

All piping and components conveying chilled water are specified to be covered with 1/2" thick elastomeric insulation. All seams and joints are glued together to prevent surrounding air from contacting cool surfaces and forming condensation. This is a critical detail that must be addressed in any chilled-water cooling system. The polypropylene buffer tank has a monolithic layer of polyurethane foam insulation to minimize heat loss or gain and prevent surface condensation during cooling mode operation.

Summary:

This system, although appearing complex in Figure 15, is just a grouping of sub-assemblies that are tailored to specific load requirements. It demonstrates that a wide variety of client requests can be accommodated using modern hydronic technology paired with a high-efficiency low-ambient air-to-water heat pump. It also provides an example for how these technologies can support growing demand for net zero homes without sacrificing comfort.

By keeping the required supply water temperature for all heating loads relatively low (105ºF average), the SIS-060A4 heat pump can achieve high coefficients of performance.

A spreadsheet simulation for this project, which examined operating hours and corresponding COPs of the SpacePak SIS-060A4 heat pump over an entire heating season, while limiting the heating capacity of the SIS-060A4 heat pump to 68,000 Btu/hr, its COP to 4.5, and a fixed average supply water temperature of 105°F, indicates a seasonal average COP of 2.75. This increases to 2.92 if the average water temperature is fixed at 10°F, and 3.47 if the water temperature is fully controlled based on outdoor reset. These average COPs closely approach the net seasonal COP of a geothermal heat pump operating in the same system under the same conditions.

The SIS-060A4 heat pump has performed flawlessly during its first heating season and is set to maintain this home at comfortable conditions through summer and winter for years to come.

WWNL-4-20

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