Lowering Water Temperature in Hydronic Heating Systems

Most residential and light commercial hydronic heating systems installed in North America during the 20th century were designed to deliver their building's full heating load using supply water temperatures of 180ºF or higher. There were several reasons for this:

- Most hydronic heat sources were combustion-based, using fuels such as #2 heating oil, propane and natural gas.

- These fuels were readily available and relatively inexpensive throughout much of the post-World War II housing boom in the 1950s through the 1970s.

- Because fuel was inexpensive, efforts to conserve it were minimal.

- When achieving peak boiler efficiency is not critical, higher water temperatures are possible.

- Operating boilers at higher water temperature effectively removes any concern over sustained flue gas condensation, and thus boilers could be made using cast iron and steel heat exchangers. Chimney temperatures remained high enough to prevent condensation damage.

- The use of higher water temperatures reduced the amount of heat emitter surface area required to deliver the building's heating load. Reducing the size of the heat emitters reduced installation cost.

Today, the market factors that encouraged high-temperature hydronic systems have been largely superseded by the following:

- Relatively high fossil fuel prices, with intermediate price spikes in certain fuels possible.

- North American interest in reducing fossil fuel imports.

- Global interest in reducing carbon emissions from fossil-fuel combustion.

- Ongoing legislative efforts to force higher efficiency standards on all heat sources.

- Greater availability of non-combustion heat sources such as electrically-driven heat pumps.

- Interest in off-peak thermal energy storage, which functions best when thermal storage tanks can be cycled through a wide range of temperatures.

These current market factors are all influenced, to some degree, by the water temperature at which hydronic heating systems operate. Furthermore, they are all *favorably* affected when hydronic systems operate at lower water temperatures.

Figure 1 shows an example of how reducing the inlet water temperature to a generic fossil-fuel boiler increases its efficiency.

Figure 1
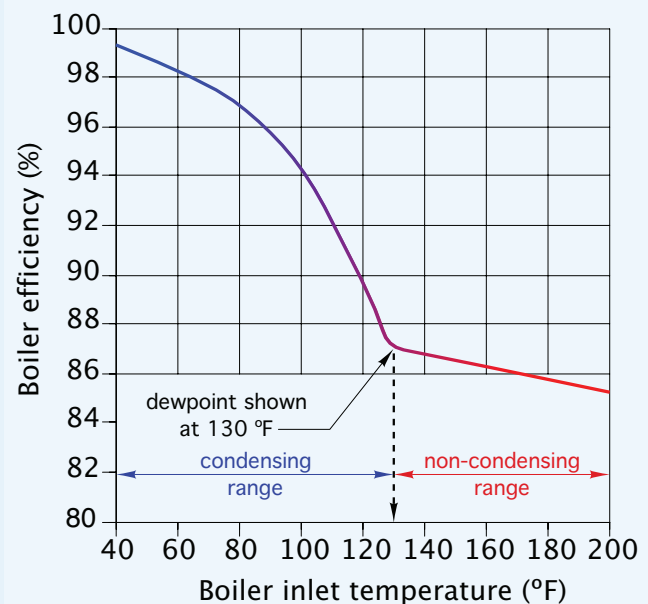
When the return water temperature is above approximately 130°F, the combustion side of the boiler's internal heat exchanger remains hot enough that flue gases, including water vapor, and other vaporous chemical compounds will not condense to liquid within the boiler. This is a favorable (and expected) condition for boilers that are not designed to operate with sustained flue gas condensation.

When the water returns to the boiler at temperatures below approximately 130°F, some of the water vapor, as well as some of the vaporous chemical compounds in the flue gas stream begin condensing into liquid on the combustion side of the boiler's heat exchanger. This condensate is highly acidic and will quickly corrode cast iron and steel surfaces. *Only boilers with internal heat exchangers made to withstand the corrosive effects of this condensate should be operated under flue gas condensing conditions.*

Figure 1 also shows a significant increase in thermal efficiency if the boiler can operate with relatively low return water temperatures. This increased efficiency is the result of captured latent heat (e.g., the heat given up when a vapor condenses to a liquid). The increased efficiency is highly desirable when reducing fuel cost and minimizing fuel usage are paramount factors in the design.

Achieving 90+ percent boiler efficiency requires a heating distribution system that can properly heat the building, while also consistently delivering low water temperatures back to the boiler. This requirement is often overlooked when selecting a boiler, and it is simply "expected" to achieve perhaps 95 percent efficiency, regardless of the distribution system to which it is connected.

Low water temperature distribution systems are also necessary for an air-to-water heat pump to achieve good performance, as shown in Figure 2.

Figure 2
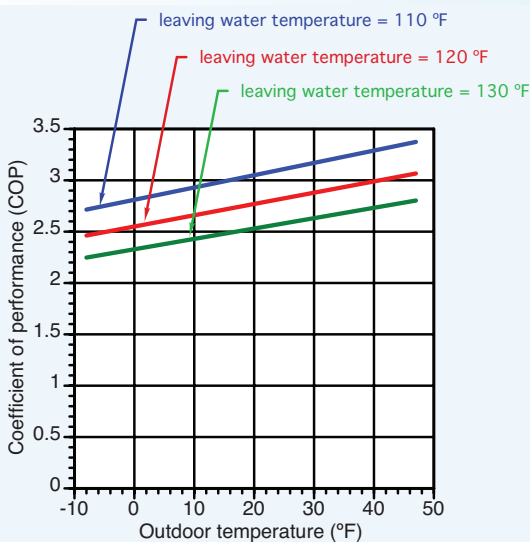
The three lines on the graph in Figure 2 indicate the coefficient of performance (COP) of the SpacePak Solstice Extreme heat pump based on the water temperature leaving the heat pump's condenser and traveling to the heating distribution system or a buffer tank. When the outdoor temperature is 20°F, and the water temperature leaving the condenser is 130°F, the heat pump has a COP of about 2.5. However, if the water temperature leaving the heat pump's condenser is only 110°F, the COP rises to about 3.05. That's a 22 percent increase in COP, due to reducing the water temperature at which the condenser operates from 130 to 110°F. Similar gains in COP are achieved across the entire outdoor temperature range of the heat pump. *This implies that lower water temperature hydronic distribution systems are highly preferred whenever an air-to-water heat pump is used.* A very similar relationship holds true for water-to-water heat pumps supplying hydronic heating systems.

Future Proof Your Hydronic Systems

Because most hydronic heat sources have higher efficiency when operated at lower water temperatures, and because of global efforts at energy conservation and reduced carbon emissions, the hydronic heating industry worldwide is steadily progressing toward low water temperature systems.

In the absence of specific regulations or codes that require otherwise, *a suggested guideline is to design all new hydronic heating systems so that they can provide design load heat output using a supply water temperature no higher than 120°F. Even lower supply water temperatures should be used when possible.*

This suggested criterion is based on the fact that the distribution piping and heat emitters in a well-planned and properly installed hydronic system should last many decades. The distribution system will likely outlast its first heat source, and perhaps even its second or third heat source. It only makes sense to create distribution systems that will be compatible with future low temperature heat sources. To do otherwise could require a costly renovation of the distribution system to accommodate a future heat source. Designers need to consider the future when designing for the present.

One response that arises from this reasoning is the following: *I understand that low water temperature hydronic systems should be used in new installations, but what can be done to modify an existing high-temperature distribution system so that it can operate at lower water temperatures?*

Fortunately, there are several ways in which a high-temperature distribution system can be modified to operate at lower water temperatures. The remainder of this issue of Water Works discusses these options.

Outdoor Reset Control

It's important to understand that even distribution systems designed to operate at high supply water temperatures under design load conditions can provide adequate heat output using lower water temperatures during partial load conditions.

Design heating load, depending upon how it is defined, only occurs between 1 and 2.5 percent of the hours in a typical year. If design load is defined as the heating load that occurs when the outdoor temperature is at or below the 99 percent design outdoor temperature, it only occurs for about 85 hours in a typical year (e.g., 1 percent of the year). If design load is defined based on the 97.5 percent design outdoor temperature, it only occurs about 219 hours in a typical year. There will be atypical years when design load will occur for more hours and some where it will occur for lesser hours.

The graph in Figure 3 shows the frequency and range of outdoor temperature for a typical year in Syracuse, NY. Notice how many hours of partial load occur in comparison to the hours of design load, as defined by the 99 percent outdoor design temperature, where the 97.5 percent design outdoor temperature is 2ºF.

Figure 3
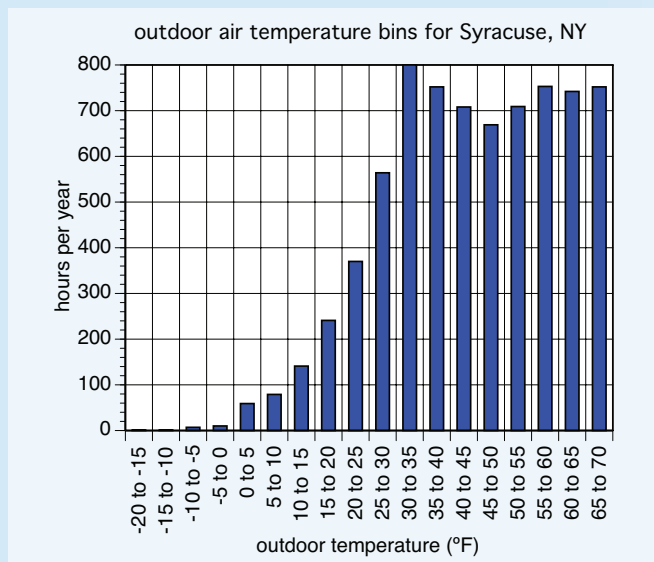
The theoretical rate of heat loss from a building maintained at a constant indoor temperature is proportional to the difference between inside and outside temperature. This implies that the heating load would be reduced whenever the outdoor temperature is higher than the outdoor design temperature. For example, if a building has a design heating load of 100,000 Btu/hr when the inside temperature is 70ºF and the outdoor temperature is 0ºF, that building would have a heating load of about 50,000 Btu/hr when the outdoor temperature is 35ºF, and the indoor temperature remains at 70ºF.

A second relationship that should also be considered is that the rate of heat output from any hydronic distribution system is approximately proportional to the difference between supply water temperature and room air temperature.

Together, these relationships imply that the supply water temperature to any hydronic distribution system can be reduced as the outdoor air temperature increases, while maintaining a stable indoor comfort temperature. These concepts are the basis of outdoor reset control. A technique that has been used for several decades to improve the efficiency of heat sources, reduce fuel use, and improve comfort.

Figure 4 shows how the supply water temperature to a hydronic distribution system using finned-tube baseboard can be reduced based on the current outdoor temperature. This graph assumes that the baseboard was sized to provide the design heating load of the building using a supply water temperature of 180ºF.

Figure 4
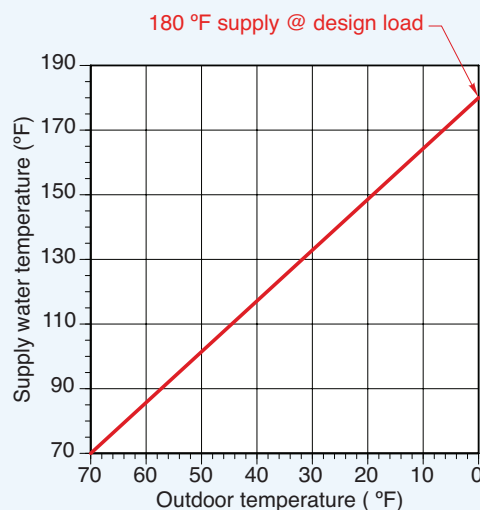
Add Heat Emitters or Reduce Building Heat Loss

Although outdoor reset will reduce the water temperature at which any hydronic system can supply ample heat *under partial load conditions,* it cannot transform a system that requires high water temperatures at design load into a system that can operate at much lower supply water temperature and still provide design load output. The only two approaches that can accomplish the latter are:

1. Reduce the design load of the building envelope through improvements such as added insulation, better windows and lower air leakage.

2. Add heat emitters to the existing system.

A combination of these two approaches is also possible.

Building envelope improvements reduce the design heating load of the building. After such improvements are made, the existing hydronic distribution system can meet the reduced design load while operating at lower supply water temperatures.

The change in supply water temperature is proportional to the change in design heating load. The new supply water temperature can be determined based on the same concepts used for outdoor reset control. It can be calculated using Formula 1:

Formula 1:

$$T_{new} = T_{in} + \left(\frac{Q_{new}}{Q_{existing}} \right) \times (T_{De} - T_{in})$$

Where:

T_{new} = supply water temperature at design load after building envelope improvements (ºF)

T_{in} = desired indoor air temperature (ºF)

Q_{new} = design heating load after building envelope improvements (Btu/hr)

$Q_{existing}$ = existing design heating load (before improvements) (Btu/hr)

T_{De} = existing supply water temperature at design load (before improvements) (Btu/hr)

For example, assume an existing building has a design heating load of 100,000 Btu/hr, based on maintaining an interior temperature of 70ºF. The existing hydronic distribution system uses standard finned-tube baseboard and requires a supply water temperature of 180ºF at design load conditions. Also assume that improvements to the building envelope will reduce this design load from 100,000 Btu/hr to 70,000 Btu/hr. The new supply water temperature to the existing distribution system under design load conditions is estimated using Formula 1:

$$T_{new} = T_{in} + \left(\frac{Q_{new}}{Q_{existing}} \right) \times (T_{De} - T_{in}) = 147^{\circ} F$$

A graph of the supply water temperature versus outdoor temperature for the existing building (e.g., with design load of 100,000 Btu/hr), after building envelope improvements which reduced the design load to 70,000 Btu/hr, is shown in Figure 5.

Figure 5
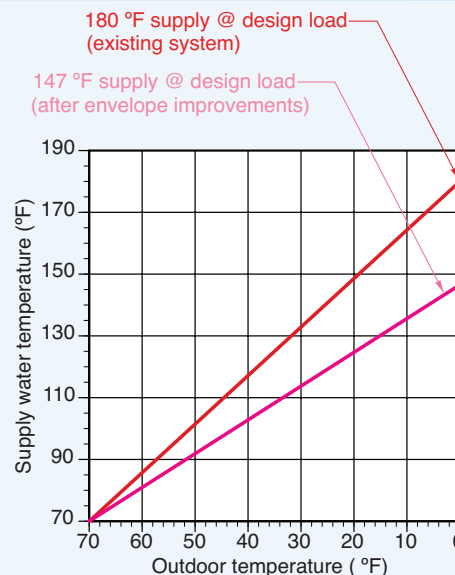
In this case, reducing the design heating load from 100,000 Btu/hr to 70,000 Btu/hr reduced the required supply water temperature from 180ºF to 147ºF. Although this is certainly an improvement, it doesn't lower the design load supply water temperature into the operating range of most hydronic heat pumps. A temperature of 147ºF is also substantially above the previously suggested design criteria of 120ºF supply water temperature at design load.

Adding More Heat Emitters:
Lowering the supply water temperature even more will require supplemental heat emitters to be added to the system.

The supplemental heat emitters might be the same make and model as the existing heat emitters. They could also be a different type of heat emitter. For example, panel radiators or fan coil convectors could be added to an existing distribution system that contains standard finned-tube baseboard. It might also be possible to add a radiant floor panel, radiant ceiling panel or radiant wall panel to one or more locations in the building.

The choice of which type of heat emitter to add will depend on several factors, including:

1. Availability of different makes/models of heat emitters
2. Cost of the new heat emitters
3. How difficult it is to integrate the new heat emitters into the building
4. Aesthetic preferences
5. Floor coverings (in the case of radiant floor panels)
6. Surface temperature limitations (in the case of radiant panels)
7. The specific supply water temperature that is to supply design load output in the renovated distribution system.

Adding More Finned-tube Baseboard

One way to lower the required supply water temperature for an existing baseboard system is to add more baseboard.

The following procedure can be used to calculate the amount of finned-tube baseboard to be added to reduce the supply water temperature at design load to a pre-determined value. *It assumes that the baseboard being added is the same make and model as the existing baseboard. It also assumes that the existing baseboard is a standard residential-grade product with nominal 2.25" square aluminum fins with an I=B=R rated output of approximately 600 Btu/hr/ft at 200ºF water temperature.*

Step 1: Accurately determine the building's design heat load using Manual J or equivalent procedures.
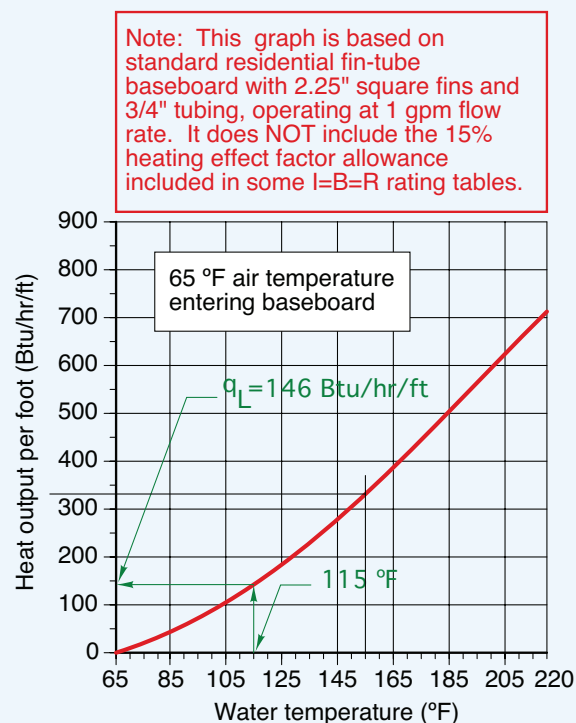
Step 2: Determine the total length of *finned-tube* in the existing distribution system. Do not include the length of tubing that doesn't have fins on it. The existing finned-tube length will be designated as L_e.

Step 3: Determine the desired (lower) supply water temperature for which the system is to supply design load output. *A suggested value for systems using heat pumps is 120ºF.*

Step 4: Estimate the lower *average* circuit water temperature by subtracting 5 to 10ºF from the supply water temperature determined in Step 3. In circuits with more than 2 gallons per minute flow rate through the baseboard, assume the average water temperature will be 5ºF *below* the supply water temperature. In circuits with less than 2 gallons per minute flow rate through the baseboard, assume the average water temperature will be 10ºF below the lower supply water temperature.

Step 5: Find the new average circuit water temperature on the horizontal axis of the graph in Figure 6. Draw a vertical line up from this point until it intersects the red curve. Draw a horizontal line from this intersection to the vertical axis of the graph, and read the heat output of the finned-tube at the lower average circuit water temperature. This number is designated as q_L. The green lines and numbers in Figure 6 show how q_L is determined for an average circuit water temperature of 115ºF.

Figure 6

Note: This graph is based on standard residential fin-tube baseboard with 2.25" square fins and 3/4" tubing, operating at 1 gpm flow rate. It does NOT include the 15% heating effect factor allowance included in some I=B=R rating tables.

65 ºF air temperature entering baseboard

q_L=146 Btu/hr/ft

115 ºF

Step 6: Determine the length of baseboard to be added using Formula 2.

Formula 2:

$$L_{added} = \frac{\text{design load}}{q_L} - L_e$$

Where:

L_{added} = length of finned-tube of same make/model baseboard to be added (feet)

design load = design heating load of building (Btu/hr)

q_L = output of baseboard at the lower average circuit water temperature (Btu/hr/ft)

L_e = total existing length of baseboard in system (feet)

Example 1: Assume a building has a calculated design load of 40,000 Btu/hr, and its distribution system contains 120 feet of standard residential finned-tube baseboard. It is currently heated by a conventional cast iron boiler. The building will be retrofitted with a Solstice Extreme heat pump, which will provide a supply water temperature of 120ºF. Additional baseboard of the same make and model needs to be added to the system to allow lower water temperature operation. Assume all the existing finned-tube baseboards operate at a flow rate of at least 2.5 gallons per minute. Determine the amount of baseboard that must be added:

Solution:

Step 1: The design load has been calculated as 40,000 Btu/hr.

Step 2: The total amount of finned-tube in the system is 120 feet.

Step 3: The lower supply water temperature at design load will be 120ºF.

**Step 4:** The lower average circuit water temperature will be 120 - 5 = 115ºF.

Step 5: The output of the finned-tube at an average circuit water temperature of 115ºF is determined from Figure 6 as 146 Btu/hr/ft.

Step 6: The required additional length of baseboard is now calculated using Formula 2:

$$L_{added} = \left[\frac{\text{design load}}{q_L} - L_e \right] = \left[\frac{40,000\frac{Btu}{hr}}{146\frac{Btu}{hr \cdot ft}} - 120 \right] = 154\,ft$$

Discussion: Although it might be possible to add 154 feet of baseboard to the system, it would require lots of wall space. In most buildings, adding this much baseboard is not a practical solution. Alternatives include using baseboard with higher heat output or using other types of heat emitters to achieve the necessary design load output.

One option is to consider the use of "high-output" finned-tube baseboard for the additional heat emitter. Figure 7 shows the output of Synergy baseboard (shown as the blue curve), and for comparison, standard residential baseboard (shown as the red curve).

Figure 7
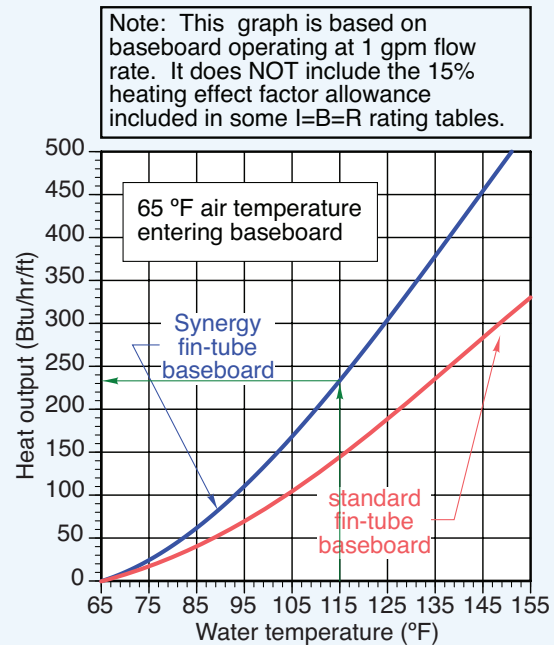
The steps of the previous procedure can be modified to determine the amount of Synergy finned-tube baseboard that is required to reduce the supply water temperature to the system under design load.

Steps 1-4 : Follow the same procedures.

Step 5: Determine the output of Synergy baseboard at the average circuit water temperature using Figure 7.

Step 6: The required length of Synergy baseboard to add to the system is found using Formula 3.

Formula 3:

$$L_{Synergy} = \frac{\text{design load-}(q_L)(L_e)}{q_{Synergy}}$$

Where:

$L_{Synergy}$ = length of Synergy finned-tube baseboard to be added (feet)

design load = design heating load of building (Btu/hr)

q_L = output of existing baseboard at the lower average water temperature (Btu/hr/ft)

L_e = total existing length of baseboard in system (feet)

$q_{Synergy}$ = output of Synergy baseboard at the lower average water temperature (Btu/hr/ft)

Example 2: Assume a building has a calculated design load of 40,000 Btu/hr, and its distribution system contains 120 feet of standard residential finned-tube baseboard. The building will be retrofitted with a Solstice Extreme heat pump, which will provide a supply water temperature of 120°F. Additional Synergy baseboard will be added to allow this lower water temperature operation. Assume that the existing finned-tube baseboards operate at a flow rate of at least 2.5 gallons per minute and have the same output as in the previous example (146 Btu/hr/ft at average circuit water temperature of 115°F). Determine the amount of Synergy baseboard that must be added.

Solution:

Step 1: The design load has been calculated as 40,000 Btu/hr.

Step 2: The total amount of finned-tube in the system is 120 feet.

Step 3: The new lower supply water temperature at design load will be 120°F.

Step 4: The new lower average circuit water temperature will be 120 - 5 = 115°F.

Step 5: The output of Synergy finned-tube at an average water temperature of 115°F is determined from Figure 7 as 234 Btu/hr/ft.

Step 6: The required length of Synergy baseboard to add to the system is found using Formula 3.

$$L_{Synergy} = \frac{\text{design load-}(q_L)(L_e)}{q_{Synergy}} = \frac{40,000\text{-}(146)(120)}{234} = 96\,ft$$

Discussion: Although this is a substantial reduction compared to the 154 feet of additional standard baseboard required in Example 1, it is still a substantial length. The building must be carefully evaluated to see if this additional length of baseboard can be accommodated.

Other Heat Emitter Options

If the amount of finned-tube that must be added to the system is beyond what can be accommodated, there are several other options. They include panel radiators, fan-coils, or areas of radiant floor, radiant wall or radiant ceiling panels. In each case, the selection of these new heat emitters should be based on a selected supply water temperature at design load, along with a "credit" for the existing heat emitters in the system operating at the lower supply water temperature. The fundamental concept is given by Formula 4:

Formula 4:

$$Q_n = \text{design load - } Q_e$$

Where:

Q_n = required heat output of the new heat emitters at lower supply water temperature (Btu/hr)

design load = design heating load of building (Btu/hr)

Q_e = heat output of existing heat emitters at the lower supply water temperature (Btu/hr)

Once the value of Q_n is determined, the designer can use tables or graphs from manufacturers to determine the heat output of specific heat emitters based on the average water temperature within them. Remember that the average water temperature will be 5 to 10°F lower than the supply water temperature.

The goal is to select a grouping of new heat emitters with a total heat output that's approximately equal to the value of Q_n in Formula 4.

Example 3: Assume a building has a calculated design load of 40,000 Btu/hr, and its distribution system contains 120 feet of standard residential finned-tube baseboard. The building will be retrofitted with a Solstice Extreme heat pump, which will provide a supply water temperature of 120°F. Panel radiators are available in 24" x 72" size that can release 4,233 Btu/hr when operated at an average water temperature of 115°F in rooms with 70°F interior temperature. How many of these radiators are necessary to meet the design load?

Solution: First, use Formula 4 to determine the output required of the new radiators.

$$Q_n = \text{design load - } Q_e = \text{design load - } (q_L)(L_e) = 40,000\text{-}(146)(120) = 22,480\,Btu/hr$$

The number of radiators needed is then found as follows:

$$\frac{22,480\,Btu/hr}{4233\dfrac{Btu/hr}{radiator}} = 5.3 \text{ radiators}$$

Discussion: The designer would likely select 6 of these panel radiators. However, all the panels radiators would not have to be the same size, provided that their total output at the lower supply water temperature could meet the value of Q_n. In this example, the 6 new radiators would be combined with the 120 feet of existing baseboard to provide the 40,000 Btu/hr design load.

A similar calculation could be made for fan-coils, air handlers or other heat emitters.

In the case of radiant panels, the designer needs to determine the output of each square foot of panel based on the lower average circuit temperature and the specific construction of the panel. The total required panel area is found by dividing this number into the value of Q_n.

Figure 8 shows the room-side heat output of three specific types of radiant panels: A radiant floor panel, a radiant wall panel and a radiant ceiling panel. These outputs are for the specific construction and tube spacing shown for each panel. Panels with different construction and tube spacing will have different outputs.

Figure 8
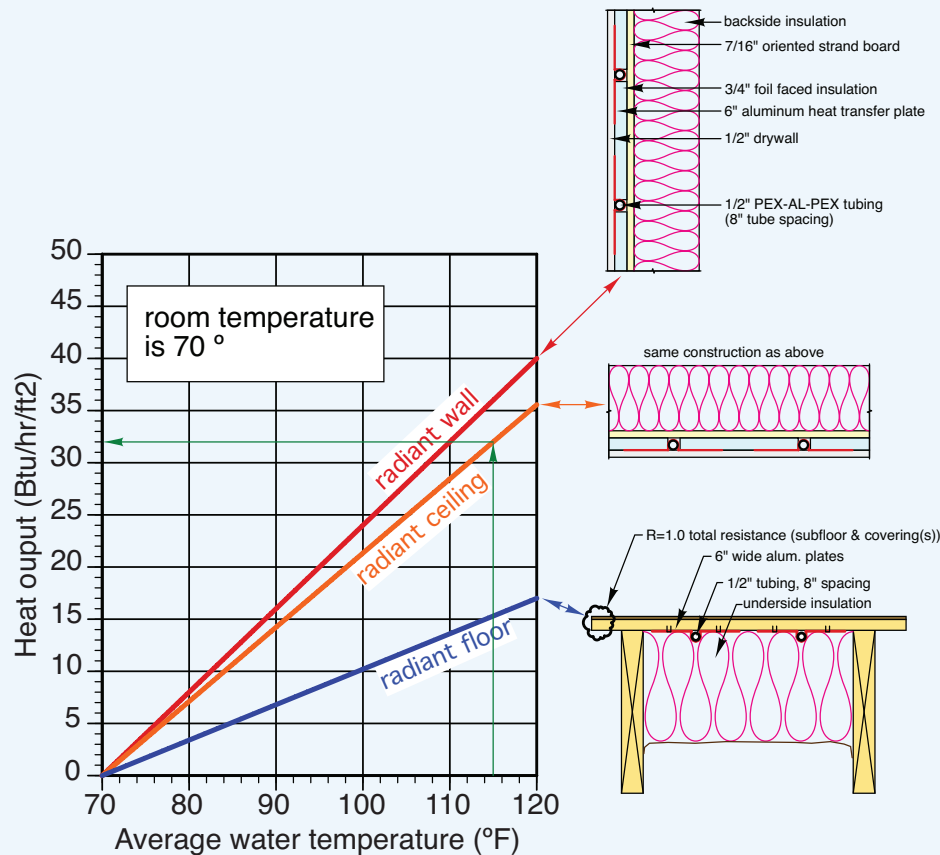
Example 4: Assume a building has a calculated design load of 40,000 Btu/hr, and its distribution system contains 120 feet of standard residential finned-tube baseboard. The interior temperature is to be maintained at 70°F. The building will be retrofitted with a Solstice Extreme heat pump, which will provide a supply water temperature of 120°F. The designer wants to add a radiant ceiling panel, of the type shown in Figure 8, to supplement the output of the existing baseboard. Both the baseboard and ceiling panel will operate at an average water temperature of 115°F. How many square feet of radiant ceiling panel will be needed?

Solution: First, use Formula 4 to determine the output required of the new radiators.

Q_n = design load - Q_e = design load - $(q_L)(L_e)$ = 40,000 - $(146)(120)$ = 22,480 Btu/hr

Next, use Figure 8 to determine the heat output of each square foot of radiant ceiling panel operated at the average circuit temperature. In this case the radiant ceiling output is 32 Btu/hr/ft². The total radiant ceiling area needed is found by dividing the 32 Btu/hr/ft² output into the required supplemental heat output.

$$\text{Heated ceiling area} = \frac{22,480\,\dfrac{Btu}{hr}}{32\,\dfrac{Btu}{hr \cdot ft^2}} = 703\,ft^2$$

Discussion: This is a significant area of radiant panel. One advantage of using radiant ceilings is that no additional wall space would be required for baseboards, panel radiators or fan-coil units. Another advantage is that the existing floor coverings would not have to be altered. A disadvantage is that this radiant ceiling construction would lower the existing ceiling height by about 1.25", and require finishing a substantial area of drywall within an existing building.

Room-By Room Analysis

The previous examples have treated the building as a single zone. The total amount of supplemental heat emitter that was required to achieve a supply water temperature of 120°F was determined. However, the exact placement of the supplemental heat emitters within the building was not considered in these calculations.

The designer can perform the same type of calculations on a room-by-room basis. This allows the possibility of different types of supplemental heat emitters in each room to meet budget or aesthetic considerations. The calculations are essentially the same with the exception that the room's design heating load is used rather than the building design heating load, and the amount of existing baseboard in that room is used rather than the total baseboard in the building.

Example 5: A room has a design heating load of 2,500 Btu/hr. It contains 6 feet of standard finned-tube baseboard. Determine the necessary output of a supplemental panel radiator if both that radiator and the existing baseboard can supply the design load while operating at an average water temperature of 115°F.

Solution: Use Formula 4, along with the previously calculated output of standard finned-tube baseboard of 146 Btu/hr/ft when operating at an average water temperature of 115°F.

$$Q_n = \text{room load} - (q_L)(L_e) = 2500 - (146)(6) = 1,624\,Btu/hr$$

The final step is to select a panel radiator that can provide approximately 1,624 Btu/hr when operating at an average water temperature of 115°F. A check of product literature, along with use of the manufacturer's correction factor for low temperature operation, shows that a panel measuring 24" high x 48" wide and using a single water plate could provide this output.

Piping for Supplemental Heat Emitters

Once the type and quantity of supplemental heat emitters is determined, the piping design must be considered. There are many factors that could influence how the supplemental panel radiators are piped. They include:

1. Are the existing baseboards piped in a series circuit?
2. Are the existing heat emitters piped as individual parallel circuits?
3. Where is the piping between existing baseboards easiest to access?
4. Are there multiple heat emitters within a given space?
5. What are the flow resistance characteristic of the supplemental heat emitter relative to those of the existing heat emitters?
6. What type of control will be used to regulate heat output to each zone of the distribution system?

There is no one best approach. Every situation must to be evaluated individually, weighing these factors to determine the best fit for that project.

Converting Series Loops to Parallel Branches

Many residential hydronic systems have finned-tube baseboards connected in series or "split-series" circuits, as shown in Figures 9a and 9b.
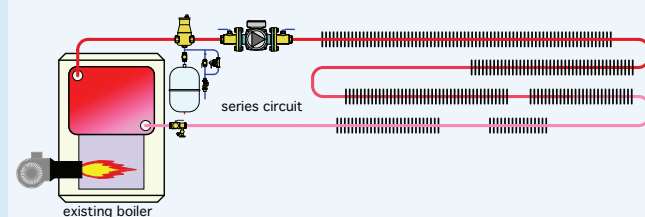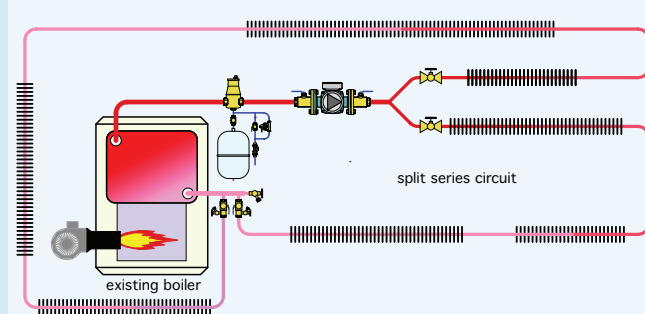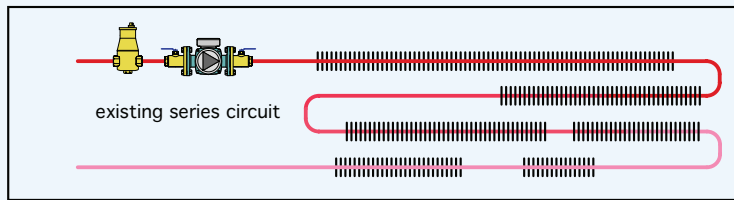
Figure 9a

Figure 9b

When several heat emitters are to be added to a system using series or split-series connected baseboards, they should **_not_** be simply cut into the series circuit. Doing so could substantially increase the flow resistance of that circuit, which will reduce flow rate, assuming the same circulator is used. Adding heat emitters in series also increases the temperature drop of the circuit. This reduces the heat output of heat emitters near the end of the circuit, especially when the supply temperature to that circuit is lowered.

One possible approach is to make strategic cuts into the series circuit where it is easiest to access, and reconnect the cut segments back into a parallel distribution system. These cuts could make each room a separate parallel circuit. They might also make a group of 2 rooms into a new zone.
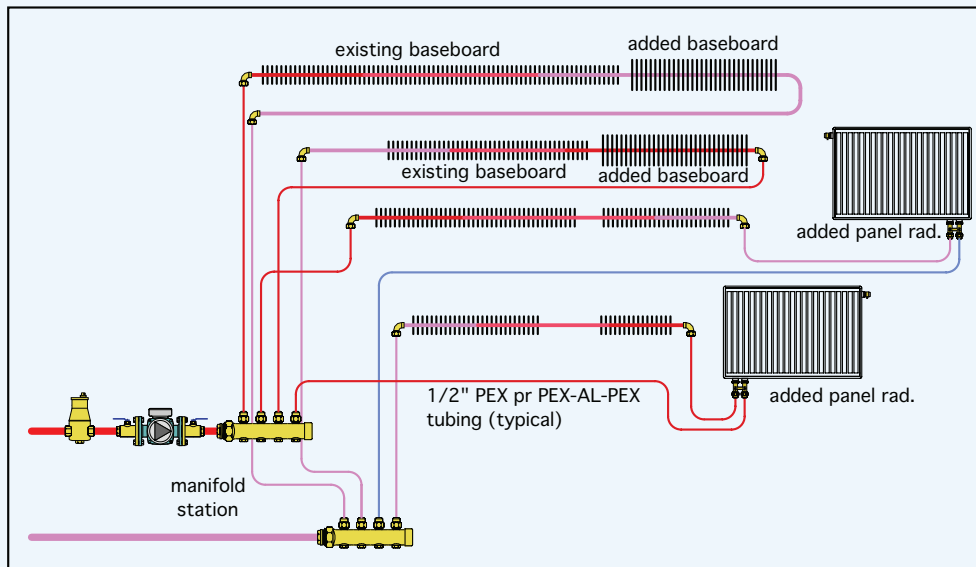
One of the easiest ways to divide an existing series loop or split-series distribution system into multiple parallel circuits is by creating a homerun distribution system. Each heat emitter, or grouping of an existing heat emitter and supplemental heat emitter, is supplied by a separate circuit of PEX or PEX-AL-PEX tubing. This tubing is easy to route through or along framing cavities. The homerun circuits begin and end at a manifold station. This concept for converting a series baseboard system into a homerun system is shown in Figure 10.

Figure 10

EXISTING DISTRIBUTION SYSTEM

existing series circuit

MODIFIED DISTRIBUTION SYSTEM

existing baseboard — added baseboard

existing baseboard — added baseboard

added panel rad.

1/2" PEX pr PEX-AL-PEX tubing (typical)

added panel rad.

manifold station

In this situation, the existing series circuit was divided into four branch circuits. Supplemental heat emitters were added to each of these circuits. Two of the circuits received additional finned-tube baseboard, and the other two received panel radiators. These heat emitter selections are only to illustrate that multiple types of supplemental heat emitters can be used depending on available wall space, budget and aesthetic preferences.

In some branch circuits, the supplemental heat emitters were added upstream of the existing baseboard. In others, they were added downstream of the existing baseboard. The choice depends on the available wall space and placement of the existing baseboard within each room. Designers should estimate the water temperature in the circuit where the supplemental heat emitter will be placed and size it accordingly.

The 3/4" copper tubing in the existing circuit was cut at locations that preserved a reasonable amount of existing copper tubing, but also allowed convenient transition to 1/2" PEX or PEX-AL-PEX tubing. Adapter fittings to transition from 3/4" copper to 1/2" PEX or PEX-AL-PEX tubing are readily available from several suppliers. The 1/2" PEX or PEX-AL-PEX supplies and returns are routed back to a manifold station.

That manifold station should be equipped with individual circuit-balancing valves that allow the flow rate through each of the new branch circuits to be adjusted if necessary.

All four branch circuits operate simultaneously (e.g., they are not configured as individual zones). As such, this distribution system presents a constant flow resistance. Due to the parallel versus series configuration, that flow resistance may be lower than that of the original series circuit. This should be verified by calculating the head loss or pressure drop of the path with the greatest flow resistance using standard hydronic pipe analysis methods. If the head loss and total flow rate through the four circuits is comparable to the flow and head loss of the existing series circuit, the same circulator can be used.

A parallel distribution system also supplies water at approximately the same temperature to each branch circuit. This is likely to boost the heat output of some existing baseboards that were previously located near the end of the series circuit.

Creating New Zones

Another advantage of parallel distribution systems is the ease of creating multiple zones. If the existing series circuit is converted to multiple branches, each of those branches can be equipped with a thermostatic radiator valve. These non-electric valves automatically modulate to vary the flow rate in each branch in response to the room temperature. As room temperature begins to drop, the thermostatic valve opens to increases flow through that branch circuit, and vice versa.

Thermostatic radiator valves are available in several configurations. One configuration, known as an angle pattern supply valve, allows the valve to be mounted on the inlet to a finned-tube baseboard. The thermostatic actuator of the valve projects through a hole in the end cap of the baseboard. Heated water enters the port of the valve facing the floor, makes a 90º turn as it passes through the valve, and flows into the baseboard element. The other end of the finned-tube element can be equipped with another transition adapter (straight or 90º) to convert from 3/4" copper to 1/2" PEX or PEX-AL-PEX.

Another type of thermostatic radiator valve allows the valve body and actuator to be mounted within the baseboard enclosure, while the adjustment knob is mounted at normal thermostat height on the wall. The adjustment knob connects to the actuator using a capillary tube.

It's also possible to use panel radiators with built-in thermostatic radiator valves.
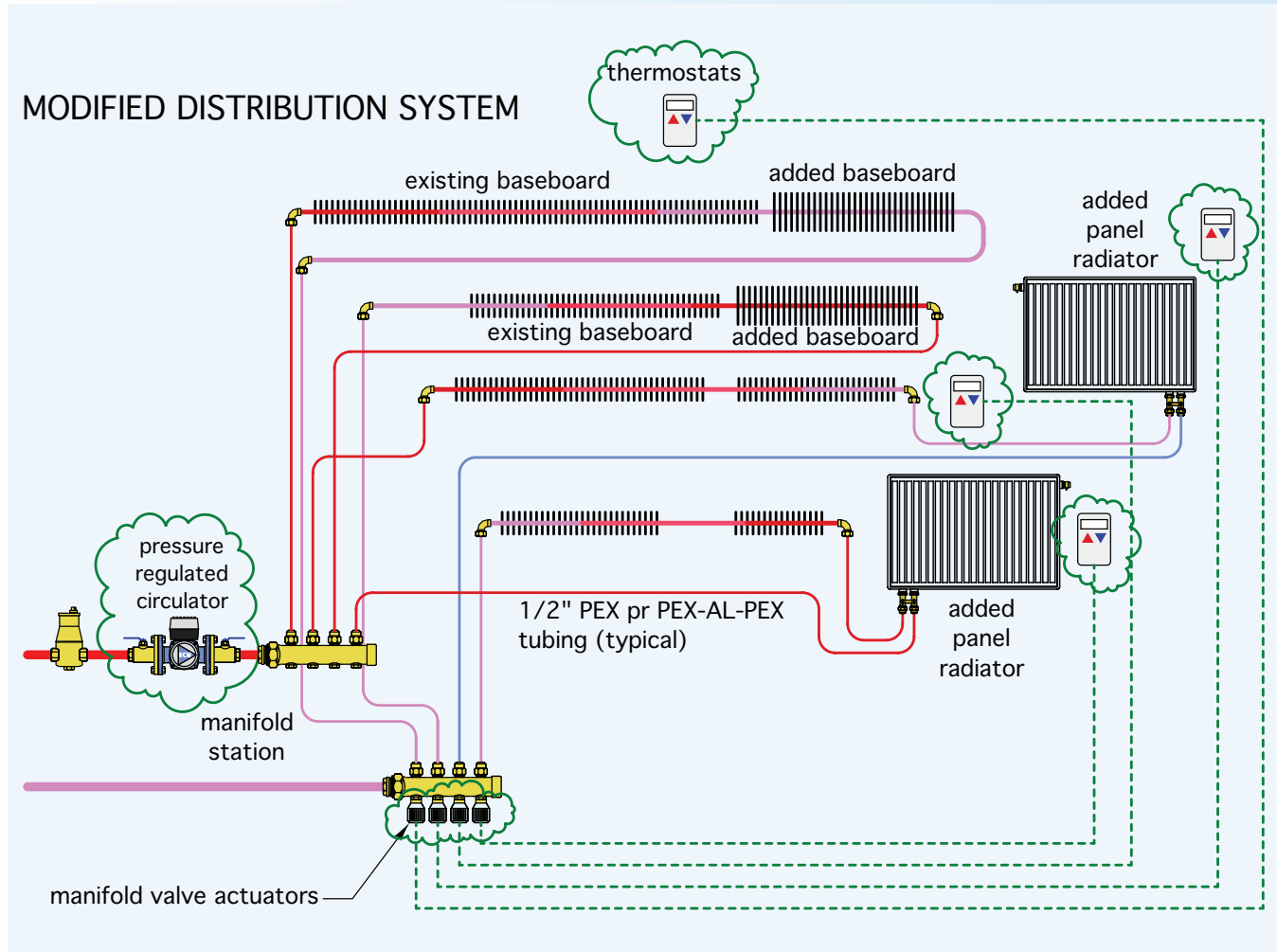
Figure 11 shows how the distribution system can be modified using thermostatic radiator valves to create a distribution system with four independently controlled zones. This adds flexibility for adjusting interior comfort conditions far beyond that of the original series loop system.

Figure 11

MODIFIED DISTRIBUTION SYSTEM
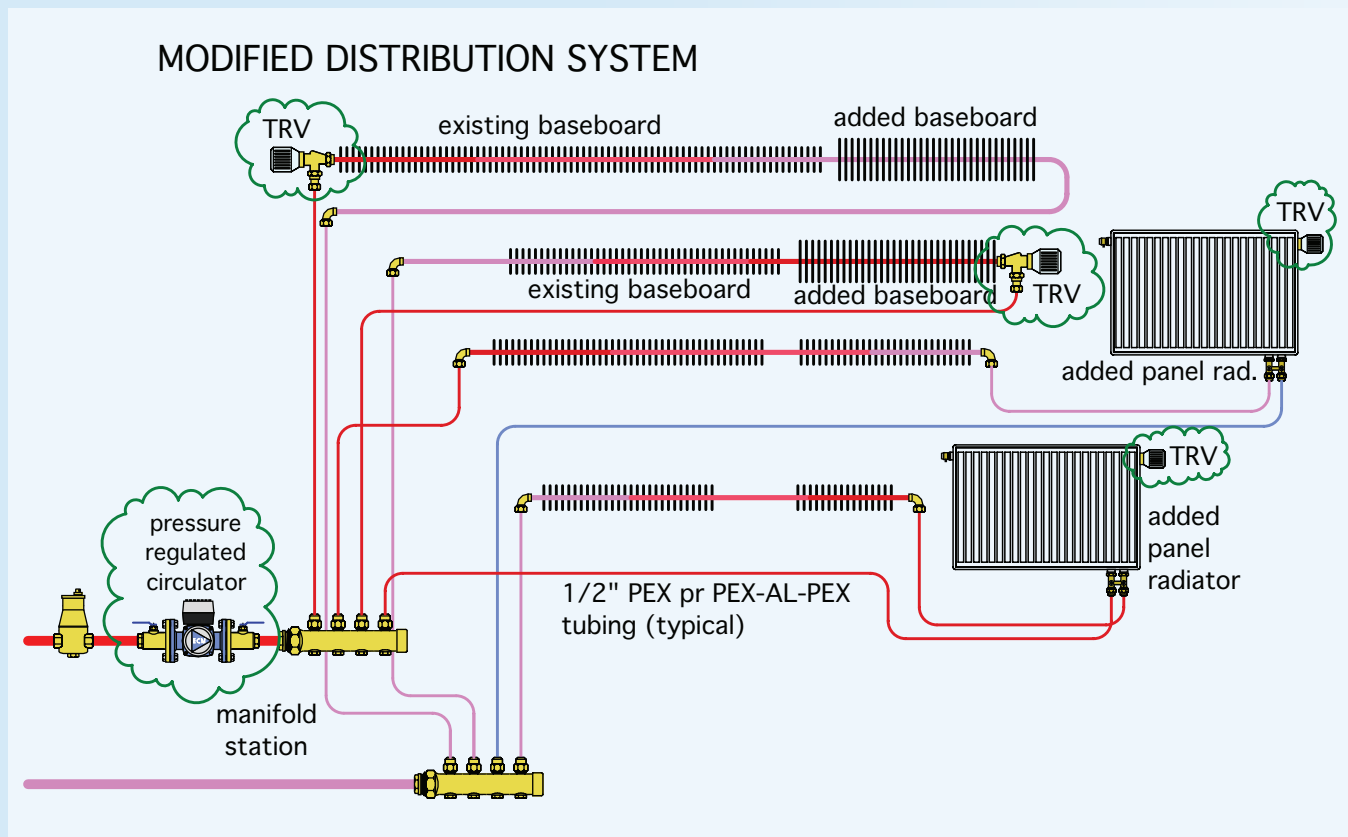
Another possibility is to install a low-voltage (24 VAC) manifold valve actuator on each circuit valve at the manifold station. These actuators are wired to four new thermostats, one for each zone. This option is shown in Figure 12.

Figure 12

MODIFIED DISTRIBUTION SYSTEM

thermostats

existing baseboard — added baseboard — added panel radiator

existing baseboard — added baseboard

pressure regulated circulator

1/2" PEX pr PEX-AL-PEX tubing (typical)

added panel radiator

manifold station

manifold valve actuators

The systems shown in Figures 11 and 12 both use valves for zoning. In Figure 11, non-electric thermostatic radiator valves are used. In Figure 12, low-voltage manifold actuators are attached to valves within the return manifold.

In both cases, the original circulator has been replaced with a variable-speed pressure-regulated circulator. These circulators automatically adjust their speed and power input as the valves open, close or modulate flow. This helps stabilize the differential pressure across the manifold station, and helps maintain stable flow rates within the zone circuit, regardless of what other zones are operating.

Design Guidelines

The modifications shown to convert a series baseboard circuit into parallel branch circuits are just a few of many possibilities. Each conversion situation must consider the exact layout of the existing heat emitters, and the practicality of modifying the system into parallel branches. Designers should follow these guidelines.

1. Always determine what type of supplemental heat emitter will be used in each room and where it will be located before modifying the piping.

2. From the standpoint of cost and installation time, it's best to use as much of the existing piping as possible.

3. Always consider the benefit versus cost of creating new zones when modifying the existing system. For example, if two bedrooms are typically maintained at the same temperature, and the existing system has accomplished this, it's likely best to keep these two bedrooms together on the same zone after adding the necessary supplemental heat emitters. However, if the piping modifications to do so are comparable in cost/time to creating two independent zones, then the latter is arguably a better choice.

4. Once all the supplemental heat emitters have been selected, and the proposed modifications to the distribution system have been sketched, always run a flow and head loss analysis for the modified system. This is used to confirm sufficient flow to each branch, and to determine a suitable circulator for the modified system.

5. When the modified distribution system contains several zones, and a Solstice heat pump will be used for the primary heat source, be sure to include a buffer tank in the system.

6. If the existing conventional boiler will be retained for use as a backup heat source for the low temperature system, be sure the boiler is protected against sustained flue gas condensation by installing a thermostatic mixing valve near the boiler, as shown in Figure 13.
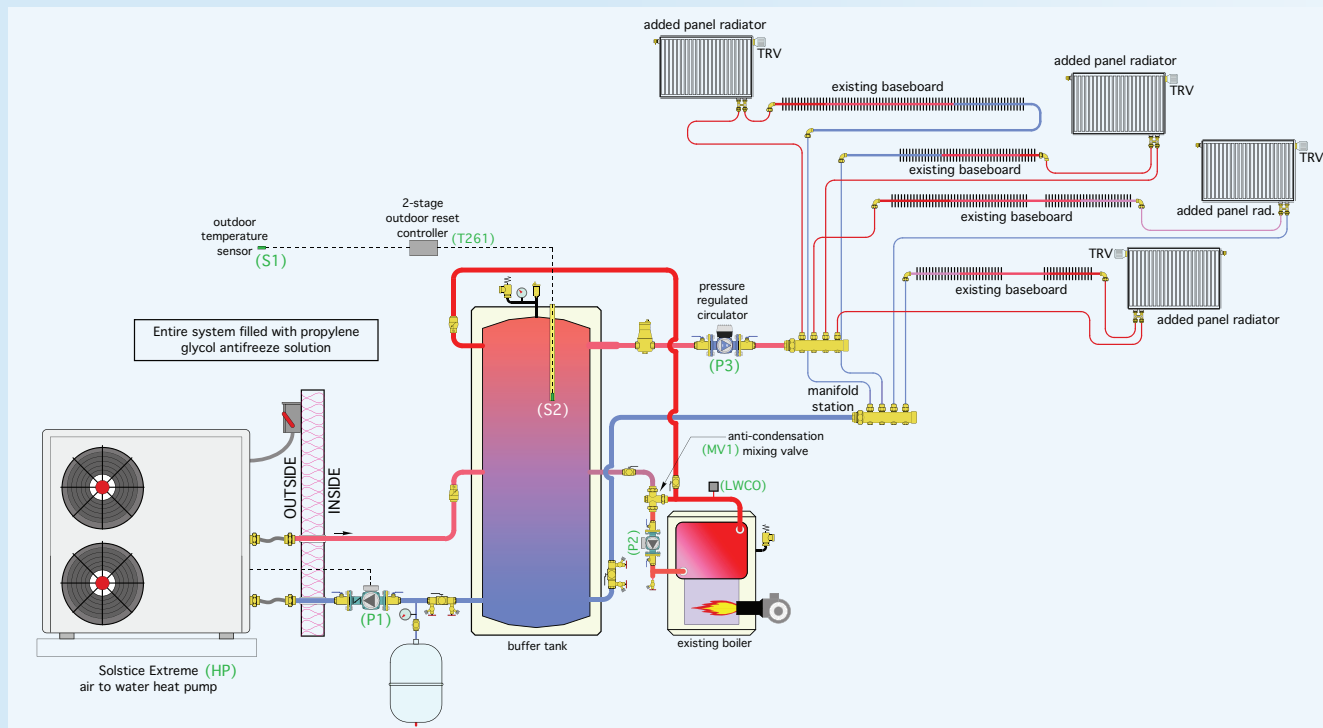
Figure 13
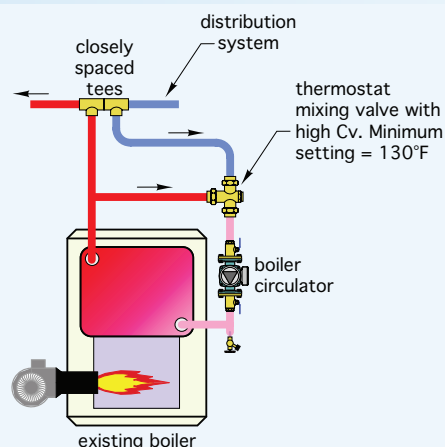
Example System

The system in Figure 14 is the result of modifying an existing system in which a single series circuit of finned-tube baseboard was supplied by an oil-fired cast iron boiler.

Figure 14

The original baseboard was sized for an average circuit temperature of 180°F. The system is being upgraded to a Solstice Extreme heat pump.

The distribution system has been divided into four space-heating zones, and the supplemental heat emitters are panel radiators. The modified distribution system will be able to deliver design load output using a supply water temperature of 120°F, when the outdoor temperature is 0°F.

The thermal envelope of the house has been upgraded with new windows, added insulation and air sealing. This makes the original oil-fired boiler 60% oversized for the current design heating load. However, the boiler is only 10 years old and will remain in the system as a backup heat source. Given the oversizing, and the dividing of the original distribution system into four independently controllable zones, the existing boiler will be connected to the upper portion of the buffer tank to help prevent short cycling.

The heat sources are turned on and off by a 2-stage outdoor reset controller, which monitors the temperature of sensor (S2) in the buffer tank. The first stage of this controller operates the heat pump. The second stage operates the existing boiler, but only if the heat pump is unable to achieve and maintain the necessary temperature at sensor (S2) in the buffer tank.

A single master thermostat provides the space-heating demand. The variable-speed pressure-regulated circulator (P3) and the 2-stage outdoor reset controller operate whenever there is a heating demand. The speed of circulator (P3) automatically adjusts as the four thermostatic radiator valves, one within each new zone of the distribution system, open, close or modulate flow rate. These valves allow the temperature within each zone to be individually adjusted.

The entire system is filled with a solution of propylene glycol to protect the heat pumps and any exposed piping from freezing.

The electrical schematic for the system is shown in Figure 15.

Figure 15
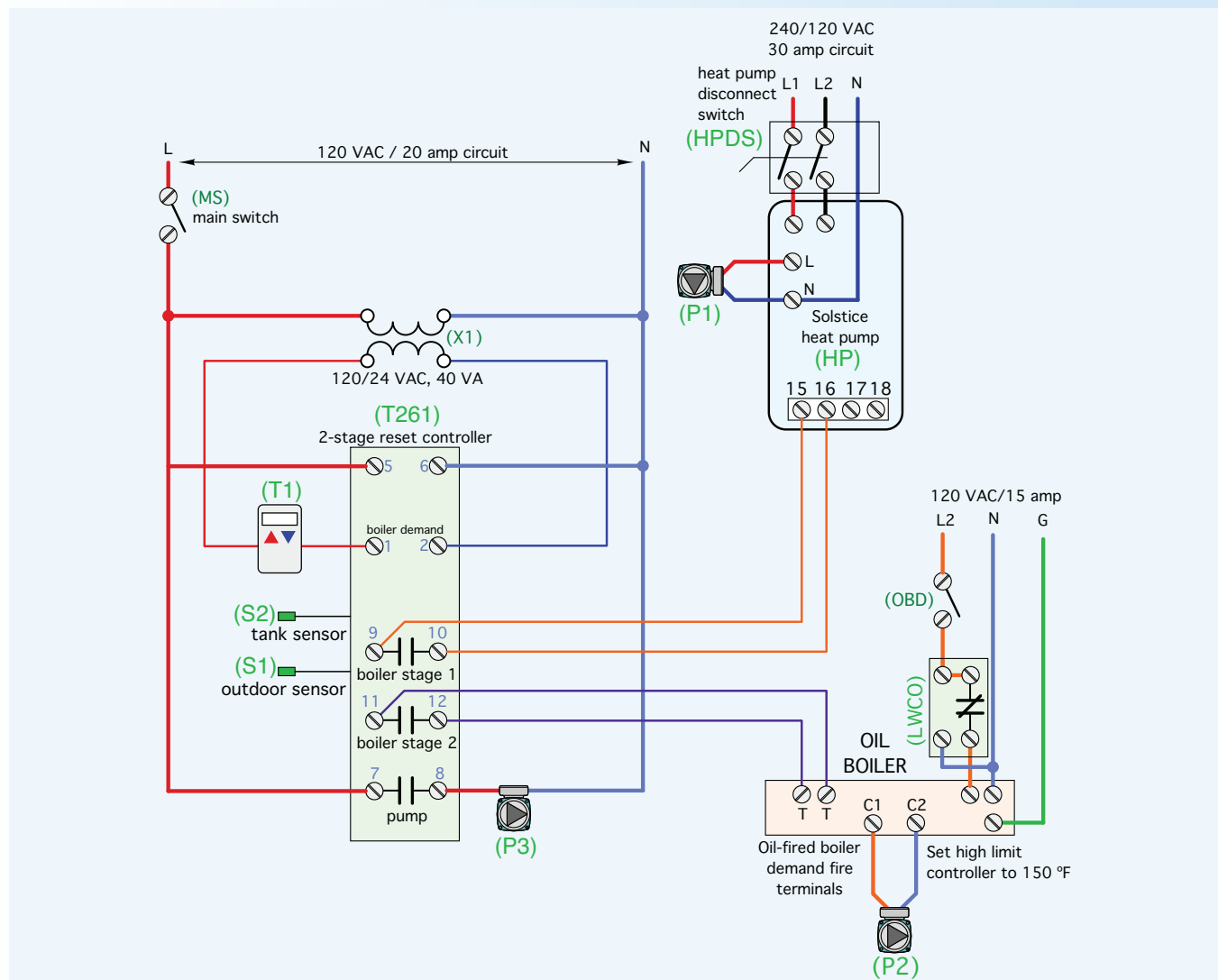
Description of Operation

POWER SUPPLY: *Power for the control system and circulator (P3) is supplied from a dedicated 120 VAC/20-amp circuit. The main switch (MS) must be closed to supply power to the control system and circulator (P3).*

The Solstice Extreme heat pump and circulator (P1) is supplied from a dedicated 240/120 VAC/30-amp circuit. The heat pump disconnect (HPD) must be closed for power to reach the heat pump or circulator (P1).

The existing boiler and circulator (P2) are powered by a 120 VAC/15-amp dedicated circuit. The boiler disconnect (OBD) must be closed, and the low water cut-off (LWCO) must detect water for power to reach the high-limit controller of the existing boiler

SPACE HEATING: *Whenever the main switch (MS) is closed, 24 VAC is supplied from the secondary winding of transformer (X1), and 120 VAC is supplied to the (T261) controller.*

A space-heating demand occurs when the contacts in master thermostat (T1) close, which supplies 24 VAC to the boiler demand terminals (1 & 2) of the 2-stage outdoor reset controller (T261). Circulator (P3) is also turned on at this time by the (T261) controller. The (T261) measures the outdoor temperature at sensor (S1) and uses this temperature, along with its settings, to calculate the target supply water temperature for the distribution system. It then measures the temperature of sensor (S2). If the temperature at sensor (S2) is 5ºF or more below the calculated target temperature, the stage 1 contacts in the (T261) close. This completes a circuit between terminals 15 and 16 in the Solstice Extreme heat pump (HP). Circulator (P1) is then turned on by the heat pump. After a

short time delay, the heat pump compressor turns on and the unit operates in heating mode. Heated antifreeze solution from the heat pump enters the mid-point of the buffer tank. Some flows upward through the tank to the distribution system through circulator (P3). If the flow rate through (P3) is lower than the flow rate through (P1), there will be some vertical downward flow of heated fluid in the buffer tank. The heat pump will remain in operation until the temperature at sensor (S2) reaches 5ºF above the current target supply temperature. At that point, the heat pump and circulator (P1) shut off.

EXISTING BOILER OPERATION: *The existing boiler will fire and circulator (P2) will turn on only if the heat pump is unable to meet the target water temperature at sensor (S2) within a short time. Heated fluid from the boiler will enter the upper left header of the buffer tank, from which it can flow across the tank to the distribution system and/or add heat to the buffer tank. The boiler and circulator (P2) will turn off when the temperature at sensor (S2) reaches a few degrees above the target water temperature calculated by the (T261) controller.*

A high flow-capacity thermostatic mixing valve (MV1) is used to ensure that the boiler's inlet temperature remains above 130ºF whenever possible. This protects the boiler from sustained flue gas condensation, which otherwise would occur due to the new lower operating temperature of the distribution system. The boiler's high limit controller should be set to 145ºF.

There are many potential variations on this system. For example, it could be expanded to provide chilled water cooling. The system could also be expanded to include domestic water heating.

Summary
Modern heat sources such as air-to-water heat pumps and modulating/condensing boilers require low-temperature hydronic distribution systems for optimal performance. Many existing hydronic systems, especially those installed several decades ago, were designed around relatively high water temperatures. By adding supplemental heat emitters, it is possible to reduce the water temperature at which the system can provide design load output. This issue of Water Works has discussed several approaches for modifying existing systems to make them compatible with modern high-performance hydronic distribution systems.

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