State-of-the-Art Hydronic Design Concepts for Solar Thermal Professionals

May 2, 2009 - Sustainable Energy Summit

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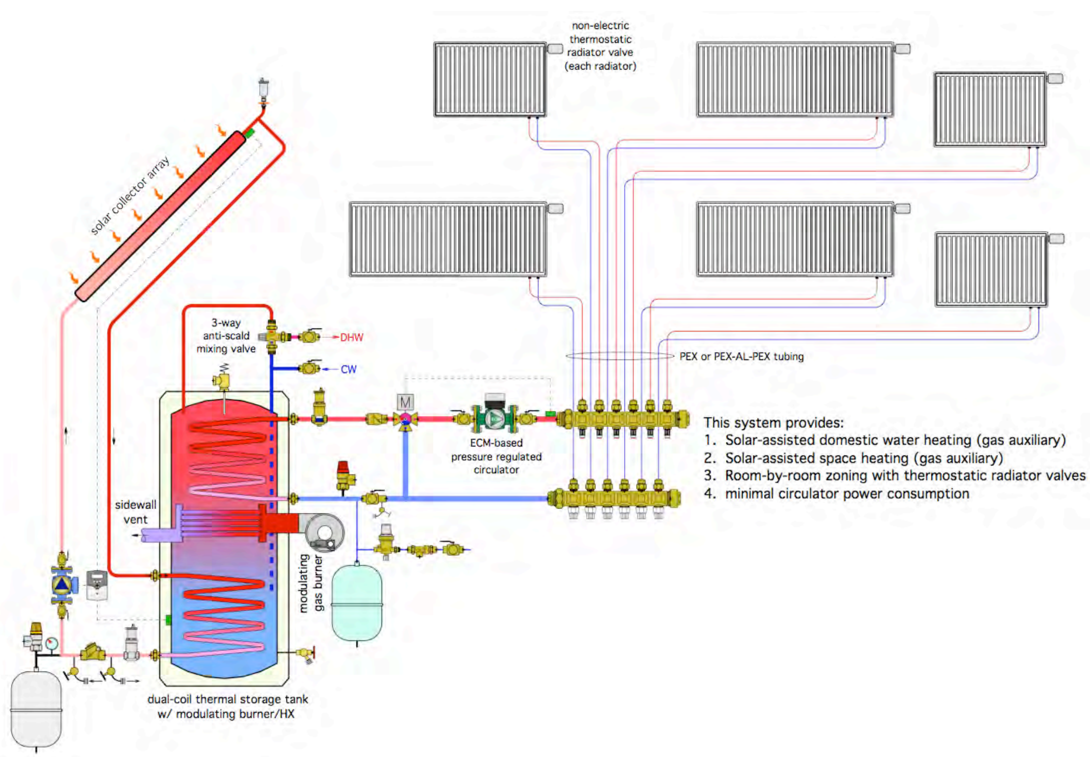
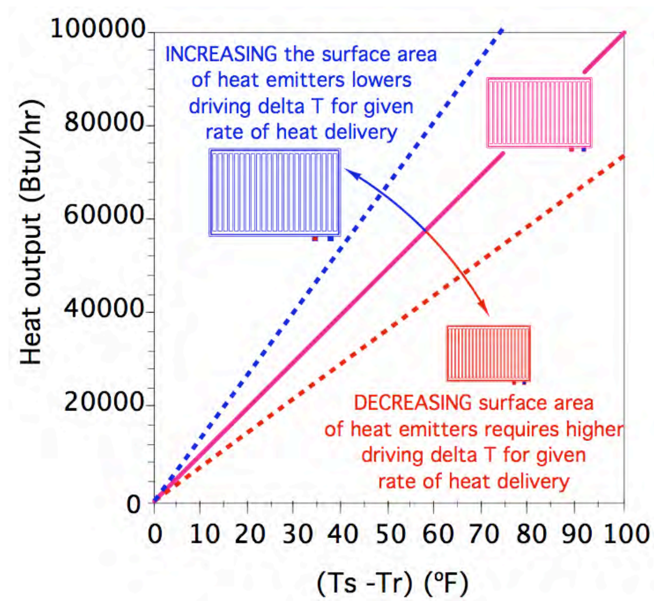
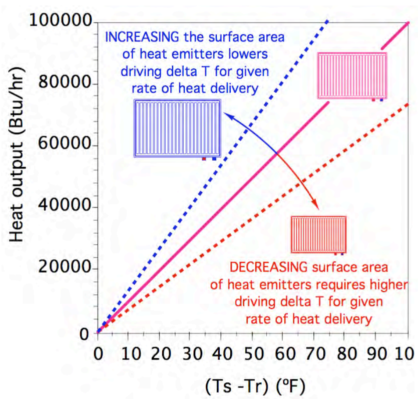
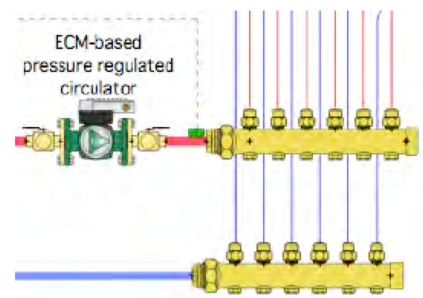


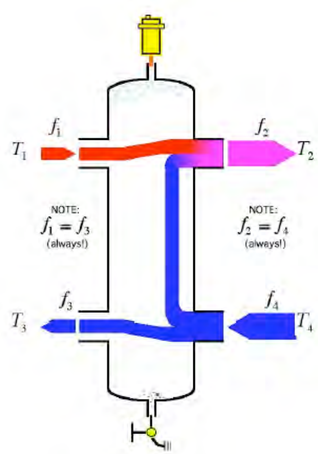


Today's Topics...

- SECTION 1: Thermal & Hydraulic Equilibrium - conditions EVERY hydronic system seeks
- SECTION 2: Hydraulic Separation: Life After Primary / Secondary Piping
- SECTION 3: The future of Low Power Pumping - about as Green as it gets!
- SECTION 4: BTU Metering - a great opportunity for energy savings through hydronics
- SECTION 5: Homerun Distribution Systems
- SECTION 6: System design Concepts for Solar Space Heating & Domestic Hot Water

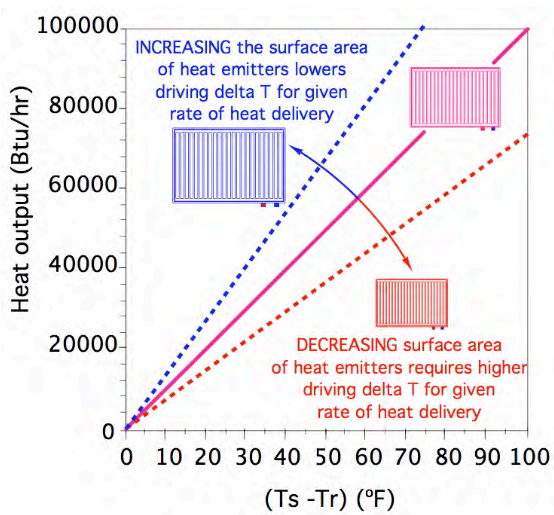


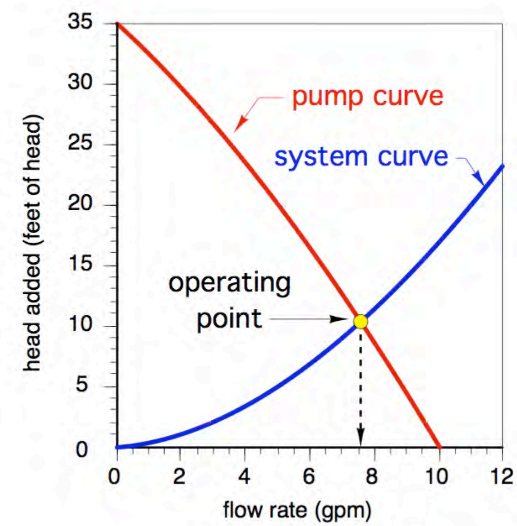




Thermal & Hydraulic Equilibrium

Conditions ***EVERY*** hydronic system seeks





In this system, hydraulic equilibrium occurs at 7.6 gpm

Most systems that involve energy input and energy output seek to operate at "equilibrium" conditions

An airplane, in level flight, always stabilizes at an airspeed where the rate of energy generated by its engine exactly matches the rate energy is dissipated by the drag of the plane's body

Want to go faster ? ***add more input power...***

A car, always seeks an speed where the rate of energy generated by its engine exactly matches the rate energy is dissipated by the drag of the body plus frictional dissipation of other moving components.

Want to go faster ? ***add more input power...***

A boat, stabilzes at a speed where the rate of energy generated by its engine exactly matches the rate energy is dissipated by the drag of the body plus frictional dissipation of other moving components.

Want to go faster ? **add more input power...**

A cyclist, always attains a speed where the rate of energy generated by its rider exactly matches the rate energy is dissipated by the drag of the body plus frictional dissipation of other moving components.

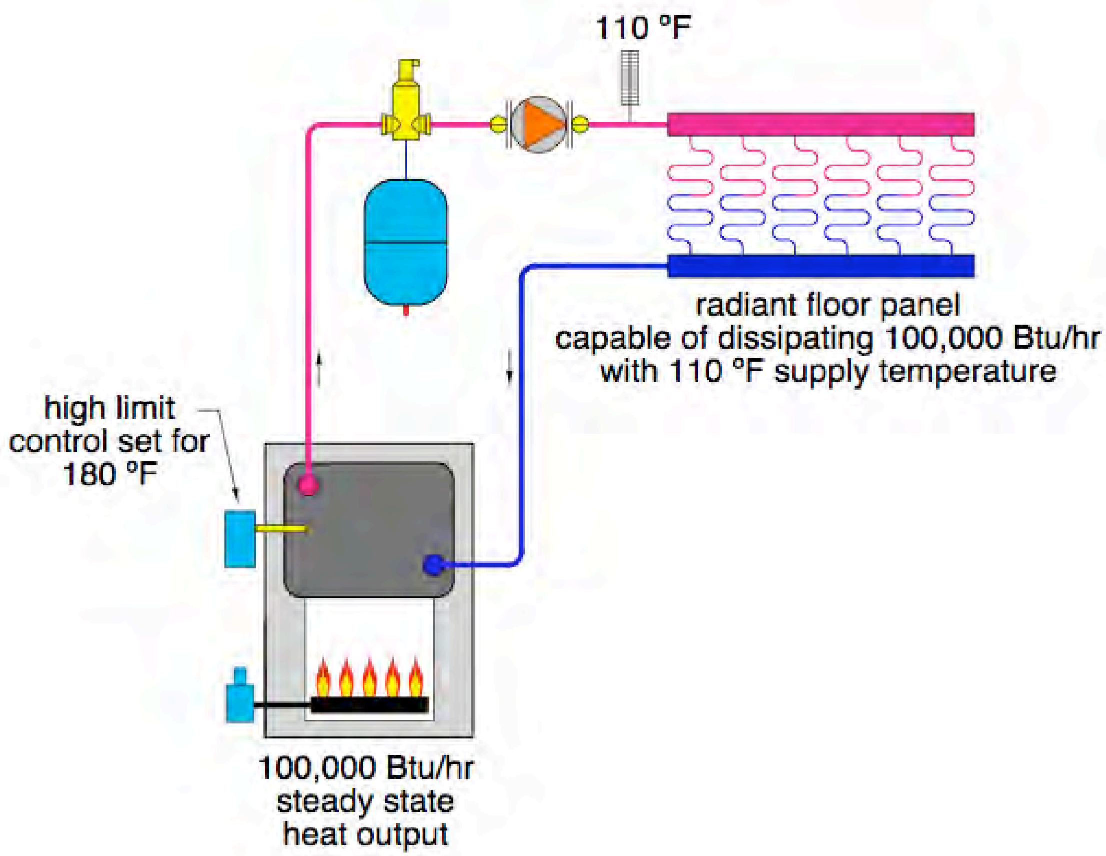
Want to go faster ? *add more input power...*

In a hydronic heating system, thermal energy (heat) is added to the water by the heat source.

Everything else the heated water flows through dissipates some of that heat.

THERMAL EQUILIBRIUM

Every hydronic system always seeks to operate at a water temperature where the rate of thermal energy input by the heat source equal the rate of thermal energy release by the rest of the system .



If thermal equilibrium exists, the setting on the high limit control is irrelevant.

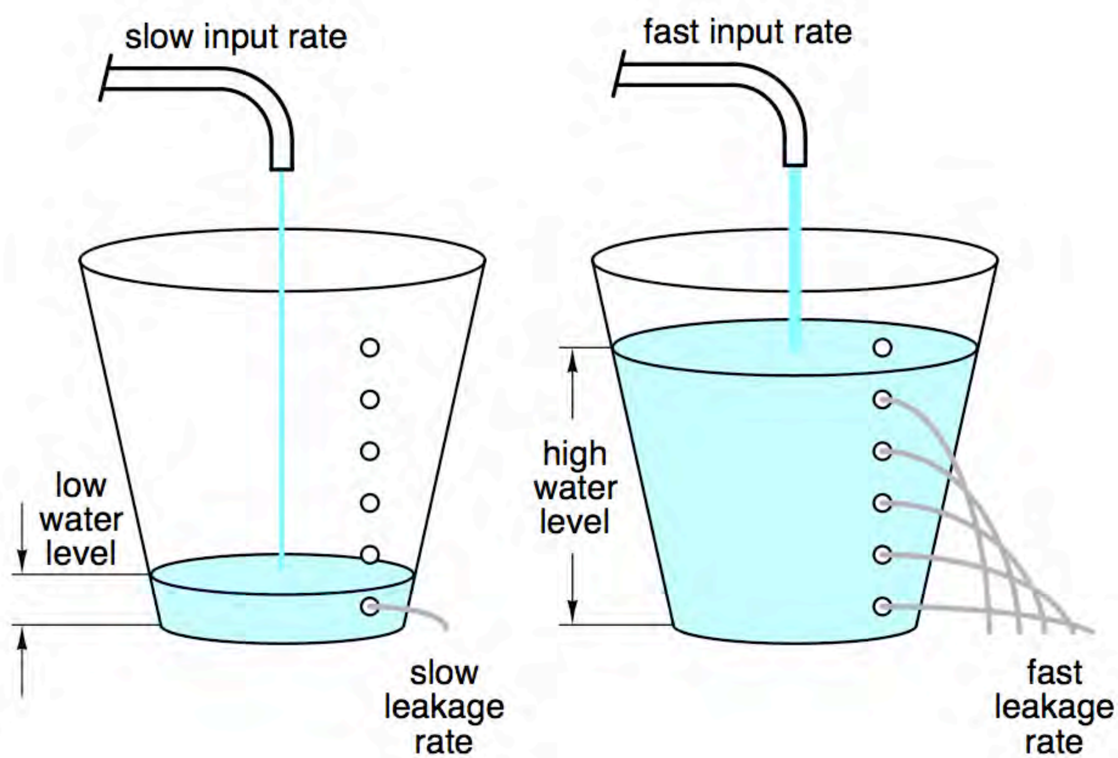
THERMAL EQUILIBRIUM

At thermal equilibrium, the water temperature leaving the heat source remains constant.

Think of the bucket with holes below as a heating system.

When the rate of heat input and heat output are low, the water level stabilizes at a low height.

When the rate of heat input and heat output are high, the water level stabilizes at a higher level.



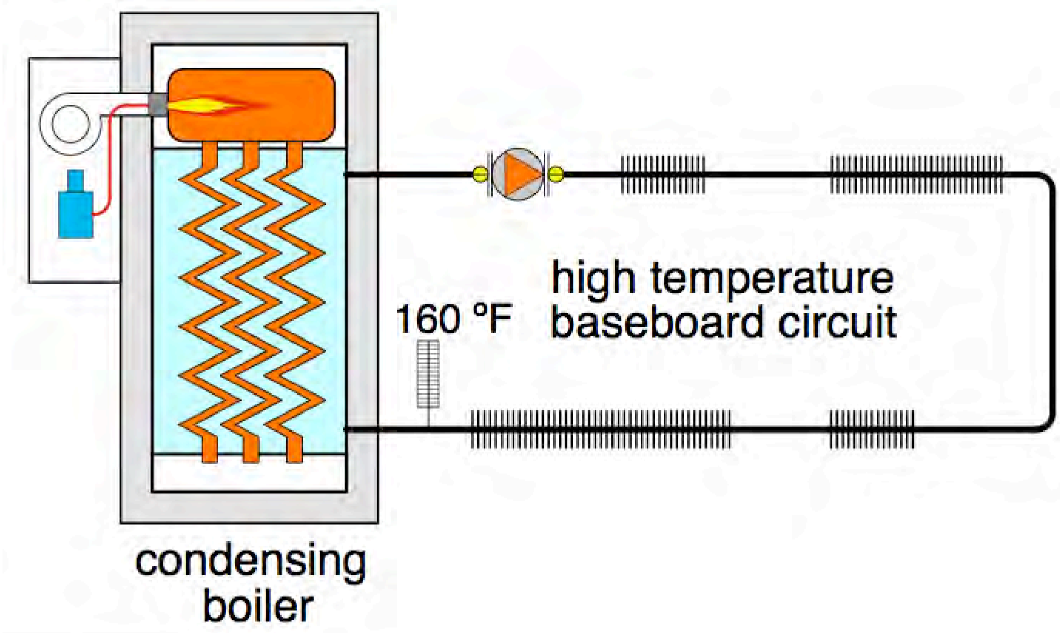
THERMAL EQUILIBRIUM

- *The system "doesn't care" if the proper amount of heat is being delivered.*

- *The system "doesn't care" if the operating conditions are safe.*

- *The system "doesn't care" if the operating conditions are conducive to long system life or high efficiency.*

- *The system only "cares" that an energy balance is being maintained.*



THERMAL EQUILIBRIUM

It's possible to predict the supply water temperature at which equilibrium will occur.

The heat output of a hydronic heat emitter is approximately proportional to the difference between supply water temperature and room air temperature.

$$Q_{output} = c \times (T_s - T_r)$$

Where:
Q_{output} = heat output of heat emitter (Btu/hr)
c= a number dependent on the type and size of heat emitter (Btu/hr/ºF)
T_s = water temperature supplied to heat emitter (ºF)
T_r = room air temperature (ºF)

(Ts-Tr) is called the "driving delta T." It's what drives heat out of the heat emitter and into the room.

THERMAL EQUILIBRIUM

$$Q_{output} = c \times (T_s - T_r)$$

This relationship holds true for a *single* heat emitters, OR an *entire group* of heat emitters that form a hydronic distribution system

For example, suppose you have a building where all the heat emitters in the system release 100,000 Btu/hr into a 70 ºF space when supplied with water at 170 ºF.

The value of the "c" can be determined (for this system) as follows:

$$c = \frac{Q}{(T_s - T_r)} = \frac{100,000}{(170 - 70)} = 1000 \frac{Btu}{hr \cdot {}^{o}F}$$

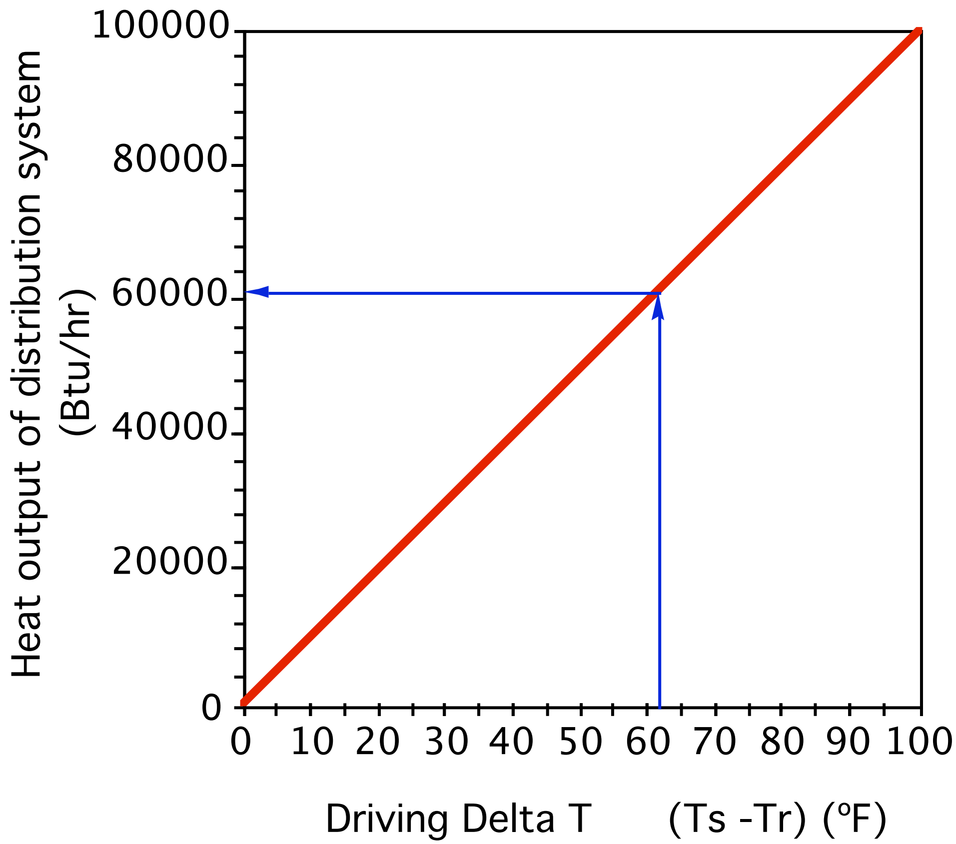
This distribution system releases 1,000 Btu/hr into the building for each degree F the supply water temperature exceeds the room air temperature.

Hence, if the supply water temperature was 130 ºF, and the space air temperature was 68 ºF, this system would provide the following heat output to the building:

$$Q = c \times (T_s - T_r) = 1000 \times (130 - 68) = 62,000\, Btu / hr$$

THERMAL EQUILIBRIUM

This relationship can be represented by a graph:

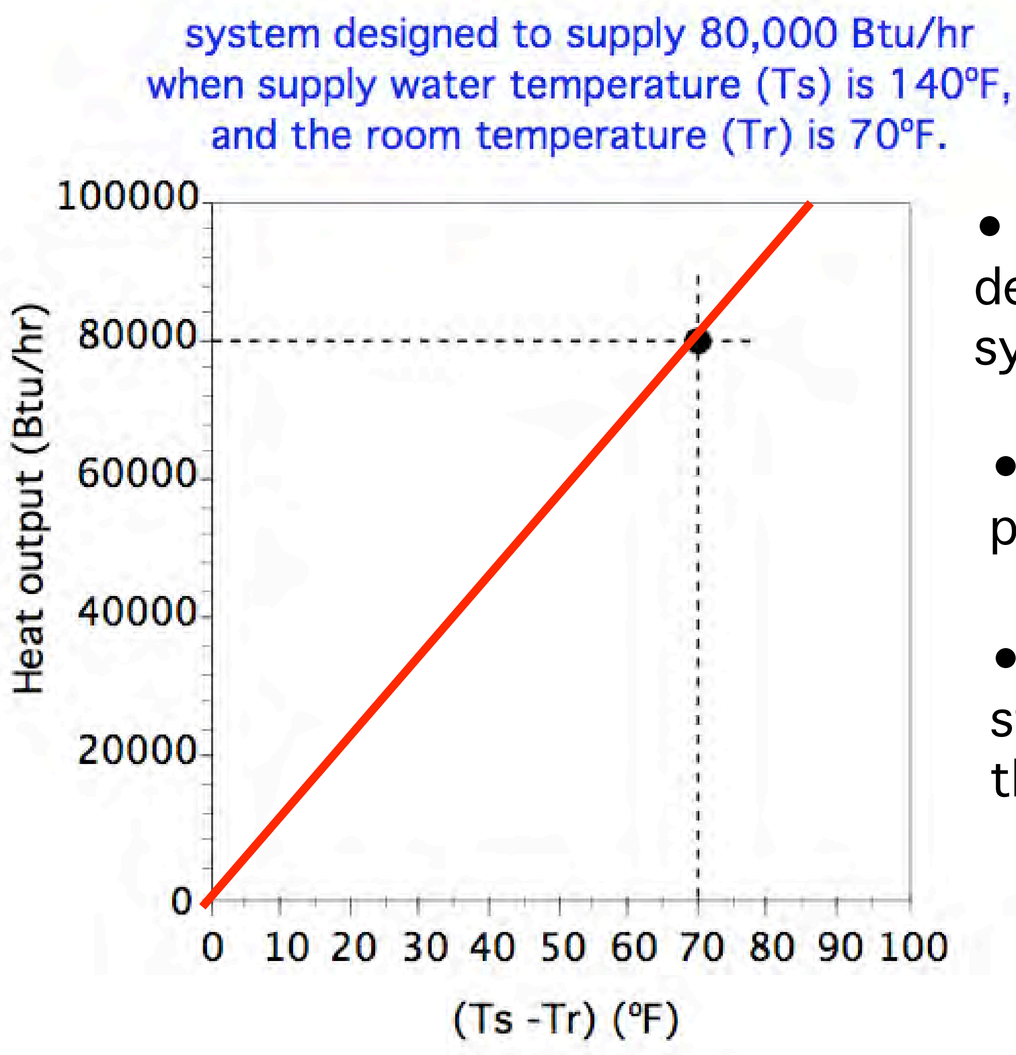


The formula that decribes the red line is:

$$Q_{output} = 1000 \times (T_s - T_r)$$

THERMAL EQUILIBRIUM

You can plot this graph by knowing the supply water temperature at design load conditions, the room temperature, and the design load.



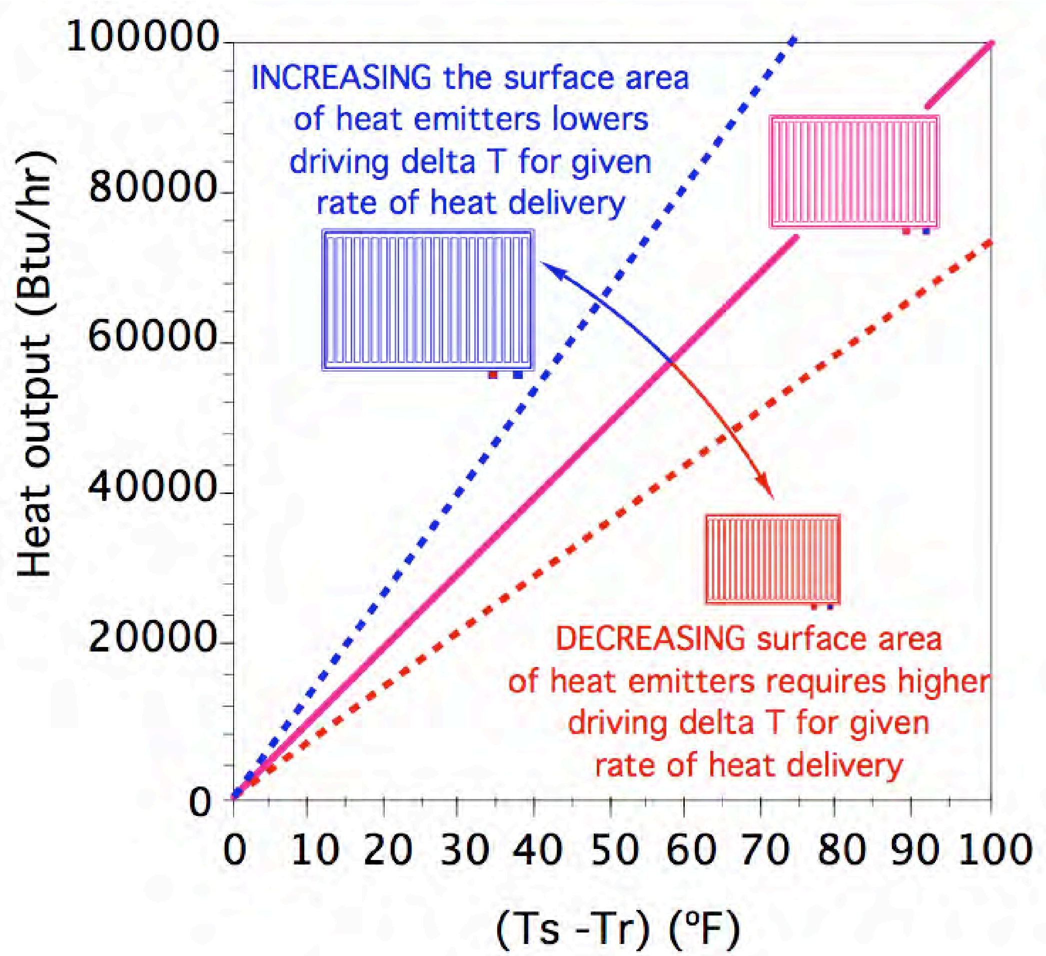
- This information is part of designing any hydronic system.

- Design software usually provides this data.

- Plot the point, then draw a straight line from 0,0 through this point.

THERMAL EQUILIBRIUM

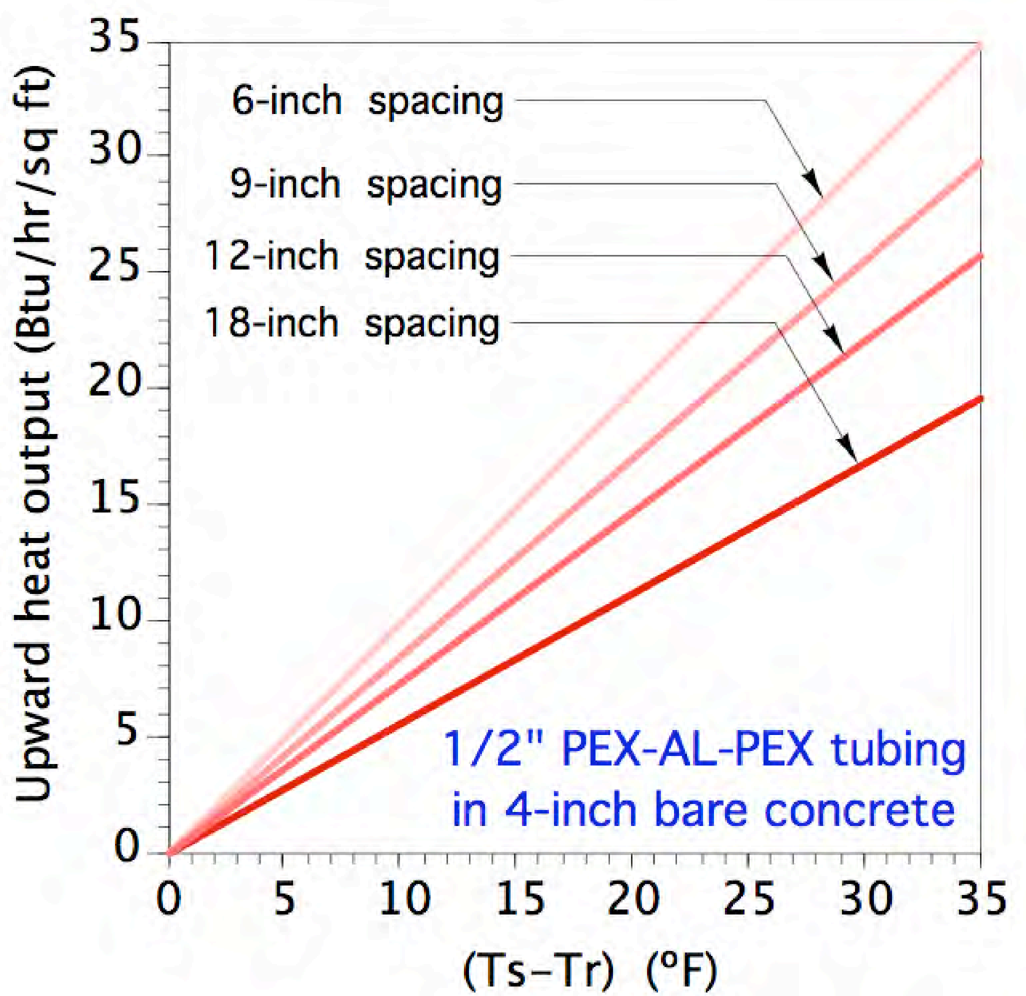
The slope of the line depends on the number and size of the heat emitters in the distribution system. The larger the surface area of the heat emitters the *steeper* the slope of the graph.



- Steeper lines mean that a given rate of heat release is achieved at lower values of the driving delta T.
- Steeper lines favor lower supply water temperature.
- *This in turn improves the efficiency of condensing boilers, geothermal heat pumps and solar collectors.*

THERMAL EQUILIBRIUM

For floor heating steeper lines are achieved by spacing tubing closer together. This lowers the supply temperature at which the floor can deliver a given rate of heat output.



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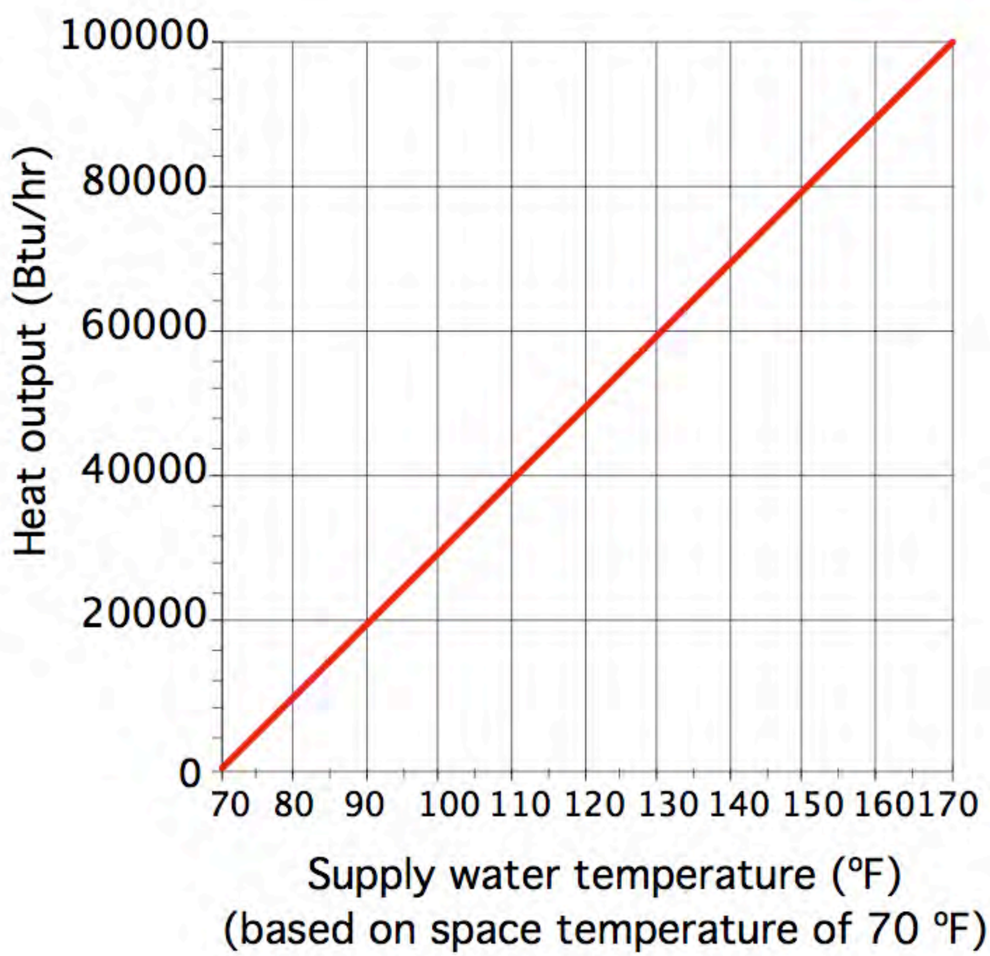
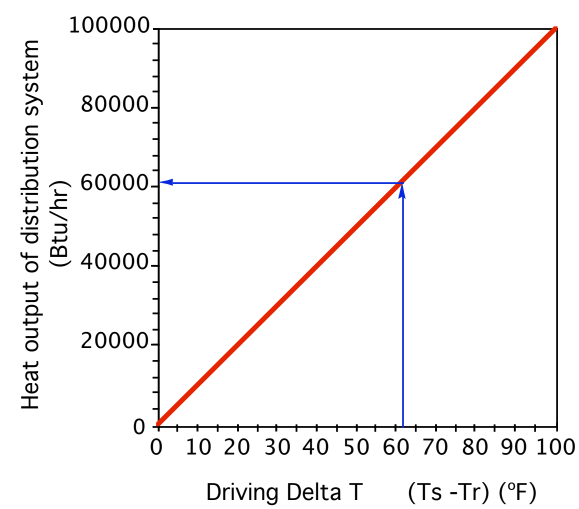
- Steeper lines favor lower supply water temperature.
- *<u>This in turn improves the efficiency of condensing boilers, geothermal heat pumps and solar collectors.</u>*

THERMAL EQUILIBRIUM

Adding the desired room temperature to the numbers along the bottom axis makes another useful variant.

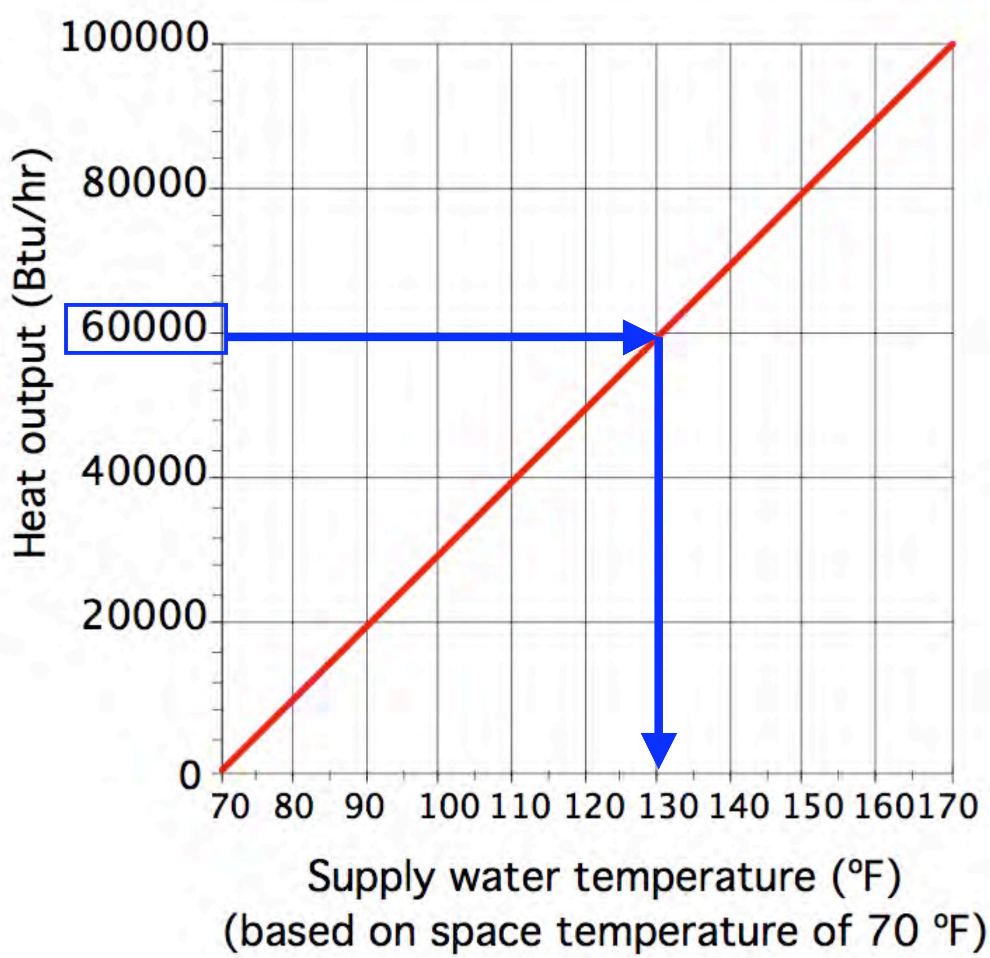


The graph now shows heat delivery versus supply water temperature..



THERMAL EQUILIBRIUM

You can use a distribution system heat output graph like this to find the supply temperature at which thermal equilibrium occurs with a given heat source.



1. Locate the heat output rate of heat source on vertical scale.
2. Draw horizontal line to right to intersect sloping line.
3. Draw vertical line down to lower axis to read supply temperature.

THERMAL EQUILIBRIUM

Control settings can sometimes "interfere" with thermal equilibrium.

1. If the temperature limiting control of the heat source is set ***below*** the thermal equilibrium temperature for a system, the heat emitters in the distribution system will not get hot enough to dissipate the full (steady state) output of the heat source.

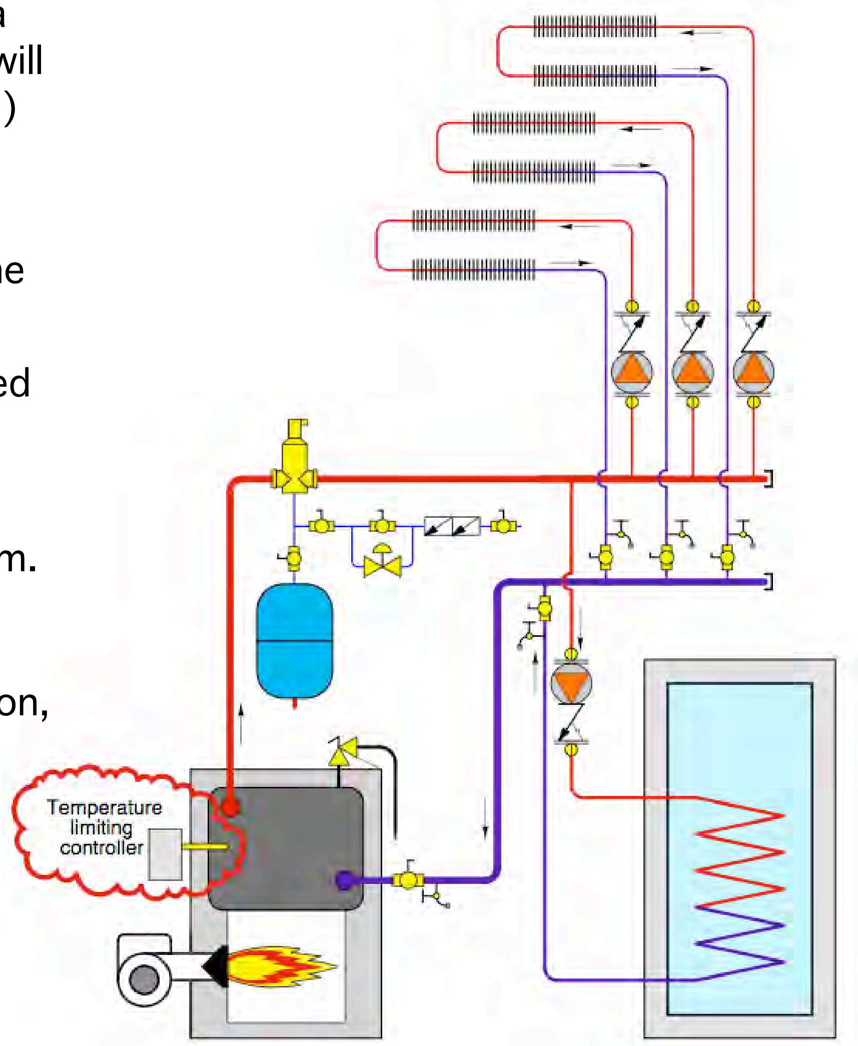
2. The water temperature leaving the heat source climbs as the system operates, eventually reaching the limit control setting.

3. The heat source (burner, compressor, etc.) is turned off.

4. The water temperature leaving the heat source decrease as heat is released by the distribution system.

5. Eventually, the temperature drops to the point where the limit controller turns the heat source back on, and the cycle repeats.

This is a very common in most systems during partial load conditions. It will also occur under design load conditions in systems with oversized heat sources.



THERMAL EQUILIBRIUM

Control settings can sometimes "interfere" with thermal equilibrium.

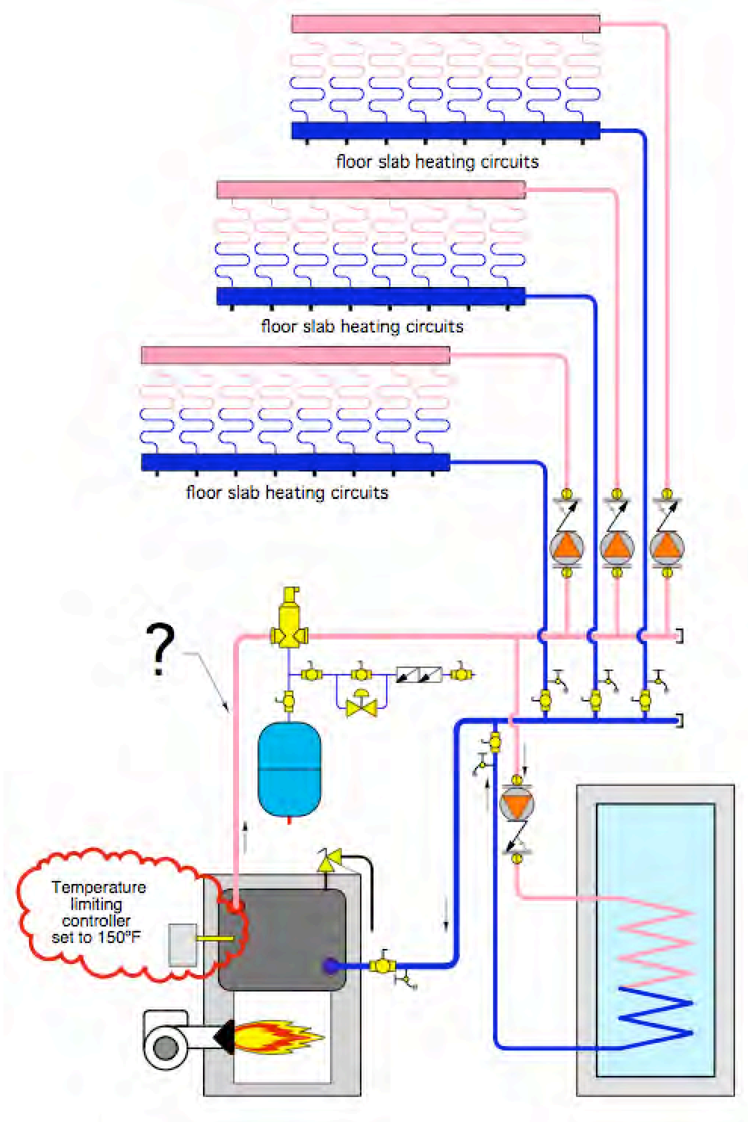
If the temperature limiting control on the heat source is set *above* the thermal equilibrium temperature for a system, water leaving the heat source will never reach that temperature unless the load is reduced or turned off.

This is why some systems never reach the setpoint of the limit controller even after hours of operation.

The distribution system doesn't need to climb to the boiler limit control setting to dissipate all the heat the boiler can send it.

The temperature in the distribution system only climbs as high as necessary to dissipate the heat coming to it from the heat source.

This is acceptable provided the heat source is not damaged by operating at the low temperature - not good for conventional boilers.



THERMAL EQUILIBRIUM

Imagine a hydronic floor heating system having 8 parallel 350 foot circuits of 1/2" PEX tubing embedded in a bare concrete slab. The system supplies 50,000 Btu/hr, and is piped as shown.

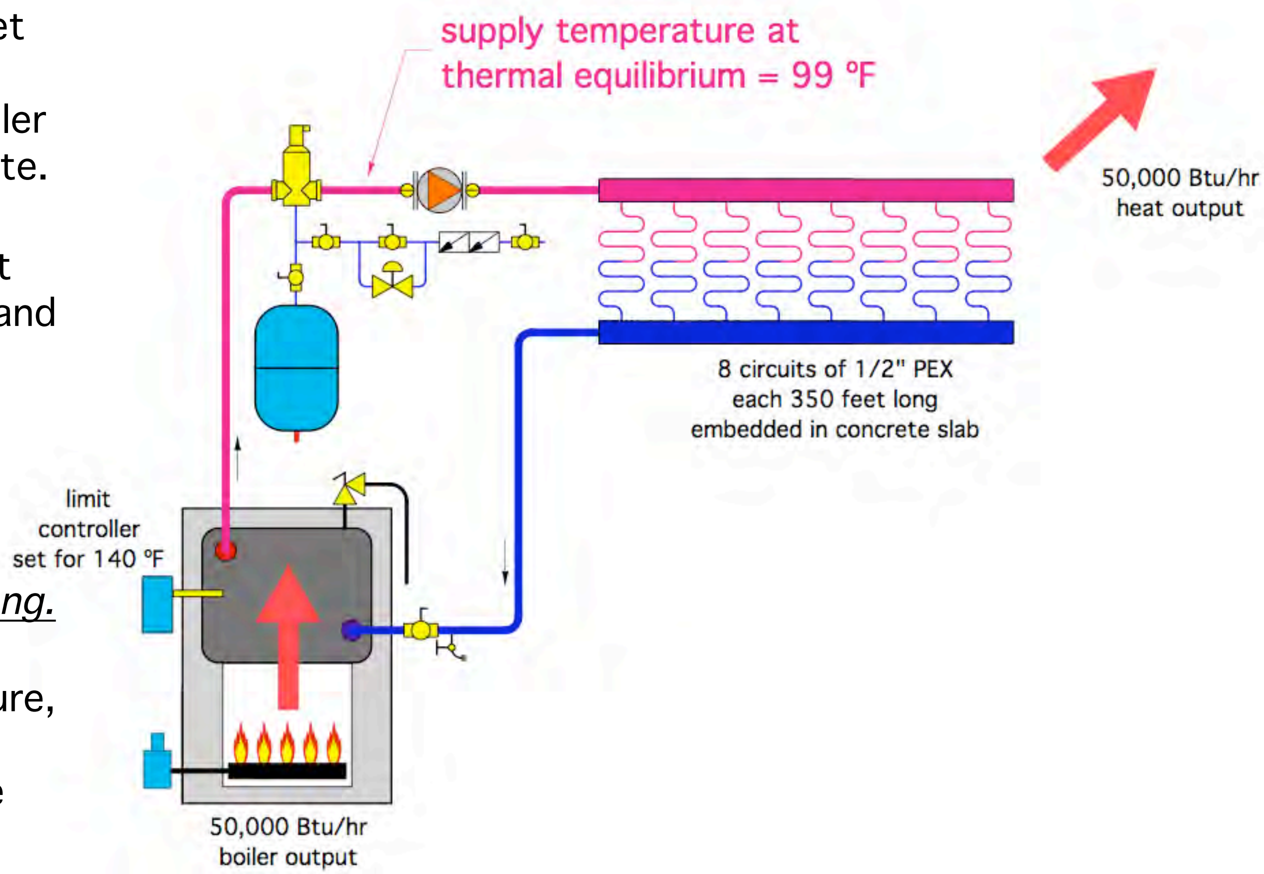
The boiler's limit controller is set for 140 °F because that's the temperature at which the installer thinks the system should operate.

When operated the boiler outlet temperature eventually climbs and stabilizes at 99°F.

What's wrong?

For the standpoint of thermodynamics *nothing is wrong.*

But at this operating temperature, flue gases will continually condense, and severely corrode the boiler's heat exchanger and vent connector.



THERMAL EQUILIBRIUM

Use the concept of thermal equilibrium to study the supply temperature required versus heat emitter size as you contemplate future systems.

Once you know the temperature at which the system "wants to operate" you can estimate the tradeoff between boiler (or solar collector) efficiency and heat emitter cost.

Keep in mind that lower system supply temperatures always favor higher efficiency of the heat source.

HYDRAULIC EQUILIBRIUM

In addition to thermal energy, hydronic systems deal with mechanical energy.

This mechanical energy is called HEAD.

Head energy is imparted to a fluid by the circulator.

Head energy is dissipated from the fluid by everything that flow flows through.

HYDRAULIC EQUILIBRIUM

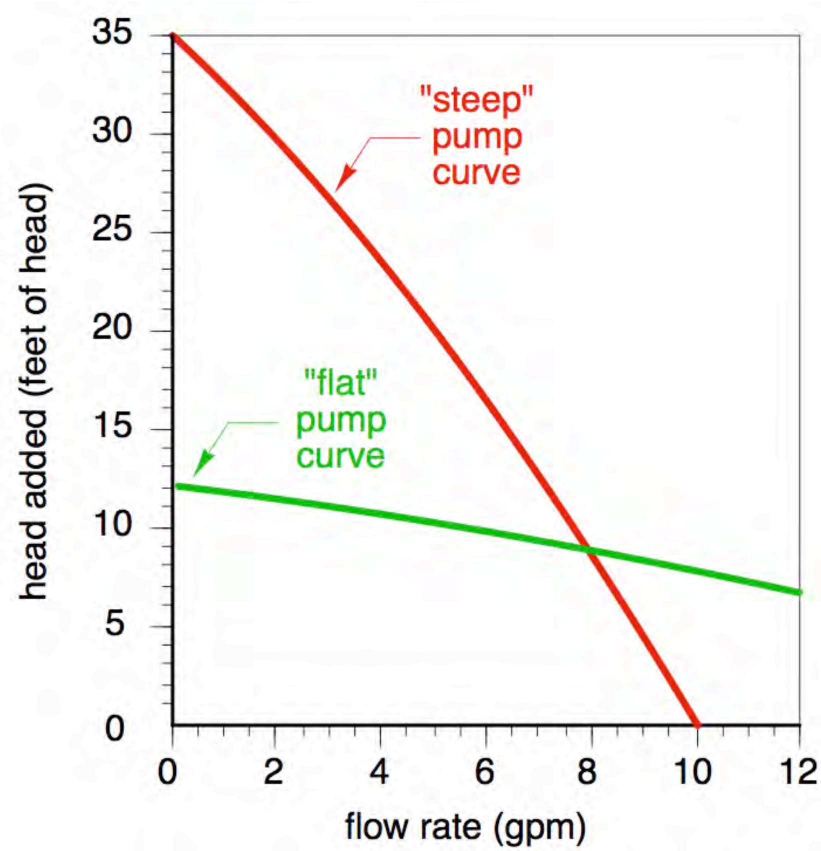
In North America, head energy is measured in FEET of head.

It comes from the following mathematical simplification.

$$head = \frac{\text{mechanical energy exchanged}}{\text{unit of fluid weight}} = \frac{ft \bullet lb}{lb} = ft$$

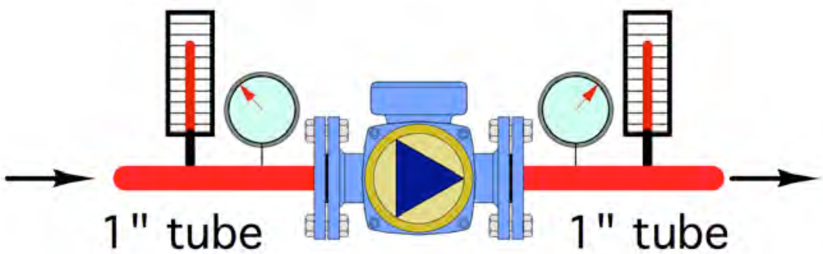
The head energy imparted to a fluid by a circulator is represented as a pump curve.

Some circulators are designed to produce "steep" pump curves, others are designed to produce "flat" pump curves.



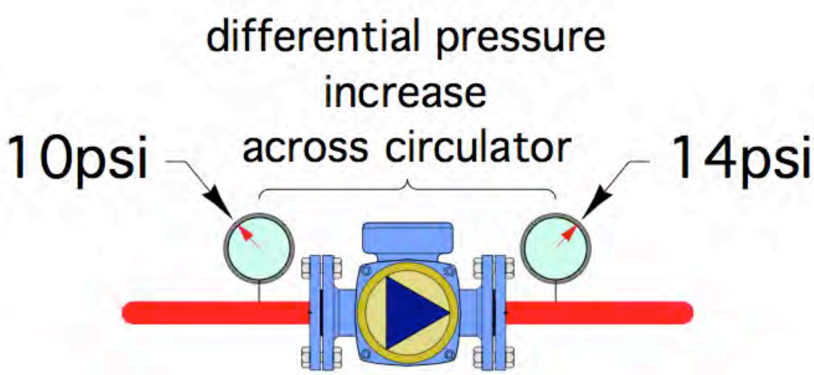
HYDRAULIC EQUILIBRIUM

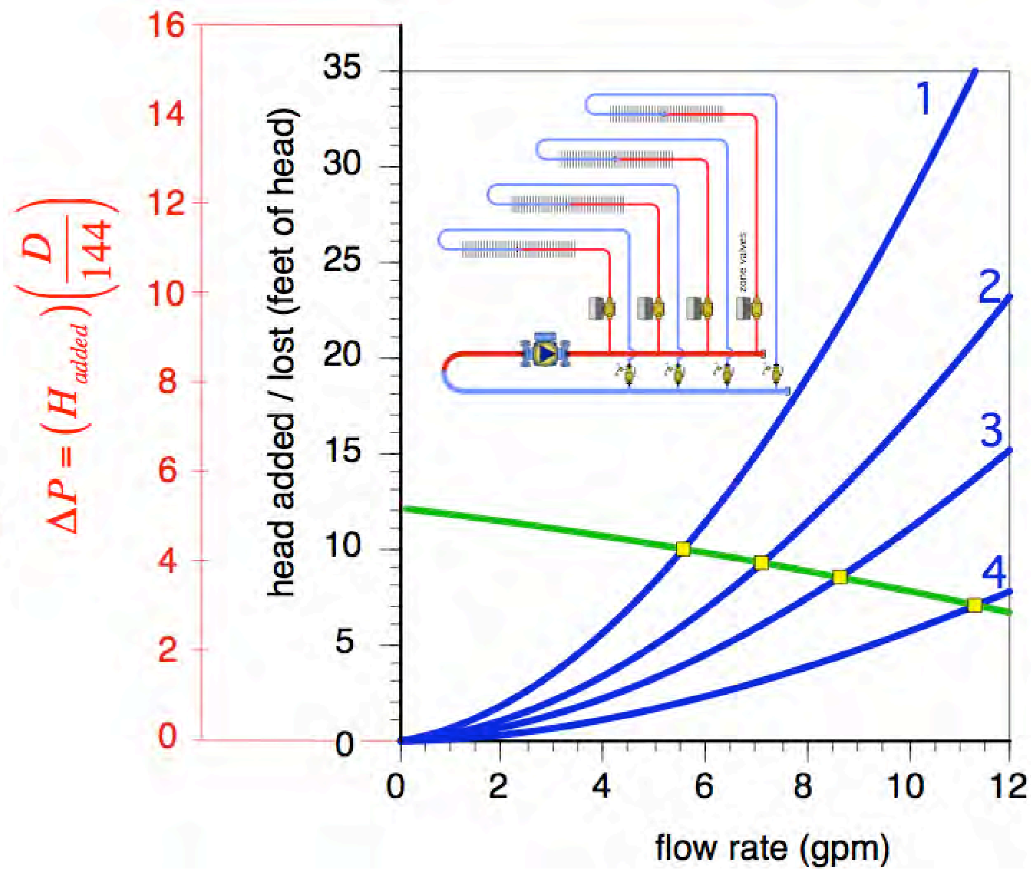
What is the EVIDENCE that head energy has been added to a fluid is?



a. The fluid's velocity increases
b. The fluid's flow rate increases
c. The fluid's temperature increases
d. None of the above

The EVIDENCE of head energy added is an increase in differential pressure across the circulator.





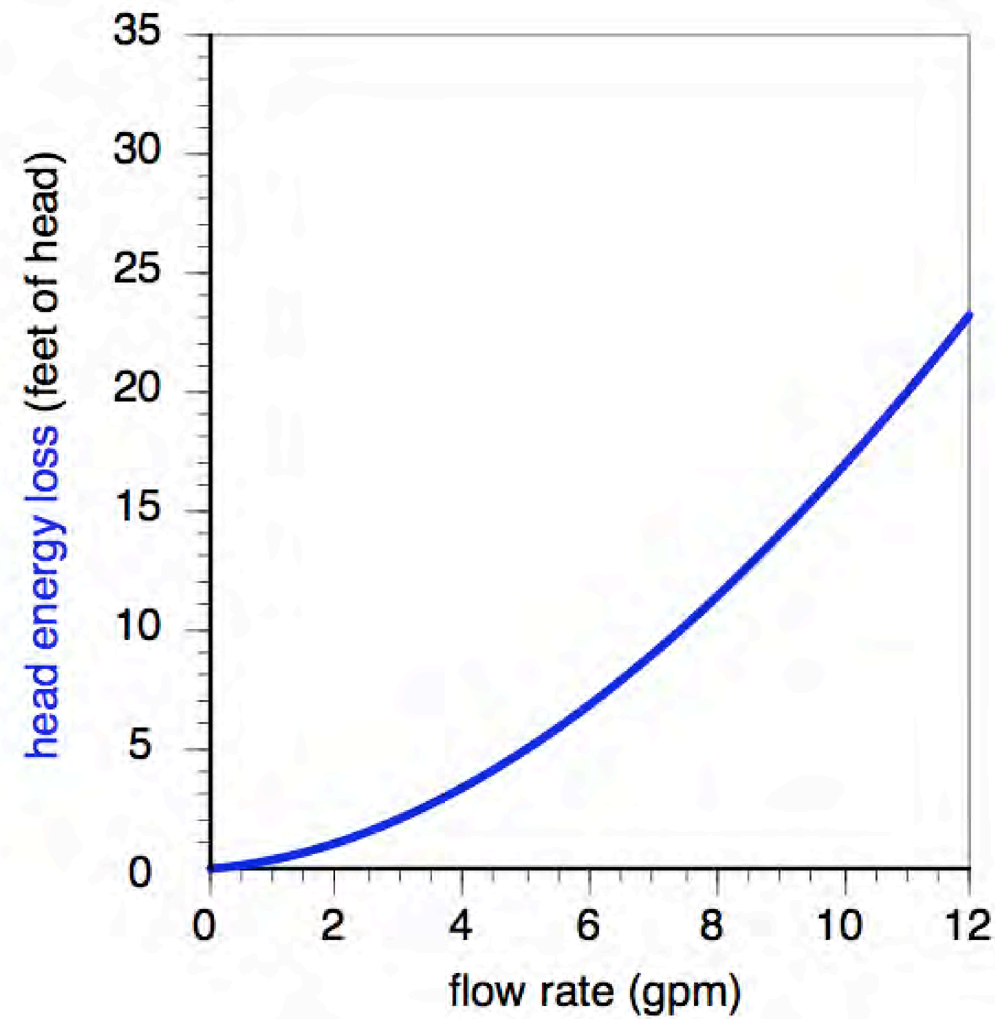
HYDRAULIC EQUILIBRIUM

The head energy dissipated by a hydronic circuit is represented by a system curve.

Notice that the units on the vertical axis are the same as with a pump curve (feet of head)

For fluid filled closed loop circuits the system curve passes through 0,0 as shown.

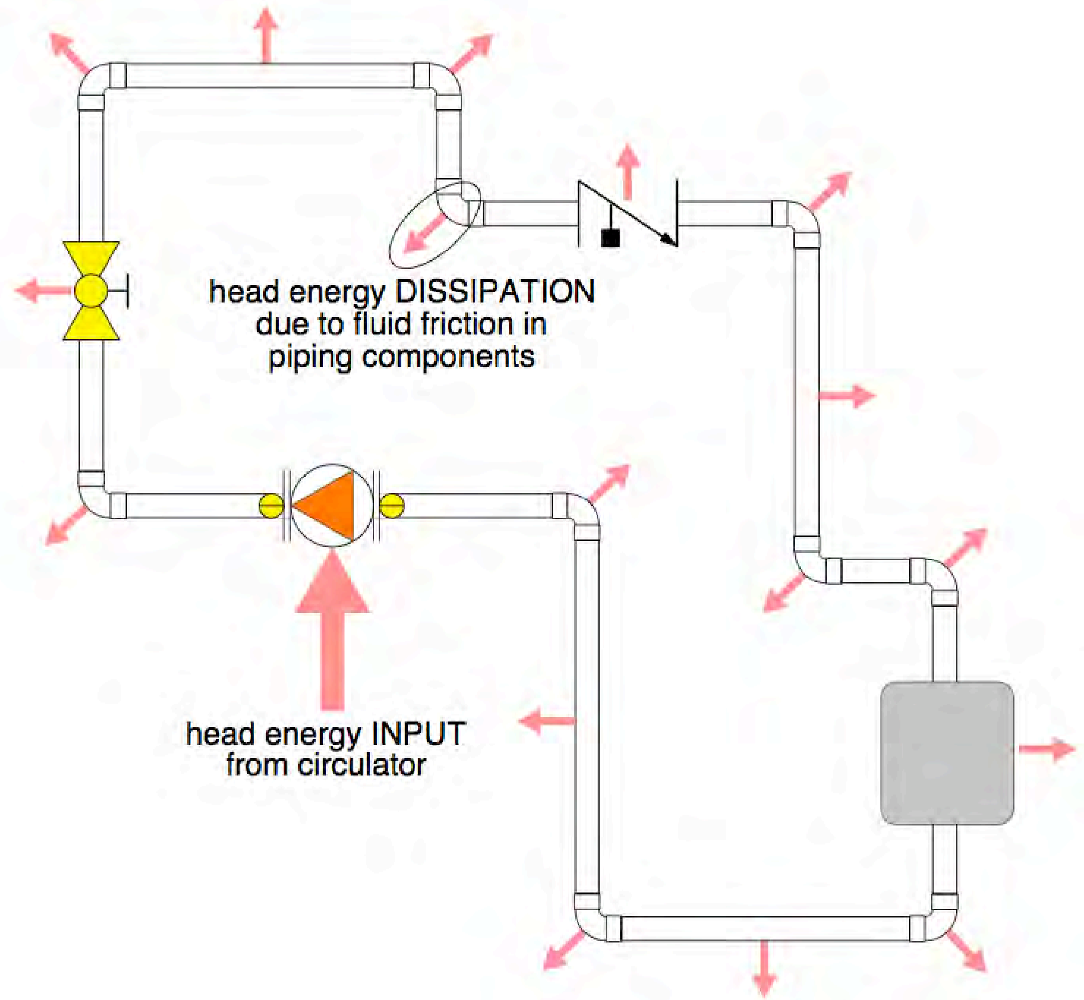
Construct the curve by calculating head loss at several flow rates, plot the points, and draw a smooth curve through them.



HYDRAULIC EQUILIBRIUM

Hydraulic equilibrium occurs when the head energy added by the circulator exactly matches the head energy dissipation by the other components in the system.

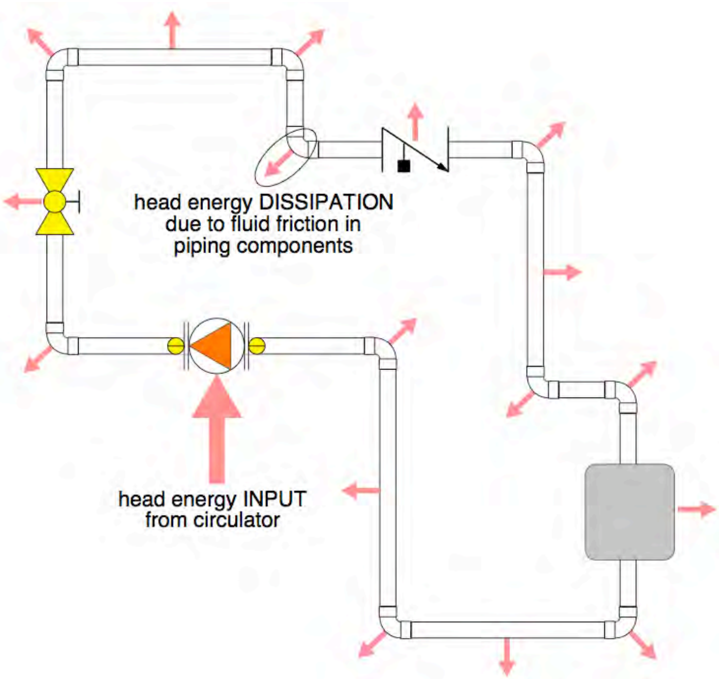
This condition is usually achieved within a few seconds of the circulator turning on.

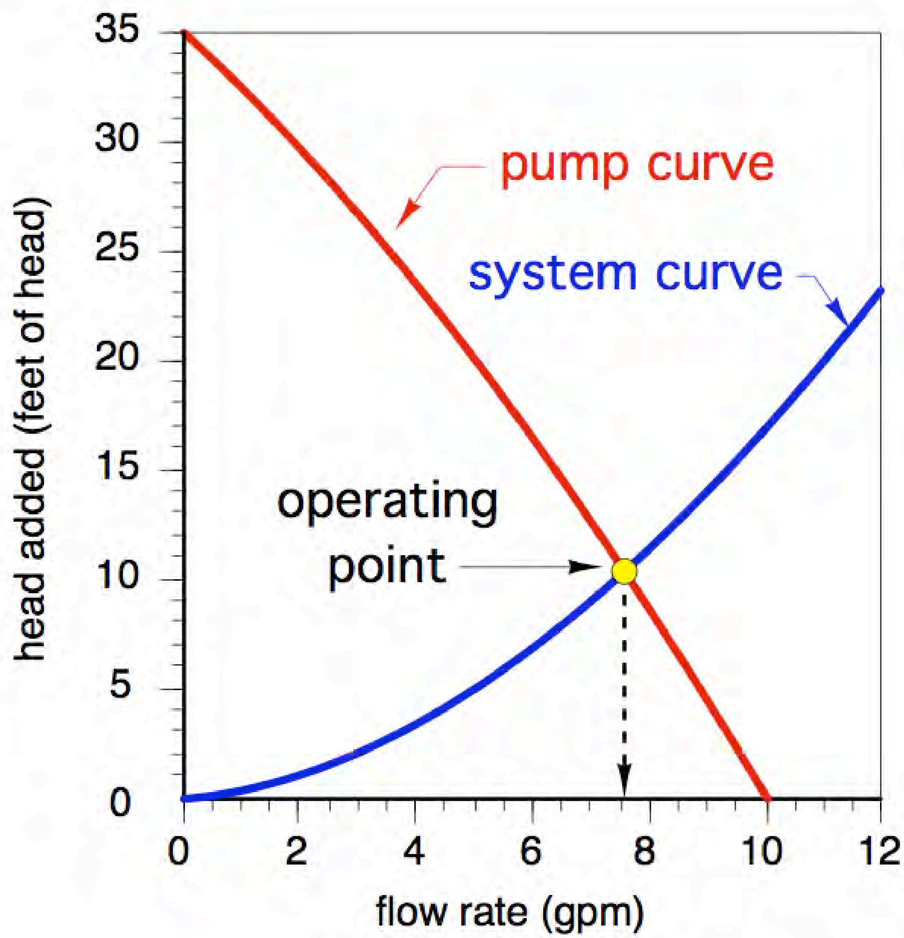


HYDRAULIC EQUILIBRIUM

Hydraulic equilibrium occurs when the head energy added by the circulator exactly matches the head energy dissipation by the other components in the system.

This condition can be found by plotting the pump curve of the circulator, and the system curve of the circuit on the same graph.





In this system, hydraulic equilibrium occurs at 7.6 gpm

HYDRAULIC EQUILIBRIUM

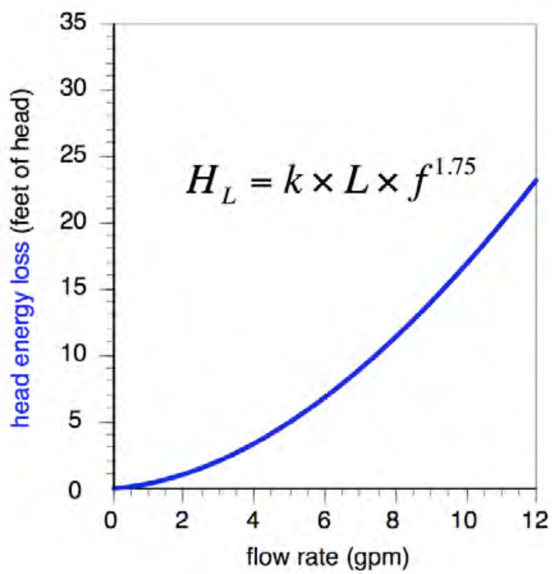
The system curve for a closed, fluid-filled hydronic circuit constructed of smooth tubing can be found as follows:

$$H_L = k \times L \times f^{1.75}$$

Where:

H_L = head loss of circuit in feet (feet of head)
k = a constant based on the fluid and pipe size (see table for k values based on water at 140°F)
L=total equivalent length of the circuit (ft)
f = flow rate through the circuit (gpm)
1.75 = an exponent of the flow rate

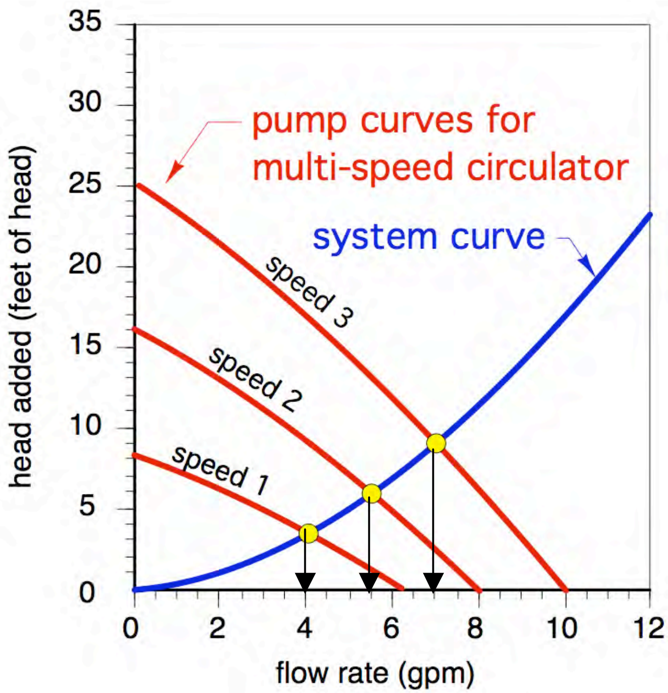
Tubing size / type	Minimum Flow rate (based on 2 ft/sec) (gpm)	Maximum Flow rate (based on 4 ft/sec) (gpm)	*k* *value*
3/8" copper	1.0	2.0	0.04828
1/2" copper	1.6	3.2	0.0158
3/4" copper	3.2	6.5	0.00294
1" copper	5.5	10.9	0.000844
1.25" copper	8.2	16.3	0.000323
1.5" copper	11.4	22.9	0.000146
2" copper	19.8	39.6	0.0000396
2.5" copper	30.5	61.1	0.0000142
3" copper	43.6	87.1	0.0000061
3/8" PEX	0.6	1.3	0.139
1/2" PEX	1.2	2.3	0.0373
5/8" PEX	1.7	3.3	0.0140
3/4" PEX	2.3	4.6	0.00729
1" PEX	3.8	7.5	0.00223
1.25" PEX	5.6	11.2	0.0007923
1.5" PEX	7.8	15.6	0.0003588
2" PEX	13.4	26.8	0.0000999
3/8" PEX-AL-PEX	0.6	1.2	0.159
1/2" PEX-AL-PEX	1.2	2.5	0.0393
5/8" PEX-AL-PEX	2	4.0	0.00977
3/4" PEX-AL-PEX	3.2	6.4	0.00333
1" PEX-AL-PEX	5.2	10.4	0.00120

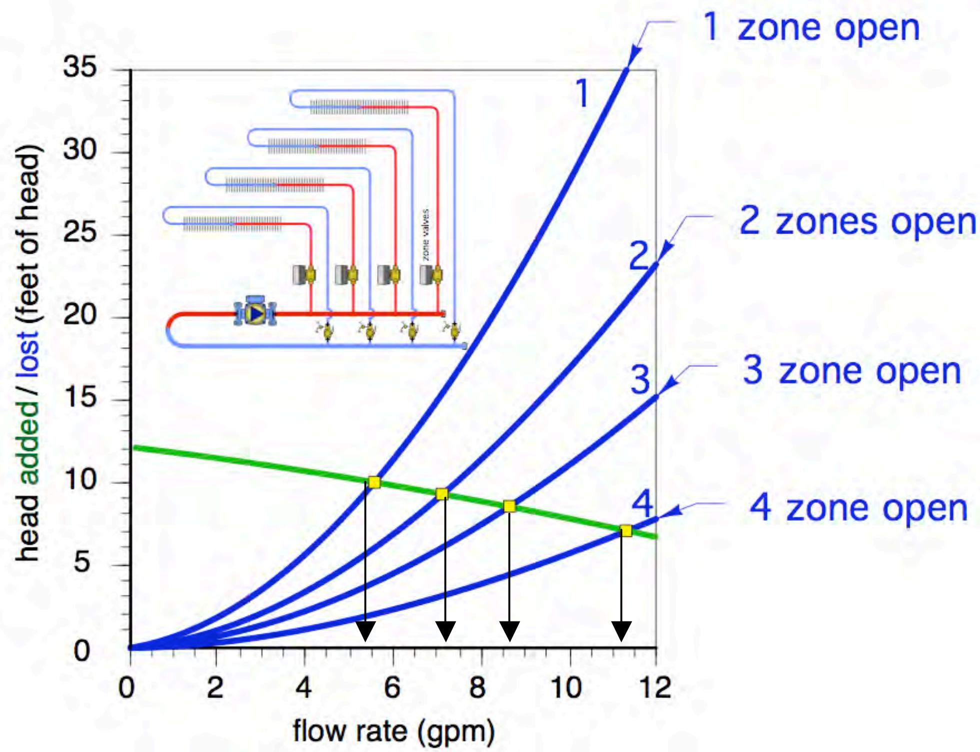


	NOMINAL TUBING SIZE							
FITTING	1/2"	3/4"	1"	1.25"	1.5"	2"	2.5"	3"
90° elbow	1.0	2.0	2.5	3.0	4.0	5.5	7.0	9.0
45° elbow	0.5	0.75	1.0	1.2	1.5	2.0	2.5	3.5
tee(straight)	0.3	0.4	0.45	0.6	0.8	1.0	0.5	1.0
tee(side)	2.0	3.0	4.5	5.5	7.0	9.0	12.0	15.0
gate valve	0.2	0.25	0.3	0.4	0.5	0.7	1.0	1.5
ball valve	1.9	2.2	4.3	7.0	6.6	14.0	0.5	1.0
flow check	N/A	83.0	54.0	74	57	177	N/A	N/A
globe valve	15.0	20.0	25.0	36.0	46.0	56.0	104.0	130.0

HYDRAULIC EQUILIBRIUM

The flow rate at which hydraulic equilibrium exists changes whenever there is a change to the pump curve, OR a change to the system curve.

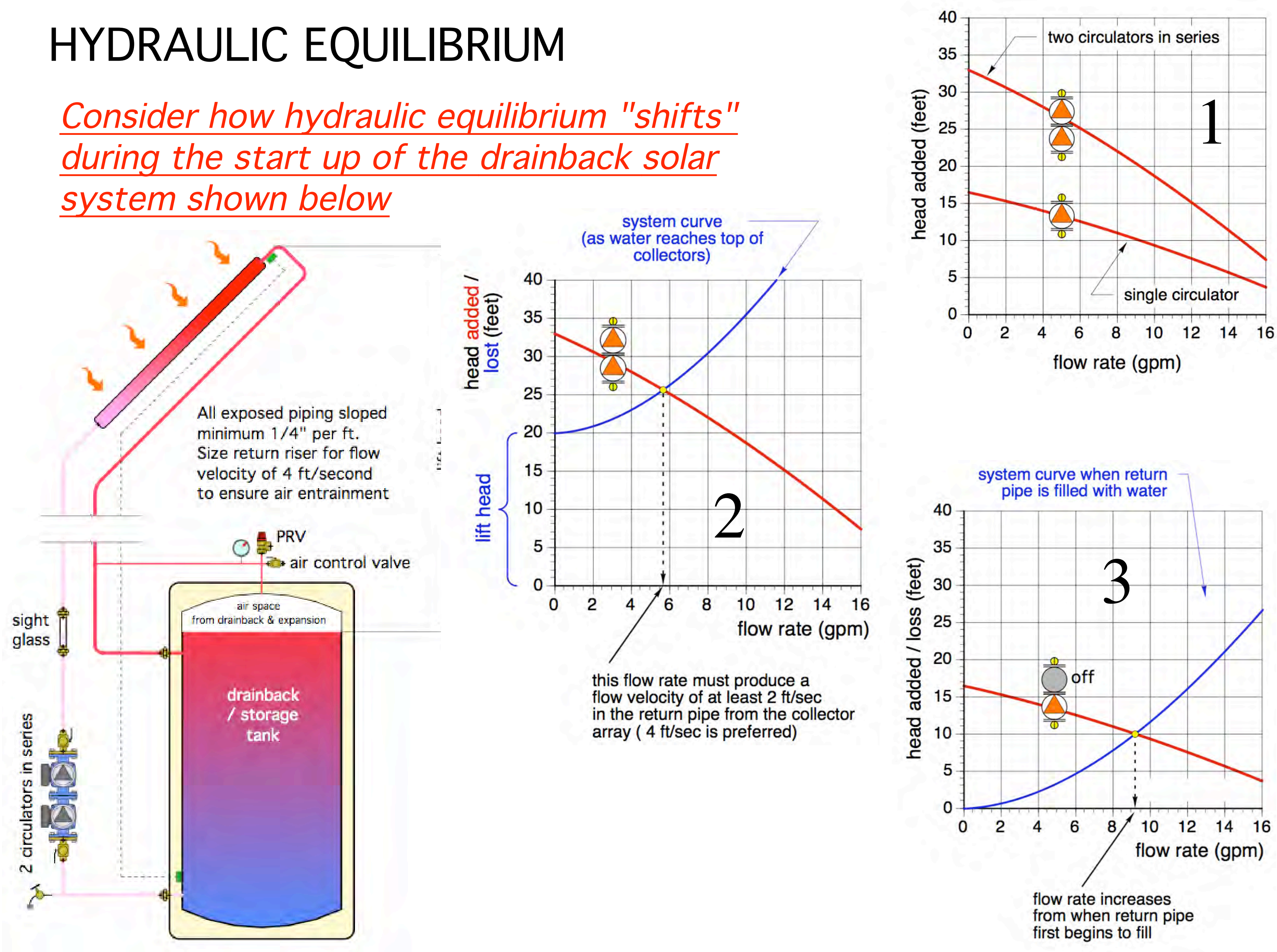




Just remember that EVERY hydronic system will ALWAYS adjust itself to a condition of hydraulic equilibrium - there's no way around it.

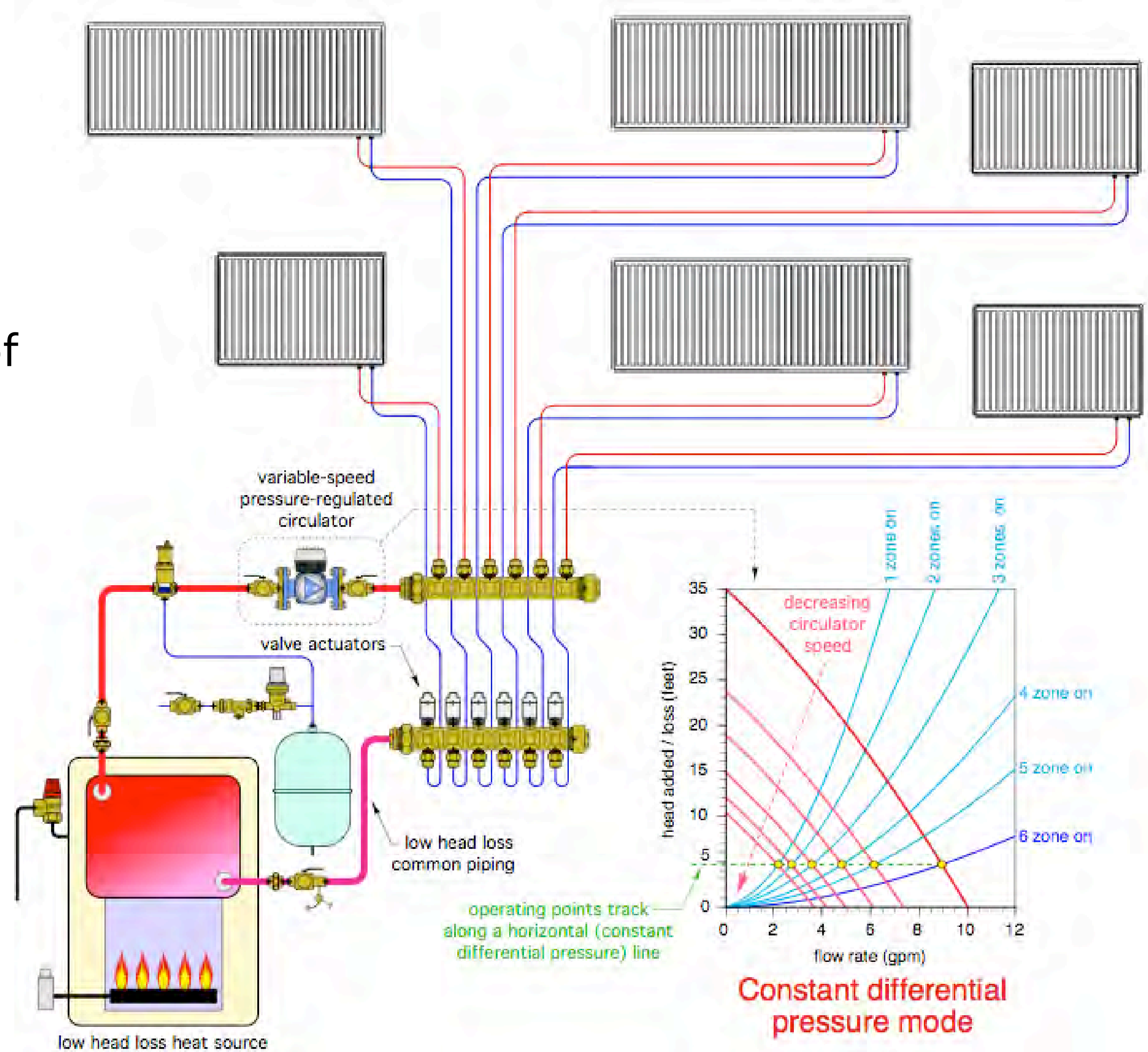
HYDRAULIC EQUILIBRIUM

Consider how hydraulic equilibrium "shifts" during the start up of the drainback solar system shown below



HYDRAULIC EQUILIBRIUM

A variable speed circulator can be controlled so that hydraulic equilibrium always occurs at the same differential pressure, regardless of the number of zones that are operating

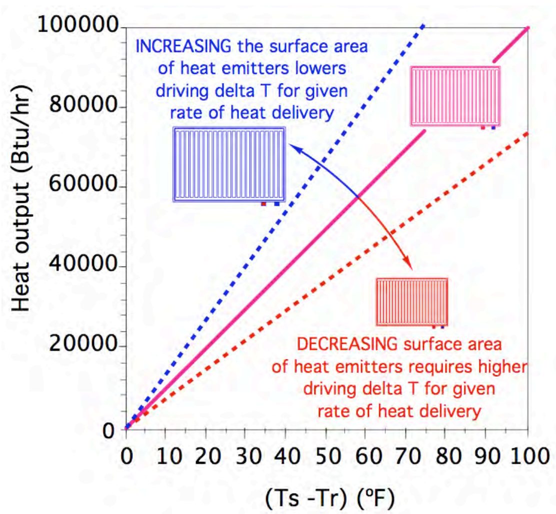


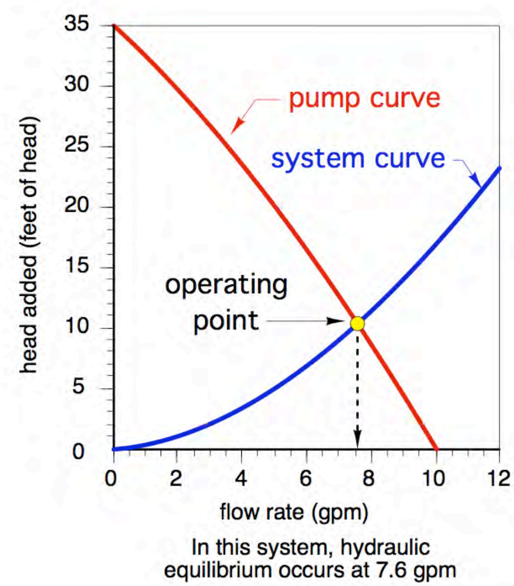
Use the concepts of THERMAL EQUILIBRIUM and HYDRAULIC EQUILIBRIUM to:

- predict performance of systems being designed

- diagnosing the performance of hydronic systems that are "not performing as expected."

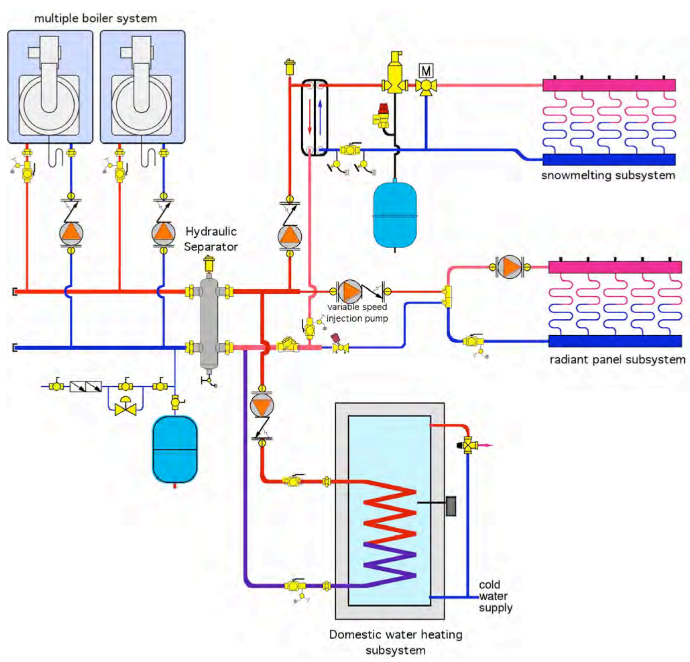
Remember, EVERY hydronic system ALWAYS seeks both of these "balanced" operating conditions.

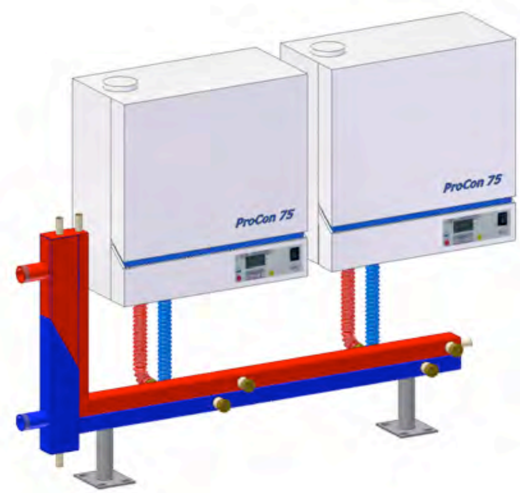


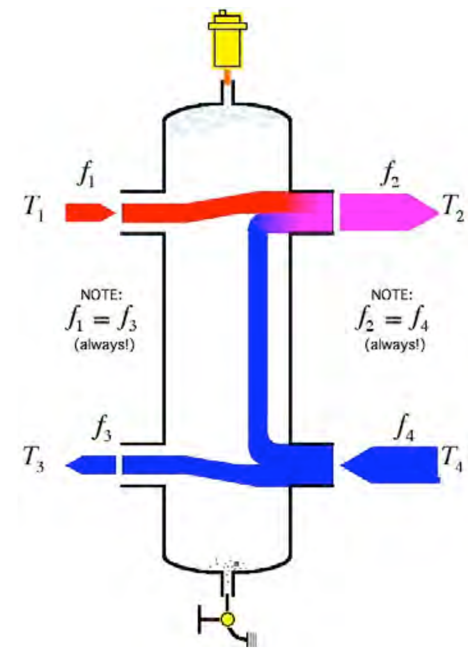


Hydraulic Separation

Beyond Primary / Secondary Piping

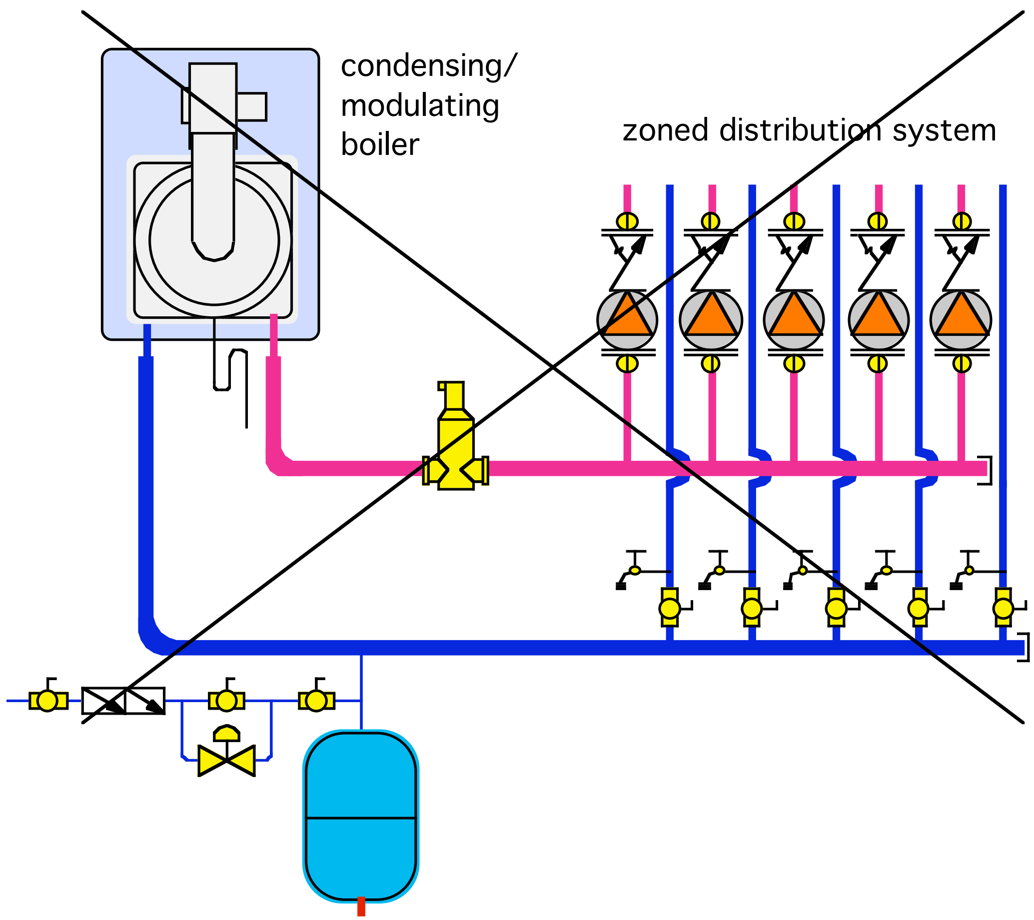






Modern compact boilers have much higher flow resistance than cast iron boilers.

If they are simply substituted for cast iron boiler problems are likely to develop, most notably interference between simultaneously operating circulators.



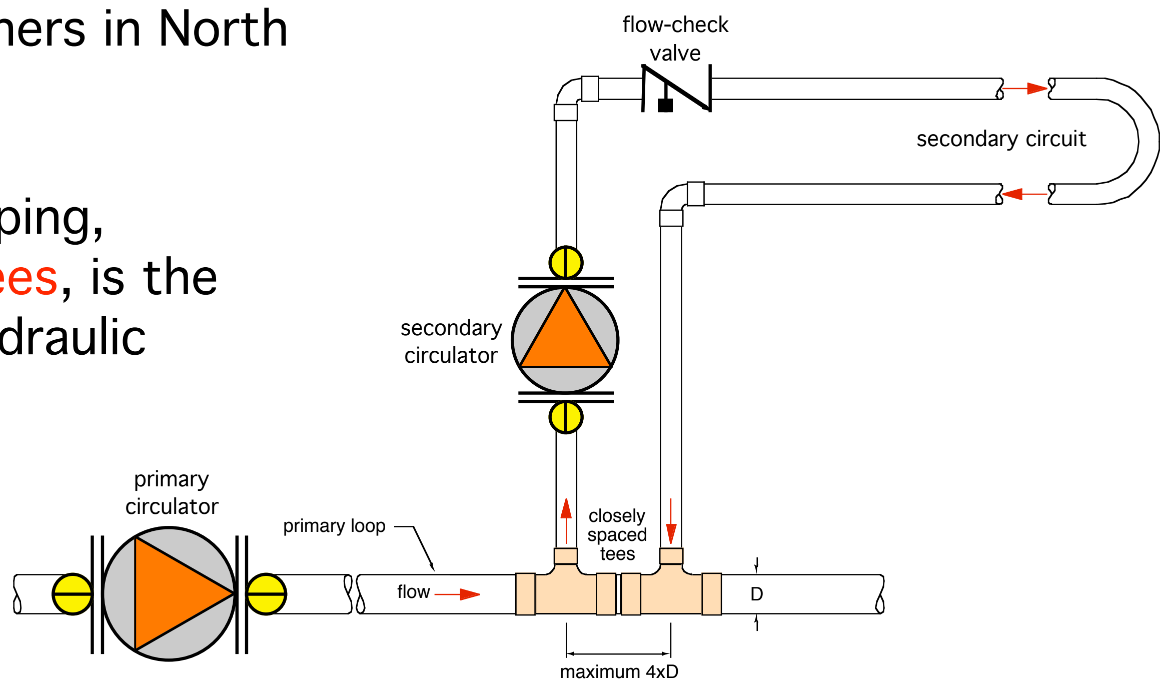
The solution to this problem is **hydraulic separation**. In short, preventing flow in one circuit from interfering with flow in another circuit.

In systems with hydraulic separation the designer can now *think of each circuit as a "stand-alone" entity:*

- Simplifying system analysis
- Preventing flow interference

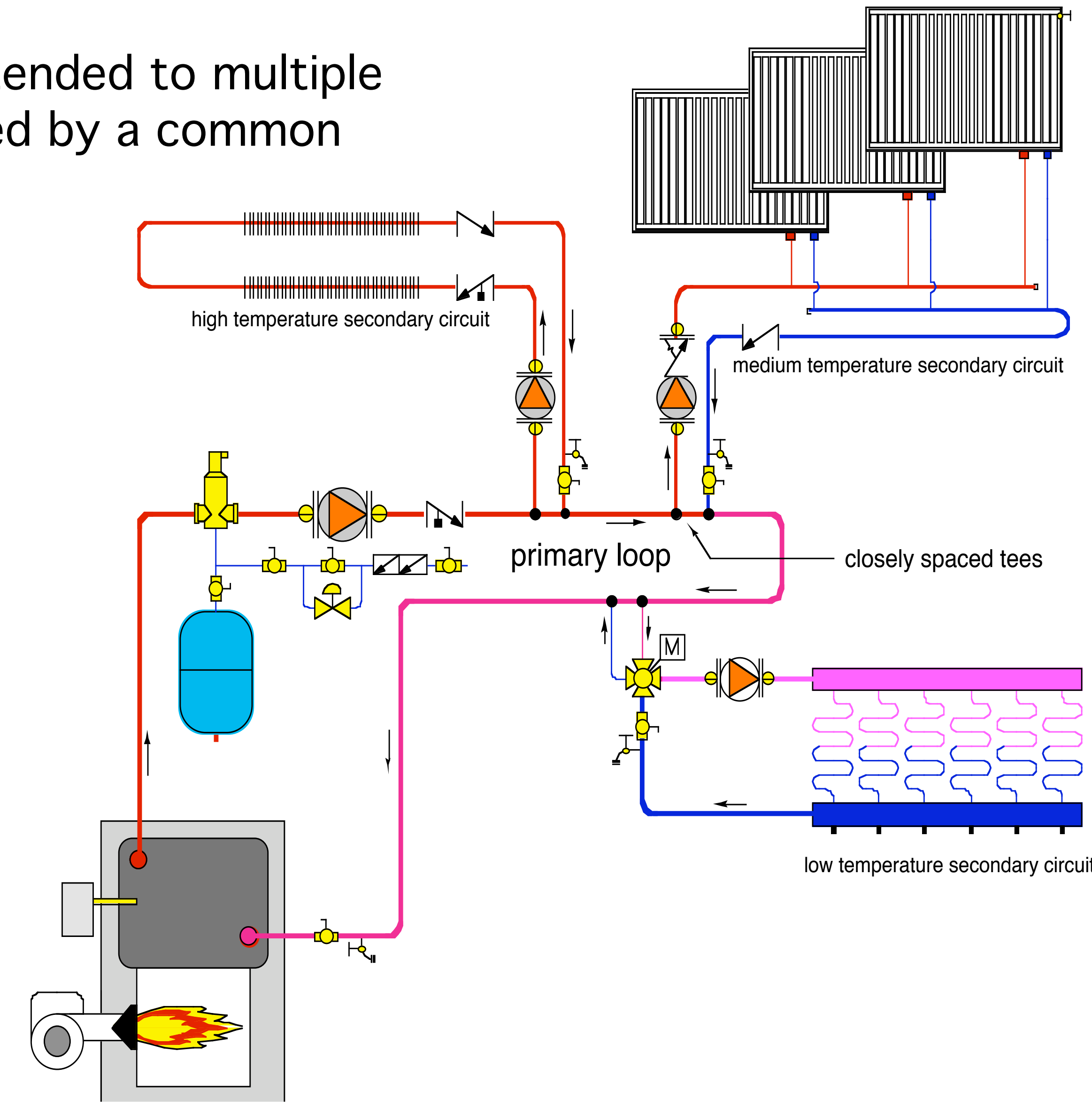
Hydraulic separation is a new term to hydronic system designers in North America.

Primary / secondary piping, using closely spaced tees, is the best known form of hydraulic separation now used in North America



The secondary circuit is “hydraulically separated” from the primary circuit by the closely spaced tees.

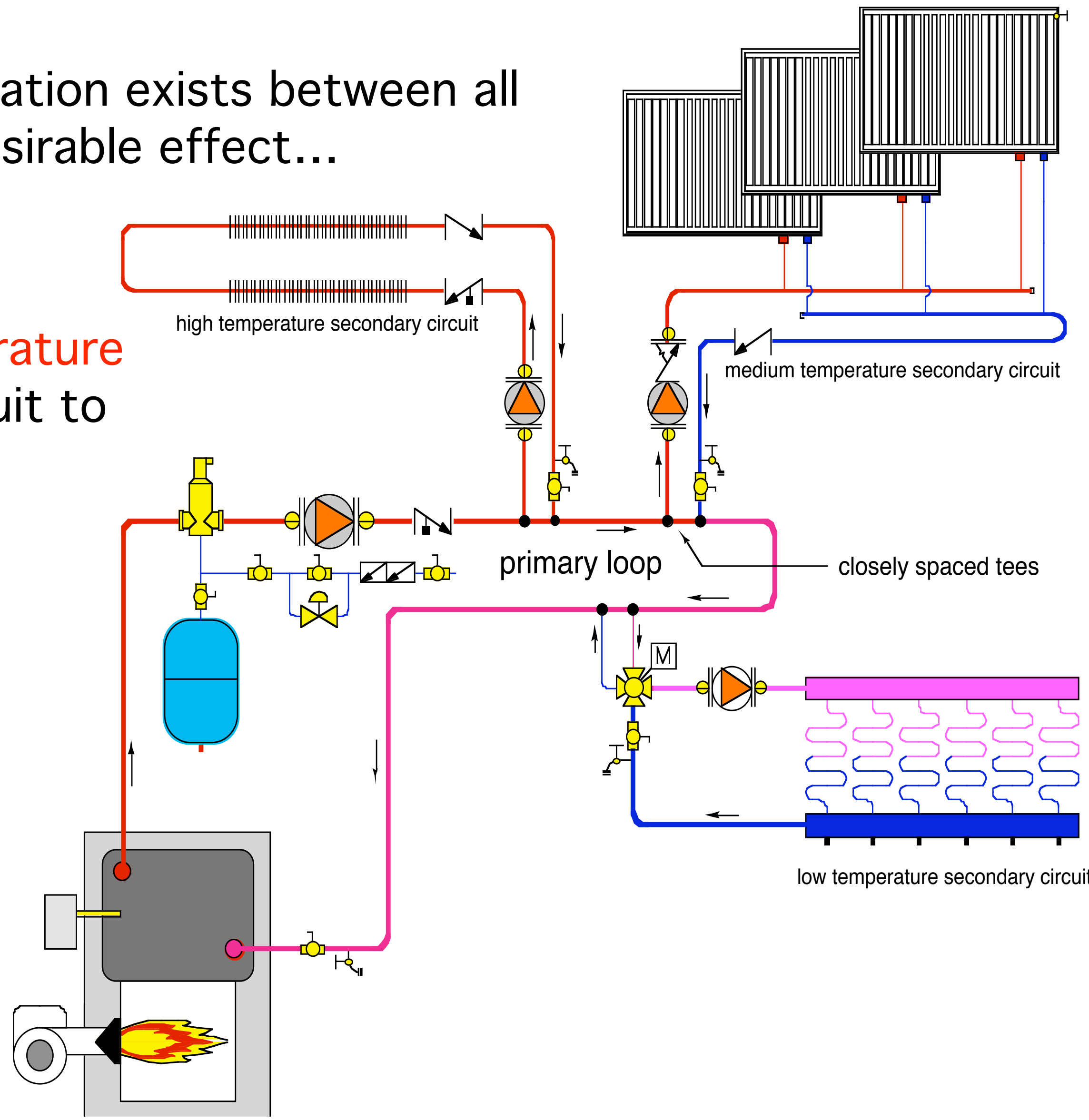
This concept can be extended to multiple secondary circuits served by a common primary loop:



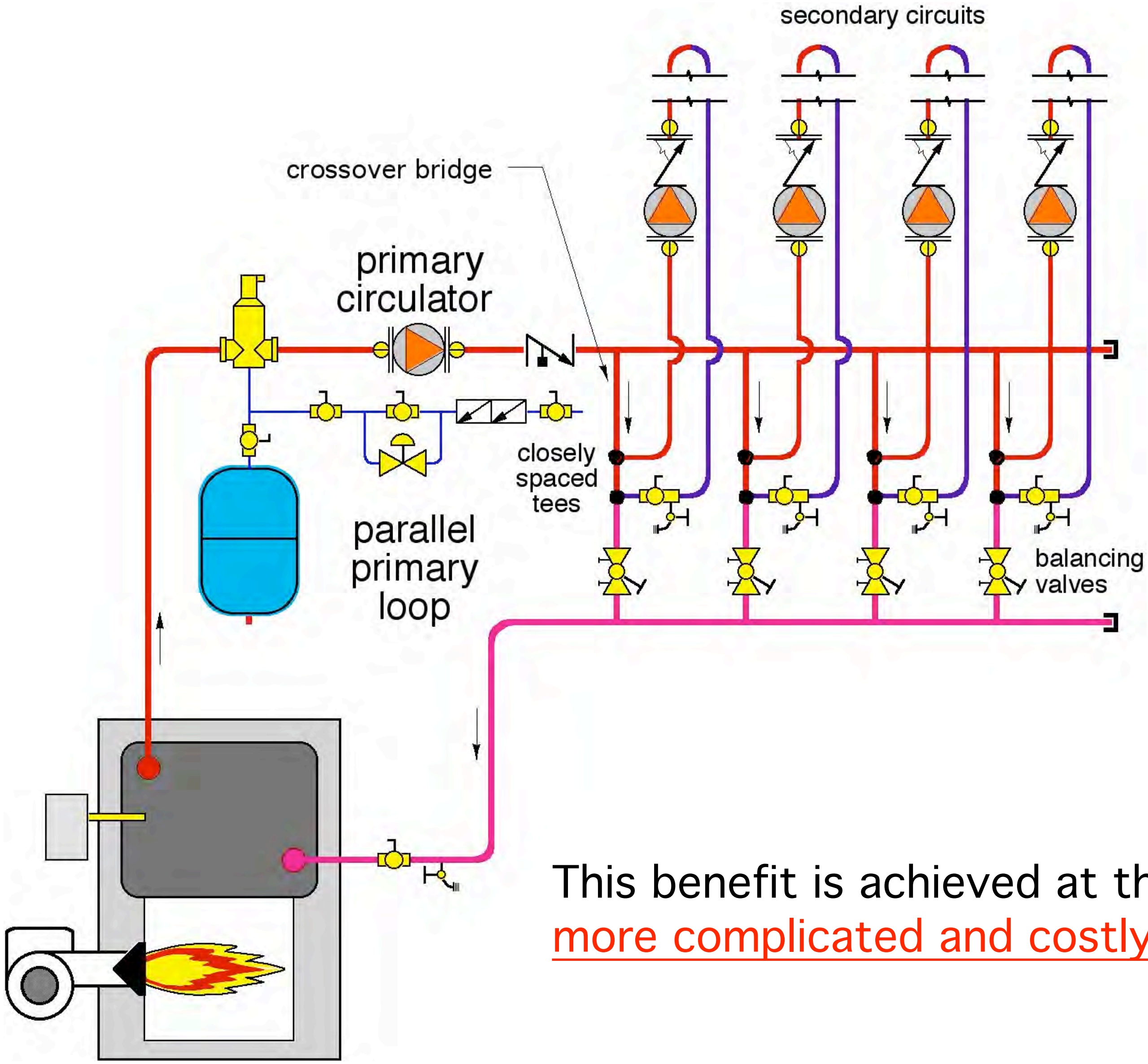
This configuration is more called a *series* primary/secondary system:

Although hydraulic separation exists between all circuits, so does an undesirable effect...

...a drop in water temperature from one secondary circuit to the next when operating simultaneously

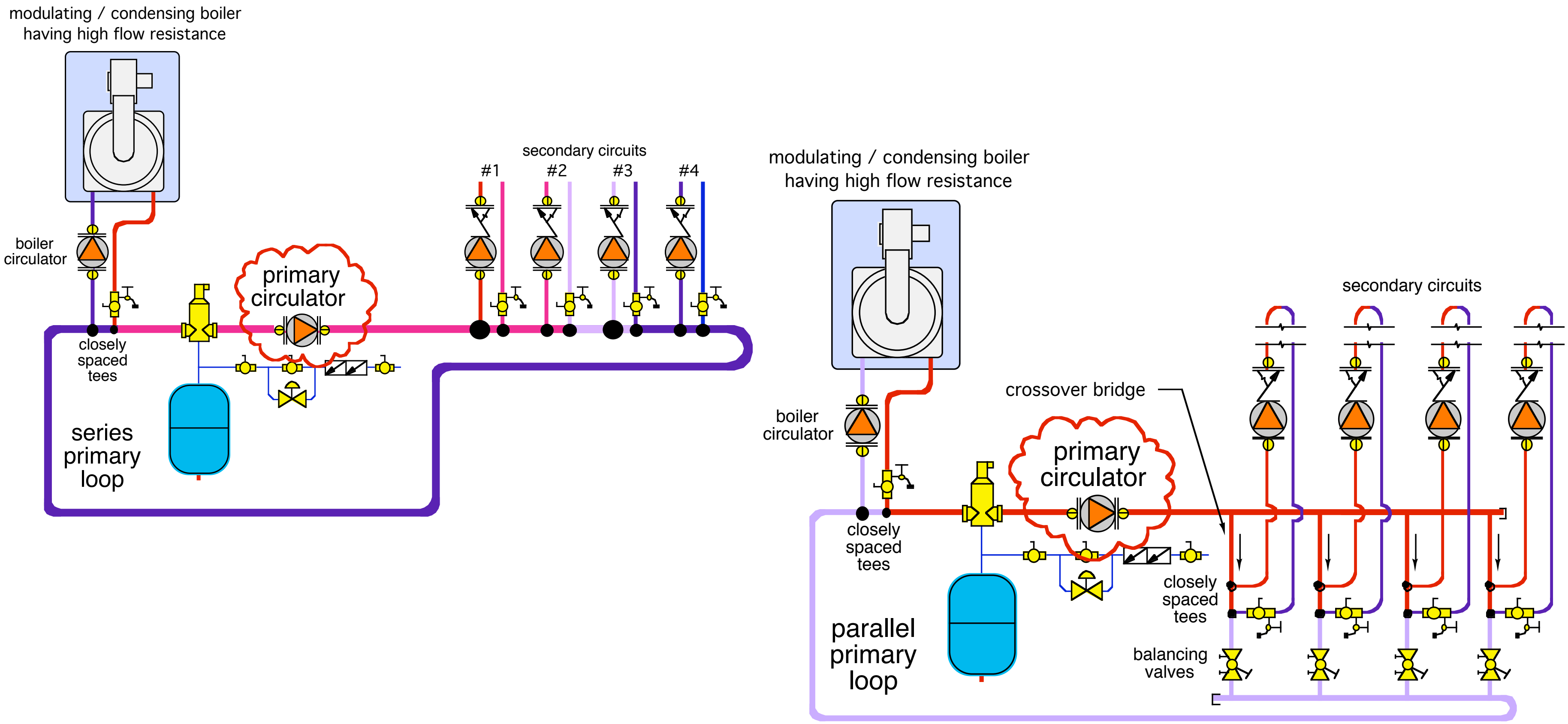


A *parallel* primary/secondary piping configuration provides the same water temperature to each secondary circuit:



This benefit is achieved at the expense of more complicated and costly piping.

In addition, both ***series*** and ***parallel*** primary/secondary systems require a primary circulator.



This adds to the installed cost of the system **AND** add hundreds, even thousands of dollars in operating cost over a typical system life.

An example of primary loop circulator operating cost:

Consider a system that supplies 500,000 Btu/hr at design load. Flow in the primary loop is 50 gpm with a corresponding head loss of 15 feet (6.35 psi pressure drop). Assume a wet rotor circulator with wire-to-water efficiency of 25 is used as the primary circulator.

The input wattage to the circulator can be estimated as follows:

$$W = \frac{0.4344 \times f \times \Delta P}{0.25} = \frac{0.4344 \times 50 \times 6.35}{0.25} = 552 watts$$

Assuming this primary circulator runs for 3000 hours per year its first year operating cost would be:

$$\text{1st year cost} = \left(\frac{3000hr}{yr}\right)\left(\frac{552w}{1}\right)\left(\frac{1kwhr}{1000whr}\right)\left(\frac{\$0.10}{kwhr}\right) = \$165.60$$

Assuming electrical cost escalates at 4% per year the total operating cost over a 20-year design life is:

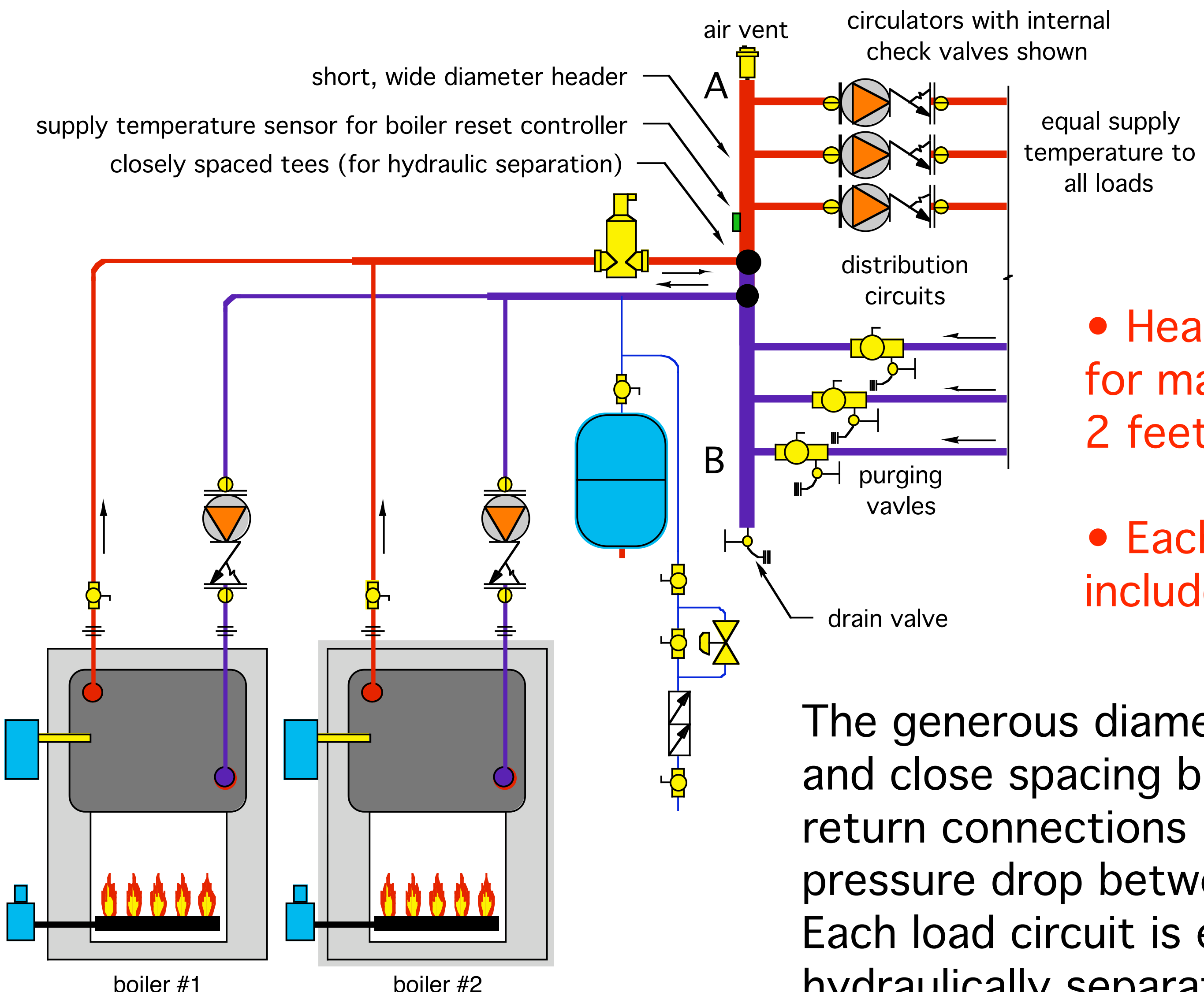
$$c_T = c_1 \times \left(\frac{(1+i)^N - 1}{i} \right) = \$165.60 \times \left(\frac{(1+0.04)^{20} - 1}{0.04} \right) = \$4,931$$

This, combined with eliminating the multi-hundred dollar installation cost of the primary circulator obviously results in significant savings.

Beyond Primary / Secondary Piping...

How is it possible to achieve the **benefits** of hydraulic separation and equal supply temperatures without the **complexities** and **costs** of a parallel system and primary circulator?

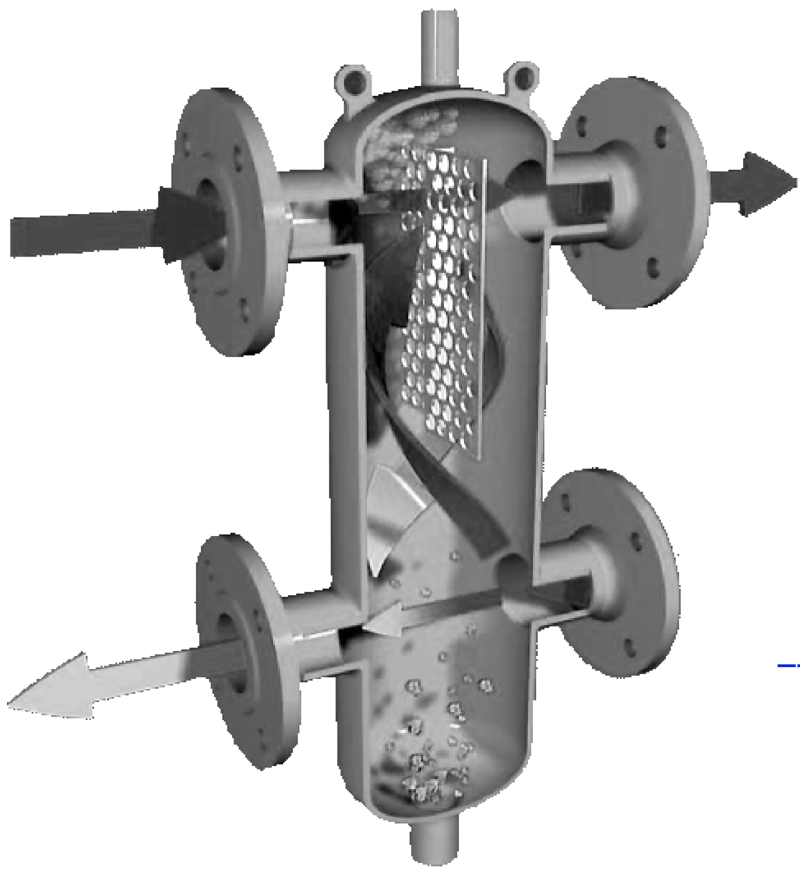
Some systems begin and end individual load circuits in the mechanical room:

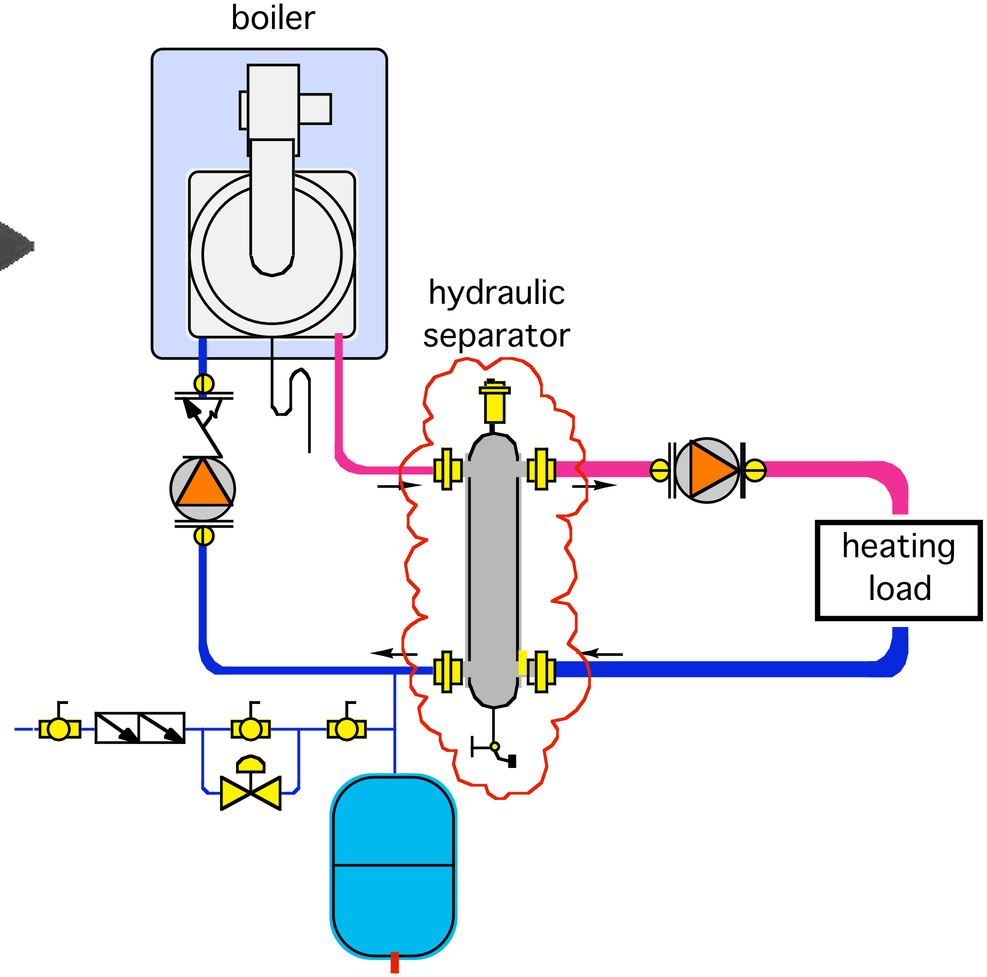


- Header should be sized for max. flow velocity of 2 feet per second
- Each circuit must include a check valve.

The generous diameter of the header and close spacing between supply and return connections results in a low pressure drop between points A and B. Each load circuit is effectively hydraulically separated from the others.

Another option is a specialized component called a ***hydraulic separator*** between the boiler and the load circuit:

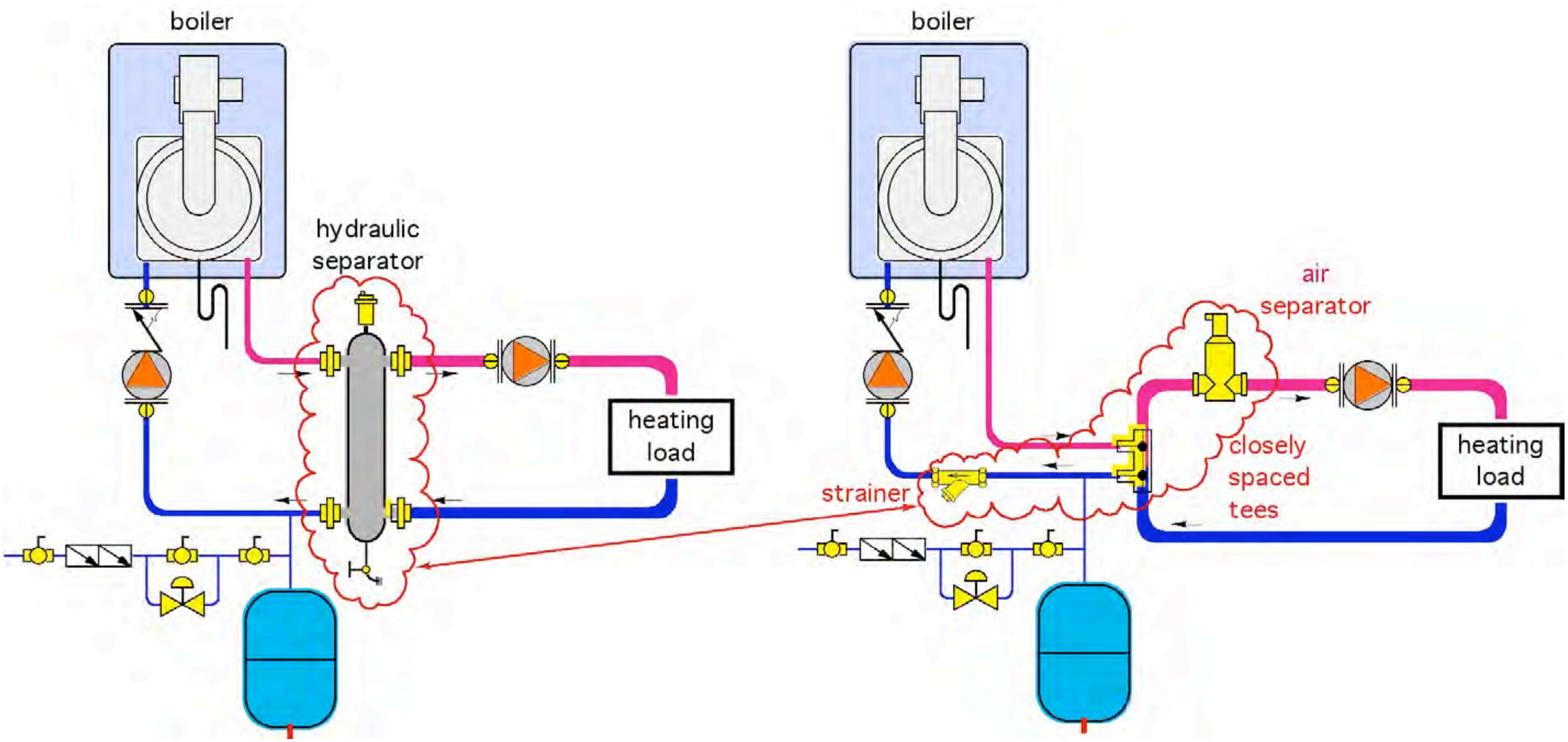




The low vertical velocity inside the separator produces minimal pressure drop top to bottom and side to side. This results in hydraulic separation between the boiler circuits and load circuits.

Some hydraulic separators also provide air separation and sediment separation.

To achieve these functions in a system using closely spaced tees additional components are required:

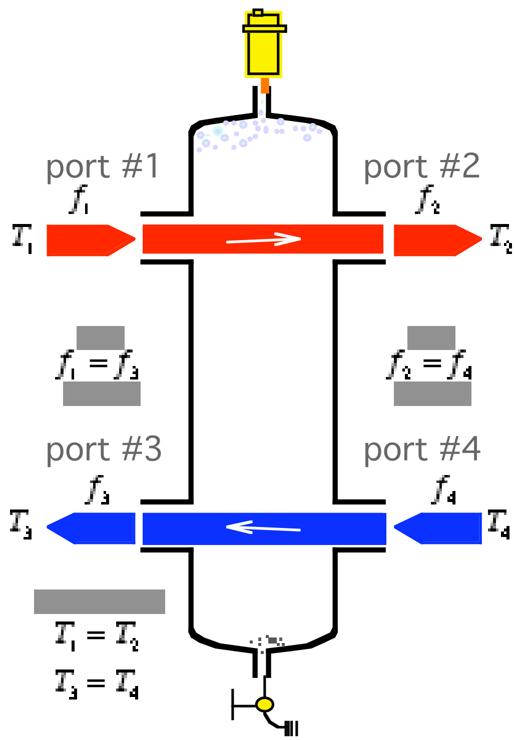


As the flow rates of the boiler circuit and distribution system change there are three possible scenarios:

- Flow in the distribution system is **equal** to the flow in the boiler circuit.
- Flow in the distribution system is **greater than** flow in the boiler circuit.
- Flow in the distribution system is **less than flow** in the boiler circuit.

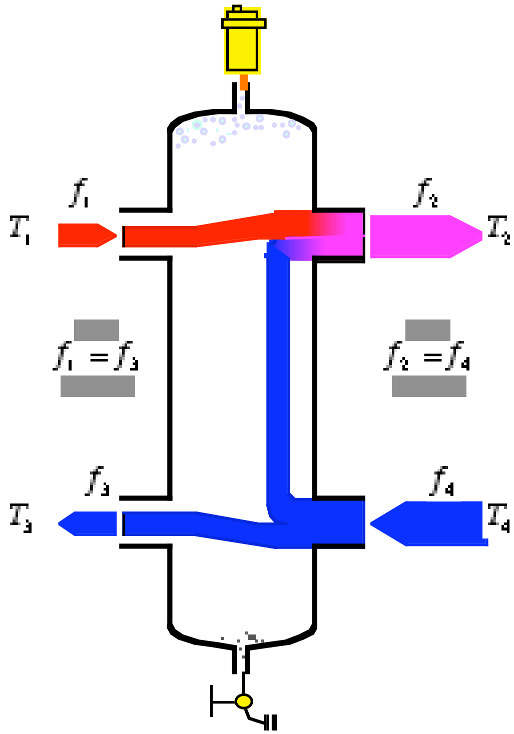
Each case is governed by basic thermodynamic...

Case #1: Distribution flow equals boiler flow:



Very little mixing occurs because the flows are balanced.

Case #2: Distribution flow is greater than boiler flow:



The mixed temperature (T_2) supplied to the distribution system can be calculated with:

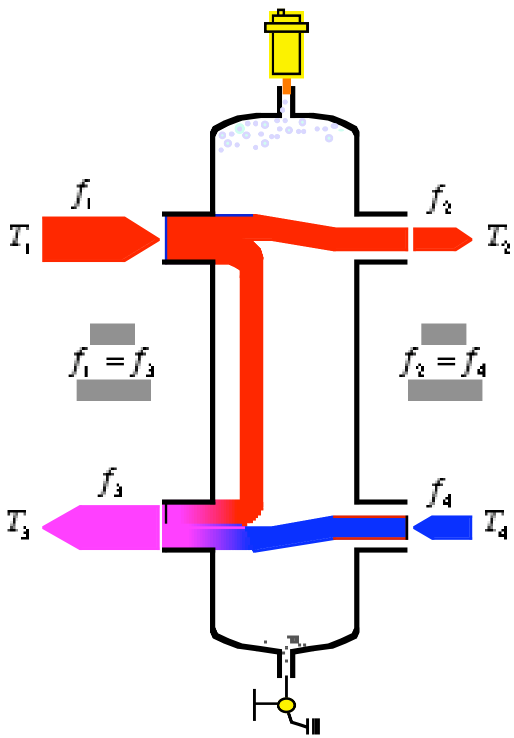
$$T_2 = \left(\frac{(f_4 - f_1)T_4 + (f_1)T_1}{f_4} \right)$$

Where:
f4 = flow rate returning from distribution system (gpm)
f1 = flow rate entering from boiler(s) (gpm)
T4 = temperature of fluid returning from distribution system (°F)
T1 = temperature of fluid entering from boiler (°F)

Mixing occurs within the hydraulic separator.

Case #3: Distribution flow is less than boiler flow:

Heat output is temporarily higher than current system load.



Heat is being injected faster than the load is removing heat.

The temperature returning to the boiler (T_3) can be calculated with:

$$T_2 = \left(\frac{(f_4 - f_1)T_4 + (f_1)T_1}{f_4} \right)$$

Where:
T3 = temperature of fluid returned to boiler(s) (°F)
f1 = flow rate entering from boiler(s) (gpm)
f2, f4 = flow rate of distribution system (gpm)
T1 = temperature of fluid entering from boiler (°F)
T4 = temperature of fluid returning from distribution system (°F)

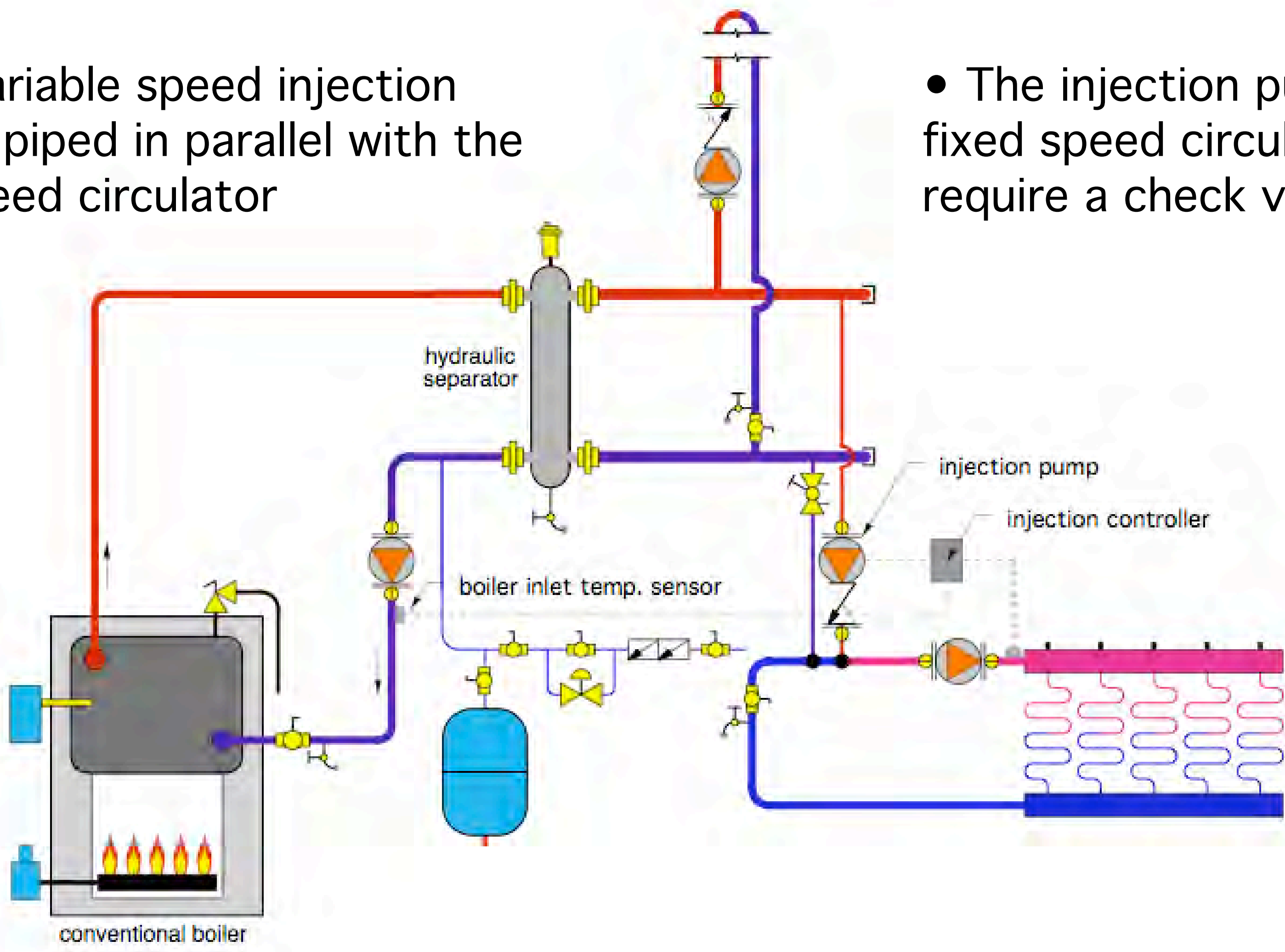
Mixing occurs within the hydraulic separator.

Use of a hydraulic separator alone does not prevent flue gas condensation under all circumstances.

To ensure such protection automatic mixing devices can be installed:

- The variable speed injection pump in piped in parallel with the fixed speed circulator

- The injection pump and fixed speed circulator both require a check valve



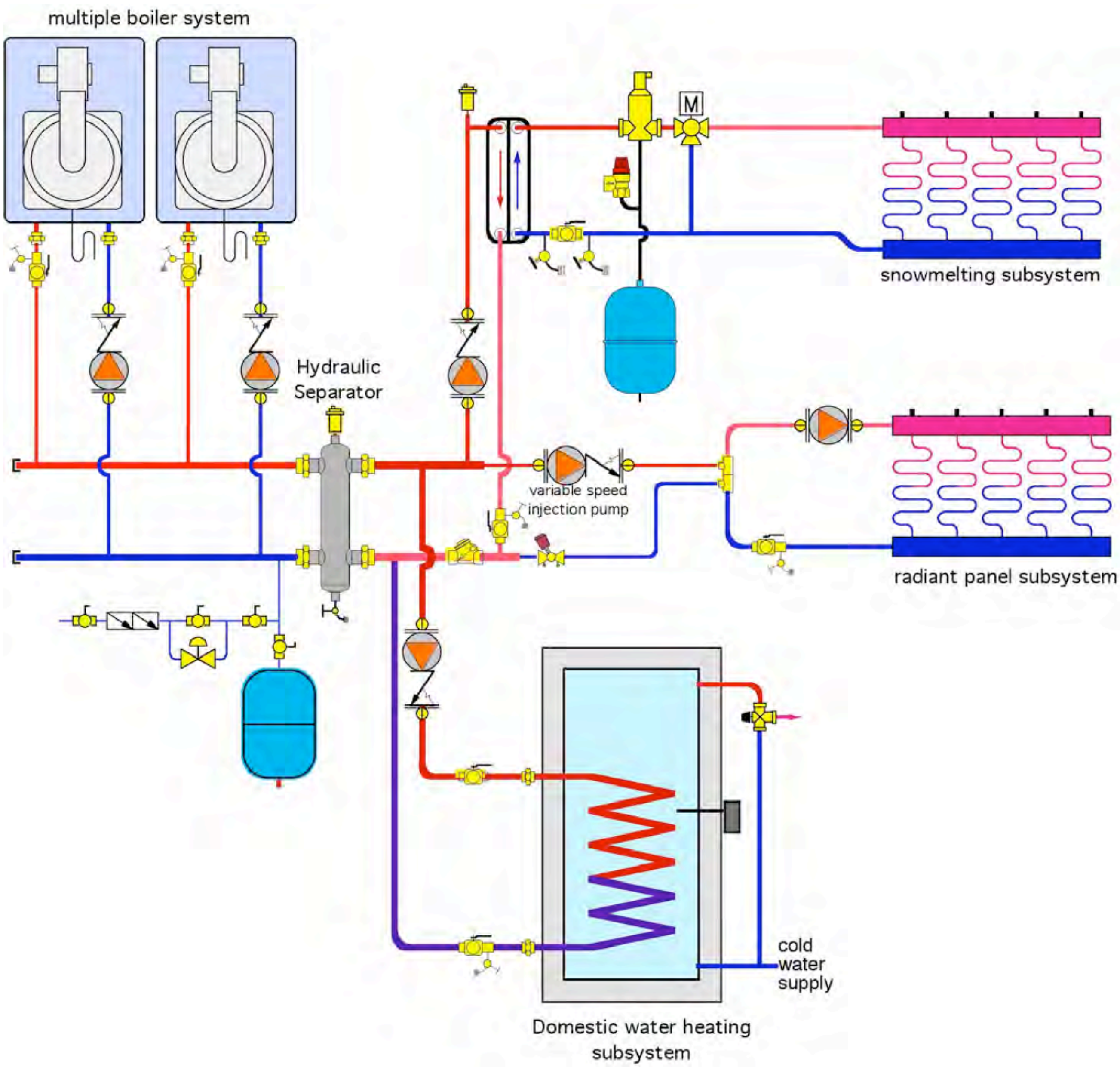
Sizing & Application:

Hydraulic separators must be properly sized to provide proper hydraulic, air, and dirt separation. Excessively high flow rates will impede these functions.

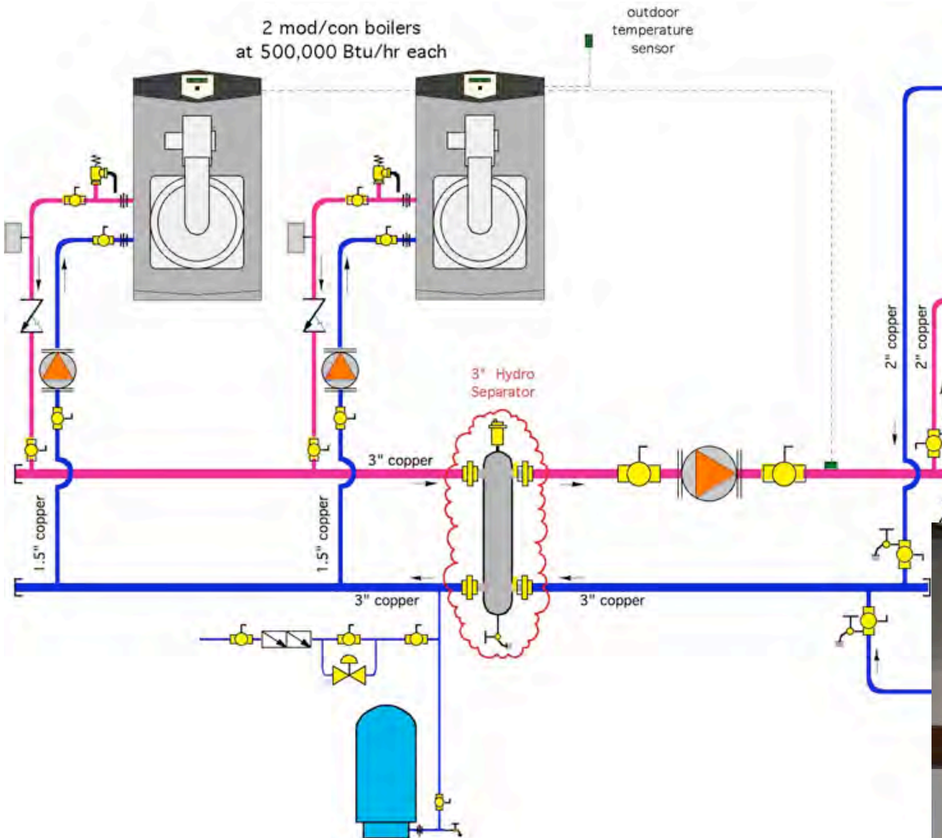
Pipe size of hydraulic separator	1”	1.25”	1.5”	2”	2.5”	3”	4”	6”
Max flow rate (GPM)	11	18	26	40	80	124	247	485

The header piping connecting to the distribution side of the Hydro Separator should be sized for a flow of 4 feet per second or less under maximum flow rate conditions.

Hydraulic separators are an ideal way to interface multiple loads to a Multiple boiler system.



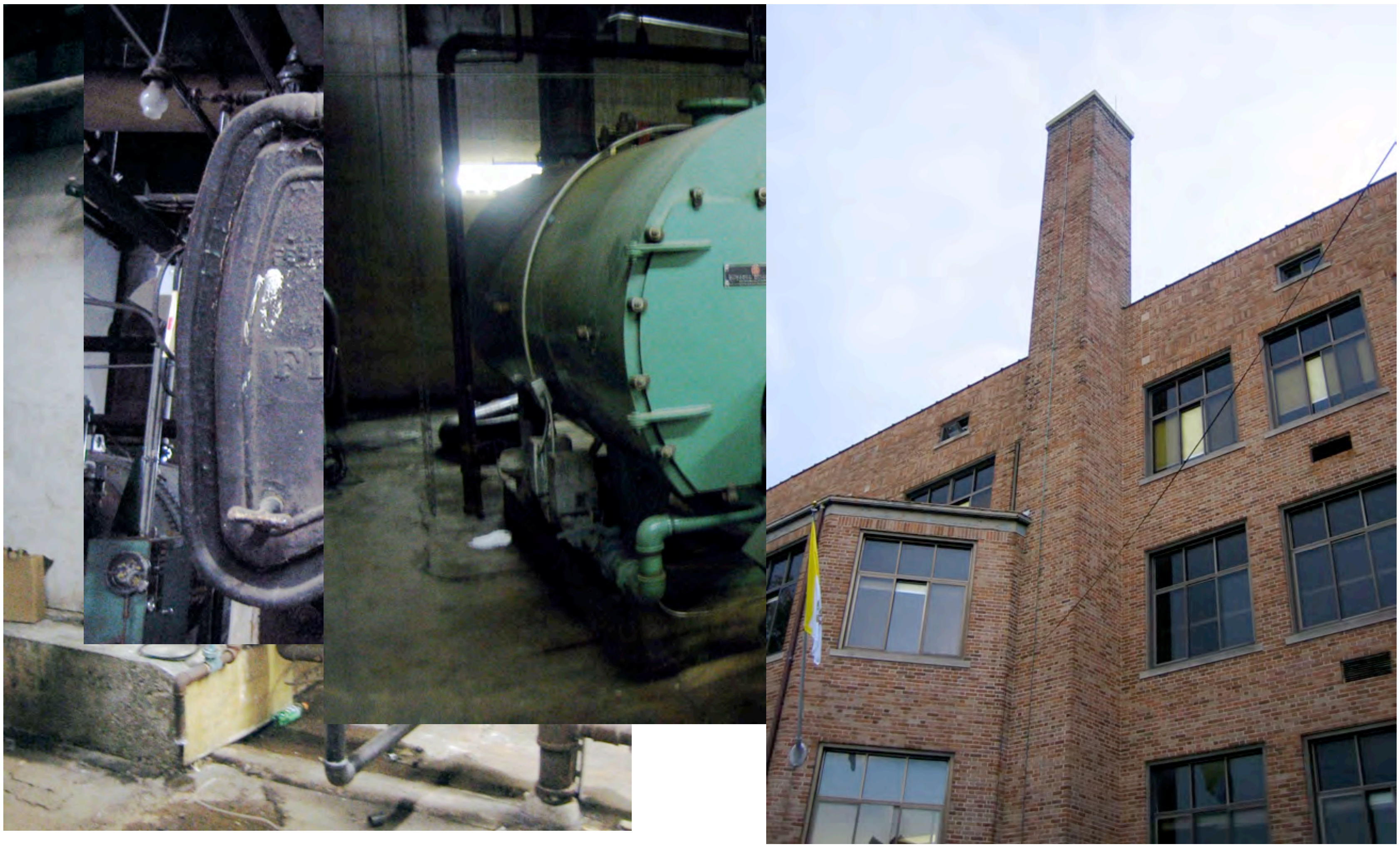
Example of Hydro Separator Installation
Magna Steel Corporation - Connecticut



Photos courtesy of Peter Gasperini - Northeast Radiant

Example of Hydro Separator Installation in Old System:

<u>Because hydraulic separators remove sediment fromsystems they're ideal for applications where new boilers are retrofit to old distribution systems.</u>



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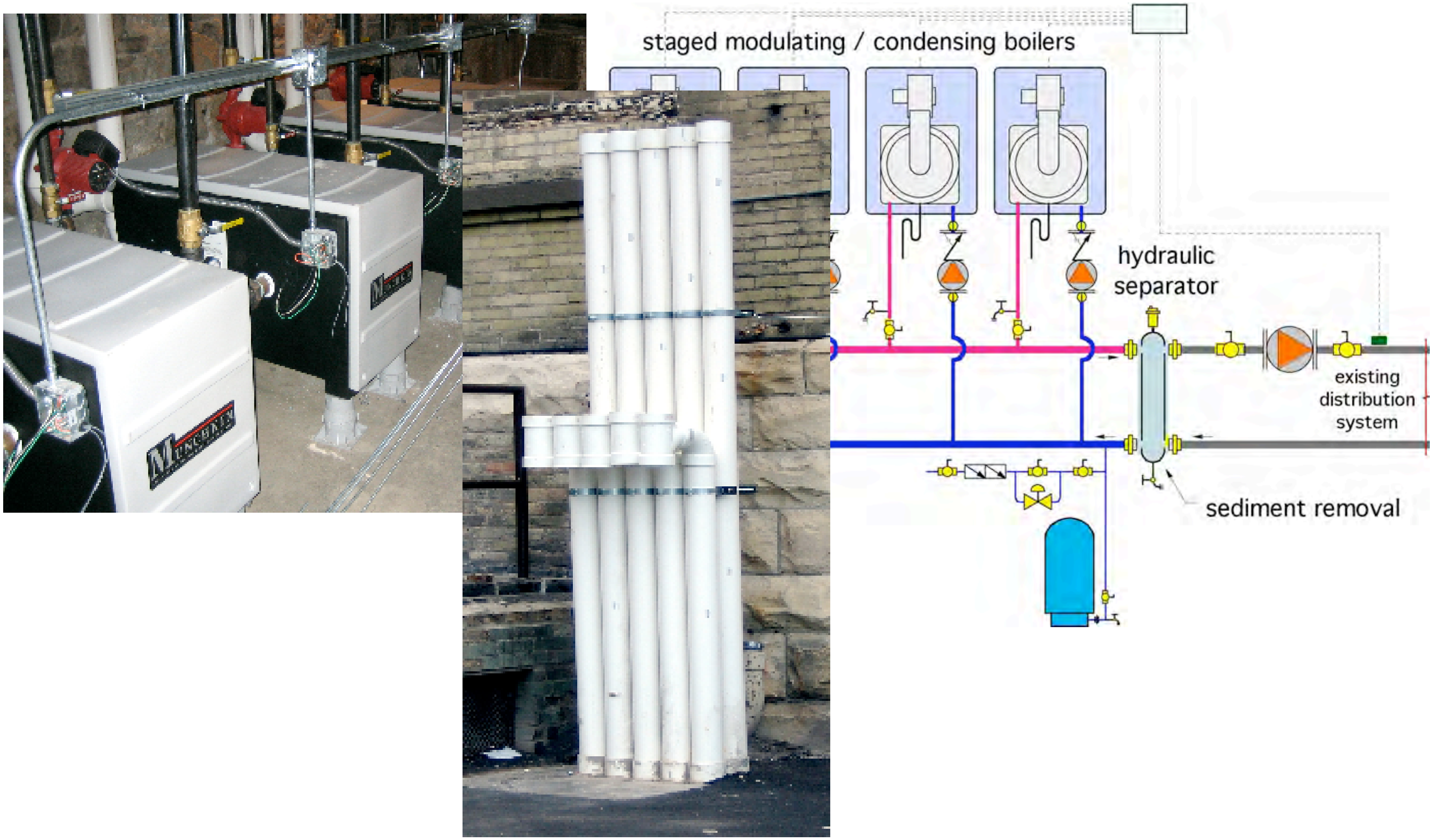
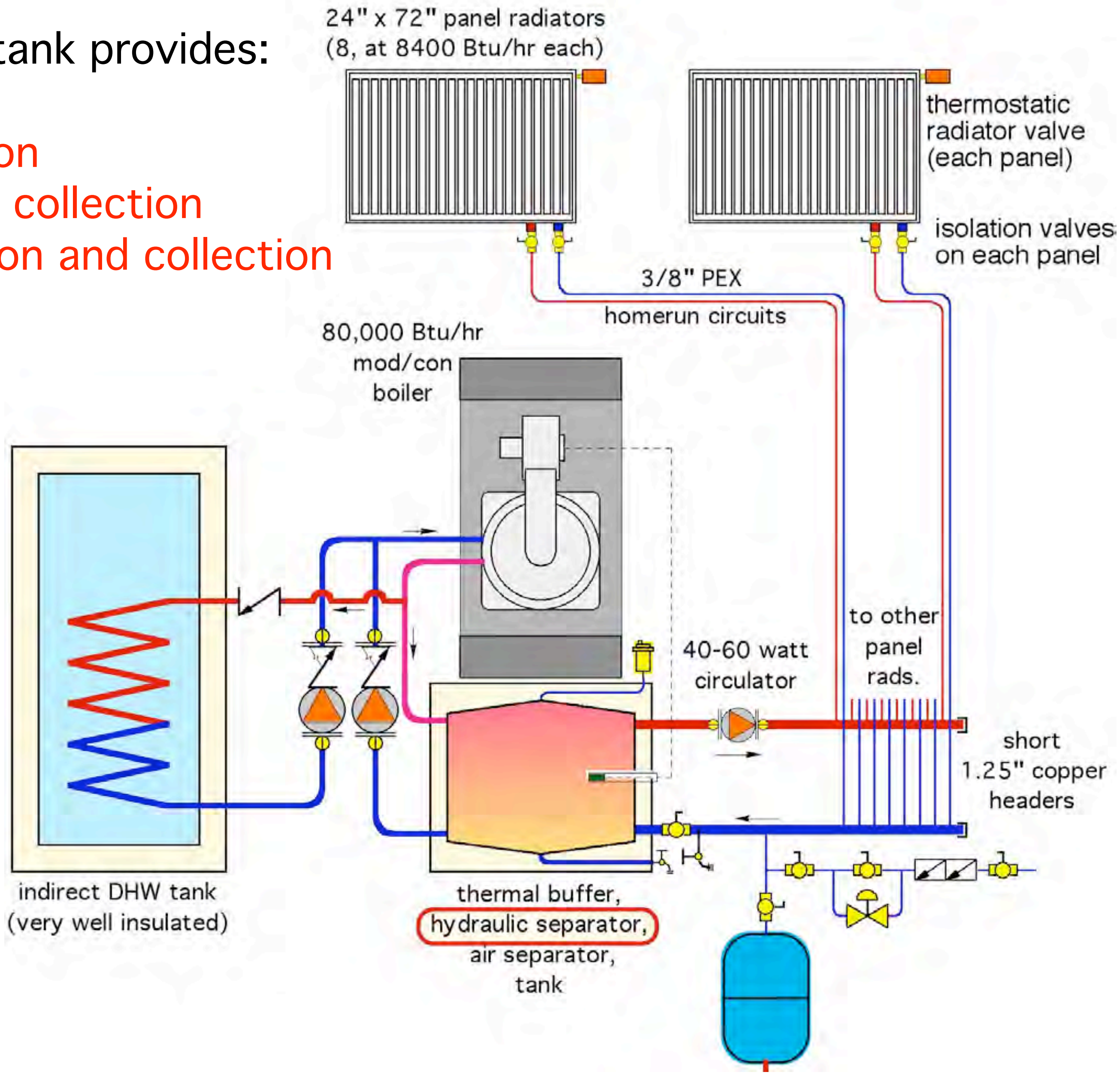


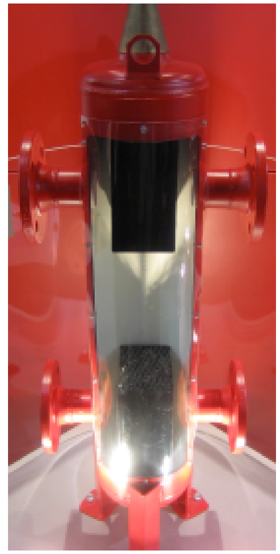
Hydraulic Separation in “Micro-load” systems:

The small insulated tank provides:

- Thermal buffering
- Hydraulic separation
- Air separation and collection
- Sediment separation and collection



Hydraulic Separators spotted at ISH 2007 – Frankfurt, Germany



Hydraulic Separators now available in North America

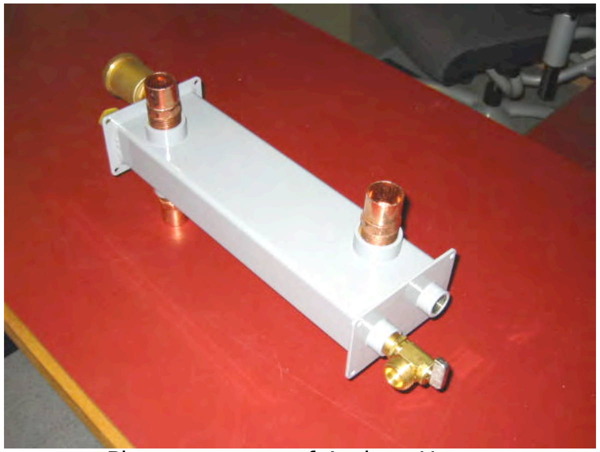


Photo courtesy of Andrew Hagen

Radiant Engineering

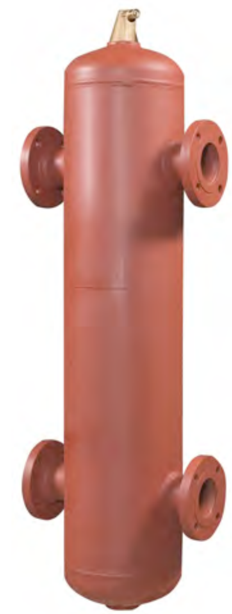
Photo courtesy of Moses Fischman

Caleffi

Bell & Gossett

Sinus North America

Precision Hydronic Products



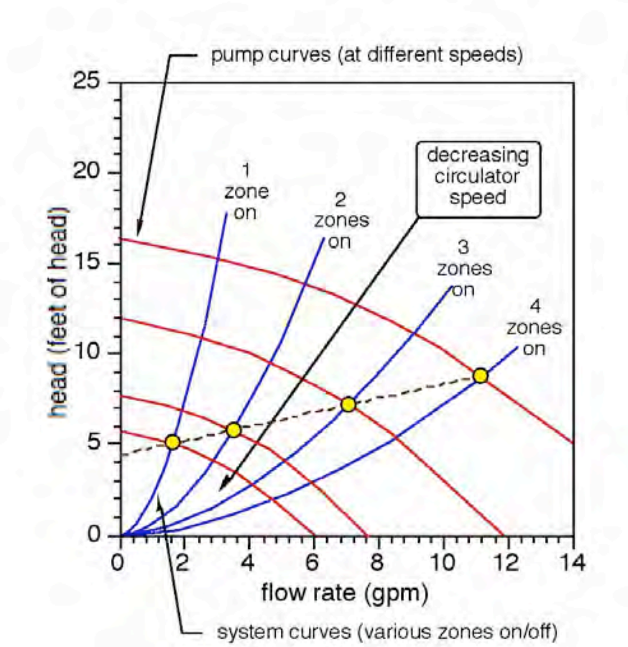
Taco

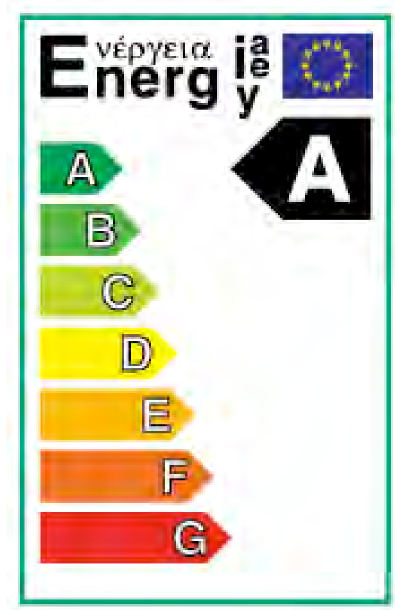
Summary:

- Hydraulic separation, when properly executed, allows multiple, independently controlled circulators to coexist in a system without interference.

- These devices eliminate the need for a primary loop circulator, which reduces system installation and operating cost.

Reducing Pumping Power:
A Deeper Shade of "Green"





The North American Hydronics market now has several "high efficiency" boiler lines

In the right applications these boilers have efficiencies in the 95+ range:

It may appear there isn't room for improving the efficiency of hydronic systems...

At least that's what people who focus *solely* on the boiler might conclude

For decades our industry has focused on incremental improvements in the thermal efficiency of heat sources.

At the same time we've largely ignored the hydraulic efficiency of the distribution system.

Increasing energy costs present a great opportunity to market hydronics based on using far less "distribution energy" relative to forced air systems.

The present situation:

What draws your attention in the photo below?

Go ahead, count them...

Did you get 21 circulators?

These are not all 80 watt zone circulators.

Those on the wall are about 240 watts each. The larger circulators may be several hundred watts each.

If all these circulators operate simultaneously (at design load) the electrical demand will be in excess of 5000 watts.

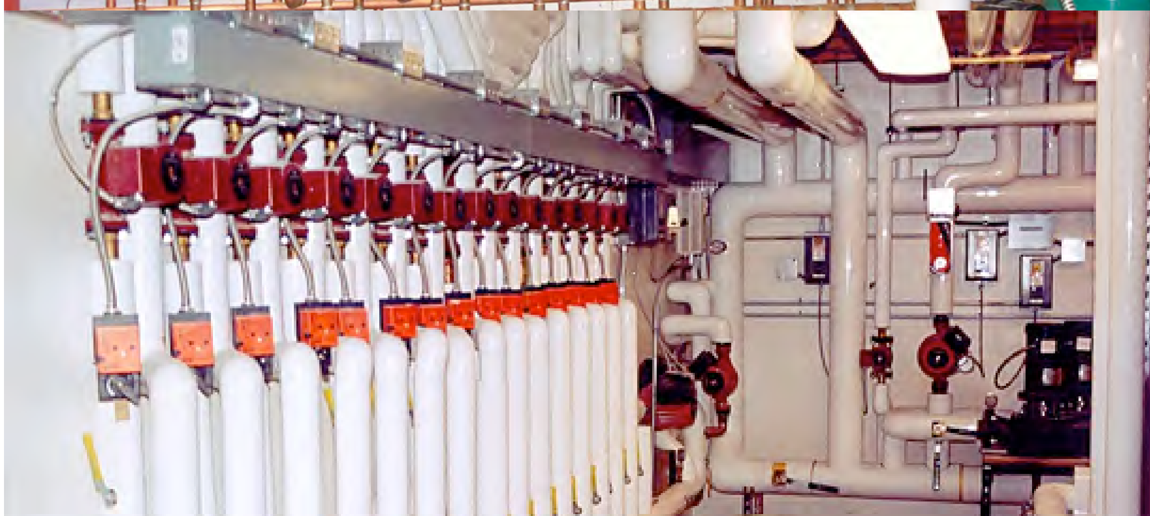
That's the heating equivalent of about 17,000 Btu/hr!

Here’s another example...

If you run out of wall space consider this installation technique...

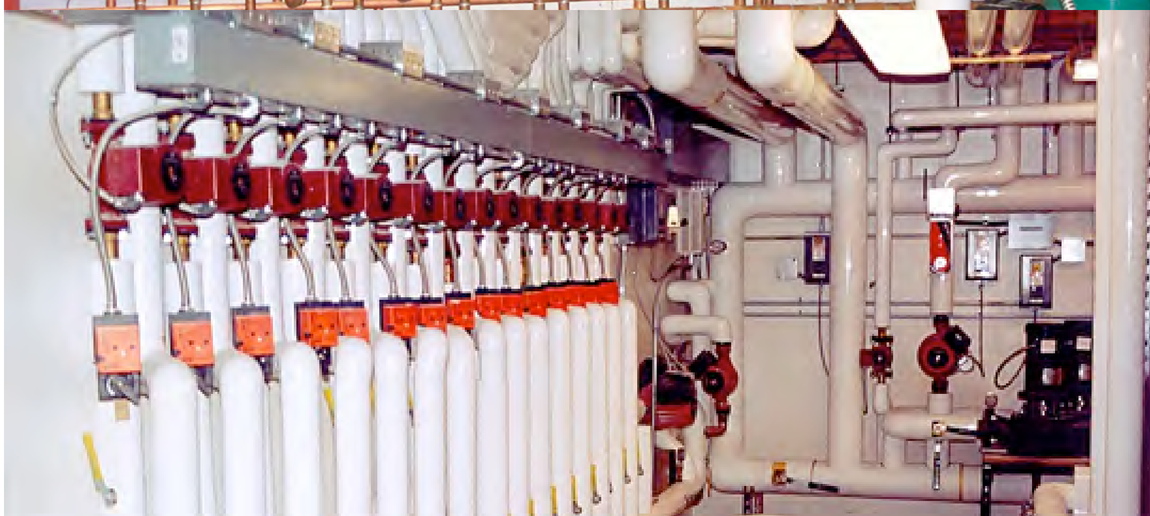
Notice the installer left provisions for additional circulators.

So what can you conclude from these photos?



Perhaps that it's <u>GOOD</u> to be in the circulator business these days!

You might also conclude that…



The North American hydronics industry tends to "**overpump**" its systems!

Although as an industry we pride ourselves on ultra high efficiency and "eco-friendly" heat sources, we...

Must look beyond the efficiency of just the heat source.

We need to look at the overall ***system*** efficiency.

This includes the efficiency of converting fuel in heated water AND *the efficiency of distributing that water throughout the building.*

There is considerable room for improvement.

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.

Room for Improvement...

A few years ago I inspected a malfunctioning hydronic heating system in a 10,000 square foot house that contained *40 circulators*.

Assume the *average* circulator wattage is 90 watts.

The design heating load is 400,000 Btu/hr

The distribution efficiency of this system at design load is:

$$\text{distribution efficiency} = \frac{400{,}000 \text{ Btu/hr}}{40 \times (90 \text{ watts})} = 111 \ \frac{\text{Btu/hr}}{\text{watt}}$$

Not much better than the previous forced air system at 94 Btu/hr/watt

Water Watts...

It's hard to say if the wattage of past or current generation circulators is "where it needs to be" without knowing the *mechanical* power needed to move fluid through a specific circuit.

$$w_m = 0.4344 \times f \times \Delta P$$

Where:
W_m = mechanical power required to maintain flow in circuit (watts)
f= flow rate in circuit (gpm)
ΔP = pressure drop along circuit (psi)
0.4344 = units conversion factor

Example: How much mechanical power is necessary to sustain a flow of 180 ºF water flows at 5 gpm through a circuit of 3/4" copper tubing having an equivalent length of 200 feet?

Solution: The pressure drop associated with this head loss is 3.83 psi.

Putting these numbers into the formula yields:

$$w_m = 0.4344 \times f \times \Delta P = 0.4344 \times 5 \times 3.83 = 8.3 watts$$

That's quite a bit lower than the electrical wattage of even the smallest currently-available circulator. Why?

Because it's only the **mechanical** wattage required (power dissipation by the fluid) - not the electrical **input** wattage to the circulator's motor.

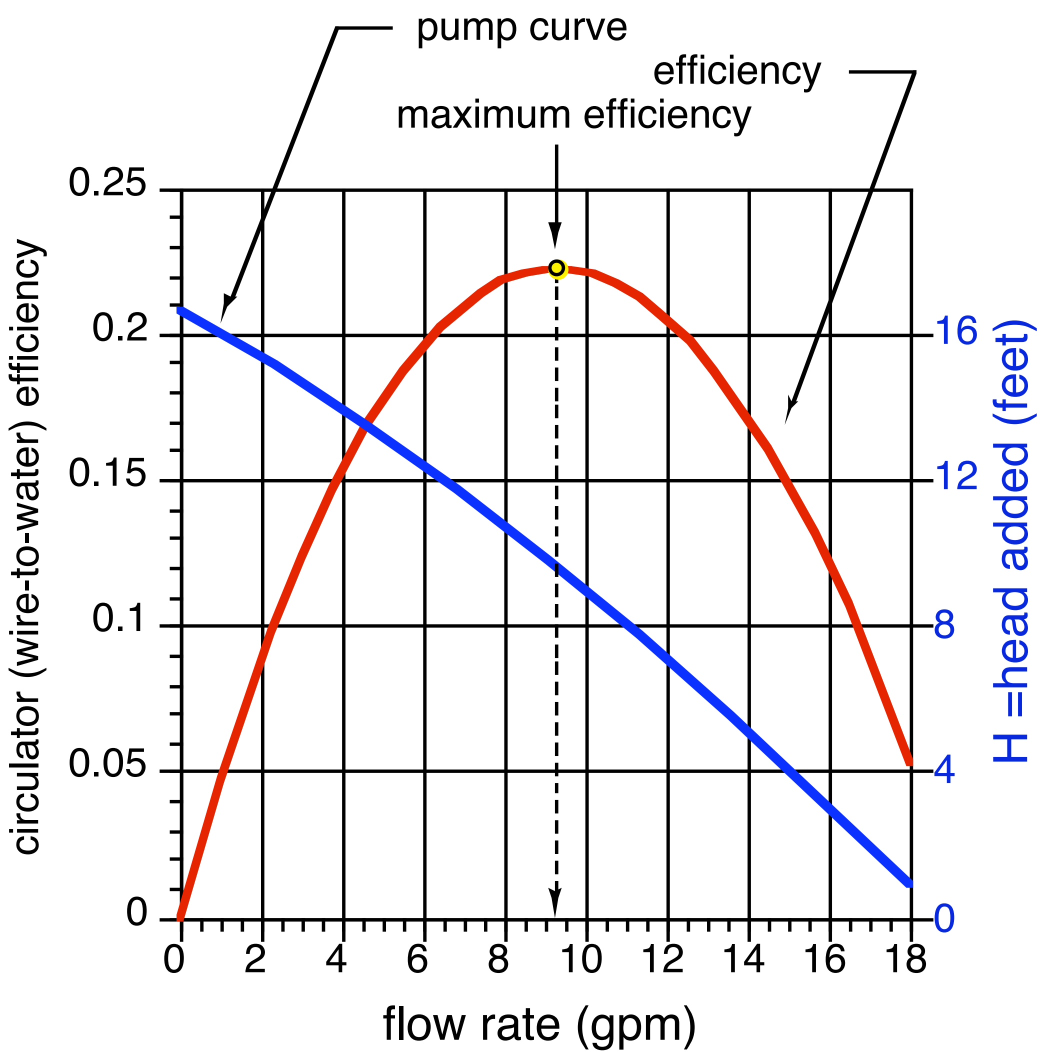
The ratio of the *mechanical wattage* the impeller imparts to the water divided by the *electrical input wattage* to operate the motor is called wire-to-water efficiency.

$$n_{w/w} = \frac{w_m}{w_e}$$

Where:

$n_{w/w}$ = wire-to-water efficiency of the circulator (decimal %)
w_m = mechanical power transferred to water by impeller (watts)
w_e = electrical power input to motor (watts)

If you take operating data for a typical 1/25 hp fixed-speed wet rotor circulator and plug it into this formula the efficiency curve looks as follows:



The electrical wattage needed by the circulator is:

$$w_e = \frac{0.4344 \times f \times \Delta P}{n_{w/w}}$$

A current-generation wet-rotor circulator has a maximum wire-to-water efficiency in the range of 25 percent. If we put the data from previous example into this formula we get the electrical wattage required to maintain flow in the circuit.

$$w_e = \frac{0.4344 \times f \times \Delta P}{n_{w/w}} = \frac{0.4344 \times 5 \times 3.83}{0.25} = 33.2 watts$$

Consider that a flow of 5 gpm in a circuit with a 20 ºF temperature drop is moving about 50,000 Btu/hr, and the electrical power to "run the conveyor belt" according to the last calculation is 33.2 watts. The distribution efficiency of such a circuit is:

$$n_d = \frac{Q}{w_e} = \frac{50,000\, Btu/hr}{33.2 watt} = 1506 \frac{Btu/hr}{watt}$$

Compare this to a 4-ton rated geothermal water-to-air heat pump delivering 48,000 Btu/hr using a blower operating on 1080 watts. The distribution efficiency of this delivery system is:

$$n_d = \frac{Q}{w_e} = \frac{48,000\, Btu/hr}{1080 watt} = 44.4 \frac{Btu/hr}{watt}$$

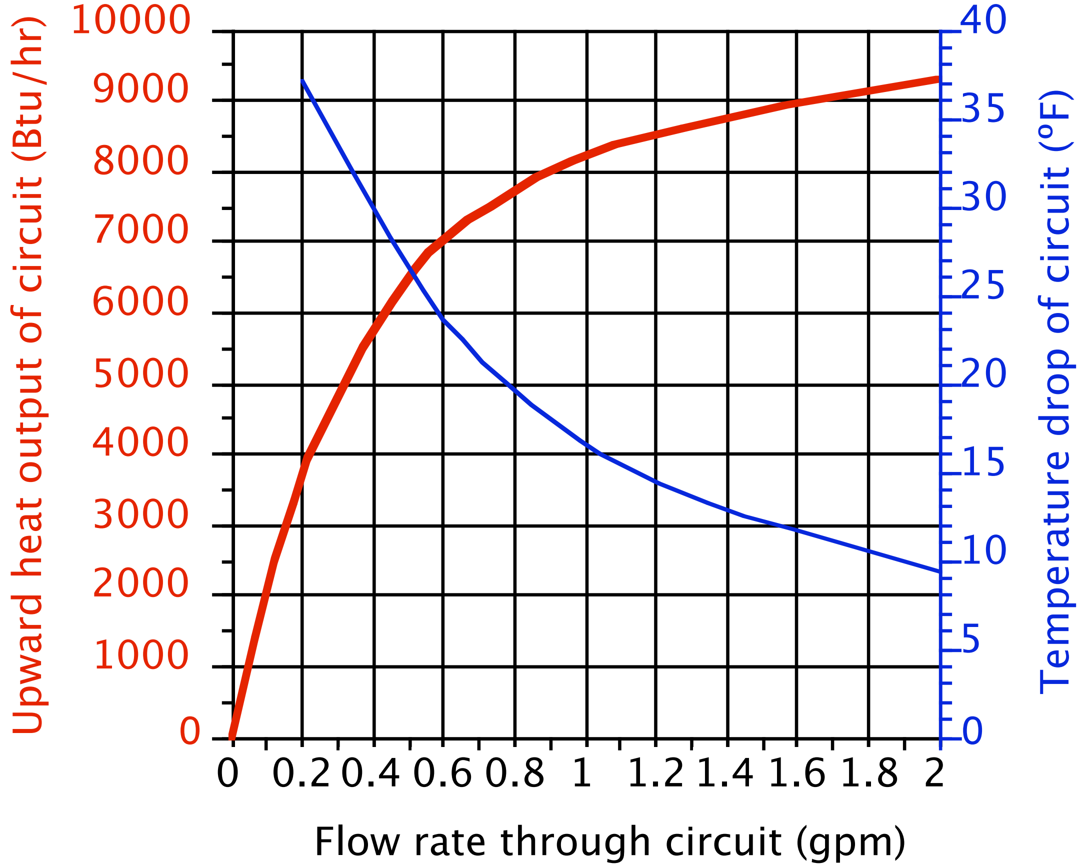
These numbers mean that the hydronic system delivers heat to the building using only 2.9 percent (e.g. 44.4/1506) of the electrical power required by the forced air delivery system.

Other factors to Consider...

The heat output from most hydronic heat emitters (including radiant panel circuits) increases rapidly at low flow rates but very slowly at high flow rates (assuming constant supply temperature).

At 50 percent of design flow rate heat output is about 89 percent of design output.

At 25 percent of design flow rate heat output is still about 71 percent of design output.



Other factors to Consider...

Another governing relationship is the third pump affinity law.

$$P_2 = P_1 \left(\frac{f_2}{f_1} \right)^3$$

Where:
P_1 = power required at flow rate f_1
P_2 = power required at flow rate f_2

Operating a circulator at 25 percent of design flow rate, in theory, requires $(0.25)^3 = 0.0156$, or about 1.6 percent of the power input required at design flow rate.

Although these theoretical power reductions are not fully realized due to losses in motors, bearings, etc., they still point to tremendous opportunities to reduce the electrical operating cost.

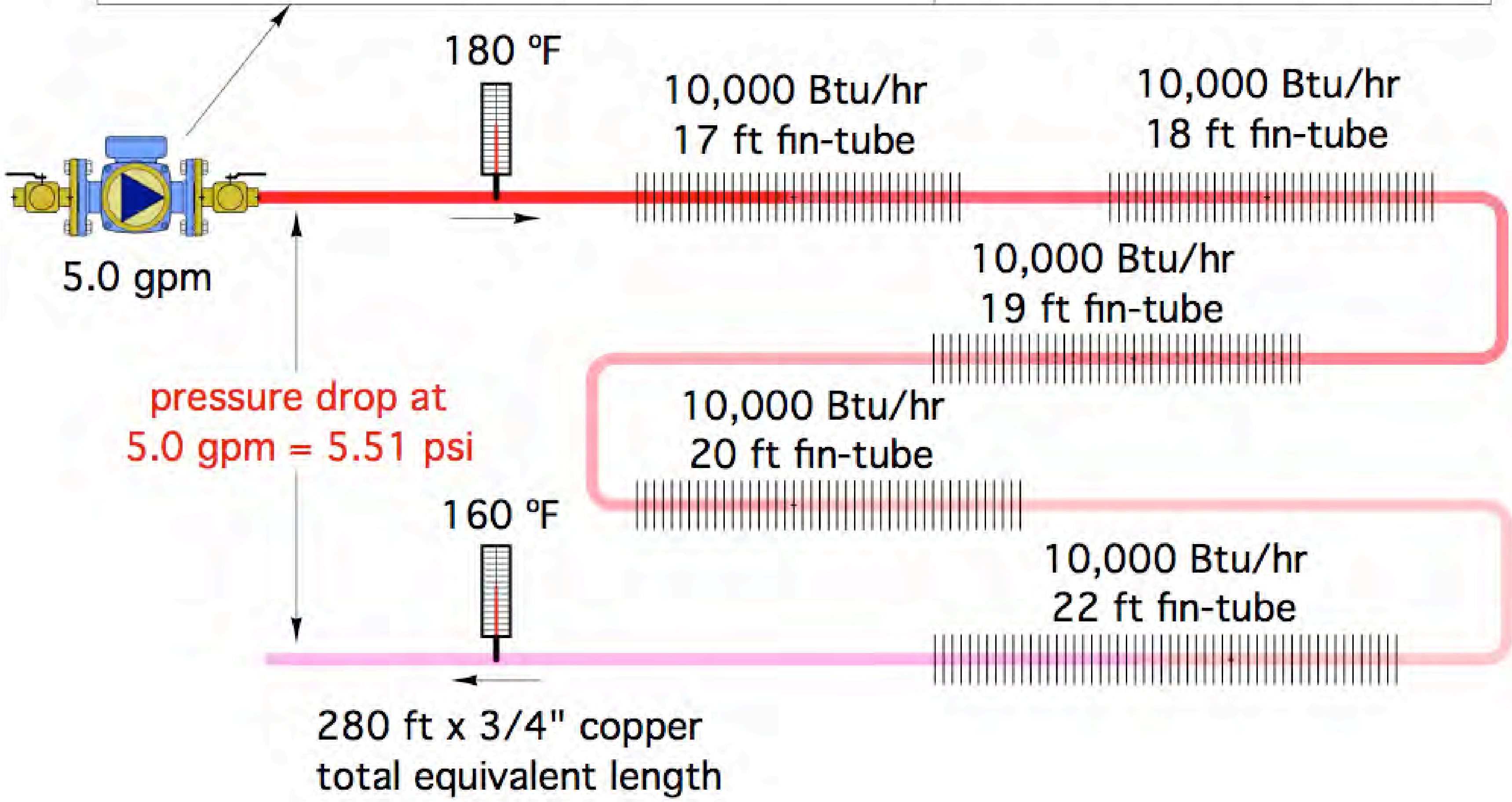
Other factors to Consider…

Reduced head loss:

Circulator energy use for series loop system

$$w_e = \frac{0.4344 \times f \times \Delta P}{n_{w/w}} = \frac{0.4344 \times 5.0 \times 5.51}{0.22} = 54.4 watts$$

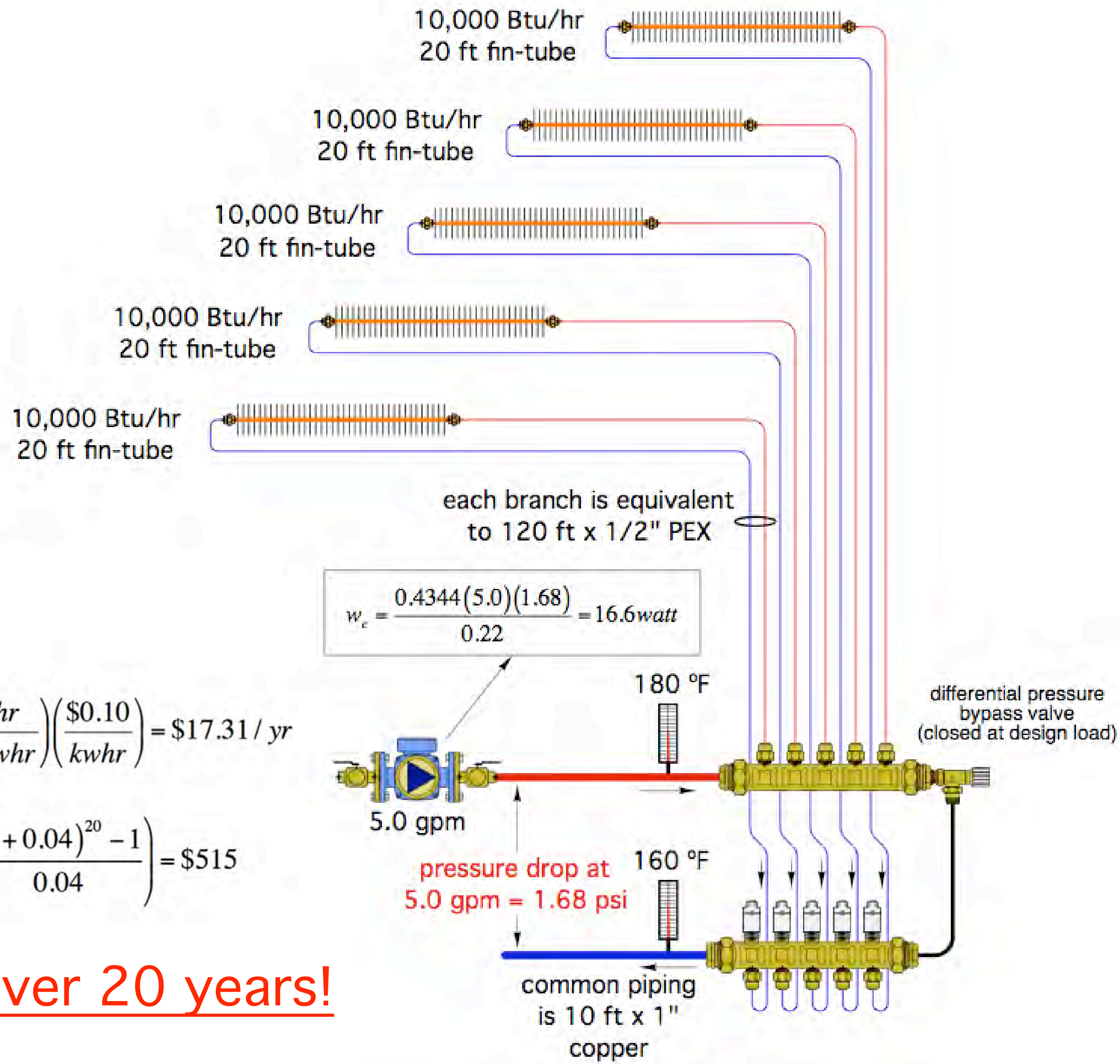
We = electrical wattage
f = flow rate (gpm)
ΔP = differential pressure (psi)
nw/w = wire-to water efficiency of circulator



Other factors to Consider...

Reduced head loss:

Circulator energy use for parallel homerun system



$$\Delta w_e = 74.3 - 16.6 = 57.7watt$$

$$\Delta cost = \left(\frac{57.7w}{1}\right)\left(\frac{3000hr}{yr}\right)\left(\frac{1kwhr}{1000whr}\right)\left(\frac{\$0.10}{kwhr}\right) = \$17.31/yr$$

$$c_T = c_1 \times \left(\frac{(1+i)^N - 1}{i}\right) = 17.31 \times \left(\frac{(1+0.04)^{20} - 1}{0.04}\right) = \$515$$

$515 savings over 20 years!

Other factors to Consider...

Reduced head loss:

Reduce Use Of Antifreeze:

"The only good thing about antifreeze is that it doesn't freeze."

- Antifreeze increases viscosity of system fluid and thus increases head loss (see example below).

- Antifreeze has a lower specific heat than water and thus requires higher flow rates for same heat capacitance.

- If not properly maintained it can lead to corrosion damage requiring major component replacement.

Consider a circuit of 200 feet of 3/4" copper tubing. Assume the circuit operates with a water flow rate of 5 gpm, an average water temperature of 140 ºF, and a ΔT of 20 ºF. Thus it conveys 50,000 Btu/hr. Assume the circulator is a standard wet rotor unit with 22% wire-to-water efficiency. The head loss of this circuit is 11.45 ft. The corresponding circuit pressure drop is 4.87 psi.

The circulator power required for this is:

$$w_e = \frac{0.4344 \times f \times \Delta P}{n_{w/w}} = \frac{0.4344 \times 5 \times 4.87}{0.22} = 48 watts$$

If this same circuit were operated with a 50% solution of propylene glycol, and is to maintain a heat delivery rate of 50,000 Btu/hr, the flow rate must increase to 5.62 gpm due to the lower specific heat of the antifreeze. The increases flow rate, in combination with increased viscosity and density, increases head loss to 16.3 feet, and pressure drop to 7.19 psi.

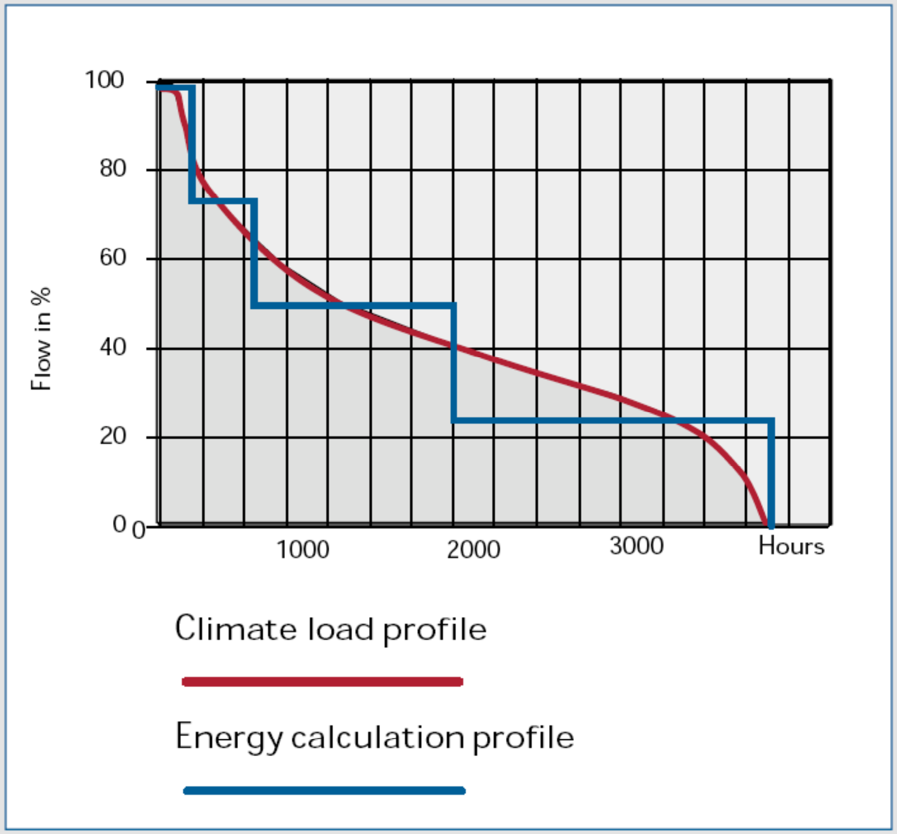
The circulator power required for this is:

$$w_e = \frac{0.4344 \times f \times \Delta P}{n_{w/w}} = \frac{0.4344 \times 5.62 \times 7.19}{0.22} = 79.8 watts$$

A 66% increase in circulator wattage due to the use of the antifreeze solution.

Other factors to Consider…

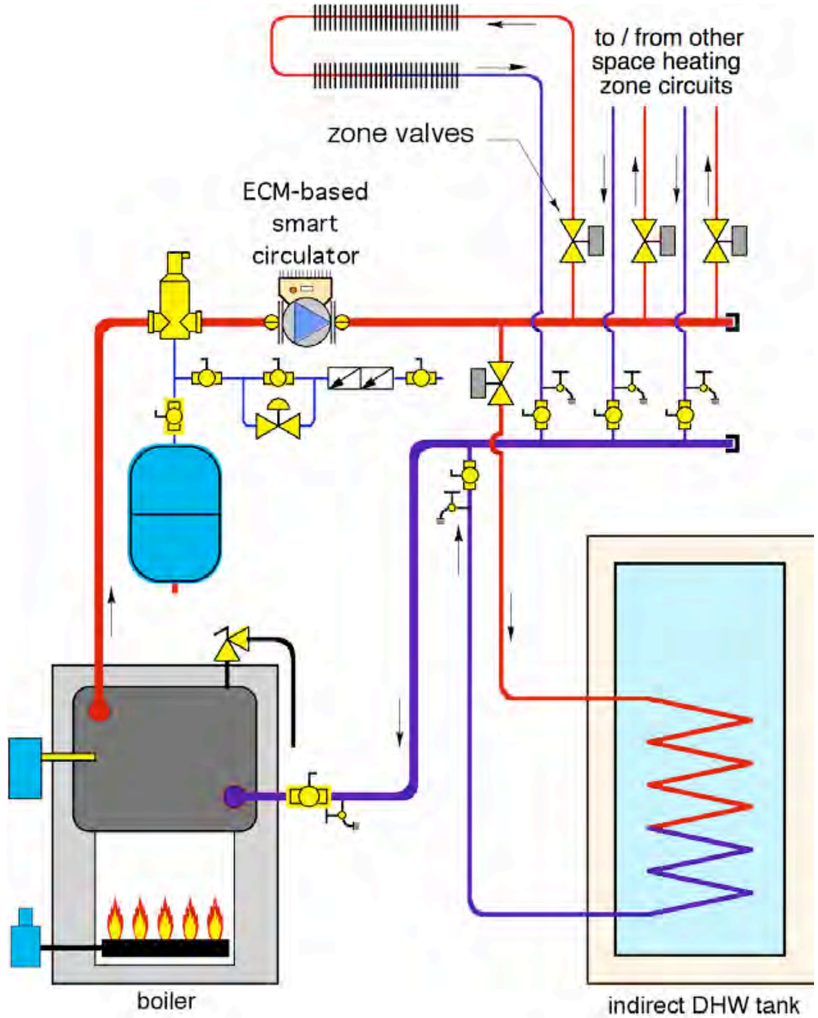
This graph shows the relationship between system flow rate vs. operating hours for a typical Northern European hydronic system.

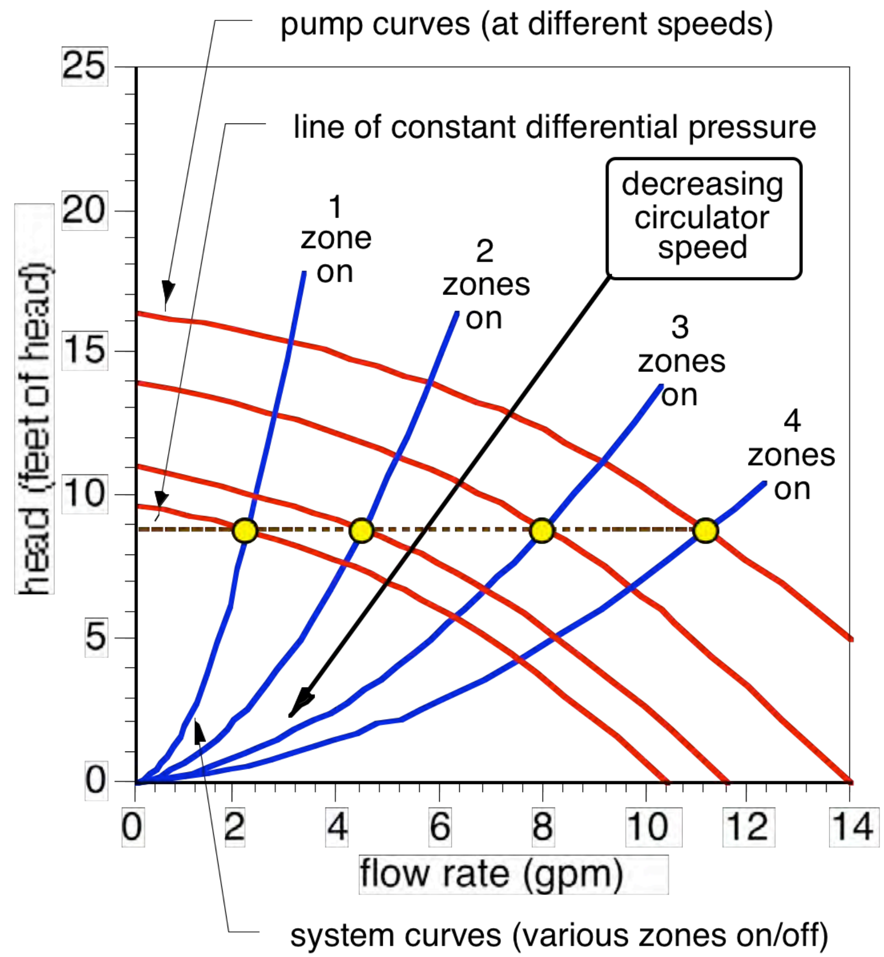


Flow in %	Hours in %
100	6
75	15
50	35
25	44

Recognizing that partial flow is common, circulator engineers have developed "intelligent" operating algorithms for variable speed circulators.

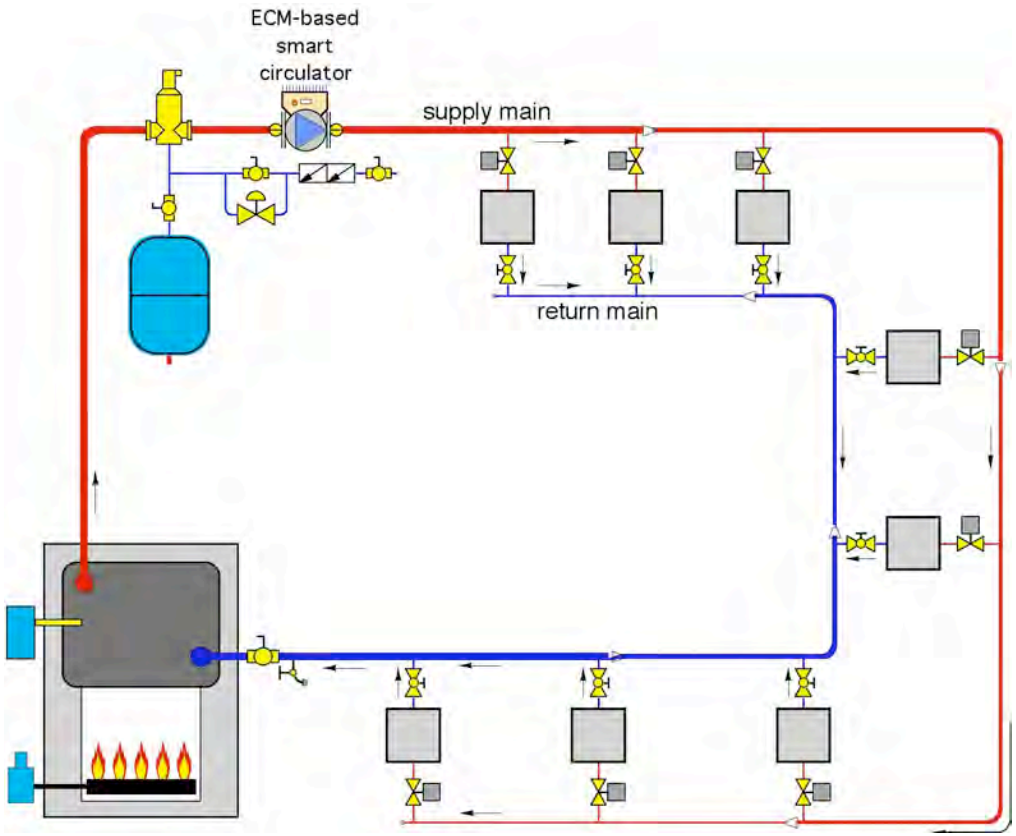
Once such algorithm is called **constant differential pressure control**.

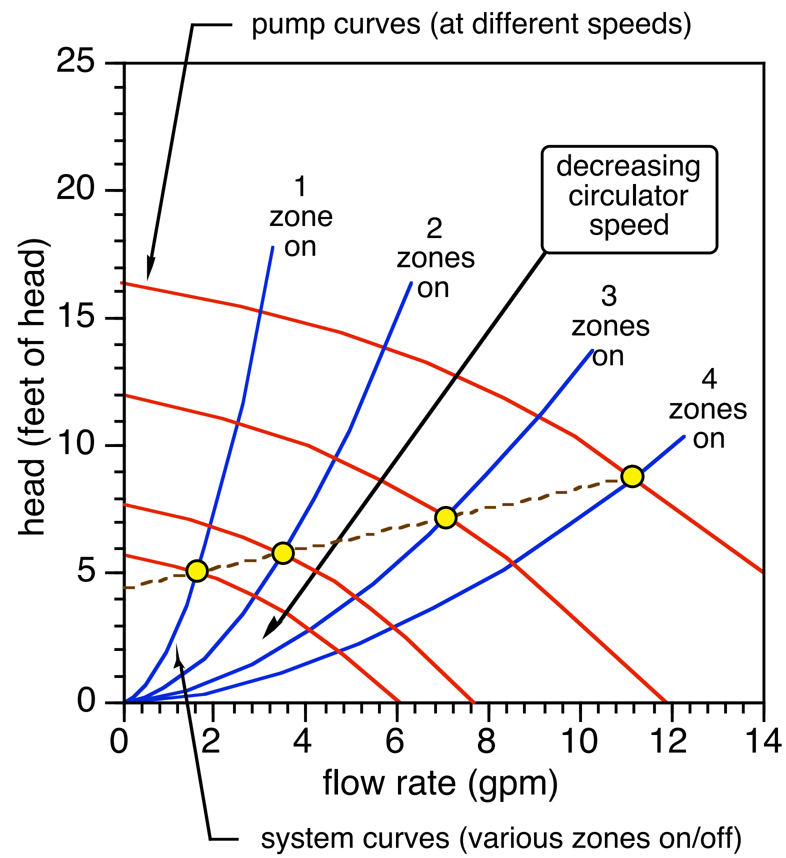




This method is best when head loss of the heat source and common piping is small compared to the head loss of the distribution system.

Another operating algorithm is called **proportional differential pressure control.**

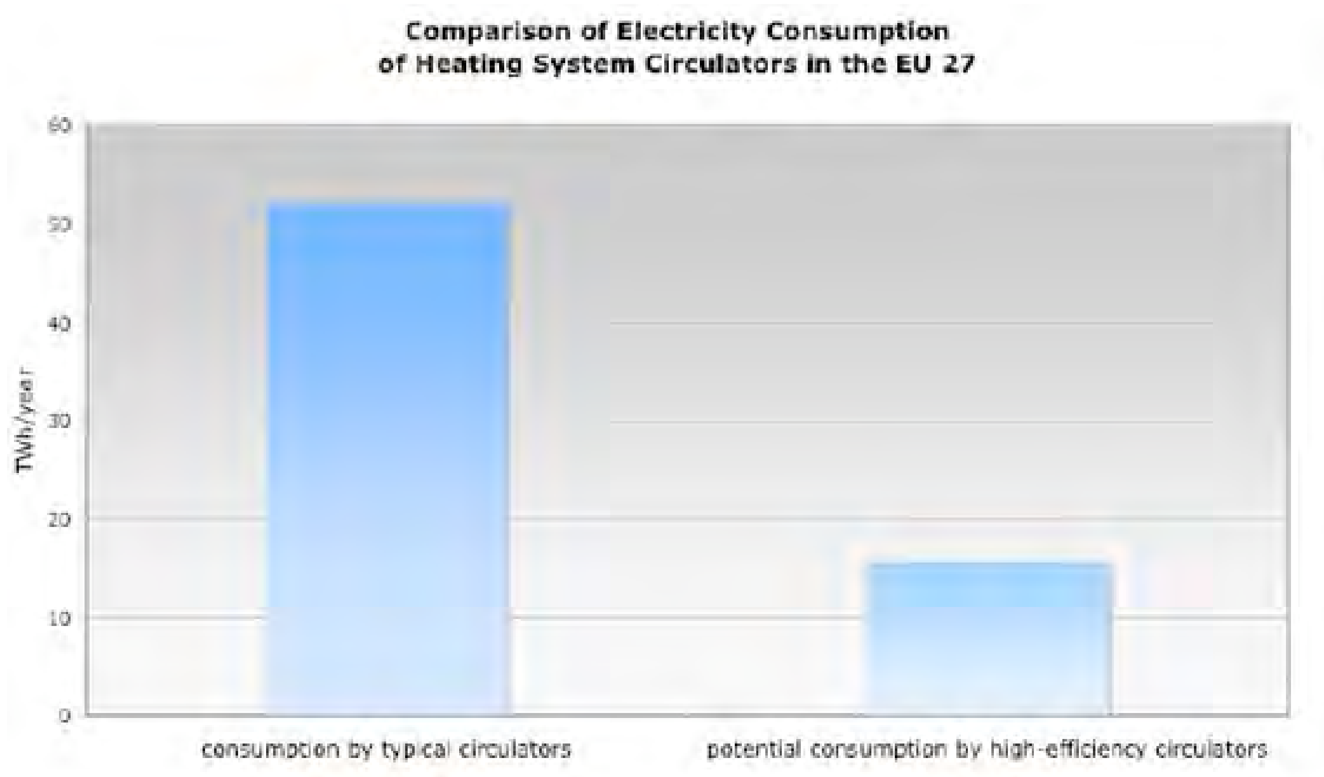




This method is best for systems where the heat source and/or “mains” piping leading to the load circuits dissipate a substantial portion of the circulator head.

Computer modeling has been used to predict electrical energy savings for an intelligently-controlled circulator with ECR motor operating in the proportional pressure mode.

Savings in electrical energy are 60 to 80 percent relative to a fixed speed circulator of equal peak performance in the same application.



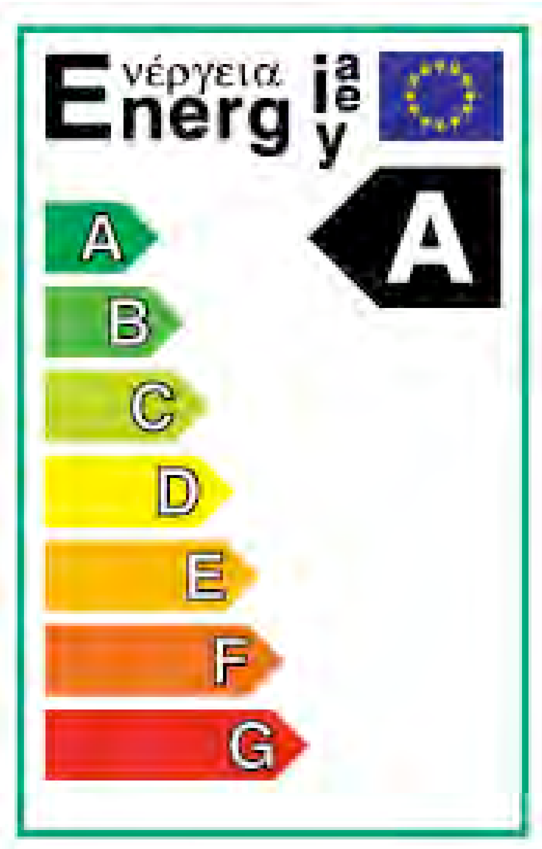
Examples of Smart Circulators:

Keep in mind that many these circulators *currently* require 230 VAC input.

All these circulators use Electronically Commuted Motors (ECM) with permanent magnet rotors.

Examples of Smart Circulators:

All the circulators shown below are rated "A" on the energy labeling system from Europump (European Association of Pump Manufacturers).



To achieve the "A" ranking the simulated energy use of a circulator has to be at least 75% less than a standard wet-rotor circulator.

Single or multi-speed wet-rotor circulators like those commonly used in North America would be rated "D" or "E" on this scale.

Examples of Smart Circulators:

Grundfos Alpha: Provides constant and proportional differential pressure and three fixed speed settings. 6-50 watt electrical input.

European version

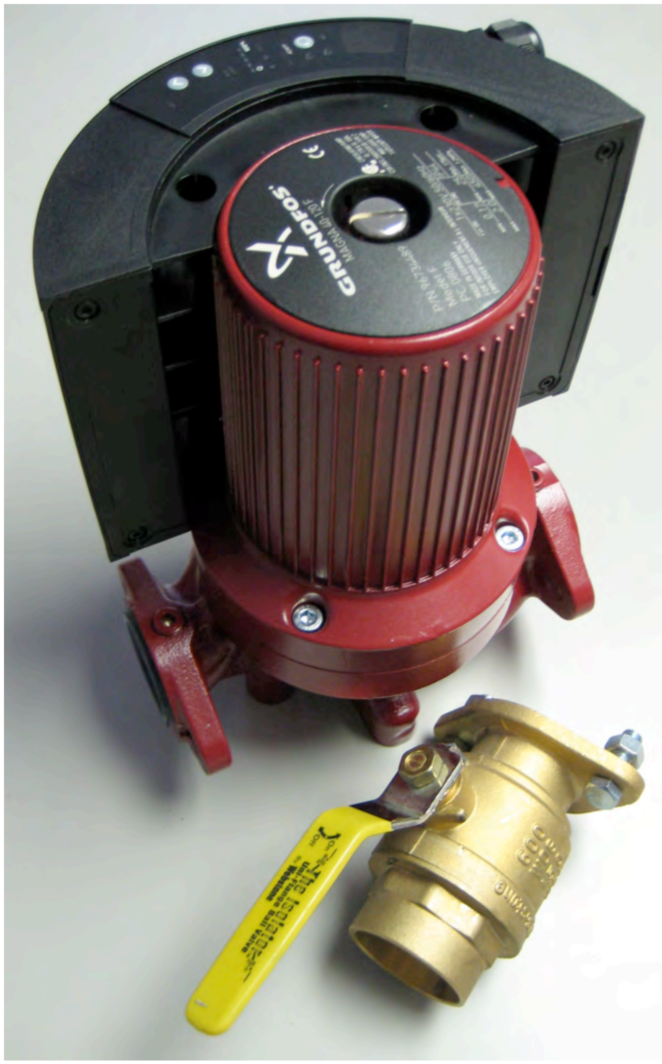
Examples of Smart Circulators:

Wilo Stratos ECO 16F: Provide constant and proportional differential pressure. 5.8-59 watt electrical input.

European version

Examples of Smart Circulators:

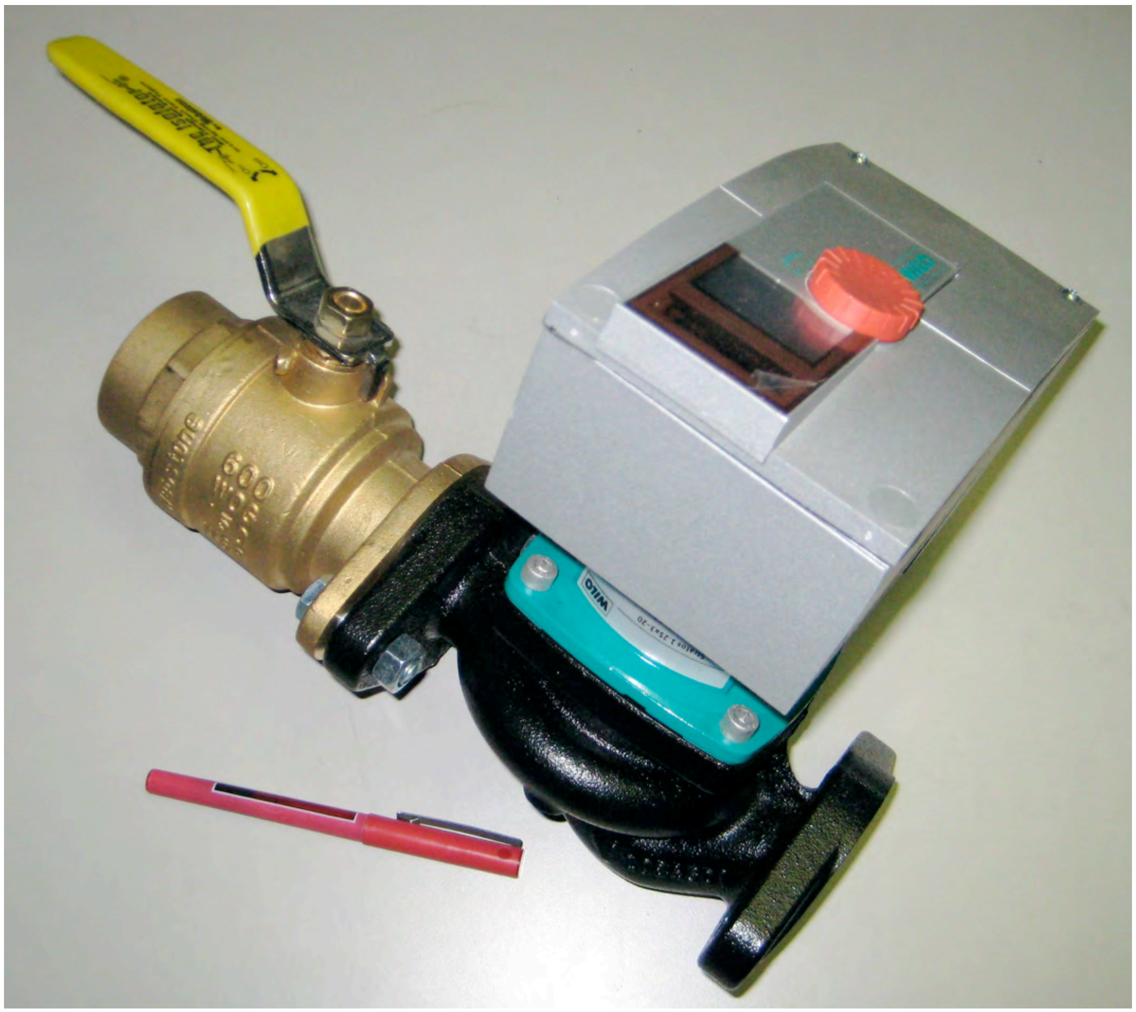
Grundfos 40-120F: Provide constant and proportional differential pressure. 10-85 watt electrical input.



European version
10-85 watt
electrical input

Examples of Smart Circulators:

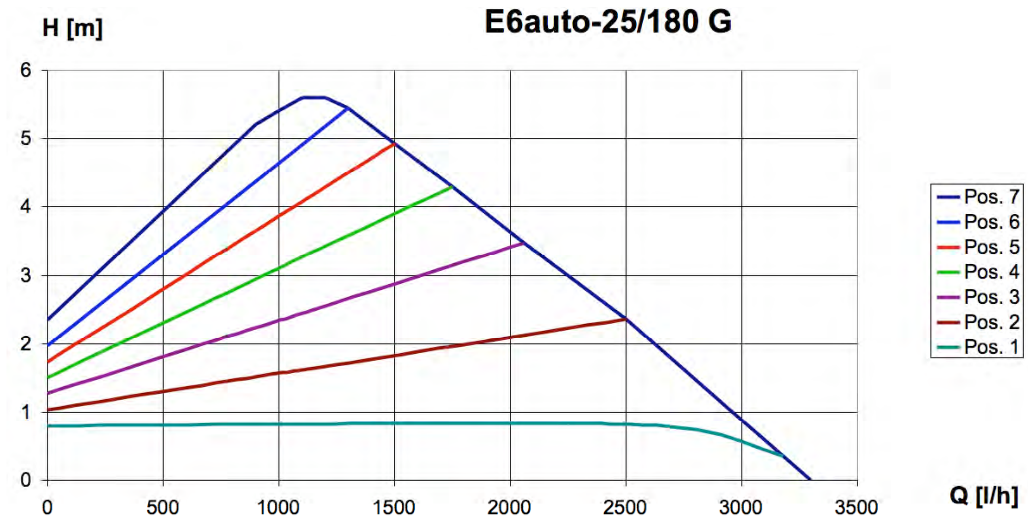
Wilo Stratos 30/1-12: Provide constant and proportional differential pressure. 16-310 watt electrical input.



European version

Examples of Smart Circulators:

Laing E4 Auto: Provide proportional differential pressure. 35 watt (peak) electrical input. Fall 2008 availability in US.



European version

Statistics on ECM circulators from Europe*:

In the current 27 countries making up the European Union (EU) there are an estimated 100 million circulators at or under 250 watt peak power input.

Estimated annual electrical consumption of these circulators exceeds ***50 billion kilowatthours per year!***

*Source:http://www.energypluspumps.eu/en/cesky/Aboutproject/what_is.html

Statistics on ECM circulators from Europe*:

ECM-based circulators with differential pressure control have are estimated to *save at least 60 percent* of the pumping energy used by PSC motor type circulators of equivalent peak performance.

ECM-based circulators have wire-to-water efficiency about ***twice*** that of conventional PSC motor circulators (40's versus low 20's, higher for larger circulators)

Current cost of small ECM-based circulators is about twice that of PSC motor circulator of same peak performance. Estimated payback based on typical European rates is about 2.5 years.

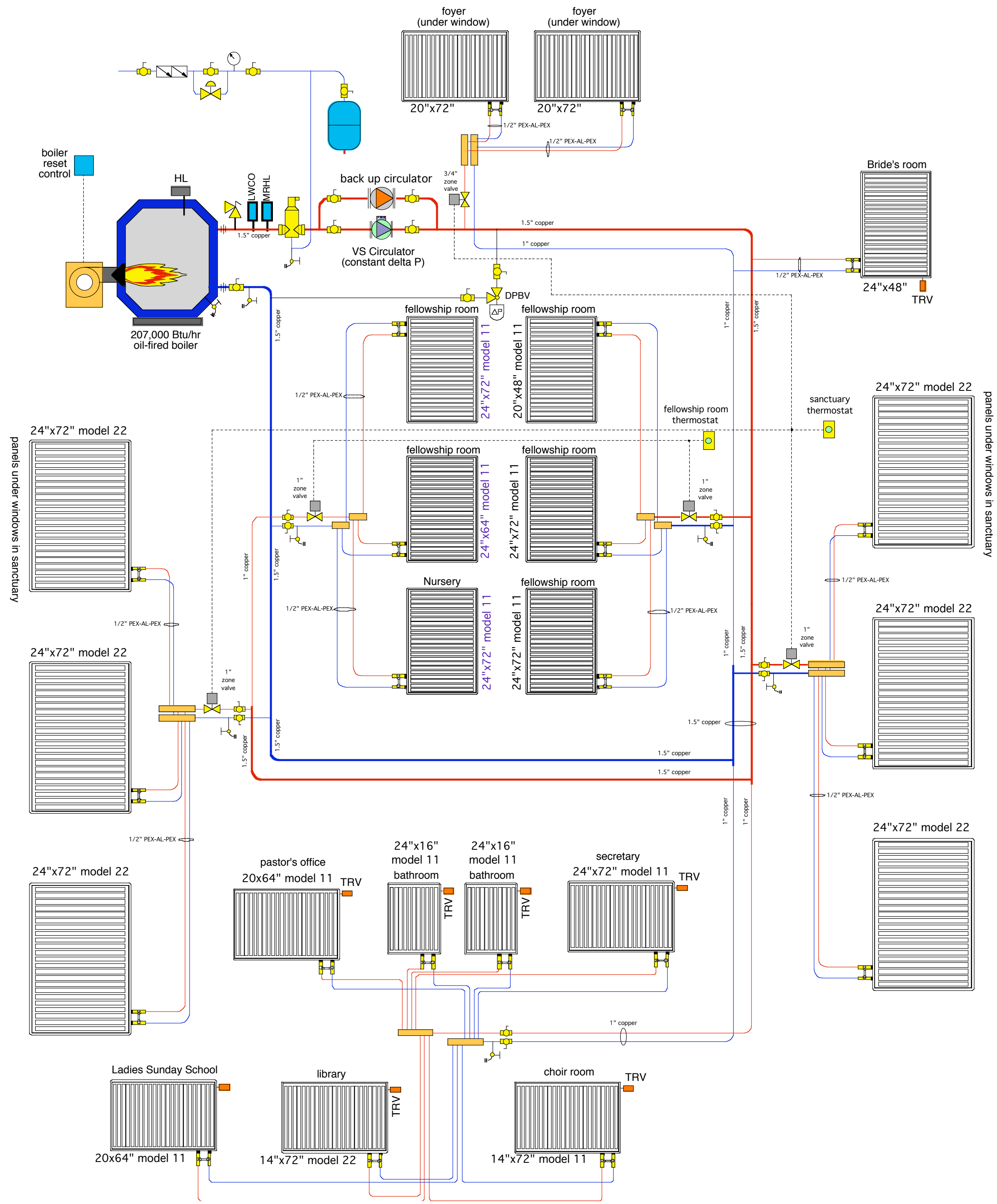
*Source:http://www.energypluspumps.eu/en/cesky/Aboutproject/what_is.html

An example…

During 2005 the old forced air heating system at a church in upstate New York was replaced with a new hydronic system.

The power consumption of the existing 2 horsepower furnace blower was estimated at 1800 watts.

The new system uses several independently controlled thermostatic radiator valves and zone valves.



The new hydronic system has two “system circulators” as seen below.

Only one circulator runs at a given time. In this system the top circulator is the “main,” while the lower circulator is the “backup.”

Let’s compare the estimated seasonal operating cost of the blower in the original system with the “backup” circulator in the new system.

Here are some assumptions for the comparison:

Assume 4000 operating hours per year on the 220 watt circulator (constant circulation during the heating season)

Assume 2000 hours per year on the blower (due to oversizing for the current building heating load)

At the current local cost of $0.14/kilowatthour for electricity, the difference in operating cost is estimated at:

[1800w x 2000hr – 220w x 4000hr] / 1000w/kw x$0.14/kwhr

= $381 per heating season!

It Gets Even Better...

The upper circulator in the photo is a variable speed circulator with ECM motor and intelligent, microprocessor-based differential pressure control operated in the proportional pressure mode

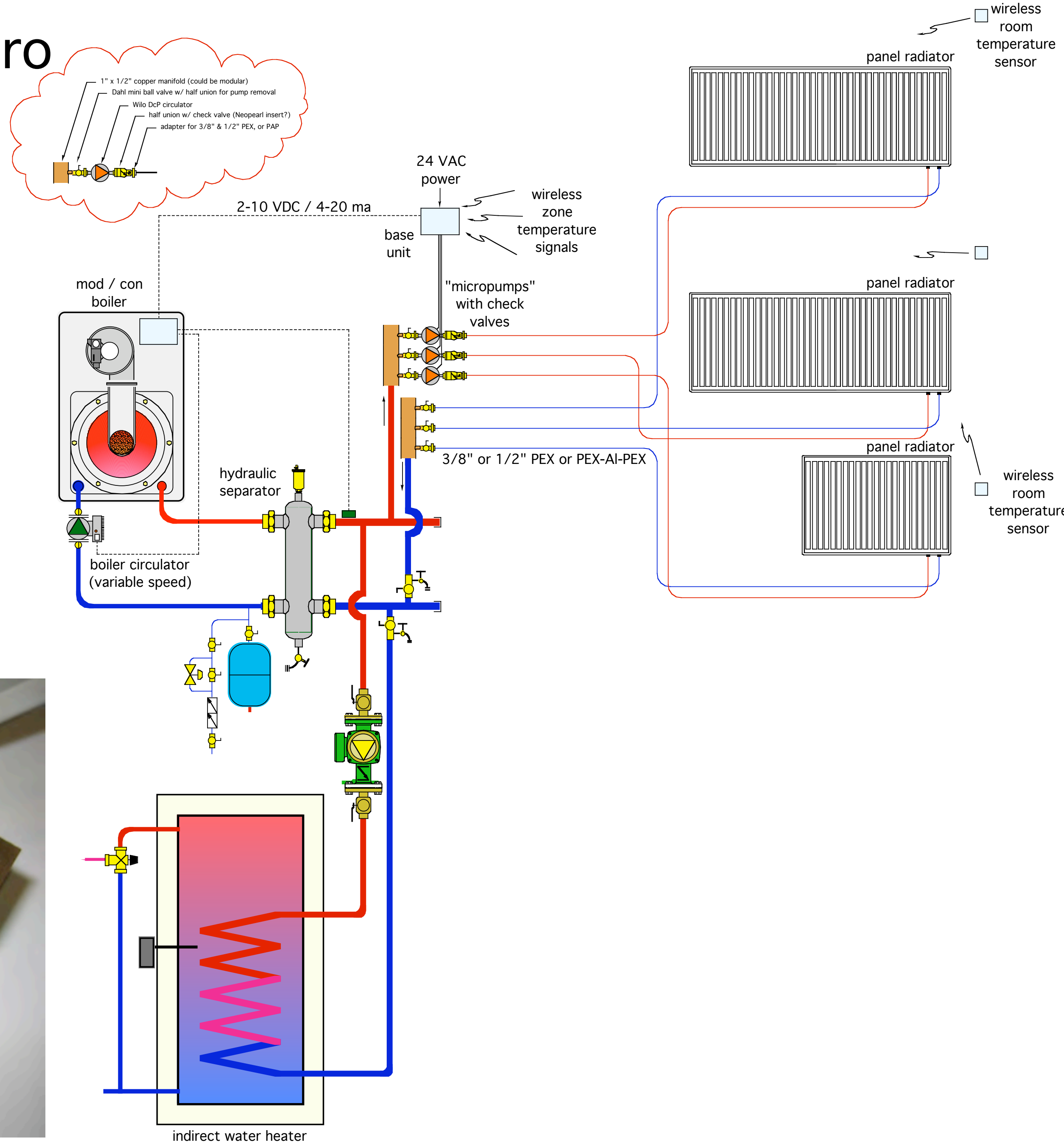
Based on a conservative estimate of 65% energy savings (cited in the European study) the seasonal operating cost of the intelligent circulator should be approximately $44 per season at $0.14/kwhr.

The intelligently controlled circulator will provide heat distribution in this building using about 8.5 percent of the electrical energy consumed by the original forced air system.

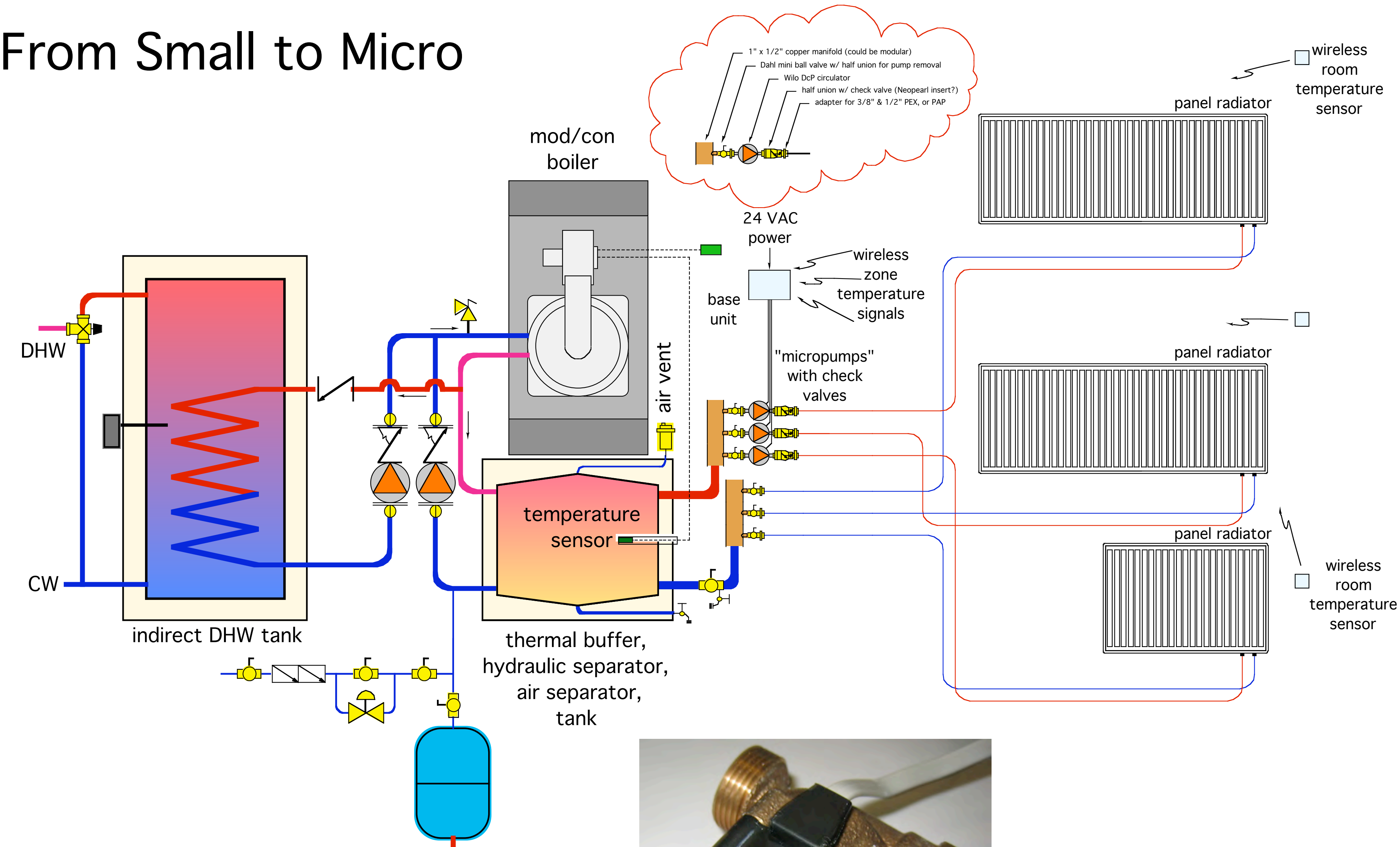
From Small to Micro

Imagine a
circulator that
PEAKS
at 2.5 watts

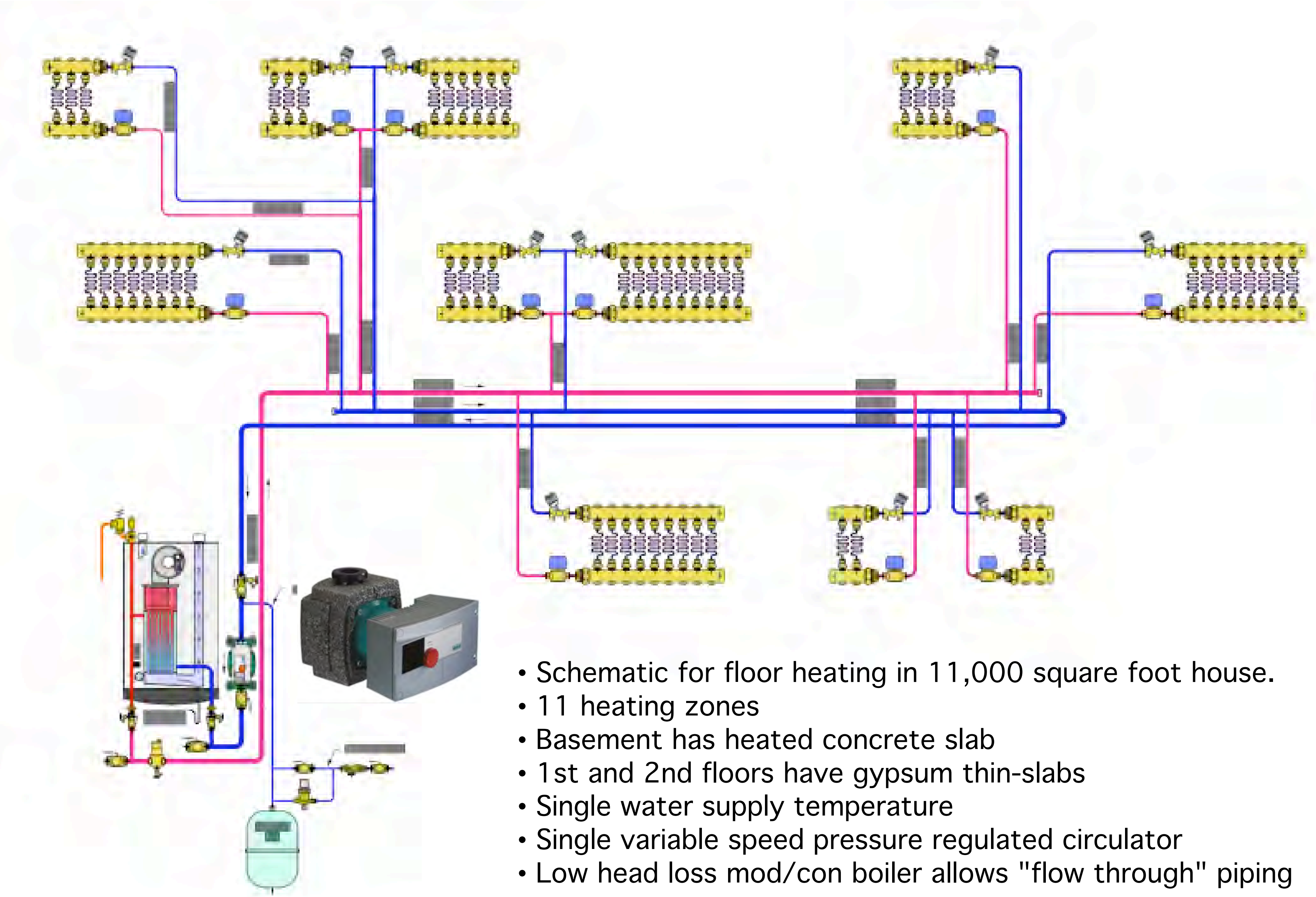
That’s about
1/2 the power
required by a
simple night
light bulb.



From Small to Micro



Examples of systems with reduced circulator power



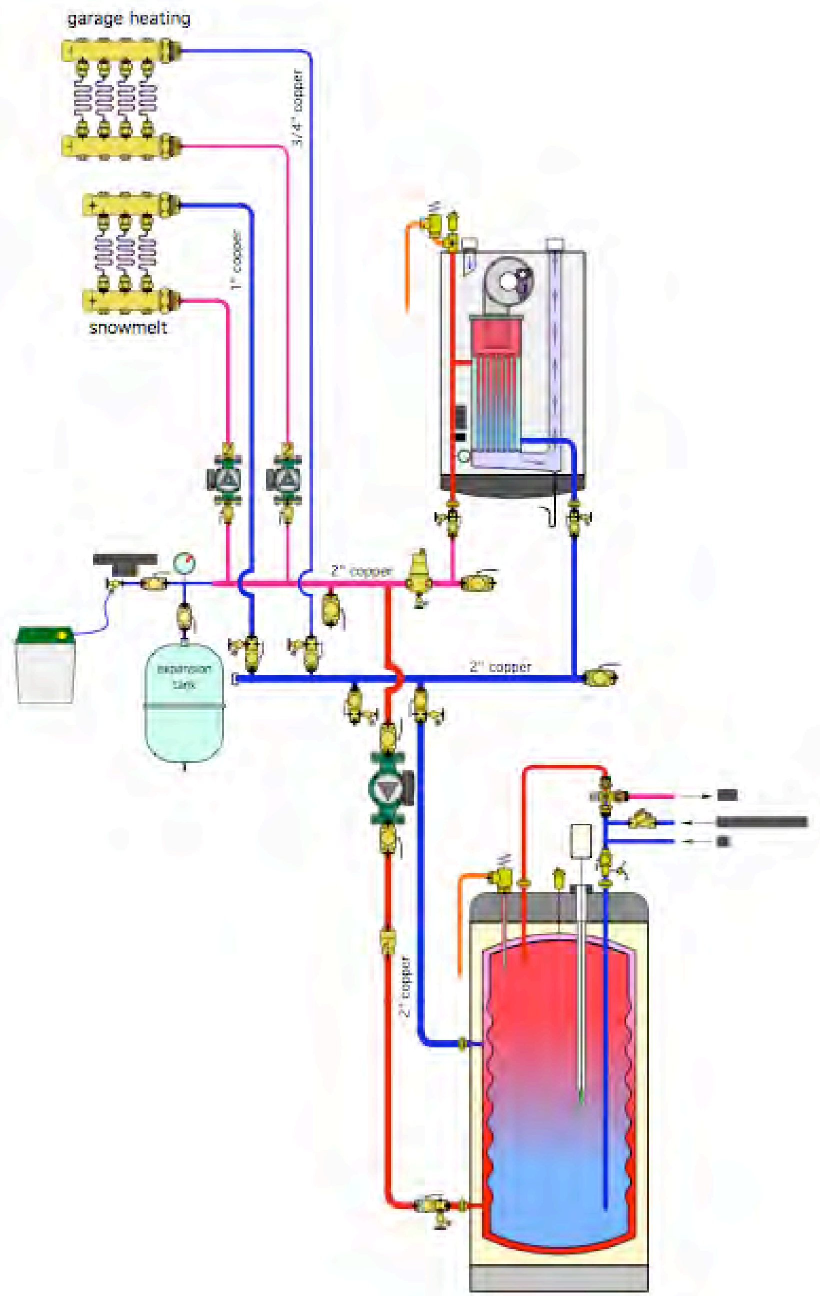
- Schematic for floor heating in 11,000 square foot house.
- 11 heating zones
- Basement has heated concrete slab
- 1st and 2nd floors have gypsum thin-slabs
- Single water supply temperature
- Single variable speed pressure regulated circulator
- Low head loss mod/con boiler allows "flow through" piping

Examples of systems with reduced circulator power

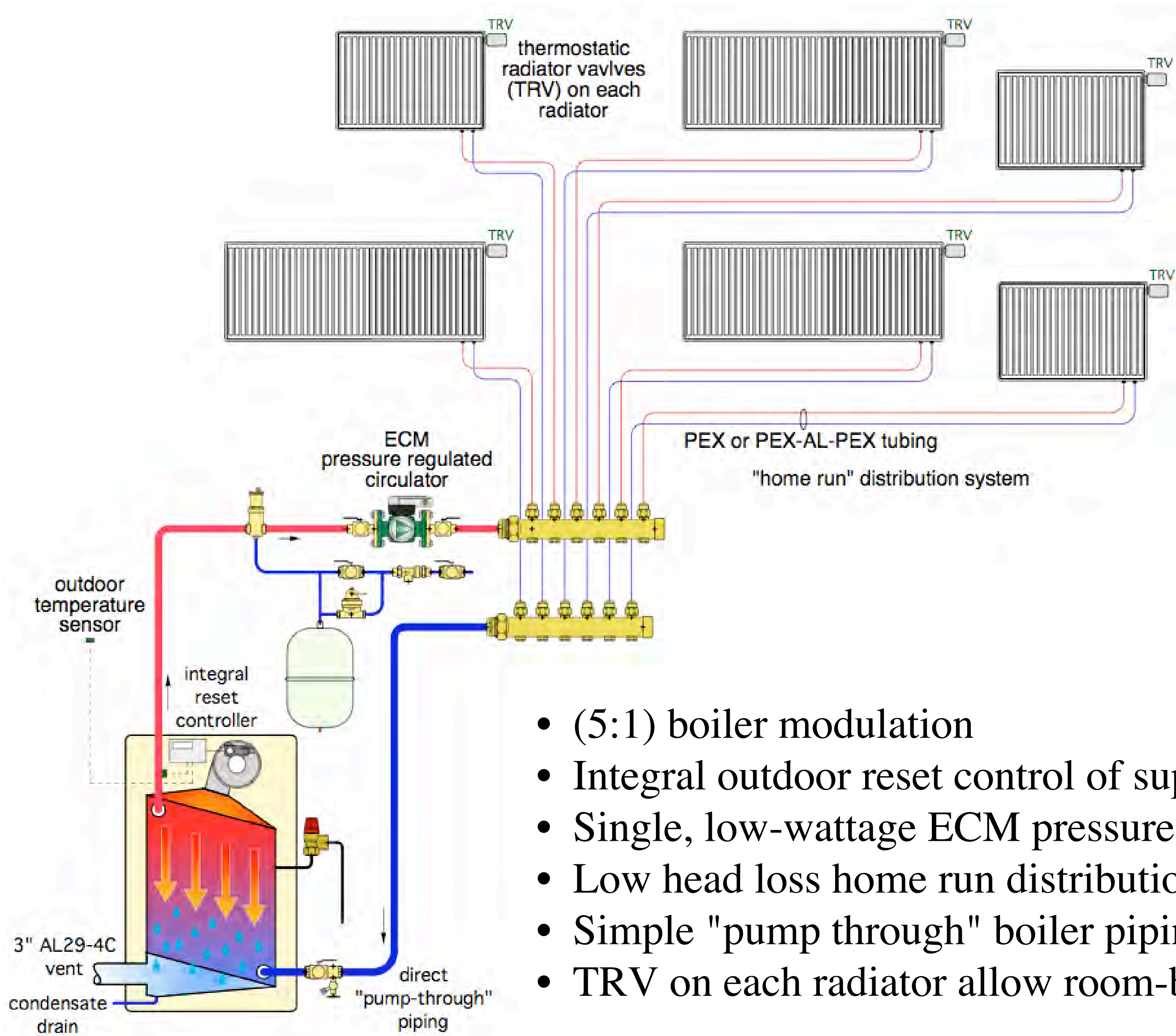
- Separate boiler handles DHW, garage floor heating, snowmelting and pool heating.

- DHW has priority

- Low head loss boiler allows direct piping through boiler. No secondary circulator is needed.

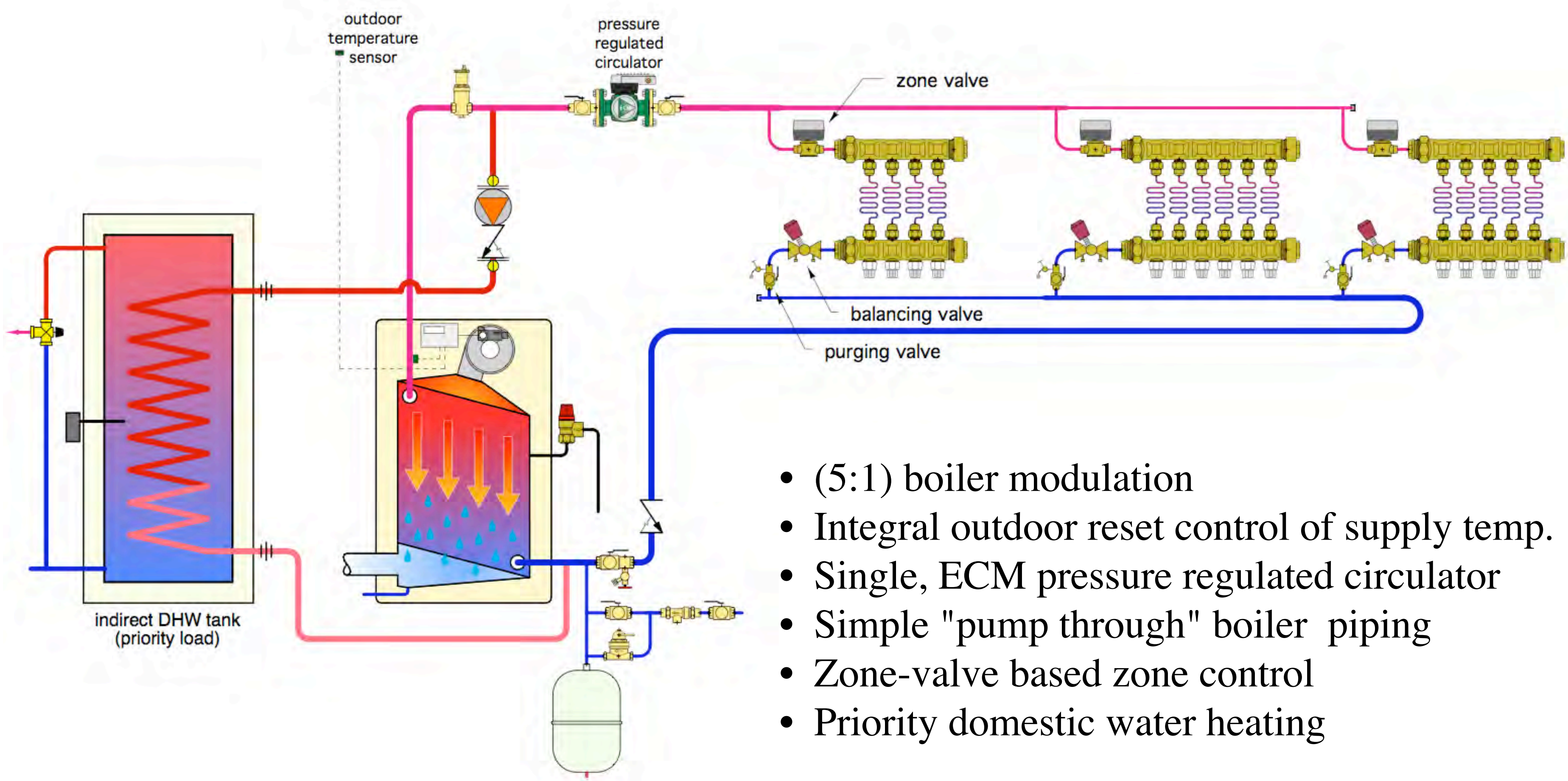


A simple system using cast-iron condensing boiler, homerun distribution, and ECM circulator:



- (5:1) boiler modulation
- Integral outdoor reset control of supply temp.
- Single, low-wattage ECM pressure regulated circulator
- Low head loss home run distribution system
- Simple "pump through" boiler piping
- TRV on each radiator allow room-by-room comfort control

A simple system using cast-iron condensing boiler, 2-pipe distribution, and ECM circulator:



- (5:1) boiler modulation
- Integral outdoor reset control of supply temp.
- Single, ECM pressure regulated circulator
- Simple "pump through" boiler piping
- Zone-valve based zone control
- Priority domestic water heating

Where Do We Go From Here:

Things that will help the North American hydronics industry improve distribution efficiency.

1. **New motor technology.** The PSC (Permanent Split Capacitor) motors used in most current-generation wet-rotor circulators will be replaced with ECM (brushless DC) motor technology.

2. **Variable speed pumping:** Just as modulating boilers have gained a significant share of the new boiler market, variable speed circulators will soon be displacing a significant share of fixed speed circulators.

   These new circulators will be multi-function programmable devices that vary speed based on their operating mode. They will also "adapt" to the circuits they are installed in.

3. Higher Temperature Drops: We have to stop thinking that water "wants" to or needs to drop 20 degrees F. as it flows around every hydronic piping loop we design.

Instead, we should design for 30 to 40 degree F. temperature drops where appropriate.

<u>Some cast iron boilers can operate with temperature drops as high as 100ºF</u>

3. Higher Temperature Drops: We have to stop thinking that water "wants" to or needs to drop 20 degrees F. as it flows around every hydronic piping loop we design.

Instead, we should design for 30 to 40 degree F. temperature drops where appropriate.

Some cast iron boilers can operate with temperature drops as high as 100ºF

4. Reduced head loss: As hydronic system designers we make daily "trade-offs" between tube size and circulator power,

For example: Should I stick with 1-inch copper for this circuit and use the 1/12 hp circulator, or go to 1.25 copper and drop down to a 1/25 hp circulator?)

The answer depends on what yields the lowest life-cycle cost, including installation cost and operating cost over an assumed design life.

The North American hydronics industry must get serious about conserving the electrical energy used to move heat from where it's produced to where it's needed.

As you read this, manufacturers are already working on the next generation of hydronic circulators. However, you don't have to wait for new high-tech products. Here are a few things you can do right now:

1. Consider upsizing you piping one size and see what a difference that makes in circulator sizing. Use accurate design tools to evaluate these trade-offs.

2. Use copper or polymer tubing rather than threaded piping and fittings to reduce head loss.

3. Don't "overpump" then correct for it with throttling valves, especially in series loops.

4. Compare the wire-to-water efficiency of currently available circulators, especially when larger circulators are needed. There are efficiency differences between wet rotor circulators and 2-piece or 3-piece circulators.

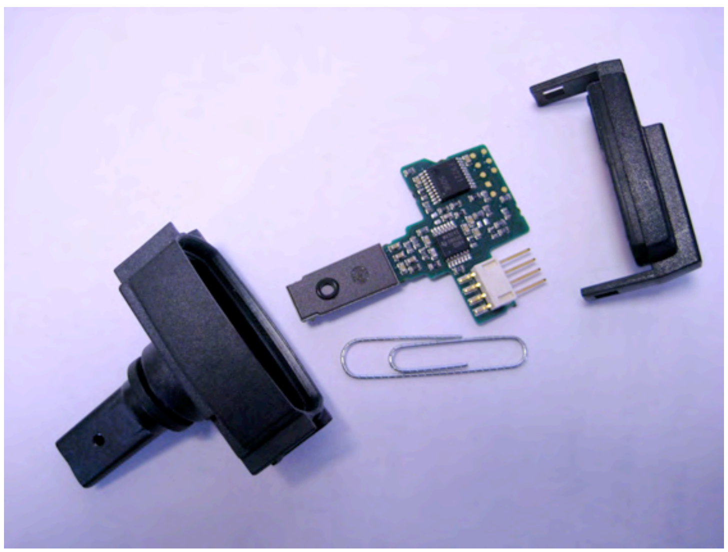
5.   Try to operate the circulator in the middle of it pump curve near the "best efficiency point."

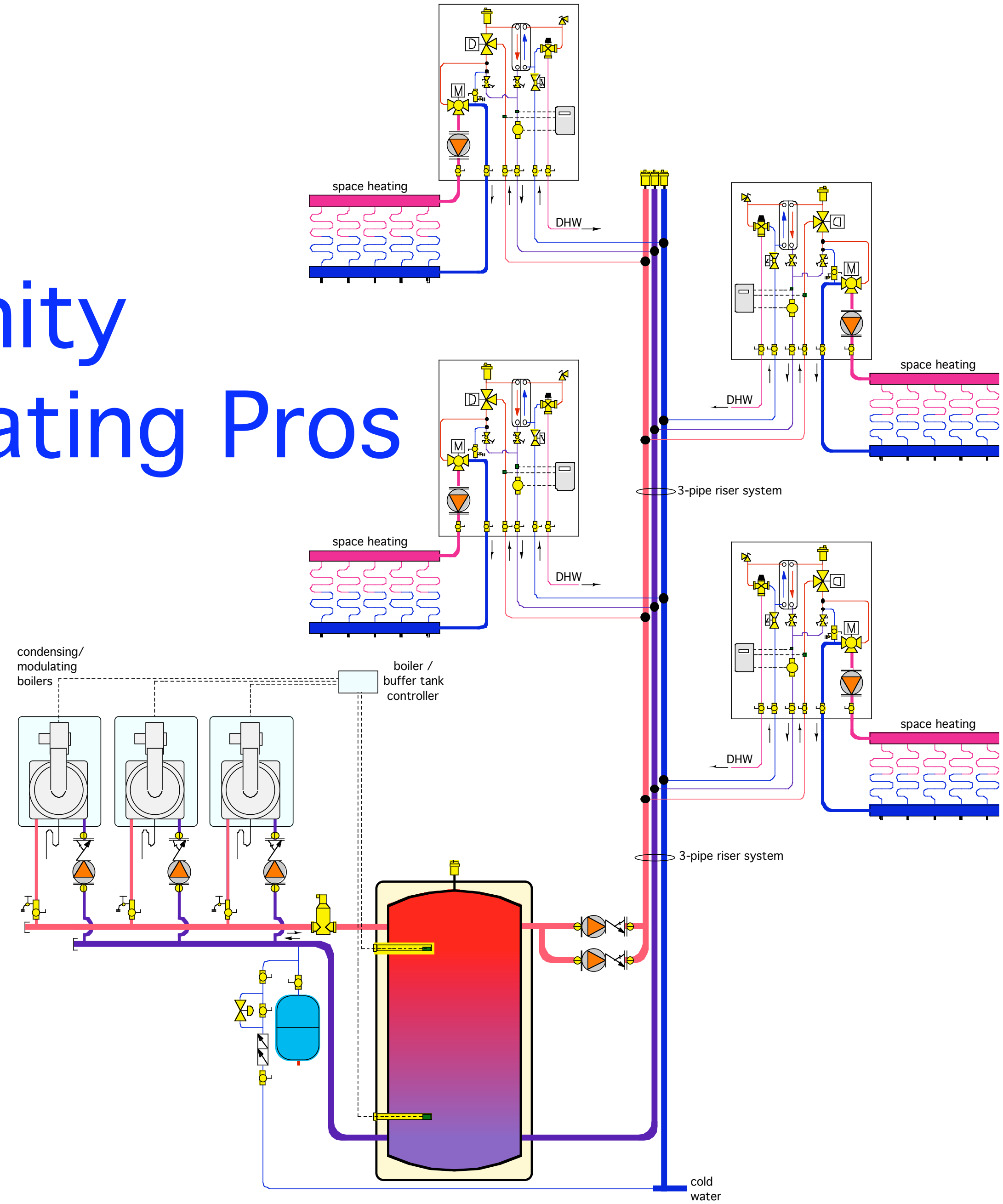
6. Don't get carried away with zone circulators. Just because you can create 20 individually-pumped zones in a house doesn't mean you should, especially when those zone may only need flow rates of 5 gpm or less.

Although we'll never achieve "perpetual flow" in hydronic piping systems it's always good to work in that direction.

It's a situation rife with opportunity!

BTU Metering...
A New Opportunity for Hydronic Heating Pros





Have you ever been asked to provide hydronic heating for a condominium complex, apartment building, or leased multi-tenant commercial building?

Maybe the owner wanted separate heat sources in each unit to keep utility costs separated.

You agreed because you knew of no alternative.

In most cases the design heating loads of such spaces are far less than the output of the smallest available boiler.

The end result was short cycling heat sources and low seasonal efficiency.

A far better approach is to “centralize” heat production and distribute this heat to each unit as needed.

In Europe,“district heating” systems use large municipal boiler plants to supply heat through insulated underground mains to buildings spread out over several city blocks.

Smaller systems use a single mechanical room to serve multiple living units or rental properties.

In each case it's essential to accurately meter heat delivered to each load.

The technology for this has existed for several years.

This heat meter is in a German hotel, and dates back to the 1960s.

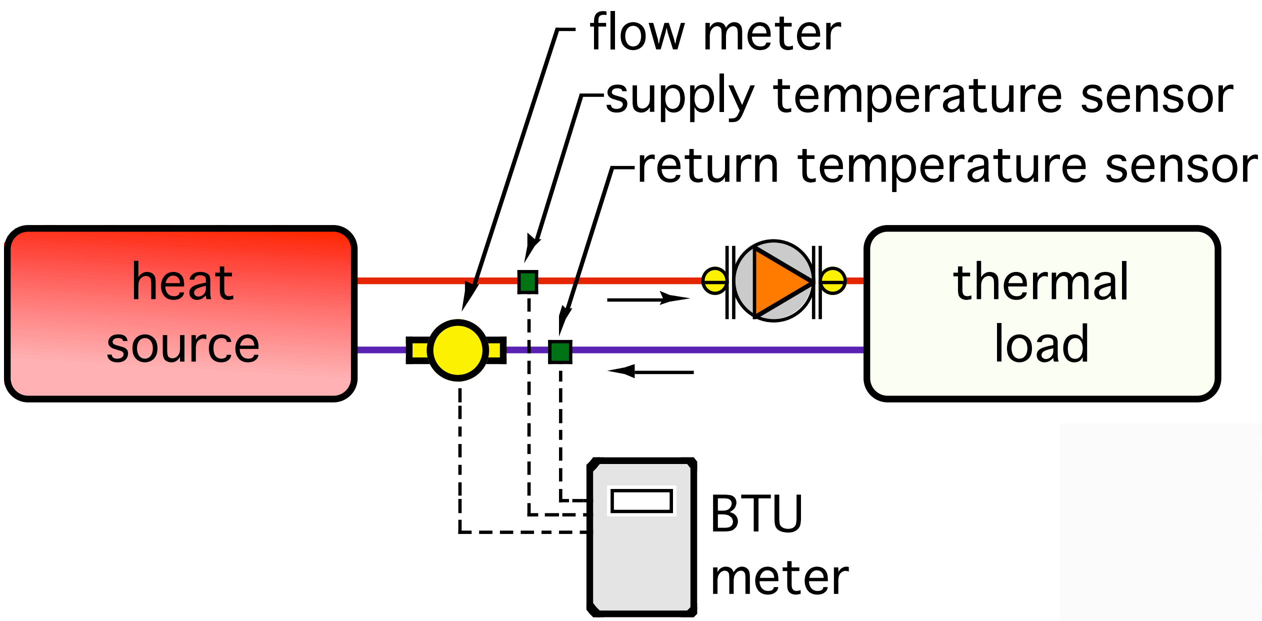
It reads in units of MWh (mega watt hours)

It also shows the current temperature Differential on the subsystem it is monitoring.

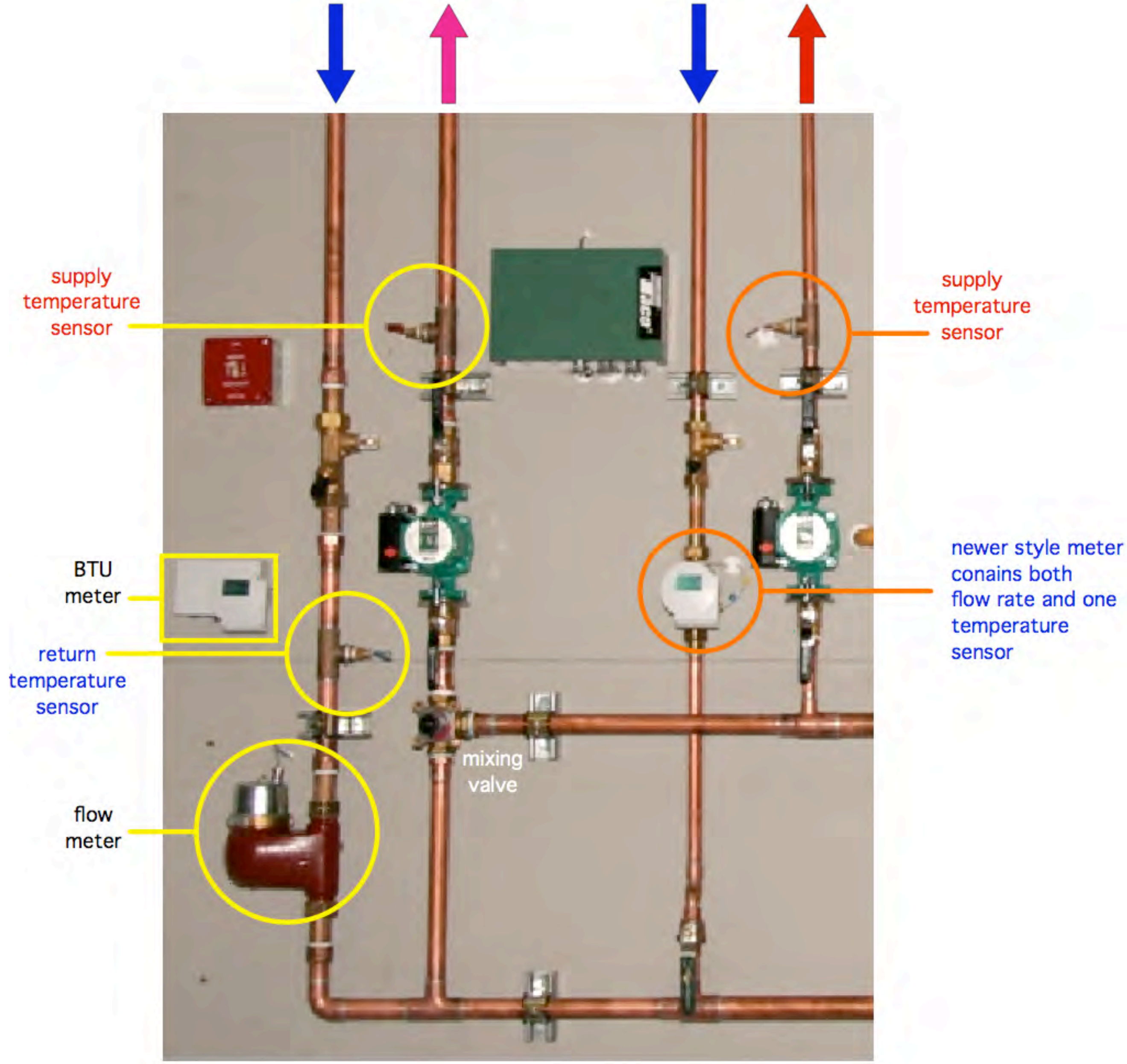
New electronics technology now makes this concept possible for smaller buildings.

Example of a small, self-contained heat metering systems (ISTEC)

Heat metering involves the simultaneous measurement of flow and temperature change.



Two types of BTU meters in a small system



Theory:

The rate of sensible heat transfer to a load can be calculated using the following formula:

$$q = \left(8.01 \times D \times c\right) \times f \times \left(\Delta T\right)$$

Where:
q = rate of heat flow (Btu/hr)
D = density of fluid (lb/ft3)
c = specific heat of fluid (Btu/lb/ºF)
f = flow rate (gpm)
ΔT = temperature change of fluid (ºF)
8.01 = units conversion factor

Here's an example:

Water at 140 ºF enters the heating distribution system for a condo at 5 gpm. The water returns from the distribution system at 127 ºF. What is the rate of heat release into the condo under these conditions?

First we have to estimate the **density** of the water at the average temperature of the system using the formula below.

$$D = 62.56 + 0.0003413 \times T - 0.00006255 \times T^2$$

Where:

D = density of water (lb/ft^3)

T = temperature of water (ºF)

At 133.5 ºF, the density of water calculates to be 61.49 lb/ft3

Putting the numbers in the formula yields:

$$q = \left(8.01 \times 61.49 \times 1.00\right) \times 5 \times \left(140 - 127\right) = 32{,}015\,Btu\,/\,hr$$

IF these flow and temperature conditions held constant for one hour the amount of heat transferred would be:

$$Heat = \left(32{,}015\,\frac{BTU}{hr}\right) \times 1hr = 32{,}015\,Btu$$

Such a scenario is very unlikely. Within an hour both temperatures and flow rate are likely to vary, in some cases considerably.

The solution is to total up the heat moved over smaller time periods using the formula below.

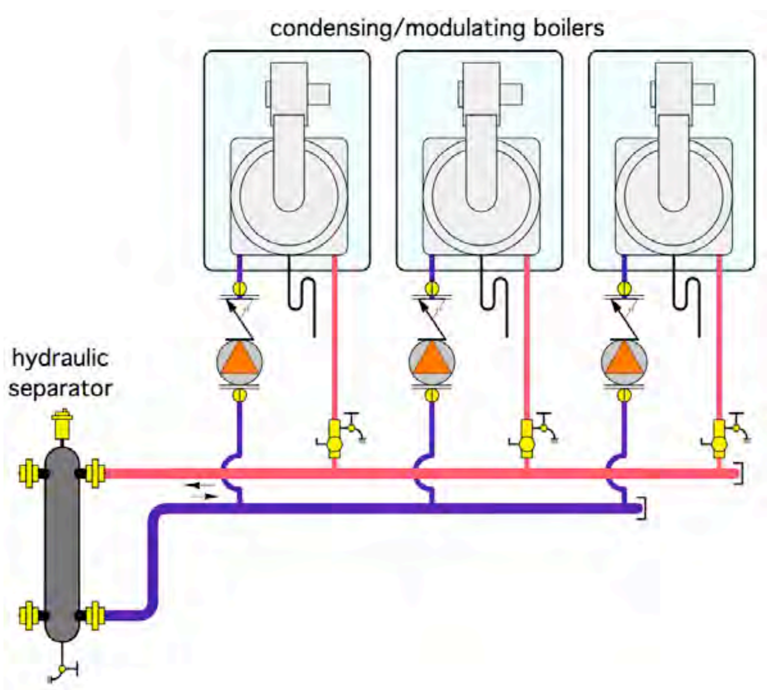
$$\text{Total heat} = \left(\text{heat transfer rate}\right) \times \text{time}$$

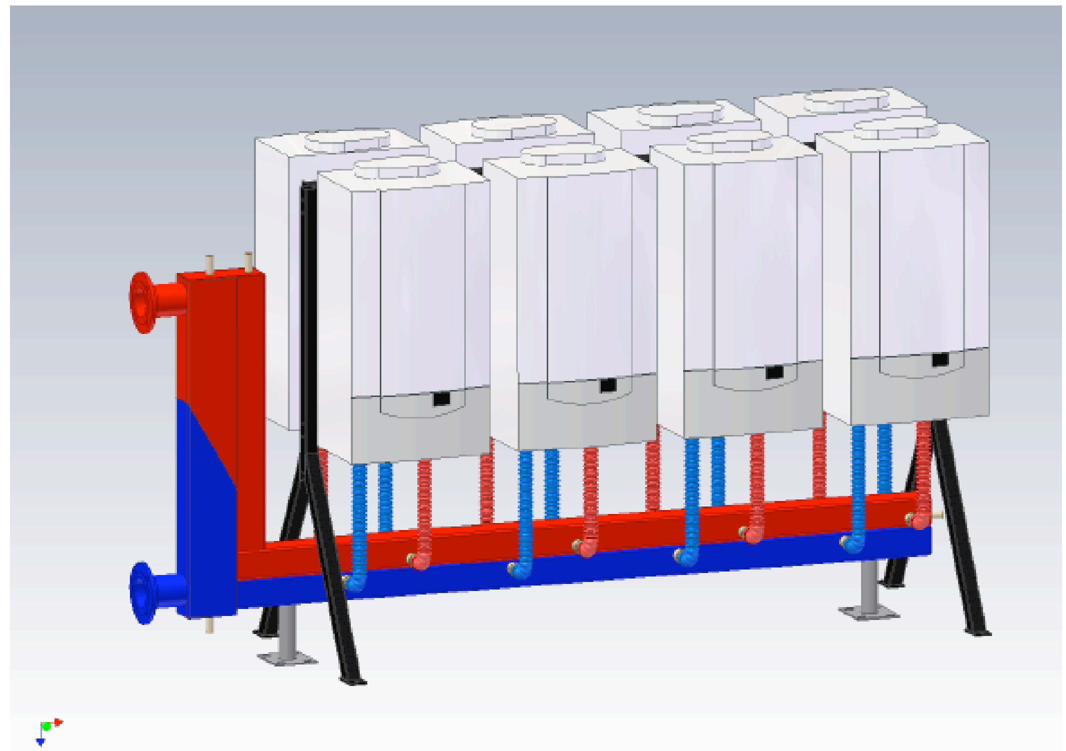
Here's an example where the time period is 1/60 hr.

Minute #	Tsupply (°F)	Treturn (°F)	Flow rate (gpm)	Heat rate (Btu/hr)	Heat Metered (Btu)
1	140	127	5.0	32015	533.5
2	139	125	4.9	33727	562.1
3	138	123	5.0	36874	614.6
				TOTAL =	1710.2

Benefits of heat metering:

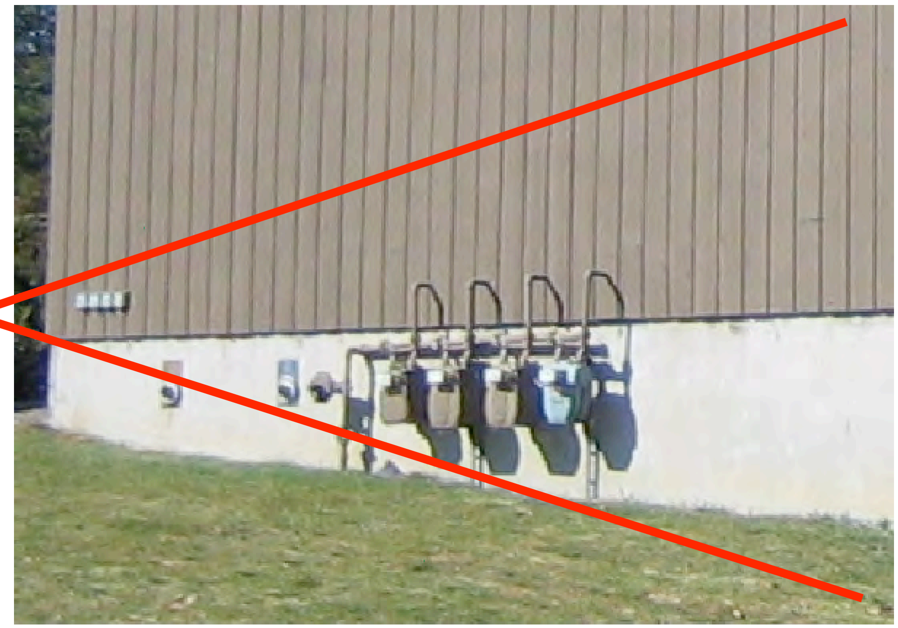
- Heat for space heating and domestic hot water (DHW) is generated by a central boiler plant that operates at higher efficiencies than individual heat sources.





Benefits of heat metering:

- Using a centralized boiler plant with a single gas meter eliminates the monthly charges associated with multiple gas meters (one for every unit).



- Eliminates need to install gas piping throughout the building. Reduce cost, and decreases danger of accidental gas leakage.

Benefits of heat metering:

- Eliminates need for venting a separate heat source in each unit.

Benefits of heat metering:

- Boiler servicing and collection of heat meter data can be done (with some metering systems) without entering individual units.

Benefits of heat metering:

- Floor space freed up by eliminating boiler and DHW tank reduces mechanical system to a compact wall-mounted panel. The extra floor space adds value to property.

Benefits of heat metering:

- Any noise associated with the heat source is confined to the mechanical room.

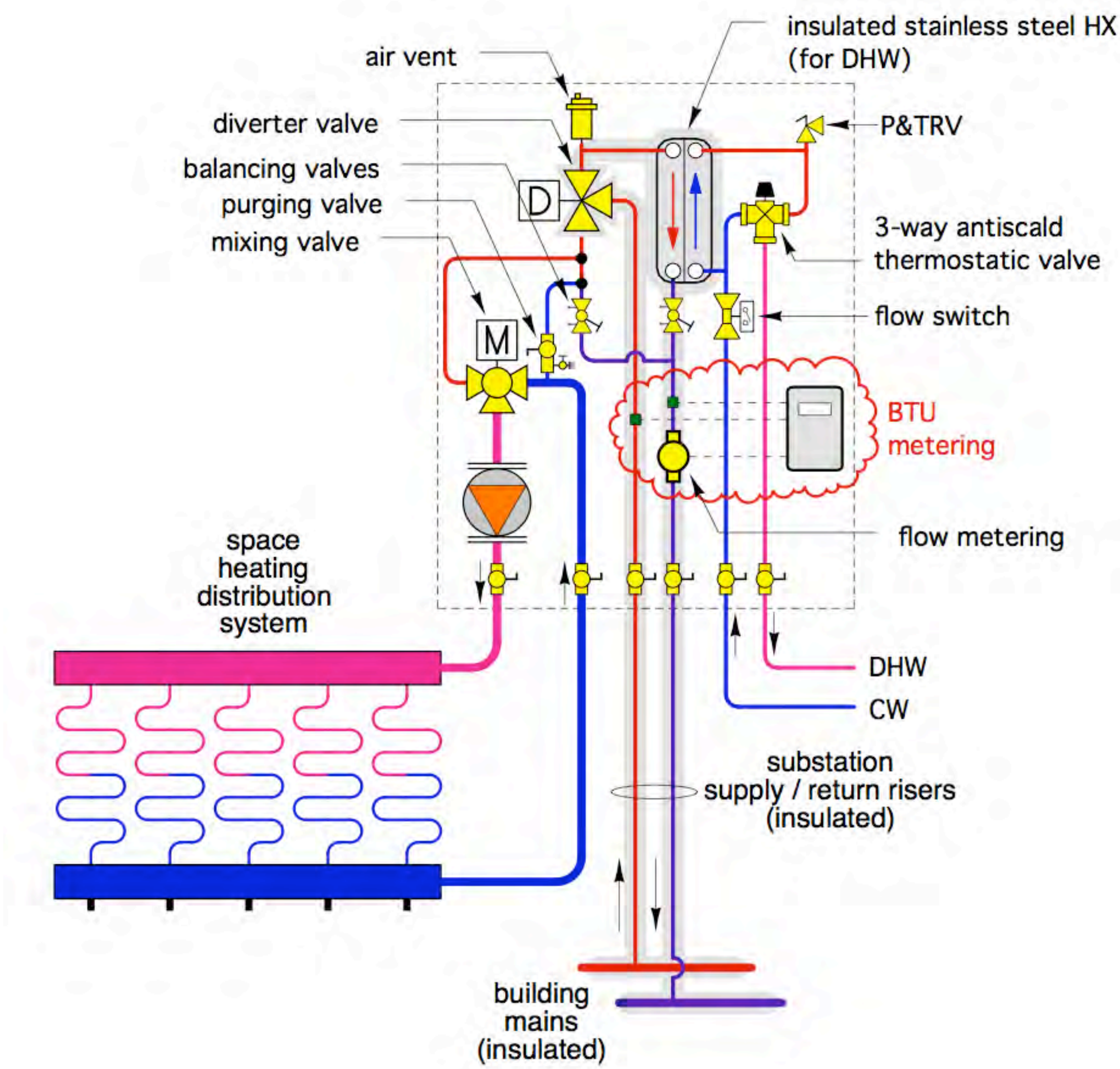
Benefits of heat metering:

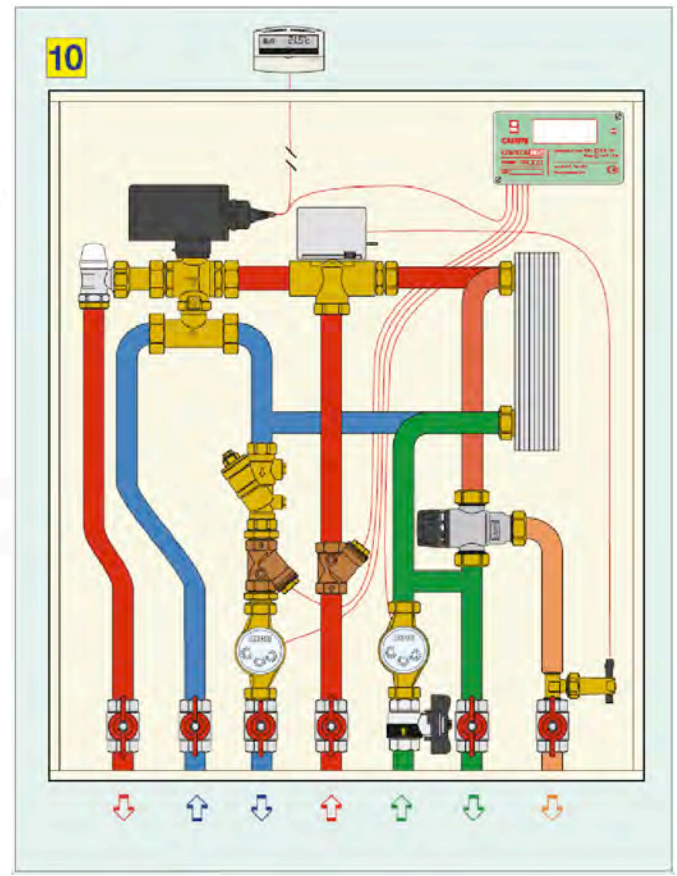
- Possibility of carbon monoxide leakage is limited to the central mechanical room.

- Renters have the option of higher space temperatures if they choose but are billed accordingly. This encourages energy conservation. *Some studies indicate* ***energy use reduction of at least 20 percent*** *based on the "user incentive" to converse energy.*

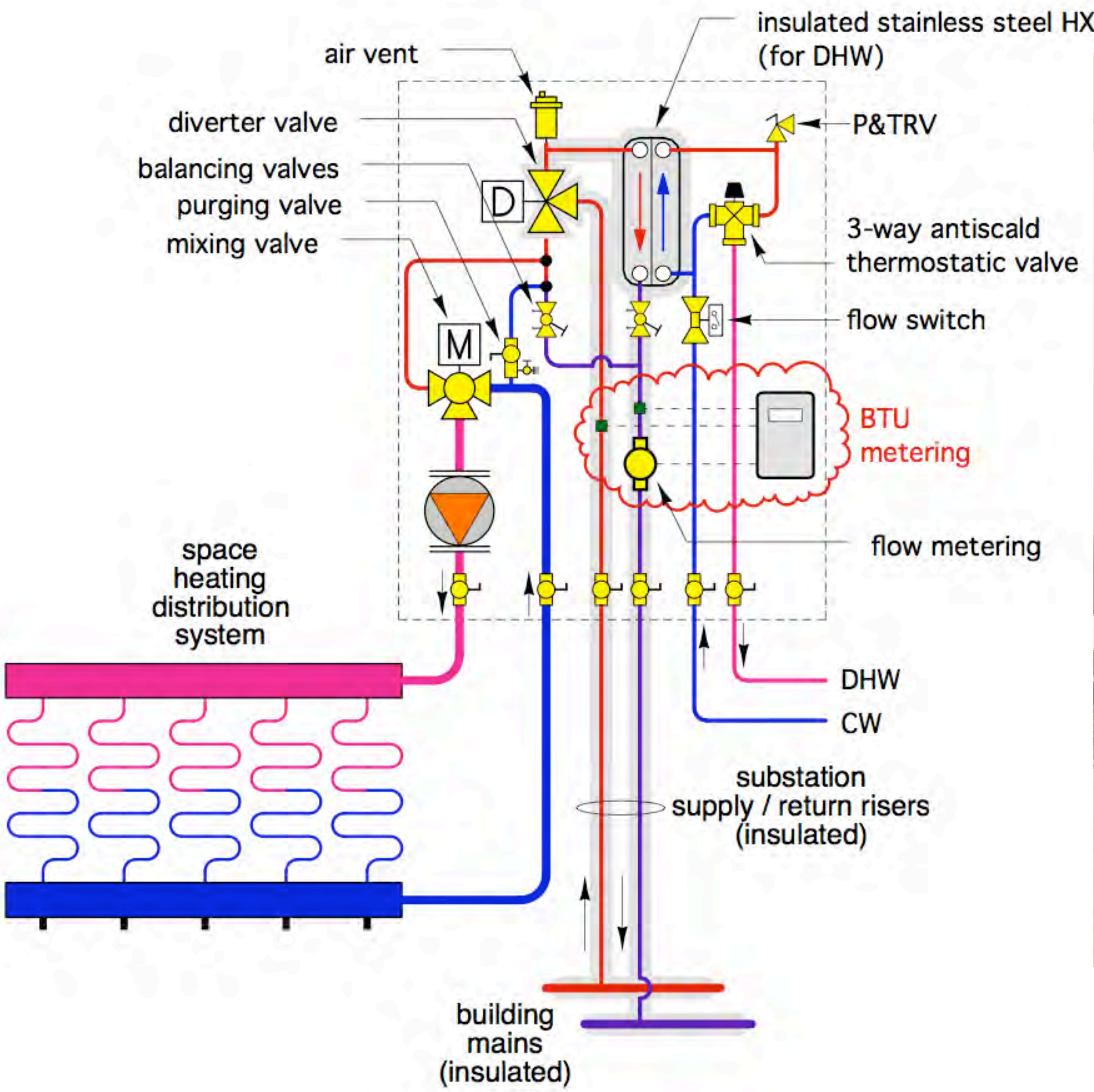
- Heat metering can be used as a trouble shooting tool to verify the actual rate of heat delivery to the space.

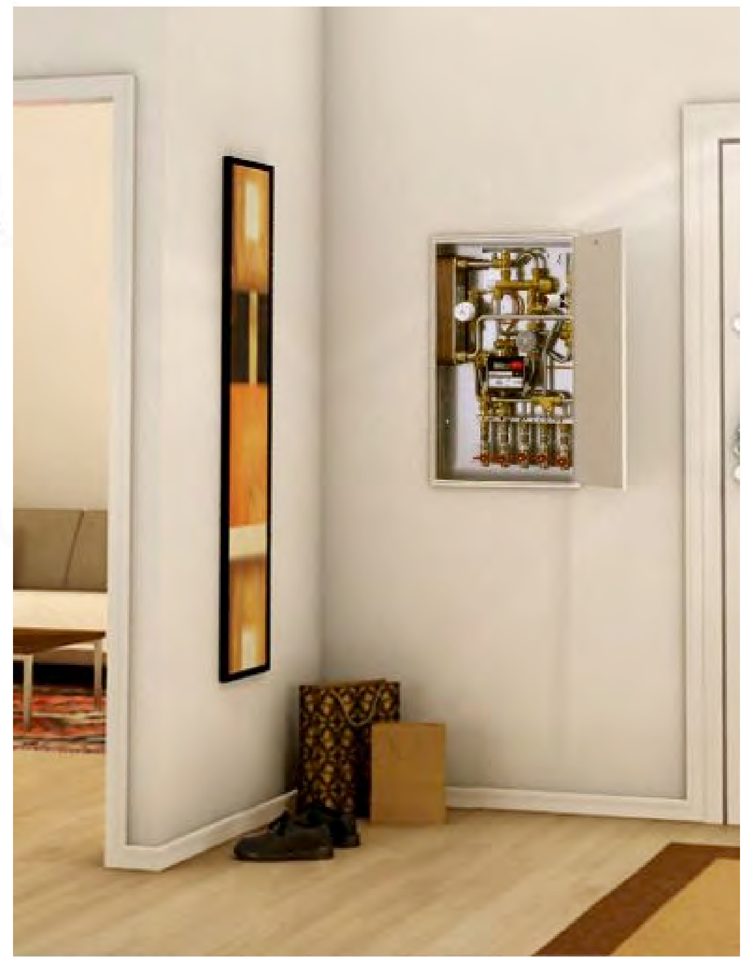
Piping of a typical "substation" for condo, apartment, or office, (space heating and instantaneous DHW)



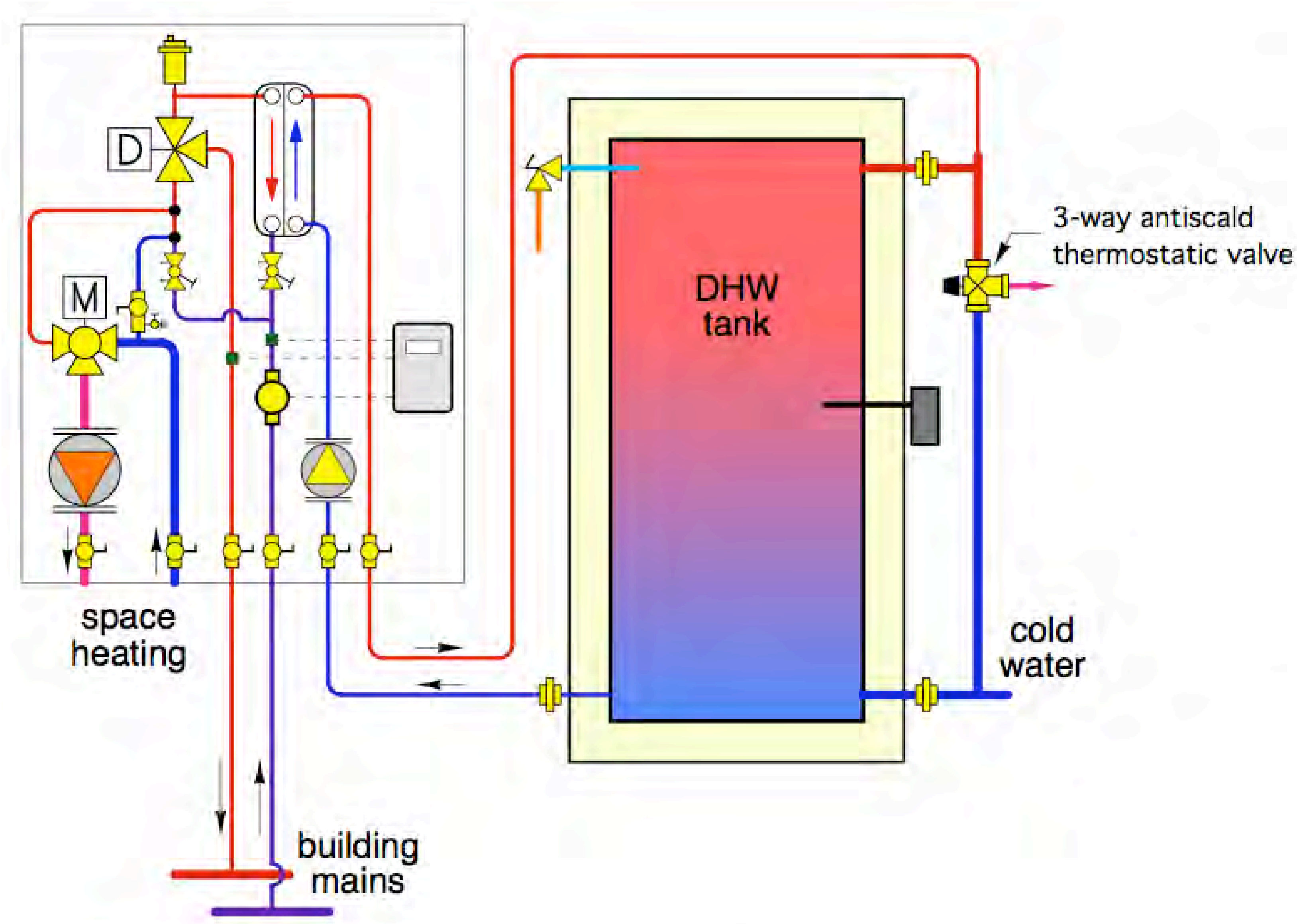


Piping of a typical "substation" for condo, apartment, or office, (space heating and instantaneous DHW)

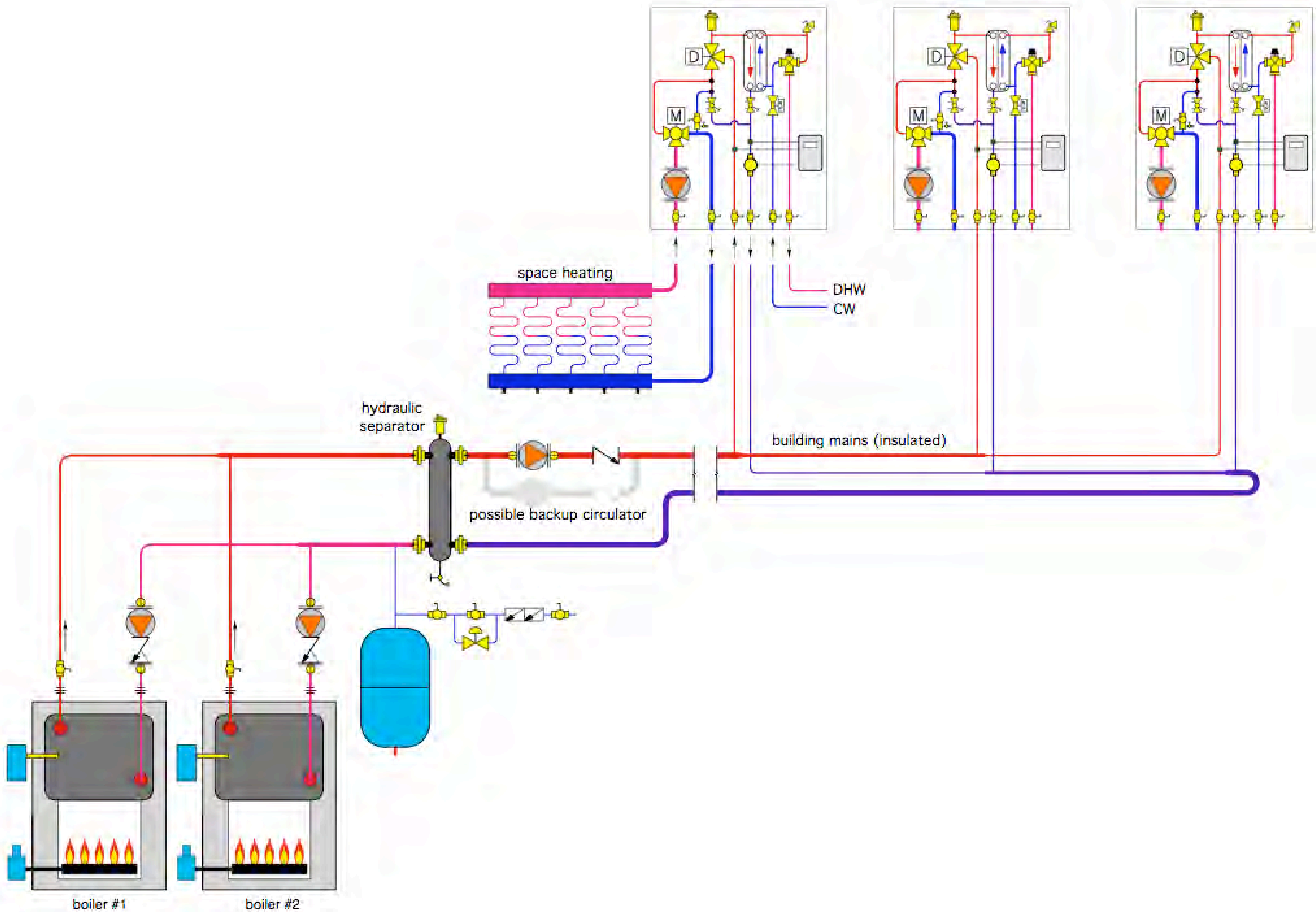




Piping of a typical "substation" for condo, apartment, or office, (space heating and storage-type DHW)



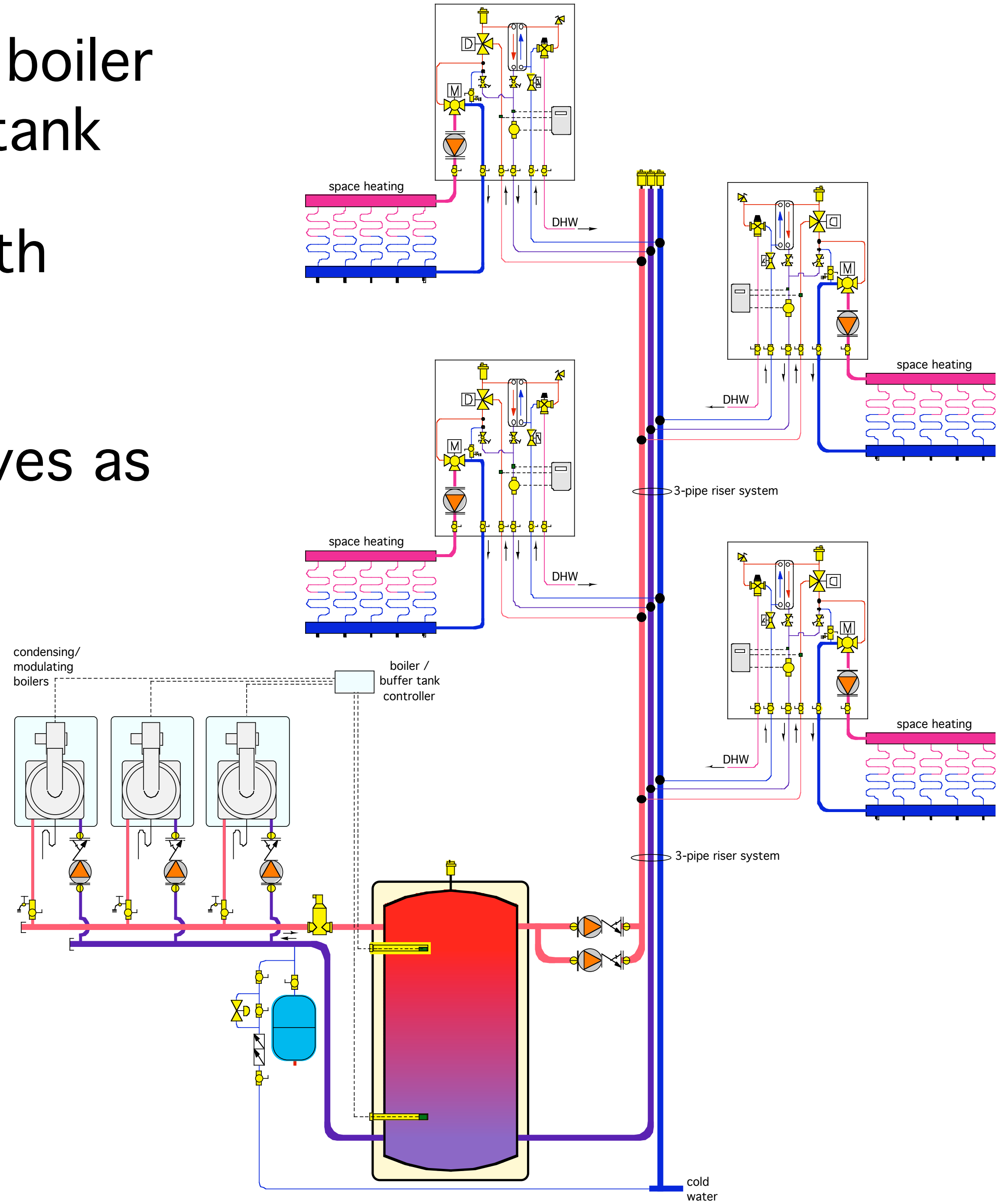
Piping Concepts (centralized multiple boiler system)



Centralized multiple boiler system with buffer tank

Buffer tank helps with high peak demands

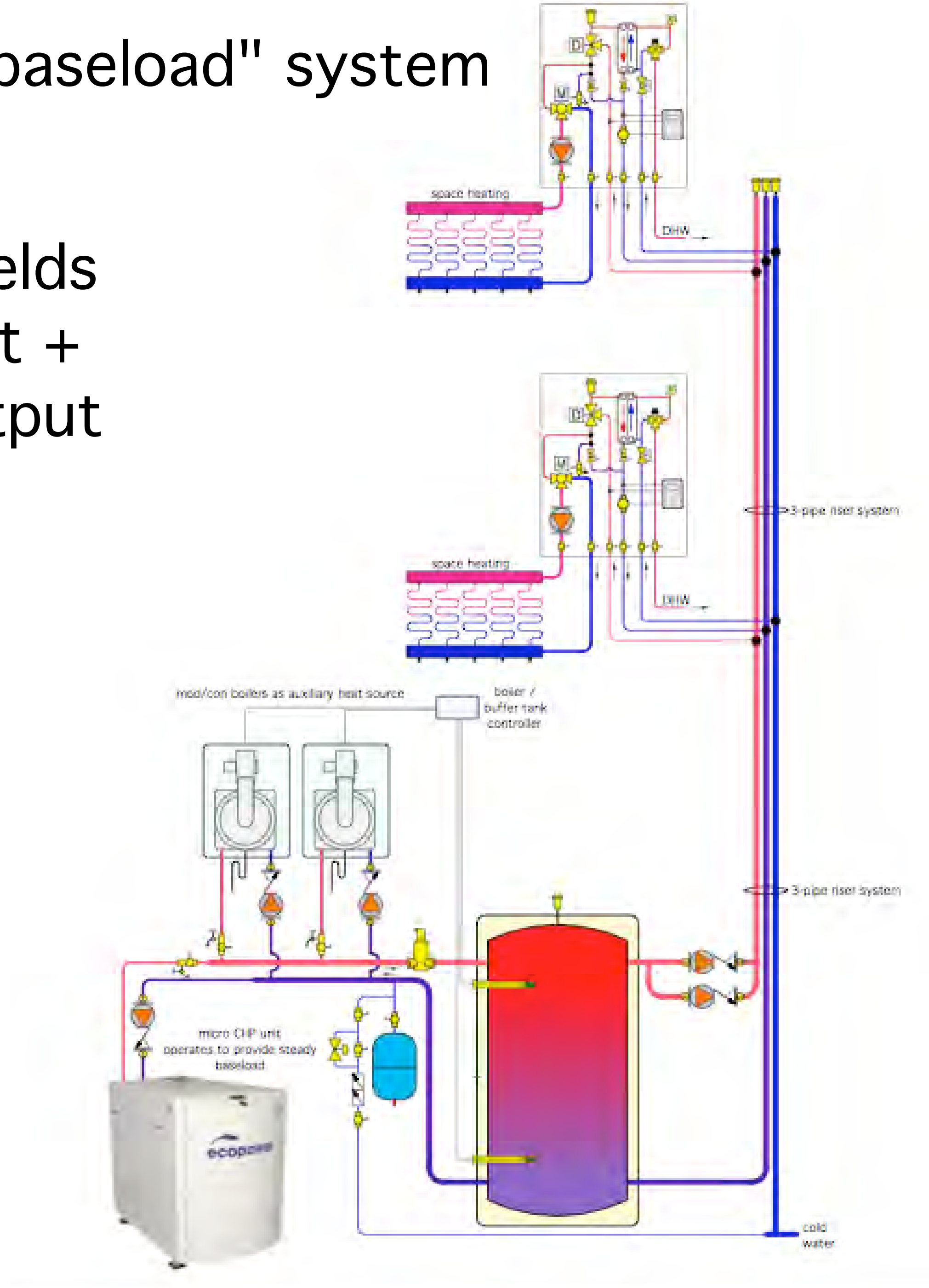
Buffer tank also serves as Hydraulic separator between boilers and distribution mains



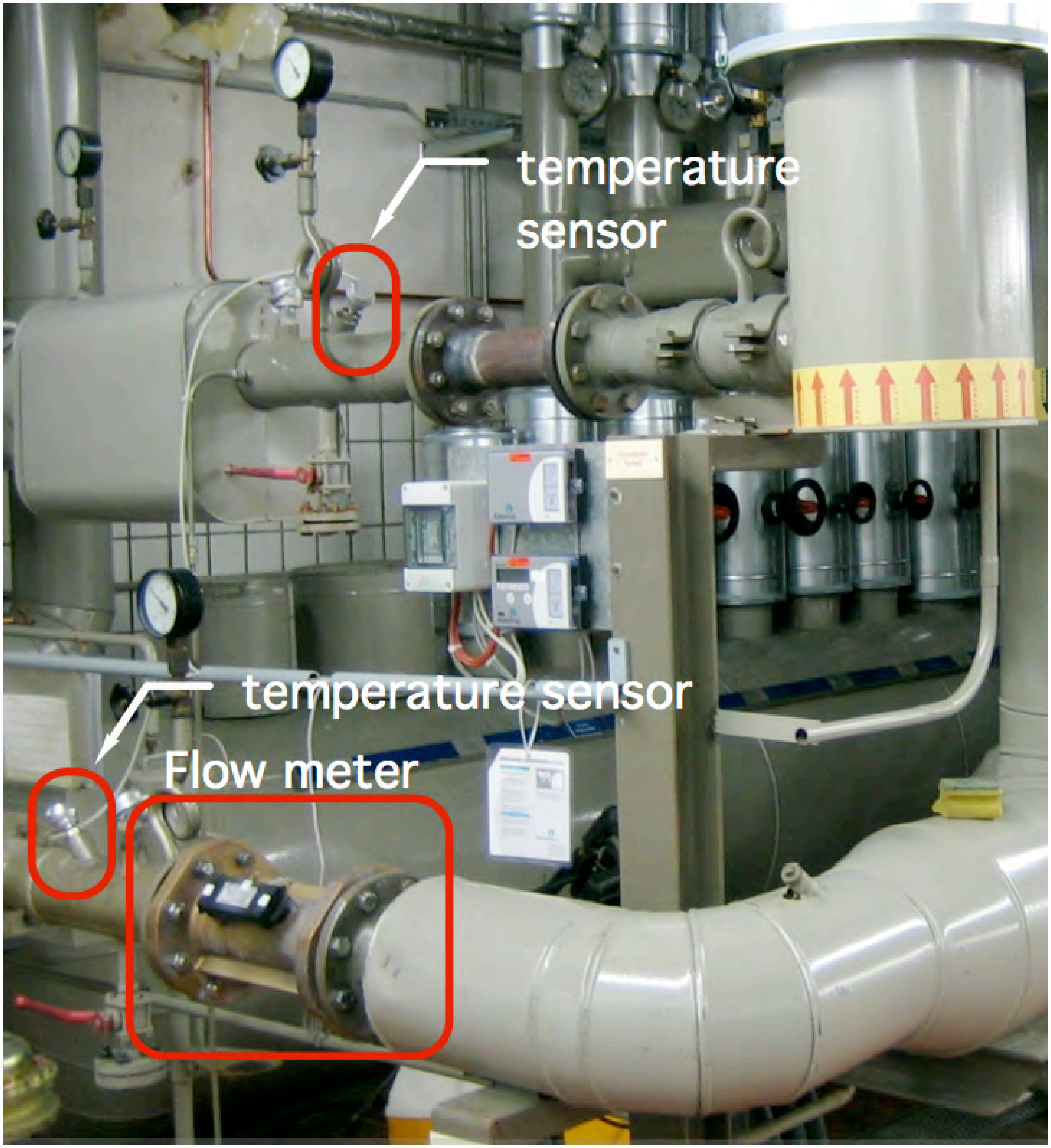
Use of micro CHP unit to "baseload" system

- Typical small CHP unit yields about 5kw electrical output + 50,000 Btu/hr thermal output

- Boilers stage / modulate as necessary during higher loads.



Heat metering in large German office building



Web-enabled BTU Metering equipment is now available.

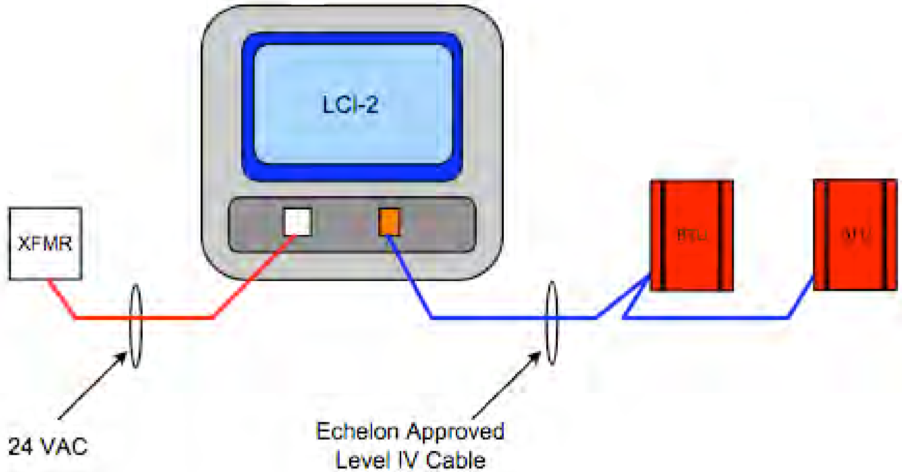
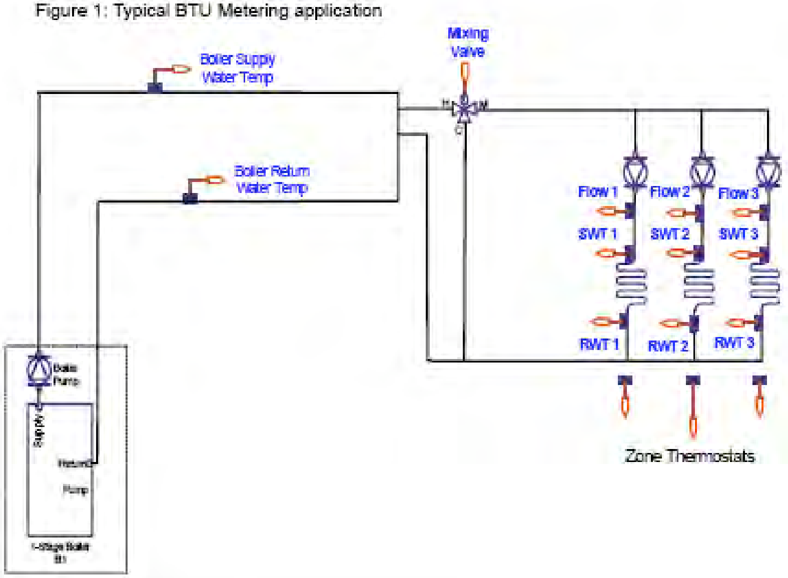
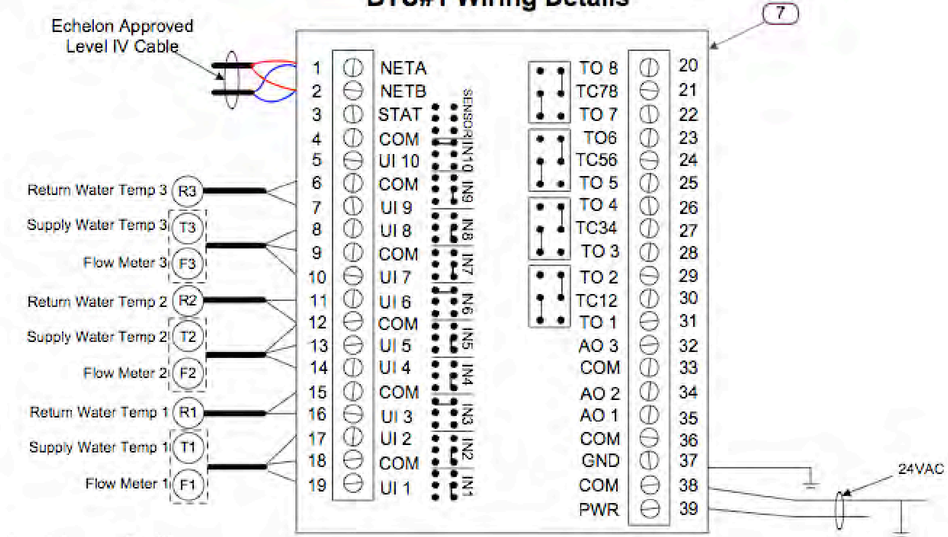


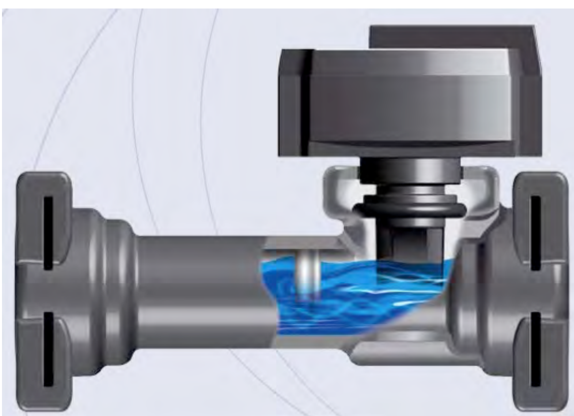
Figure 1: Typical BTU Metering application

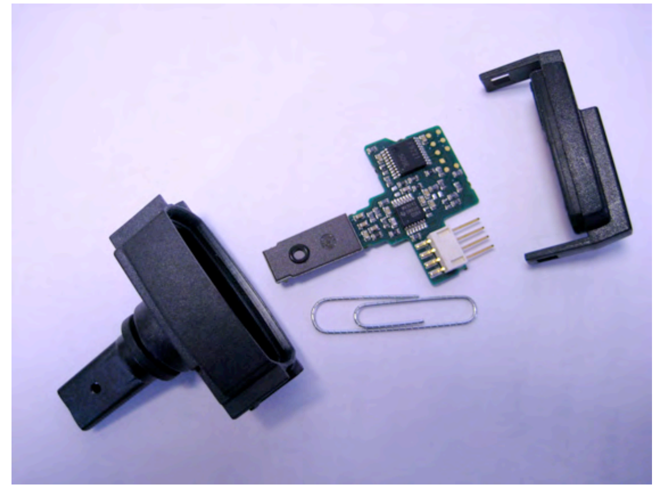


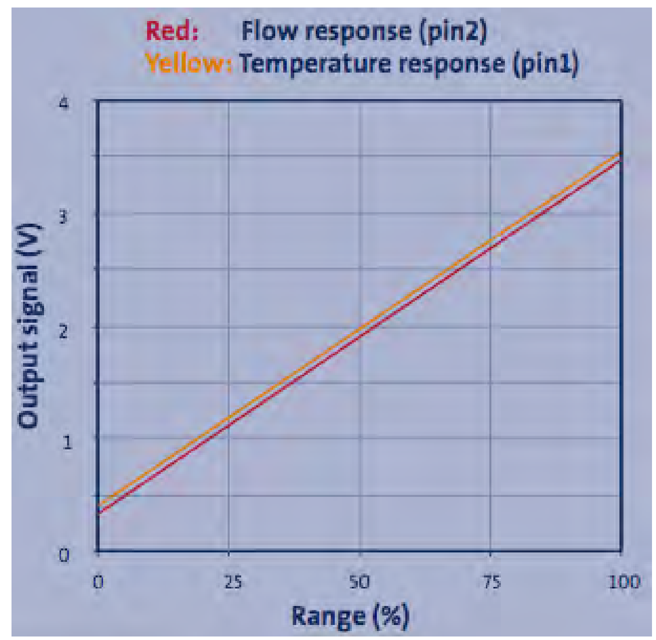
BTU#1 Wiring Details



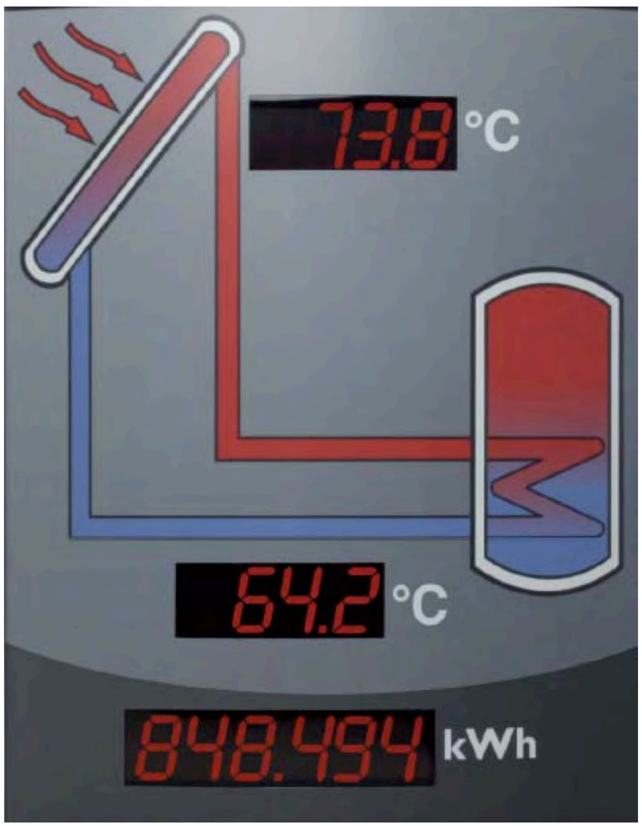
New, low-cost multi-function sensor technology (for flow, pressure, and temperature) will allow appliances to monitor and report their own energy flows.

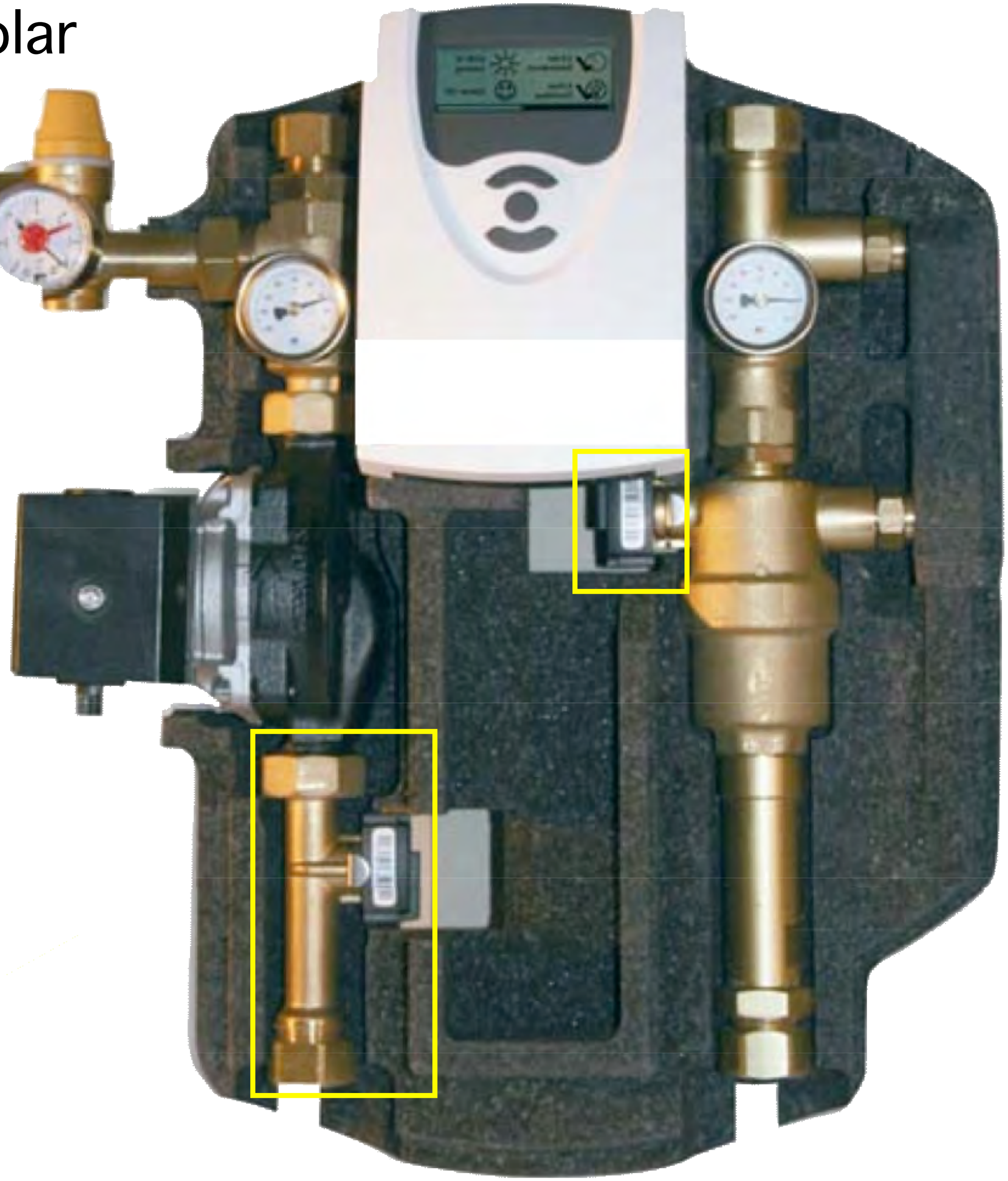




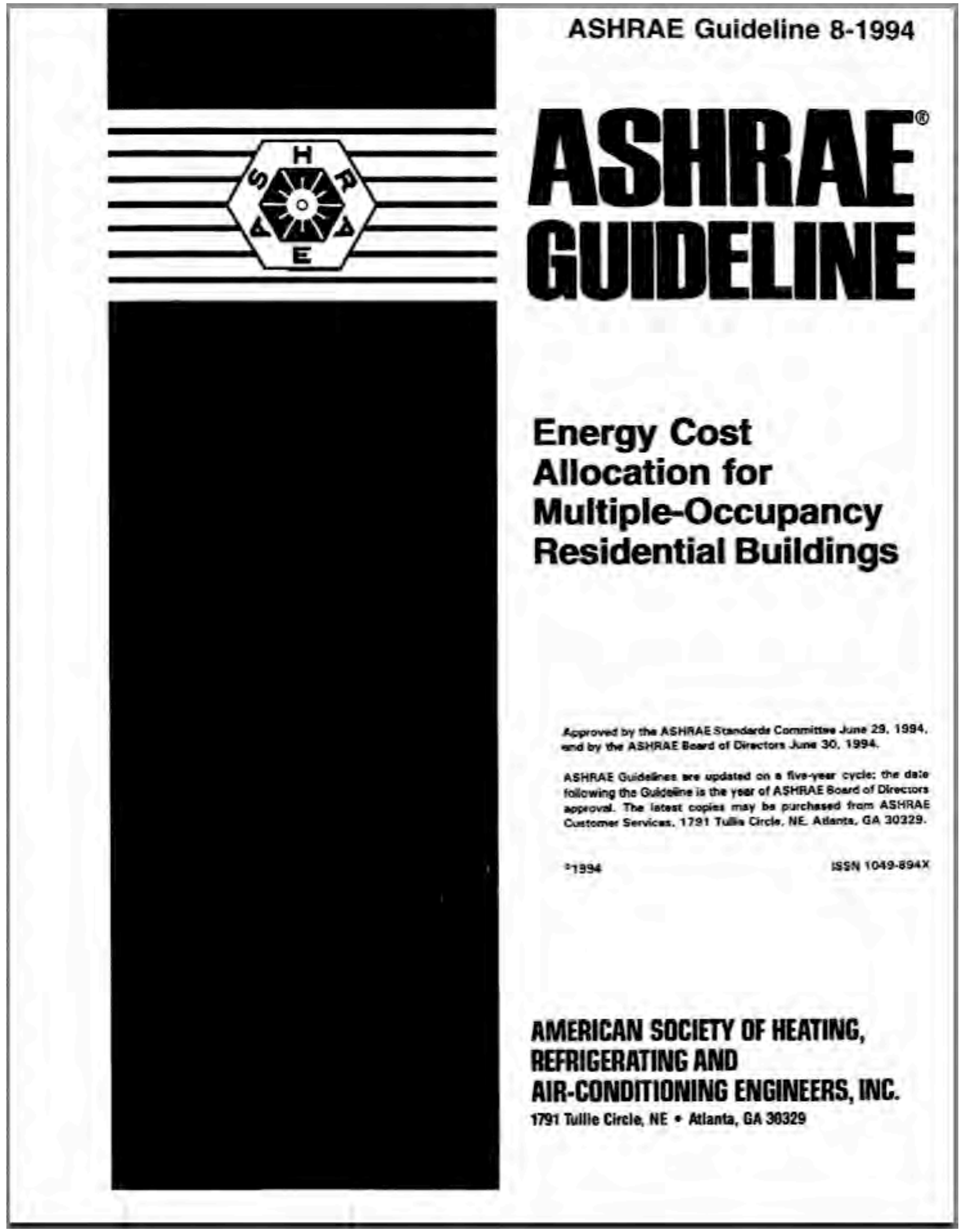


Here it is used in a solar circulation station.





ASHRAE standard on energy cost allocation



ASHRAE Guideline 8-1994

ASHRAE® GUIDELINE

Energy Cost Allocation for Multiple-Occupancy Residential Buildings

Approved by the ASHRAE Standards Committee June 29, 1994, and by the ASHRAE Board of Directors June 30, 1994.

ASHRAE Guidelines are updated on a five-year cycle; the date following the Guideline is the year of ASHRAE Board of Directors approval. The latest copies may be purchased from ASHRAE Customer Services, 1791 Tullie Circle, NE, Atlanta, GA 30329.

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AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
1791 Tullie Circle, NE • Atlanta, GA 30329

We’ve only discussed the basics of BTU metering.

In my opinion it’s a highly underutilized strategy in North America, at least for the present.

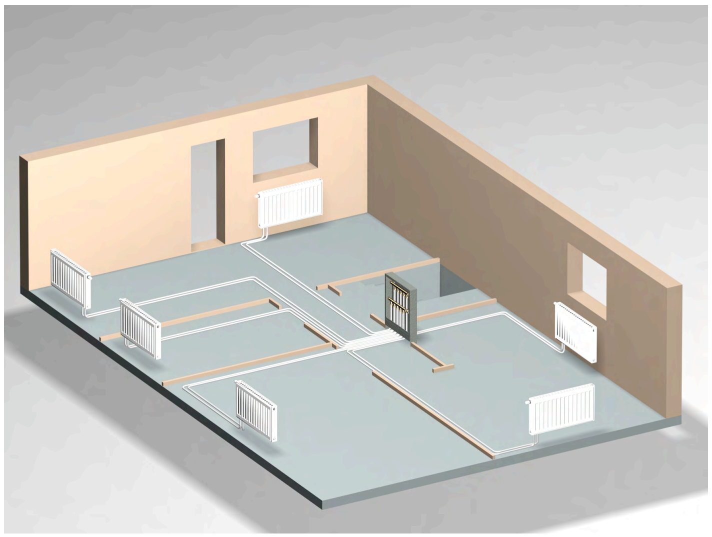
It’s perfect for the multiple unit buildings (both residential and commercial) now being built in North America.

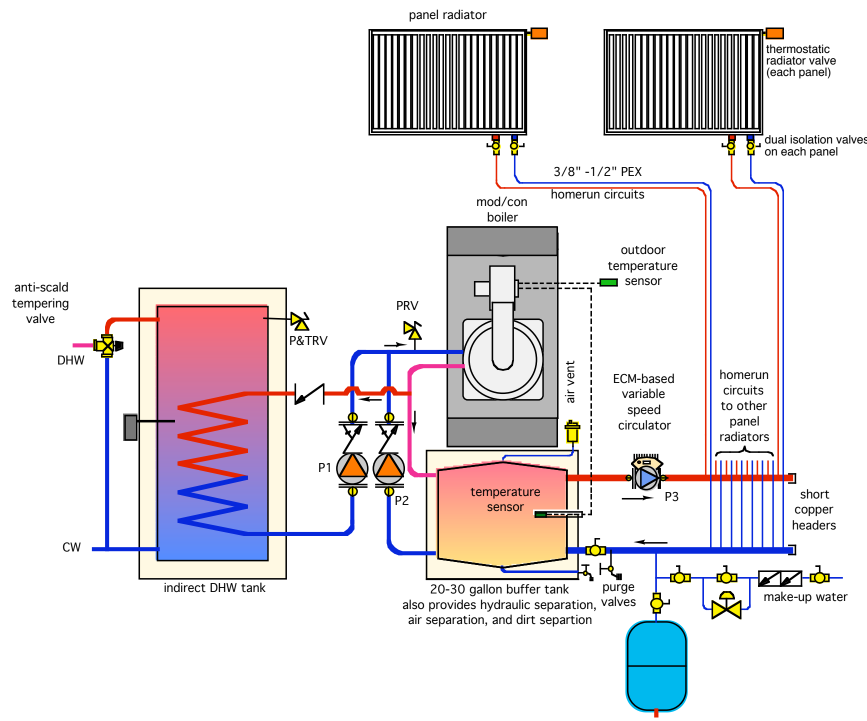
It addresses the concerns of developers, owners, and tenants in a synergistic and mutually beneficial manner.

It also encourages energy conservation while providing the potential of unsurpassed comfort heating and instantly available DHW.

It’s time for our industry to get serious with this concept and deploy it on a much larger basis.

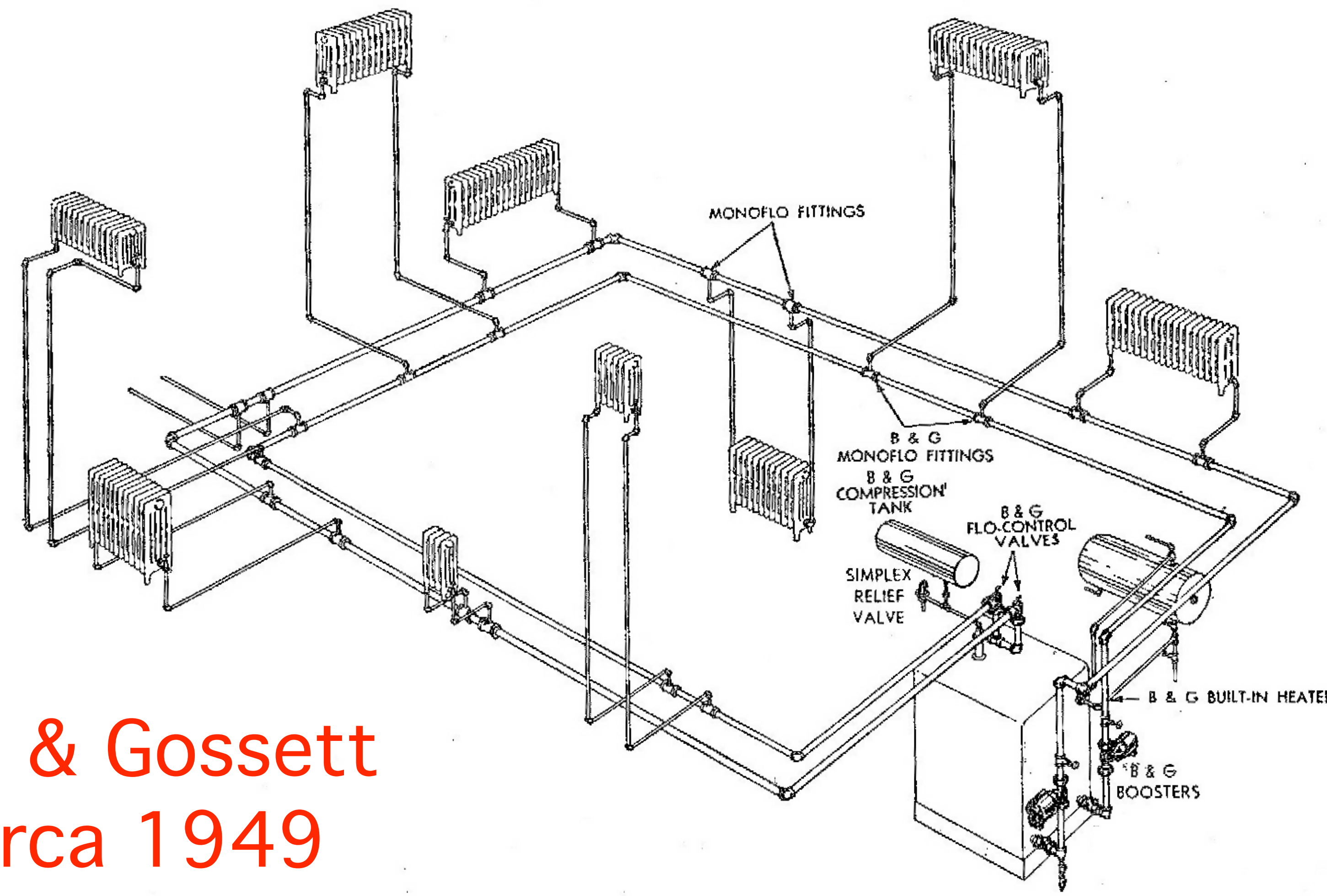
Creative Use of
Homerun Distribution Systems





Over the last few decades, many different piping layouts have been used in hydronic heating system.

Almost all were developed around RIGID PIPING.



Bell & Gossett
Circa 1949

Fast-forward 50 years to the age of:

Zones gone Wild...

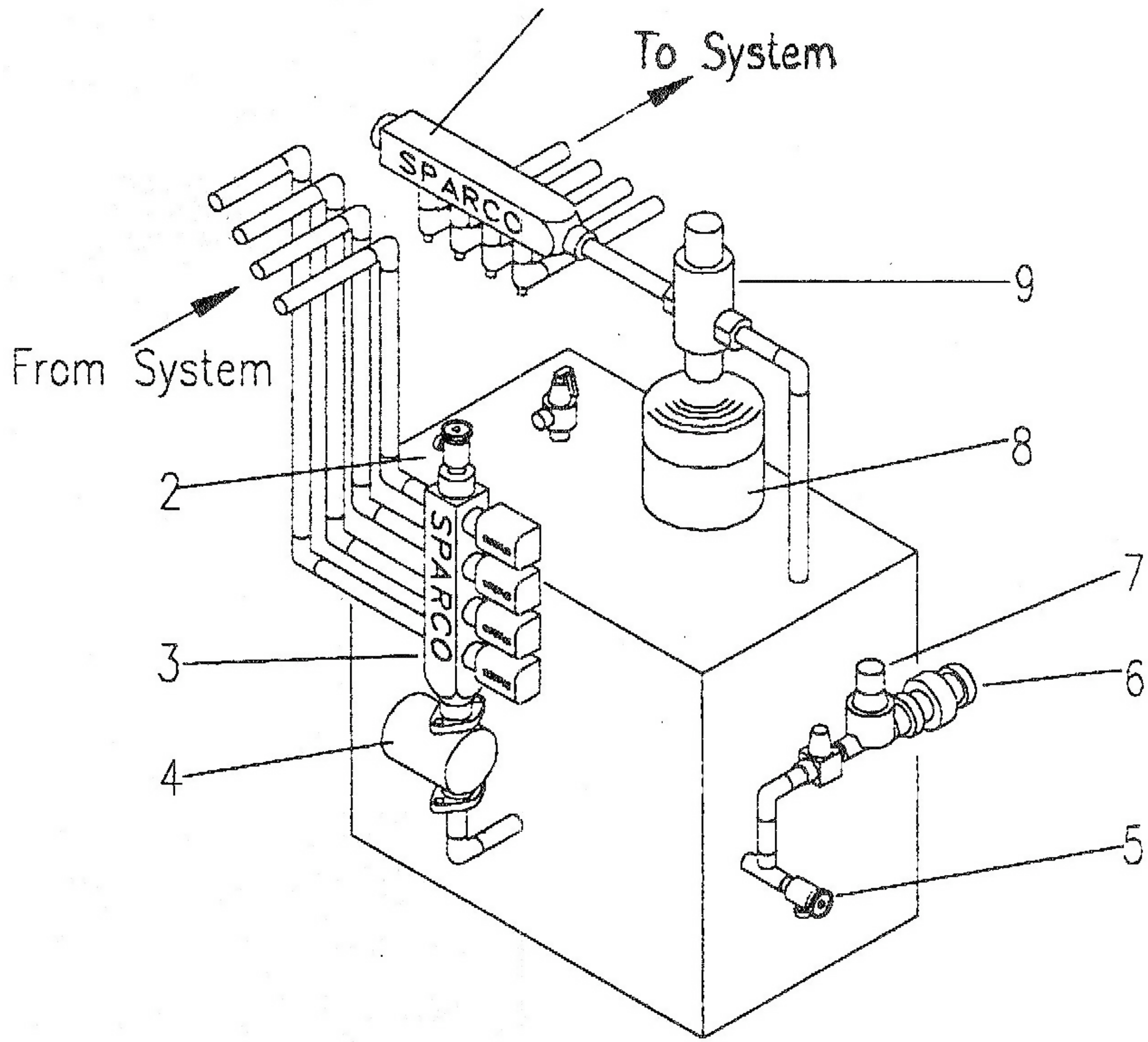
Lots or rigid pipe...

Lots of fittings...

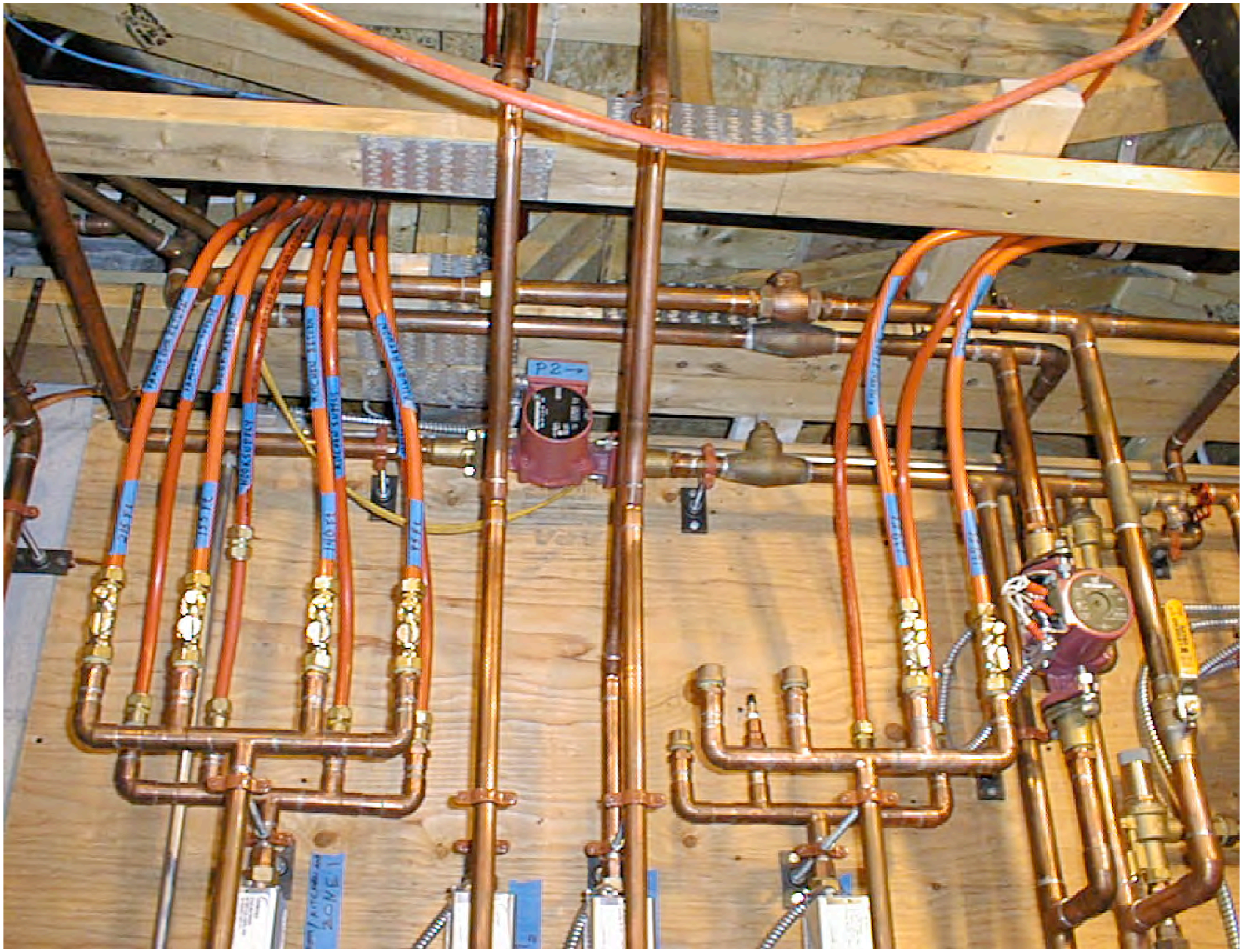
Lots of joints...

At times there were "hints" that manifolded individual circuits could be used...

But this concept was still built around the use of RIGID PIPING.



As more time passed, North American heating pros started mixing flexible PEX and PEX-AL-PEX tubing into system along with rigid tubing.



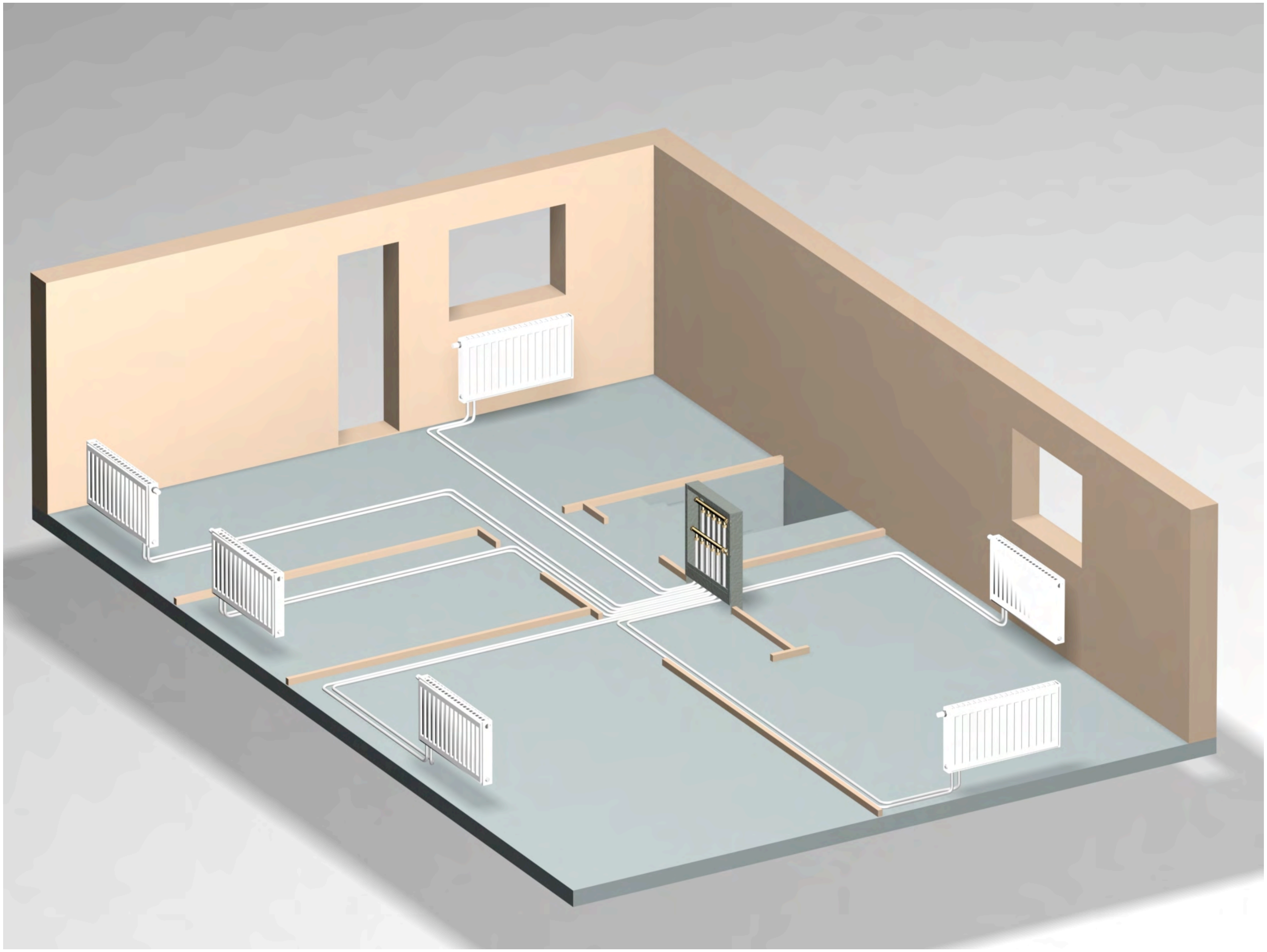
However, PEX and PEX-AL-PEX were still viewed *primarily* for use in radiant panel circuits.

Finally, many hydronic heating pros have recognized the potential of flexible PEX or PEX-AL-PEX as a ***universal hydronic distribution pipe.***

The temperature / pressure rating of these materials, along with their flexibly, allows them to be used with traditional higher temperature heat emitters.

The most common approach has come to be known as a **"homerun"** system.

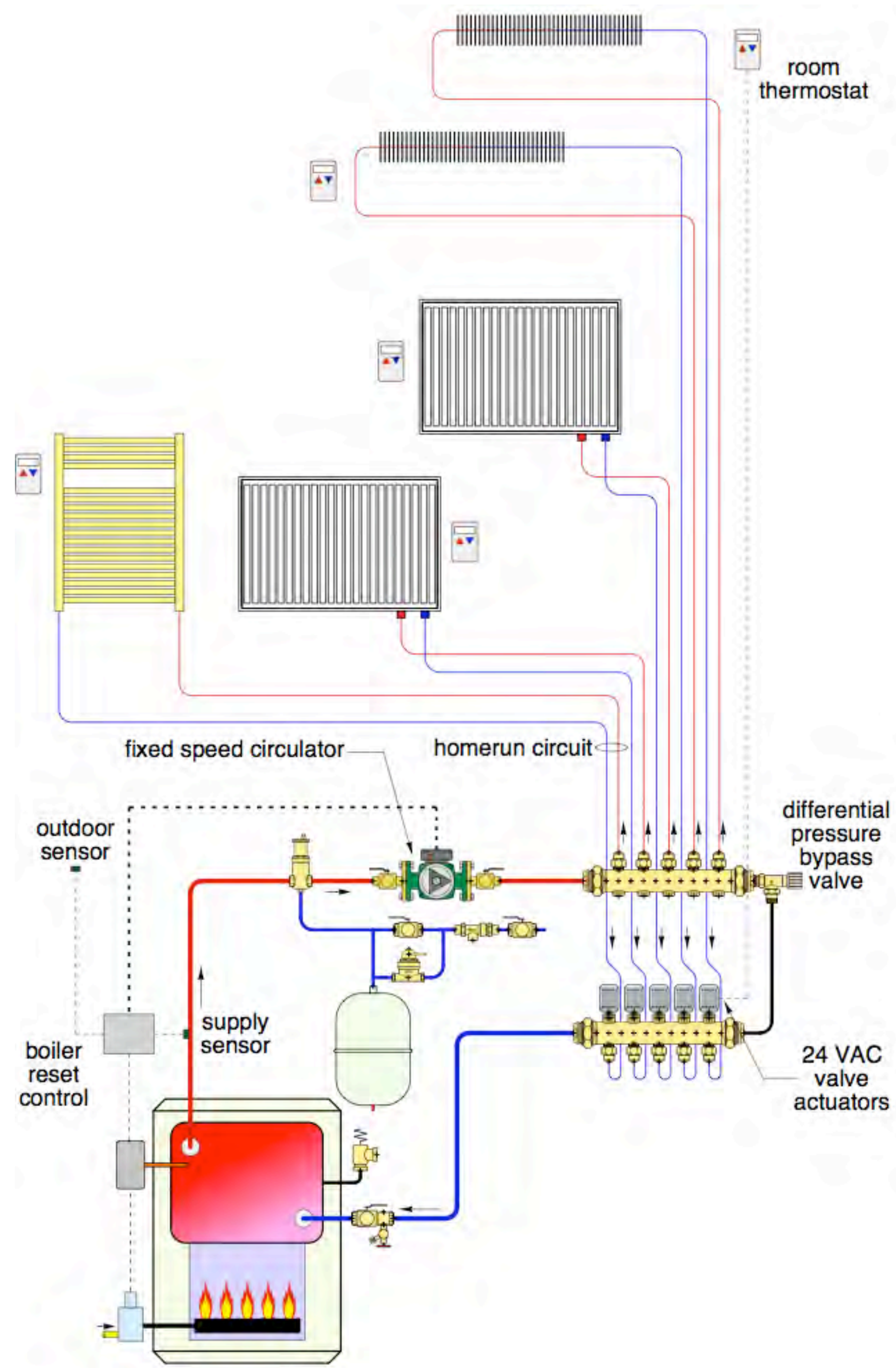
Concept of a homerun distribution system...



Schematic of a homerun distribution system

Two runs of small diameter (3/8” or 1/2”) PEX, or PEX-AL-PEX tubing is routed from a manifold station to each heat emitter.

The ability to “fish” tubing through framing cavities is a tremendous advantage over rigid tubing, especially in retrofit situations.

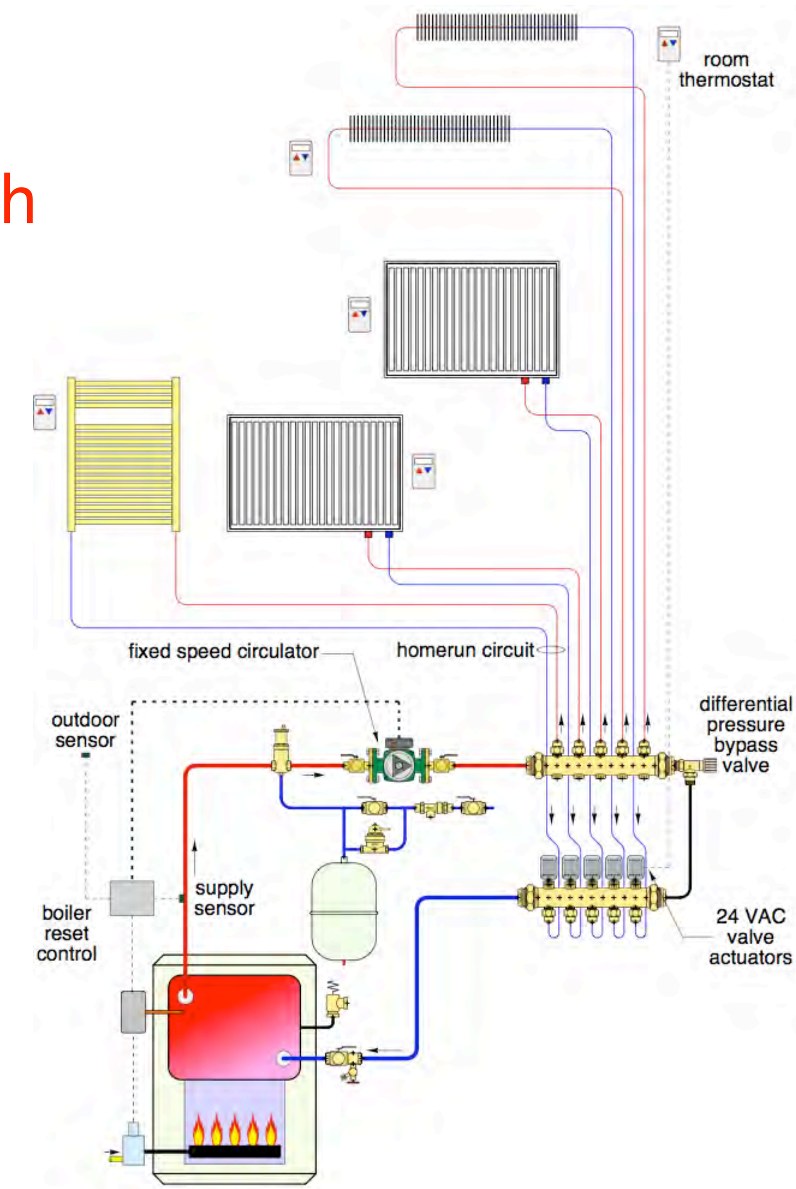


Homerun systems allow the heat output of each room to be individually controlled.

Homerun systems deliver the same water temperature to each heat emitter.

Homerun systems adapt to almost any combination of heat emitters.

Balancing valves on manifold compensate for the flow resistances of different circuits.



Homerun systems allow several methods of zoning.

One approach is to install valved manifolds equipped with low voltage valve actuators on each circuit.

Another approach is to install a thermostatic radiator valve (TRV) on each heat emitter.

Suppose you wanted to install a homerun system in a tall building such as a three-story house?

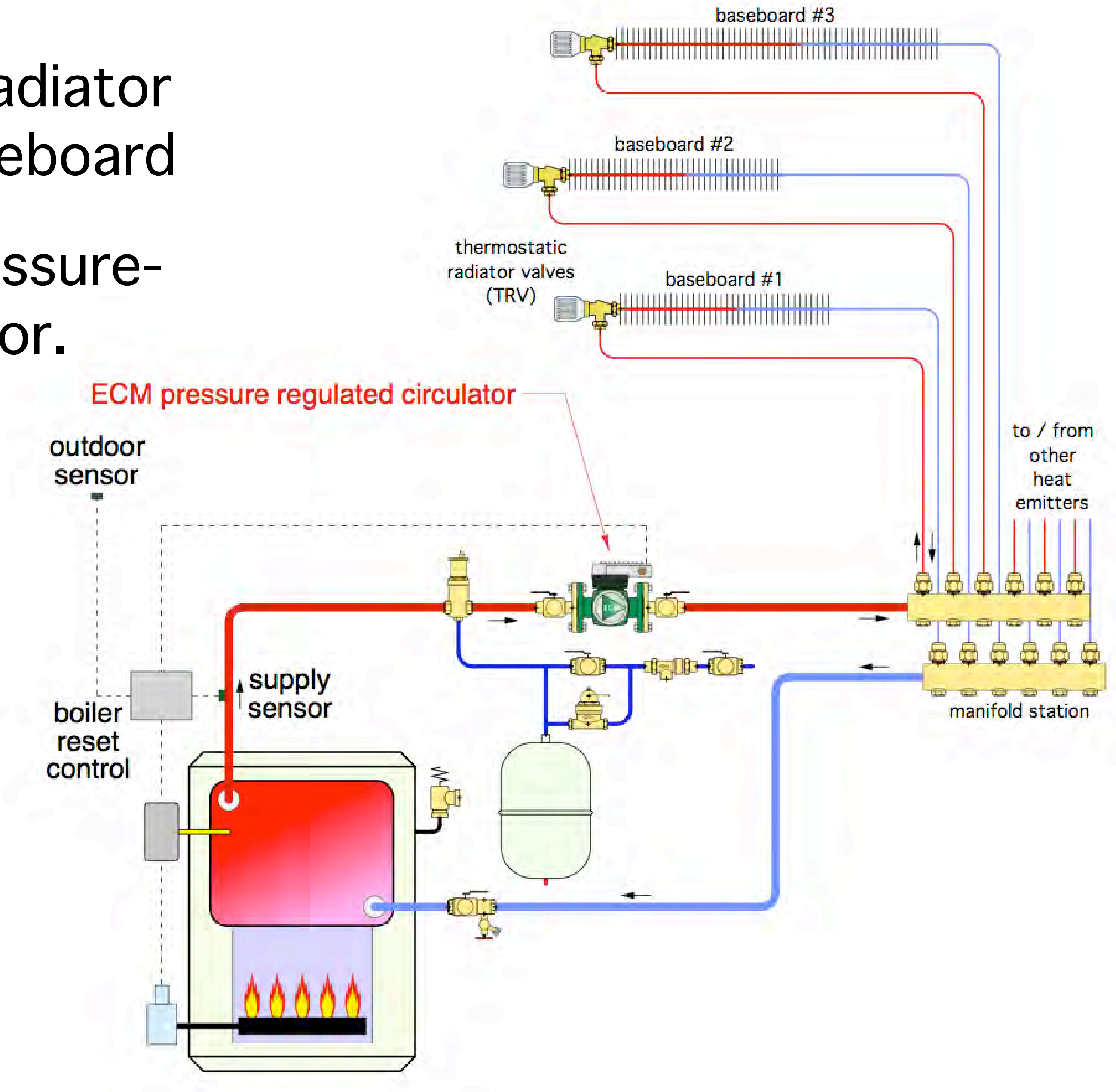
The solution is to plan a “stacked” manifold system supplied by a vertical riser system

Plan the vertical risers so they are reasonably close to the manifold station on each floor.

The modern way to install fin-tube baseboard:

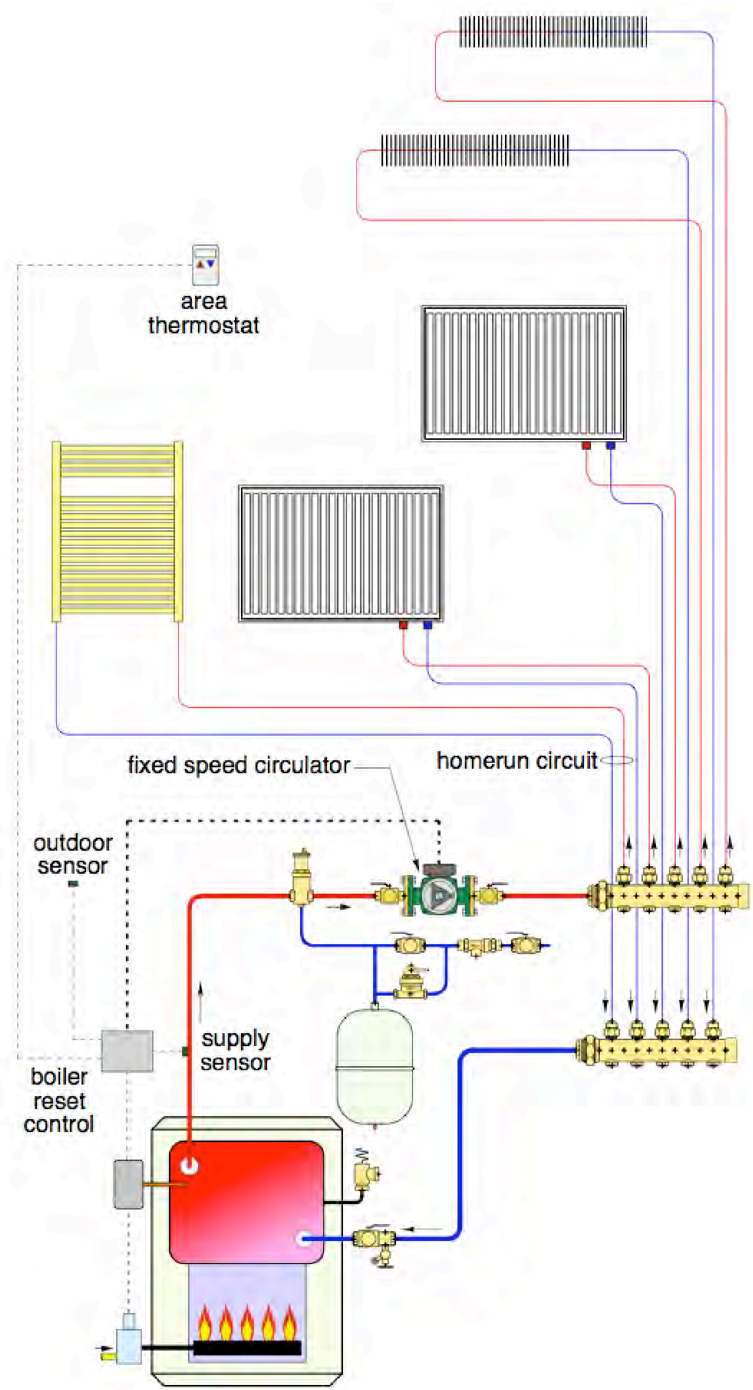
- Thermostatic radiator valve on each baseboard

- ECM-based pressure-regulated circulator.



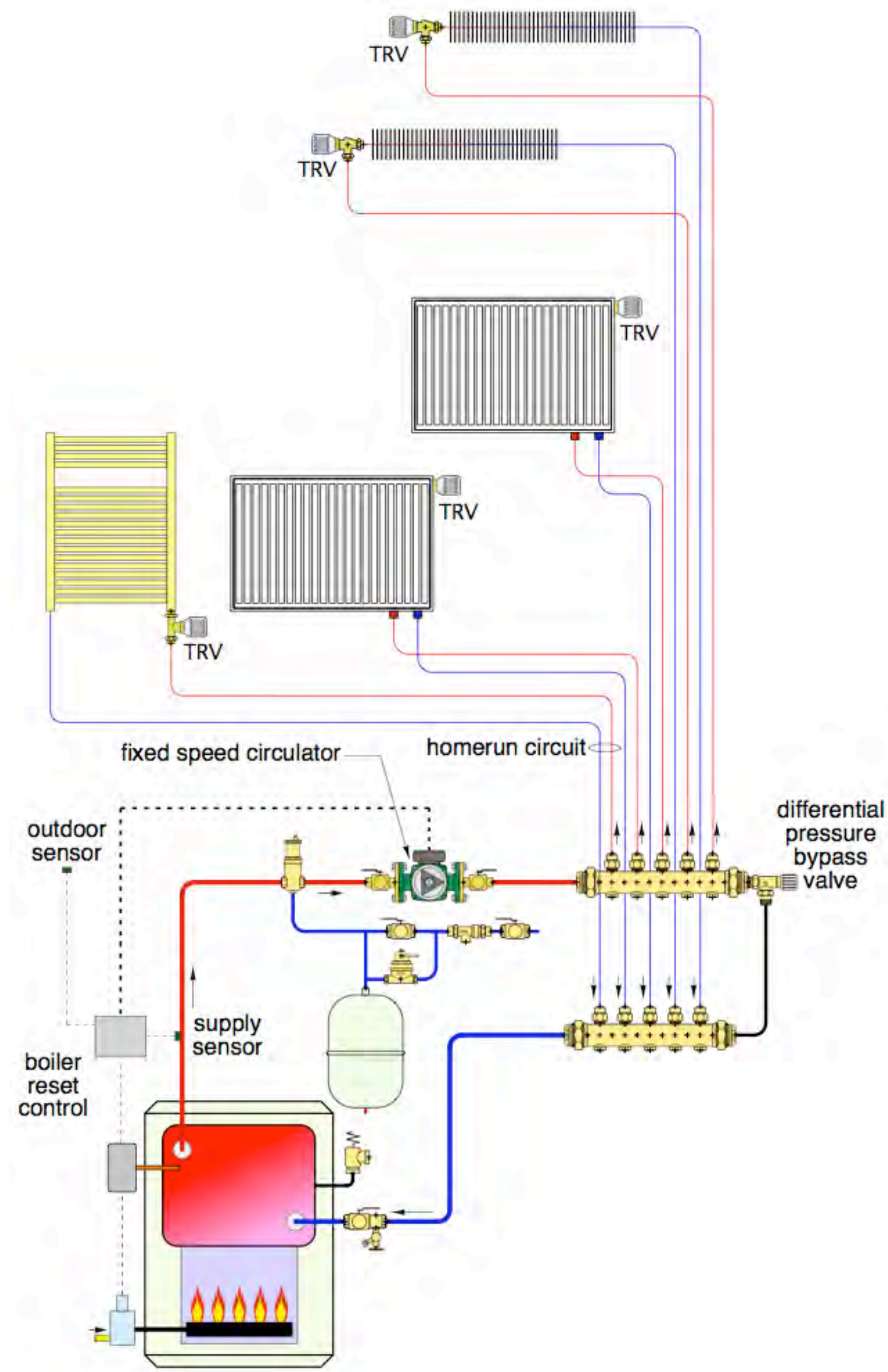
Control Options for Homerun Systems:

The simplest approach is a single zone system where all heat emitters operate simultaneously.



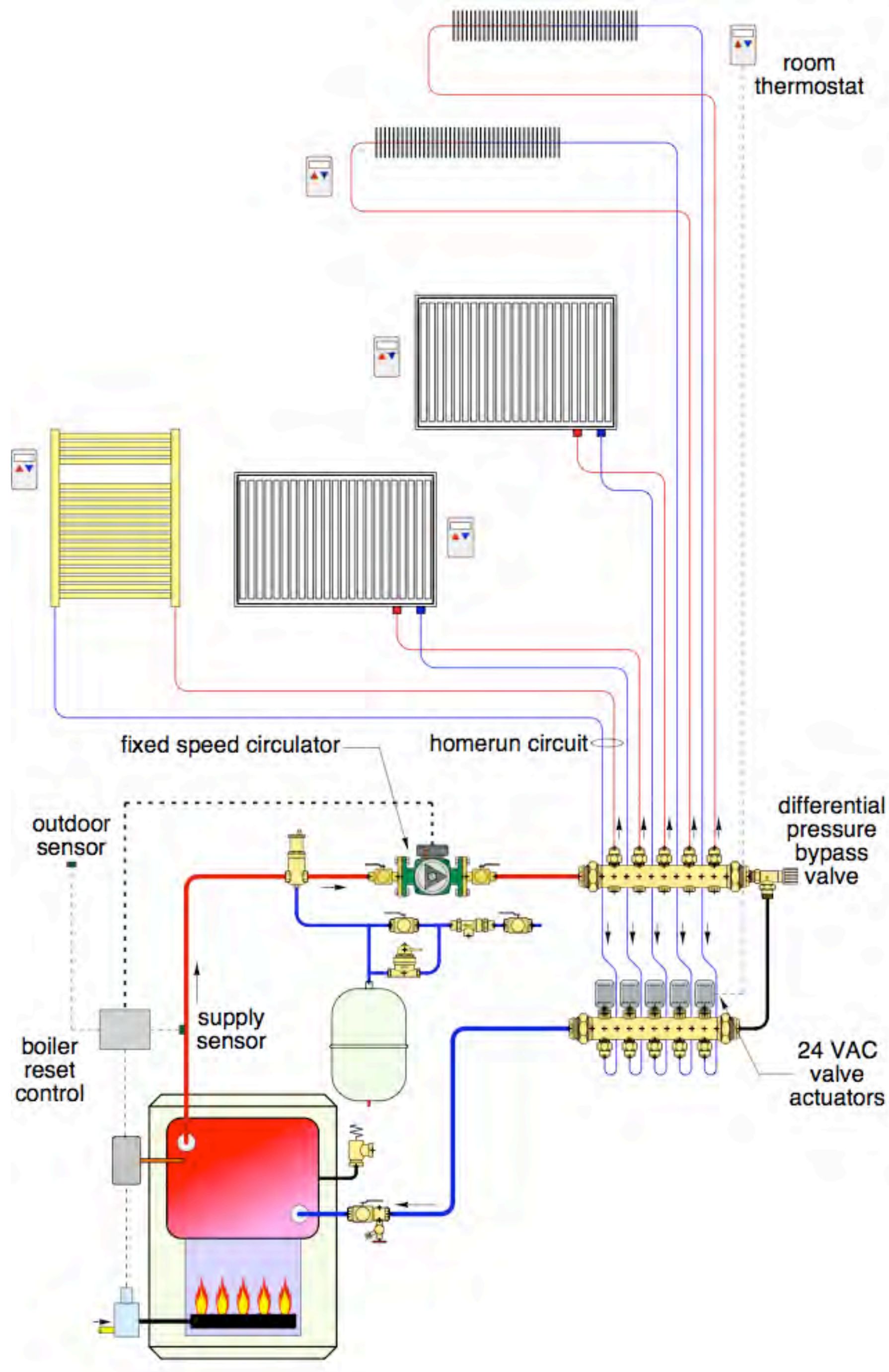
Control Options for Homerun Systems:

Adding TRVs to each heat emitter along with boiler reset provides excellent zoning and reduces fuel usage.



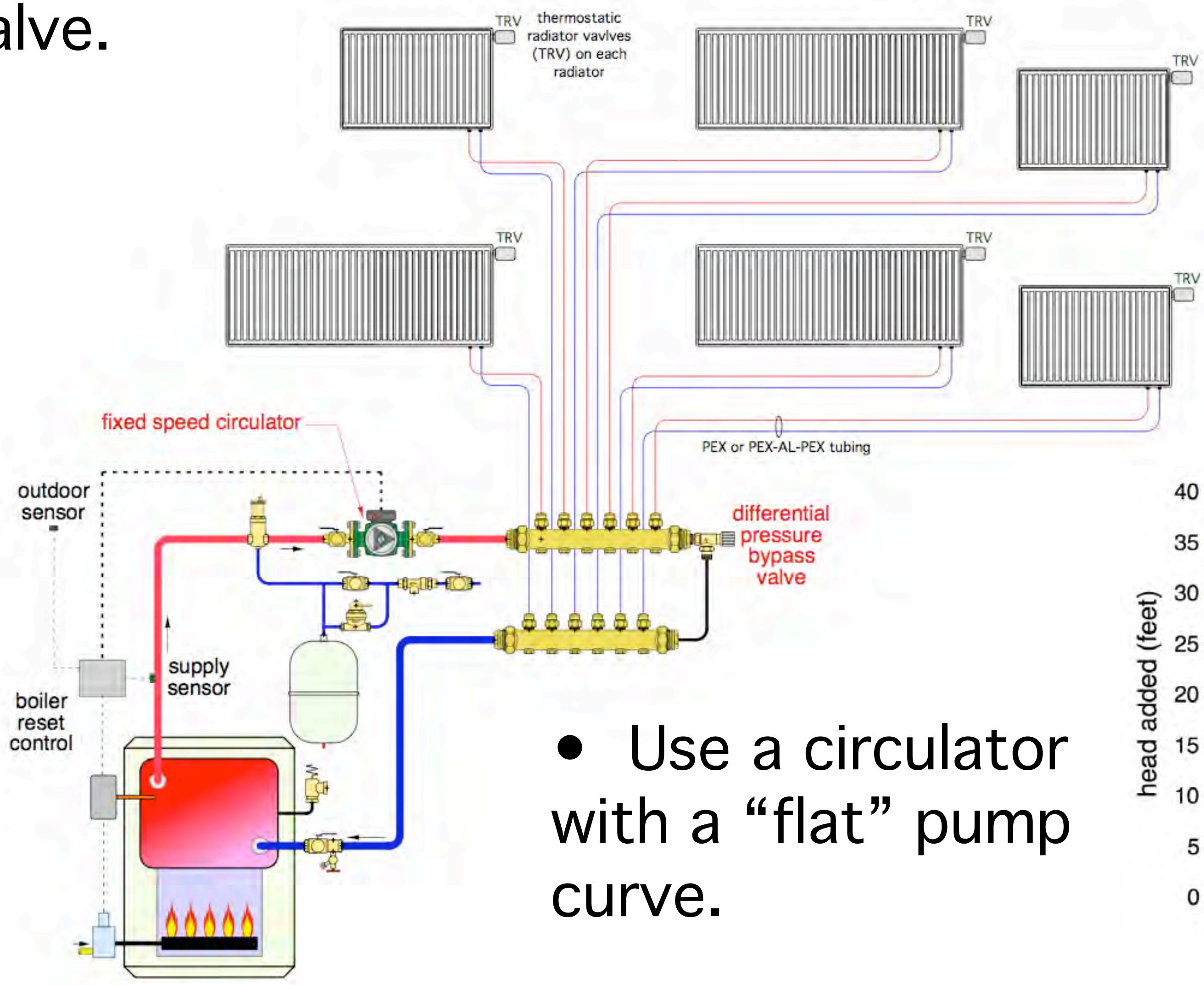
Control Options for Homerun Systems:

Zoning can also be done using room thermostats and 24VAC valve actuators.

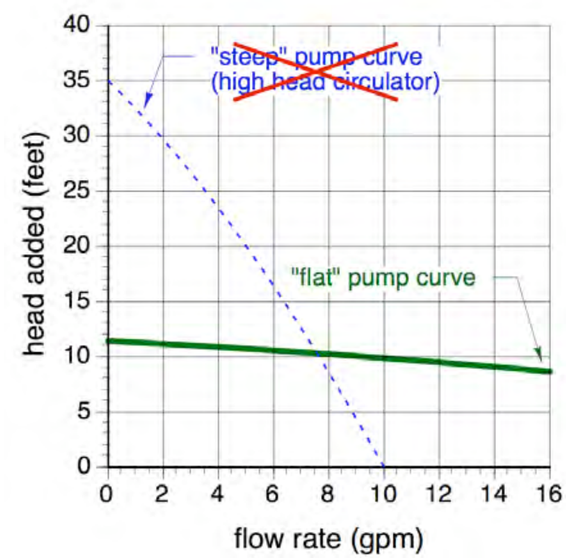


Don’t Forget the Details:

- When zoning with valves in combination with a fixed speed circulator, install a differential pressure bypass valve.



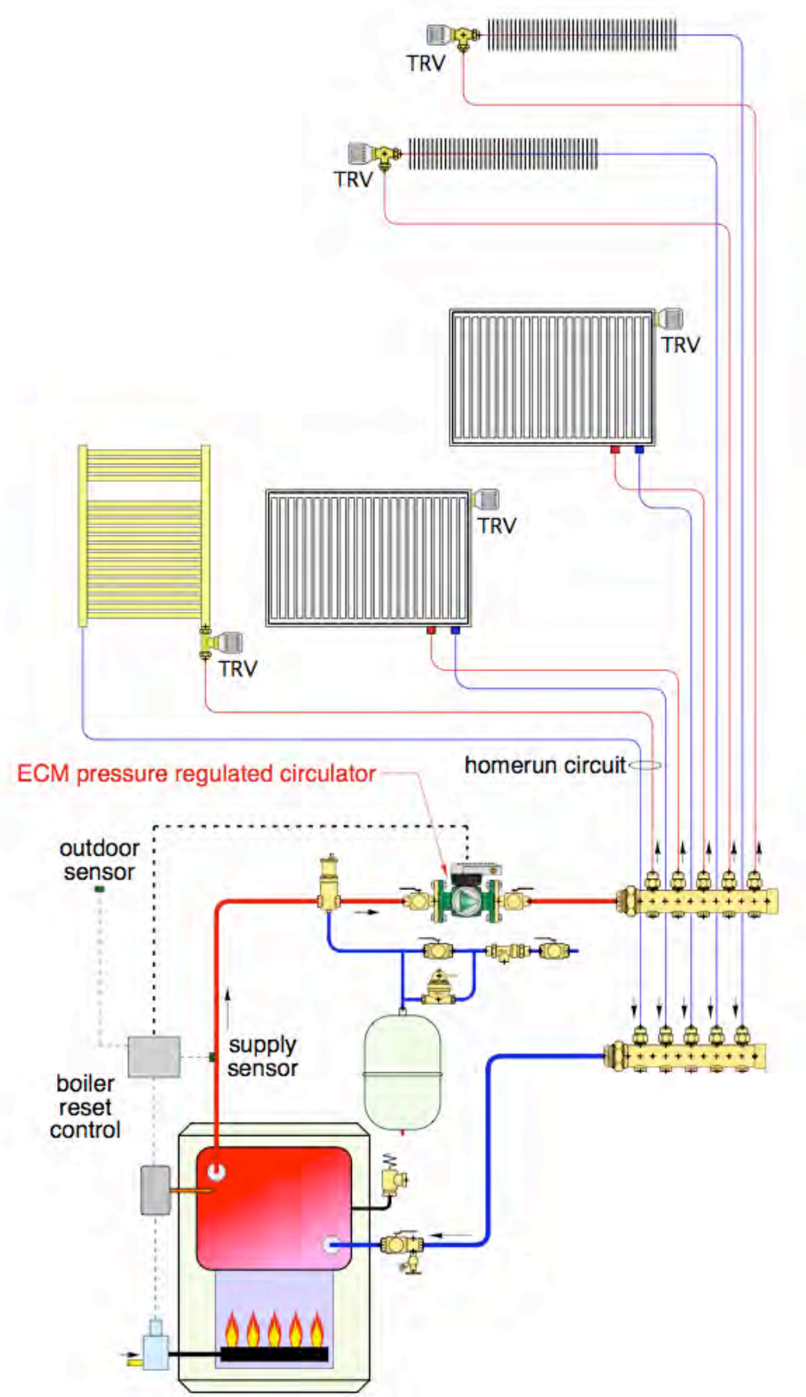
- Use a circulator with a “flat” pump curve.



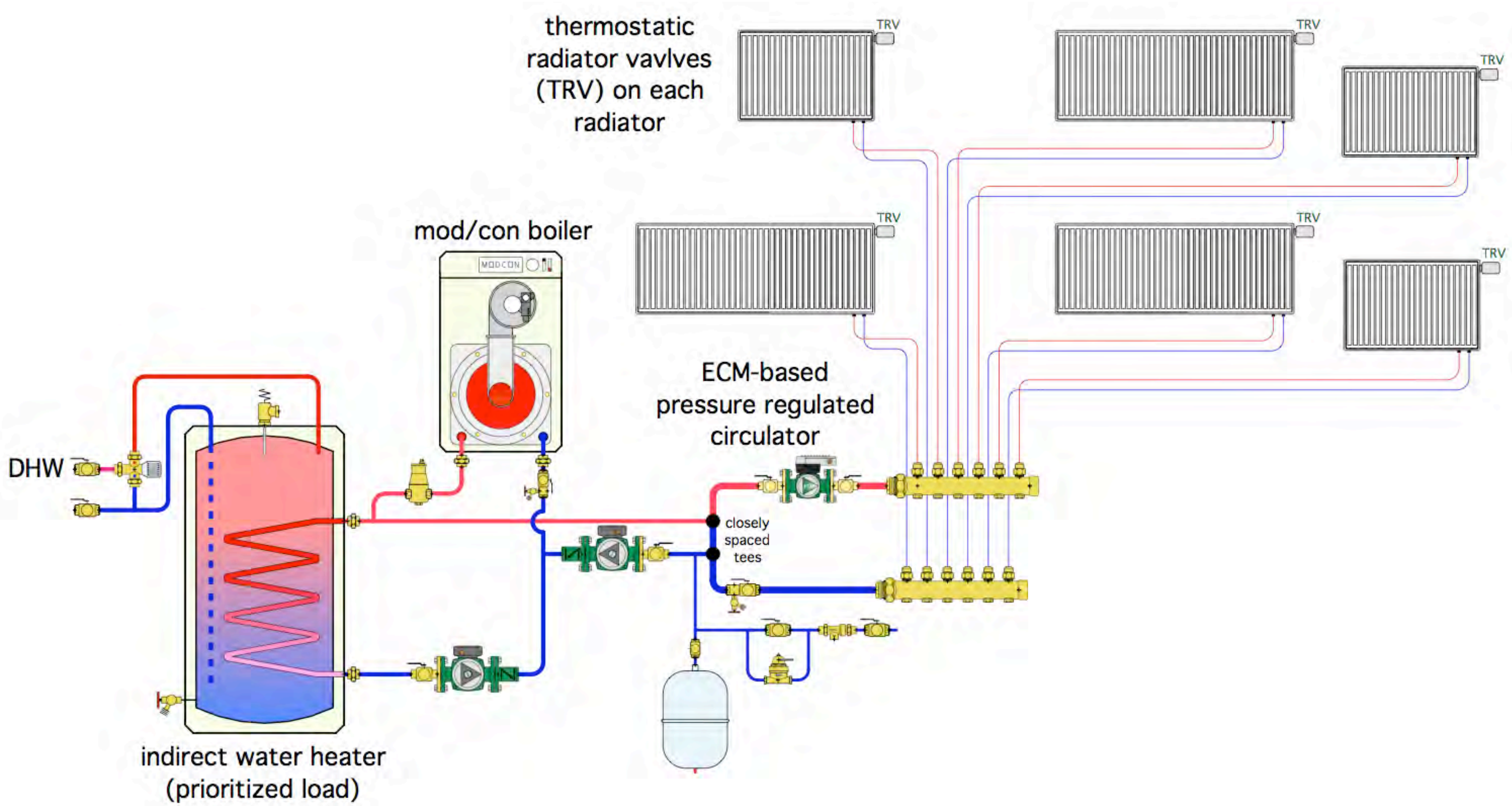
Control Options for Homerun Systems:

An ECM-based variable speed, pressure regulated circulator can be used with either TRV or actuator zoning.

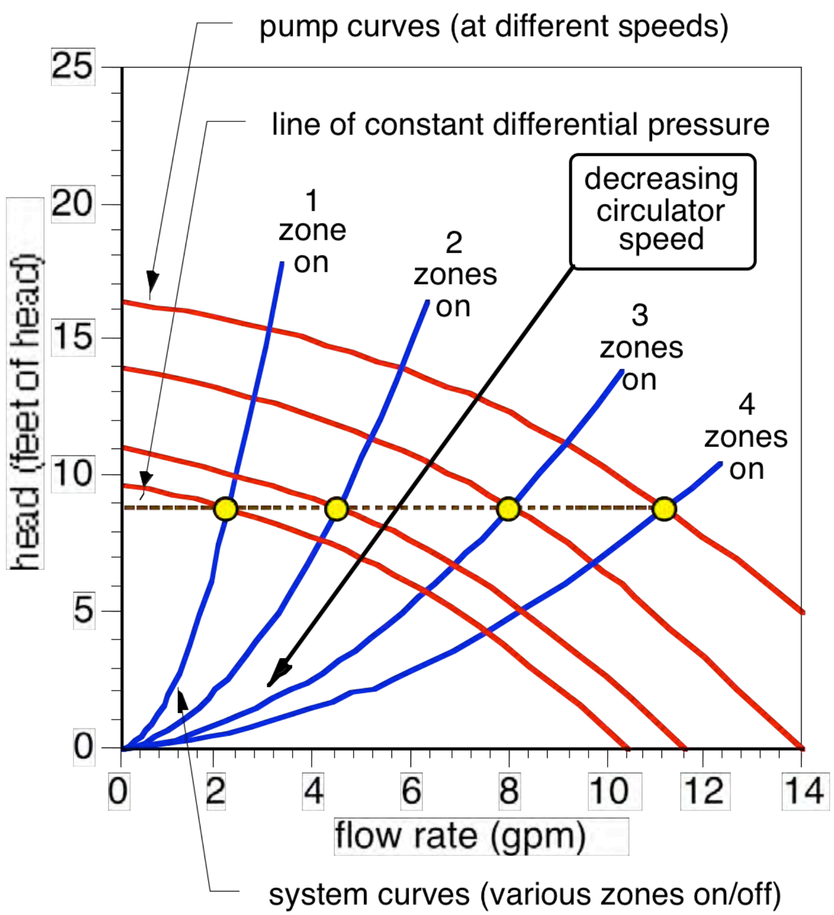
It eliminates need for differential pressure bypass valve.



Here's the same concept along with a mod/con boiler...



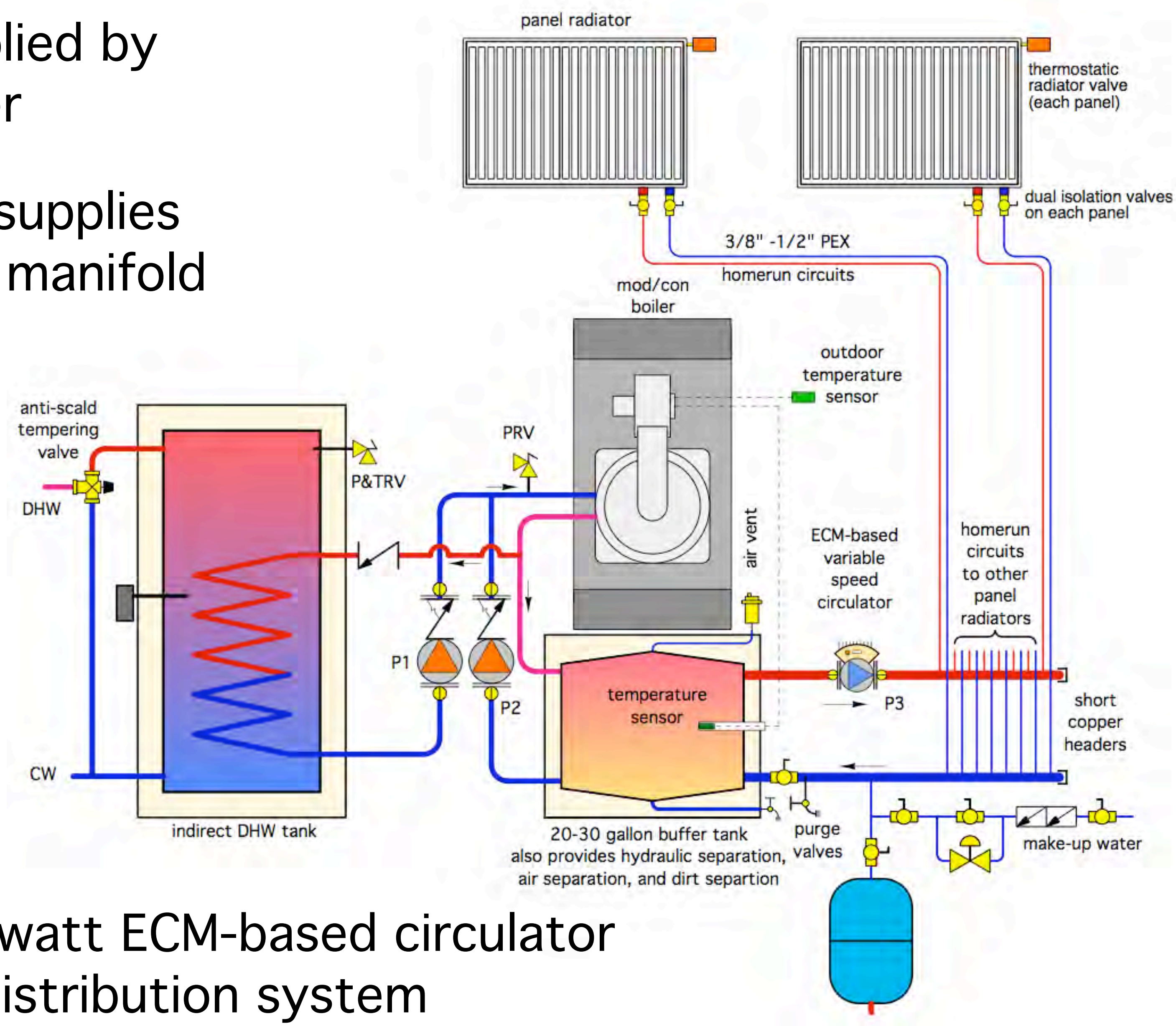
For a homerun system the pressure regulated circulator can operate in constant differential pressure mode.



A *Grand-slam* homerun system for “Micro-load” zoning:

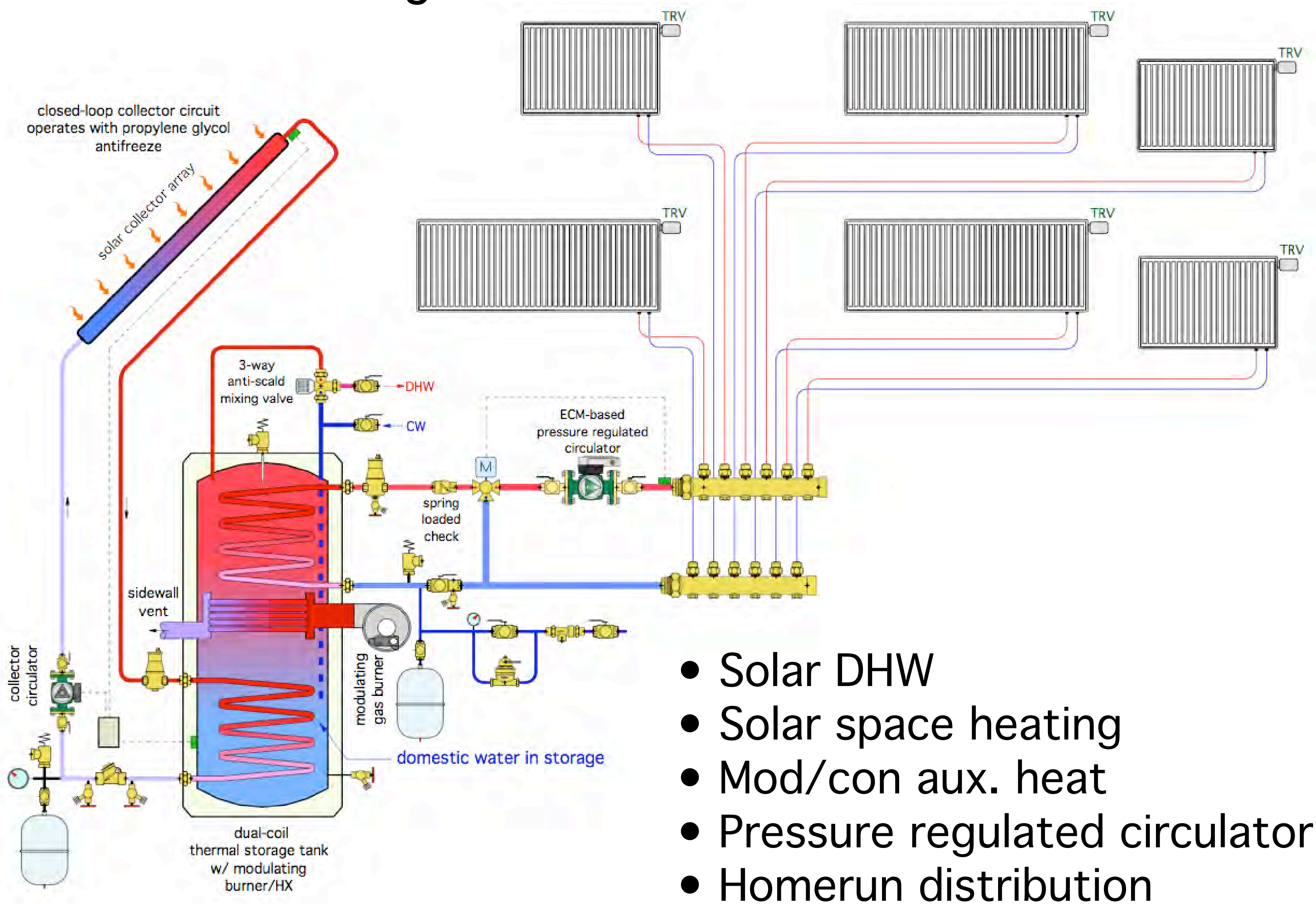
- Heat is supplied by mod/con boiler

- Buffer tank supplies simple copper manifold



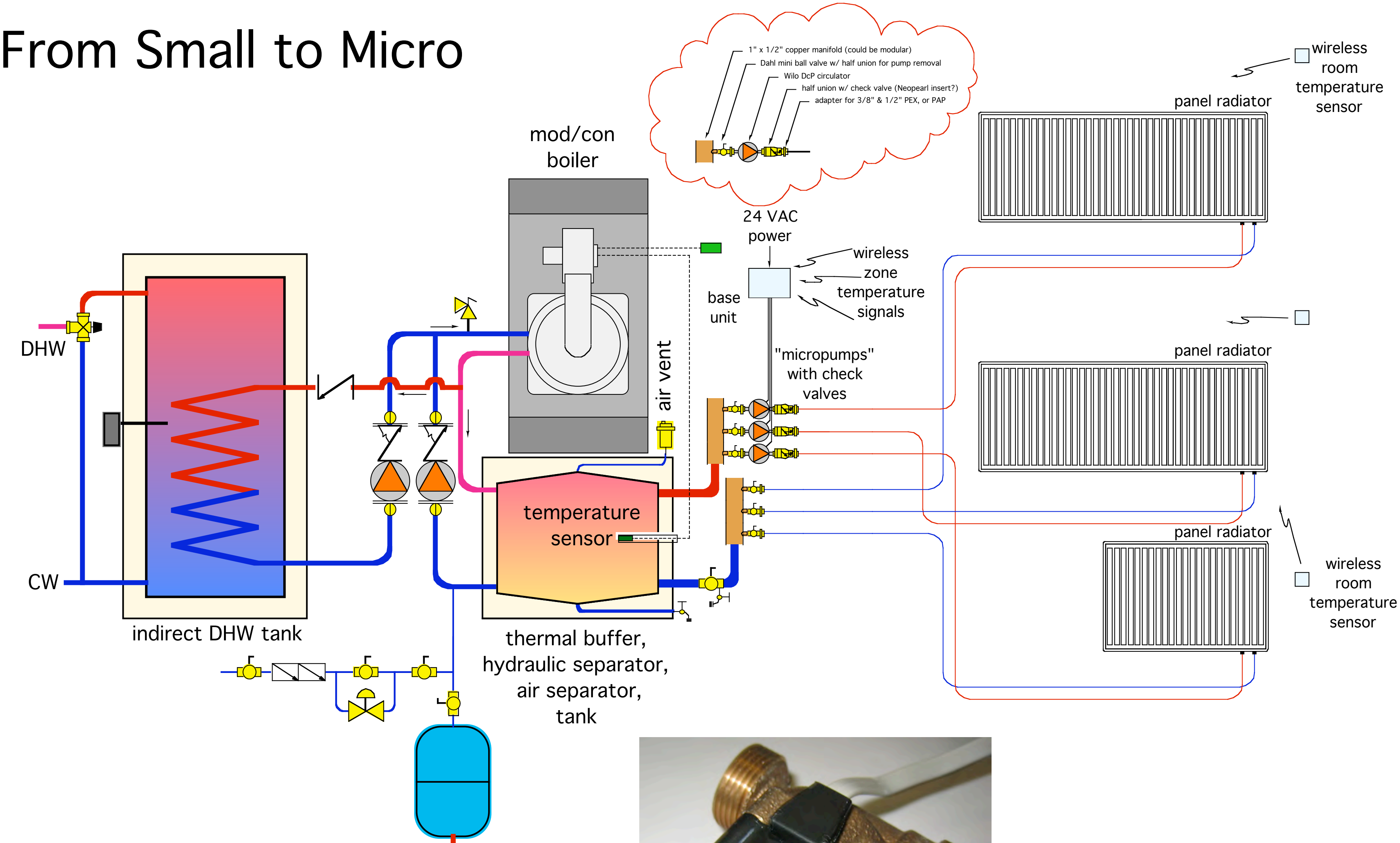
- Nominal 35 watt ECM-based circulator drives entire distribution system

Here's an interesting combination...



- Solar DHW
- Solar space heating
- Mod/con aux. heat
- Pressure regulated circulator
- Homerun distribution
- TRV zoning

From Small to Micro

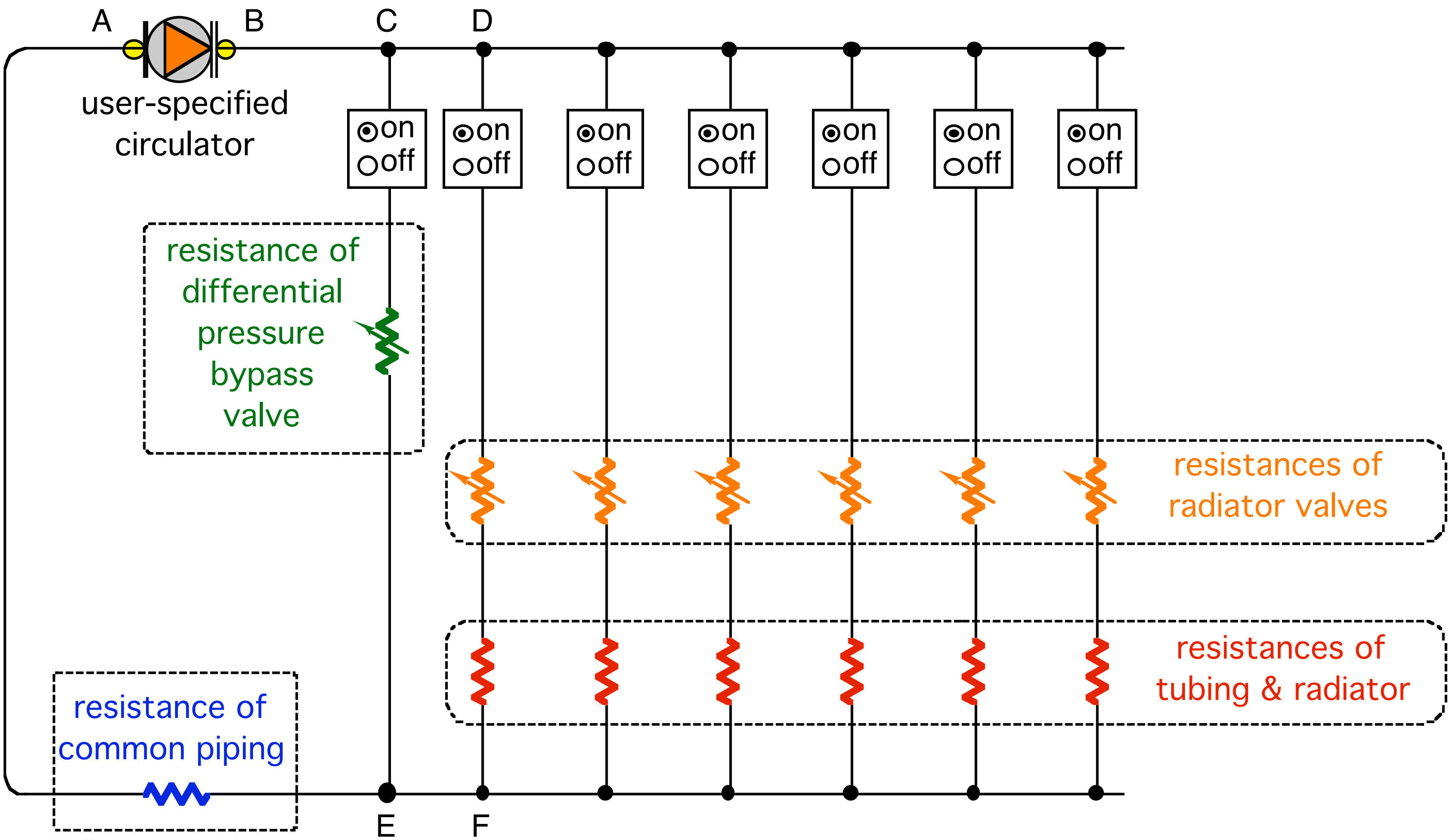


Buffer tank supplies Homerun circuits using Micro circulators.

Designing homerun systems

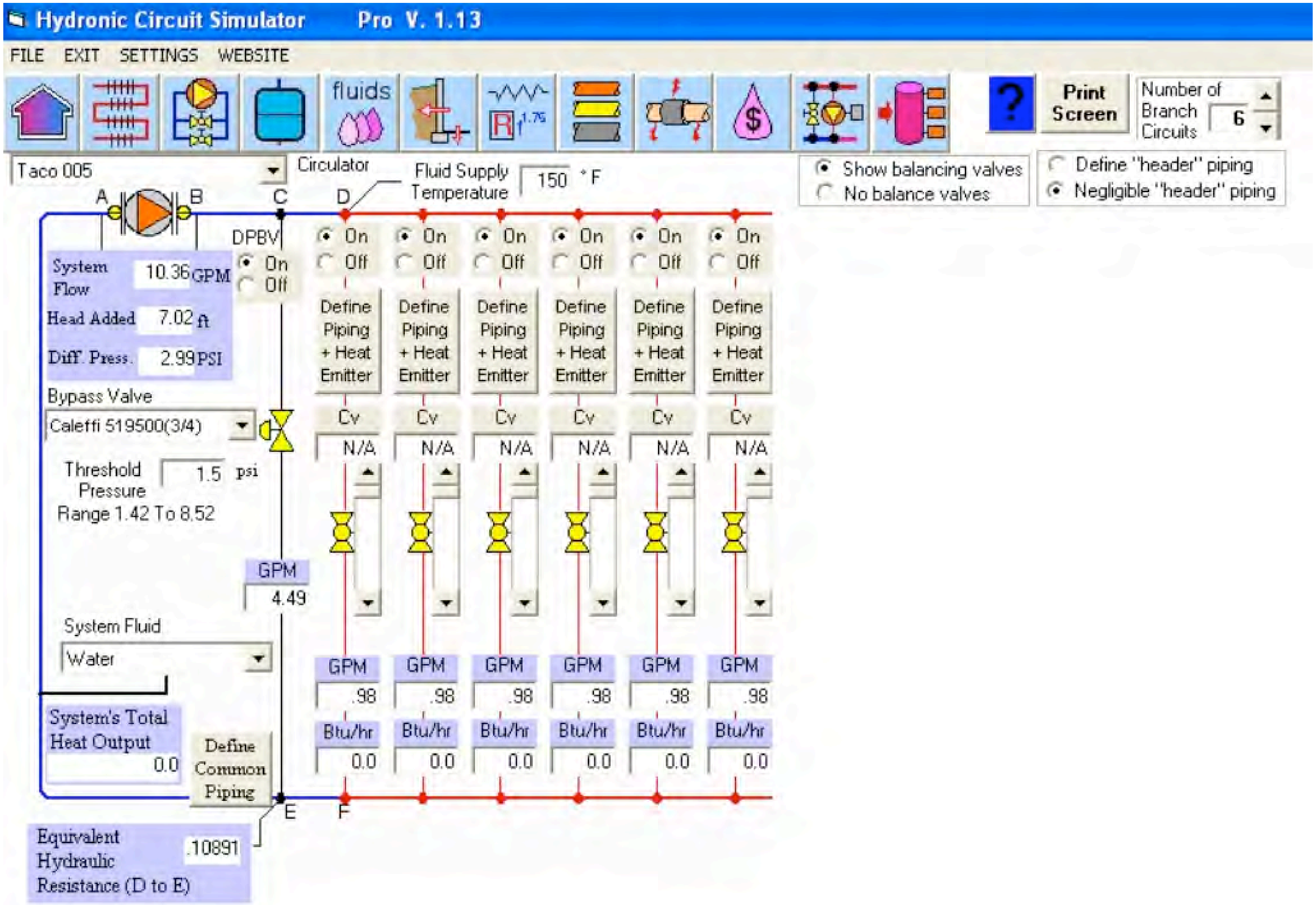
Homerun systems use parallel piping circuits.

The system can be modeled as a network of hydraulic resistors.



Designing homerun systems

This can be done "manually," or with the Hydronics Design Studio software.



Summary of Benefits of Homerun Distribution Systems:

1. Small diameter PEX or PEX-AL-PEX tubing is easily routed through framing. *If you can run an electrical cable from point A to point B, chances are you can also pull through small diameter tubing.*

2. All heat emitters operate at *same water temperature*, and thus don't require design calculations to correct for the temperature drops that occur in series or 1-pipe systems.

3. Ideal in systems requiring *room-by-room temperature control*.

4. Home run circuits can often *"use up" tubing remnants left over from radiant floor heating projects*.

Summary of Benefits of Homerun Distribution Systems:

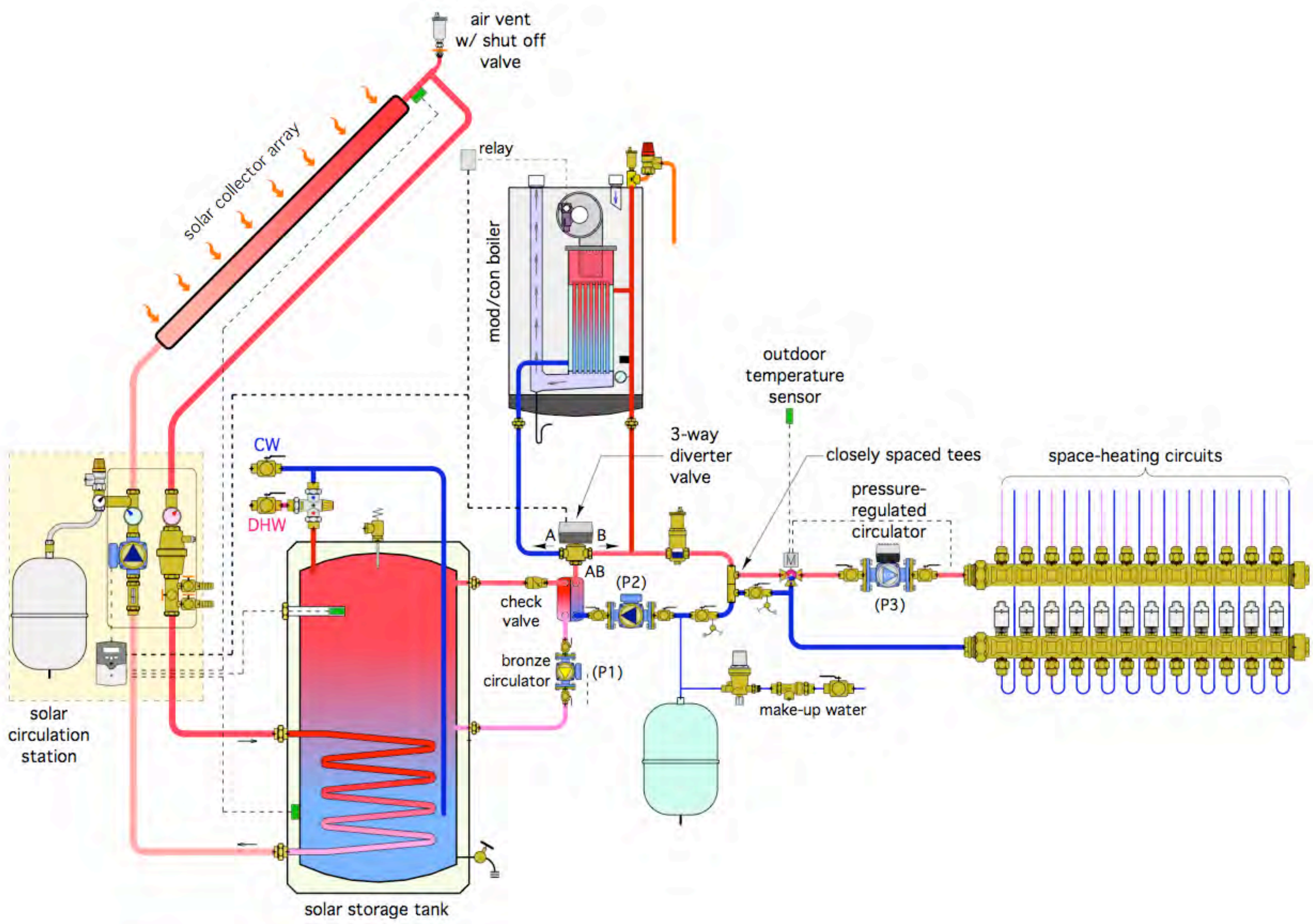
5. When necessary, *flow through individual heat emitters can be controlled from the manifold* (rather than using valves mounted in the heat emitters)

6. *Allows access to spaces not possible using rigid tubing*. This is especially helpful in retrofit and remodeling projects.

7. Most homerun circuits will be continuous from manifold to heat emitter. *Minimal if any concealed joints*.

8. *Well suited variable speed circulators* that maintain constant differential pressure or proportional differential pressure on the distribution system.

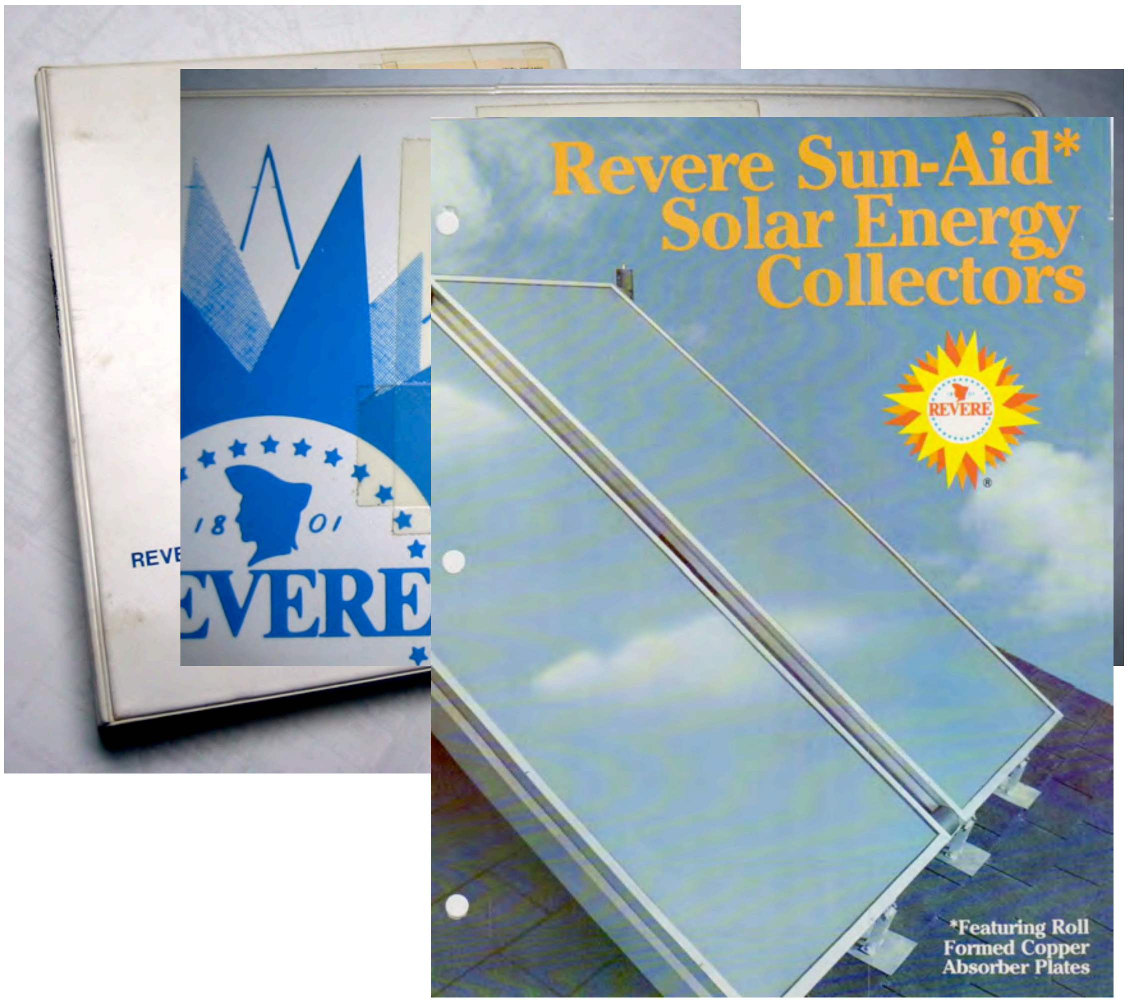
Incorporation Solar Thermal Subsystems for Hydronic Space Heating & DHW



For me, the current interest in solar heating is "like déjà vu - all over again"

My first engineering job (in 1978) was with a small company called Revere Solar & Architectural Products, Inc. in Rome, NY.

We manufactured flat plate solar collectors and solar DHW systems.



Economical water heating starts with . . .

Revere Sun-Aid™ collectors featuring roll formed copper absorber plates.

Copper is recognized as the best material for heating water with solar energy, and Revere, a long established manufacturer of copper products for the plumbing and building trades, has developed some of the best designs for solar energy collection using copper. Revere Solar Energy Collectors give you the advantages of Revere's high standards and long experience in casting and fabricating metals, and in product design and manufacturing.

These advantages have led to Revere's latest and highly efficient solar collector design: the SUN-AID Collector with a roll formed absorber plate. The special all-copper absorber plate is created by a process in which a roll formed sheet encases and metallurgically bonds the copper tube grid in a durable, high performance copper plate.

The roll formed copper absorber plate is housed in an insulated aluminum casing with a glass cover. Solar radiation which penetrates the atmosphere strikes the absorber plate and is converted into heat, raising the temperature of the fluid in the tubes. The glass cover and insulated aluminum casing prevent heat loss back into the air.

When you choose the collectors for your solar water heating system, consider the following factors, and you'll see why thousands of homeowners choose Revere.

Heating Efficiency

Revere engineers have designed the SUN-AID collector for peak performance under a wide range of conditions. The glass covers used allow the most energy through and reflect the least. The all-copper absorber plates provide a heat transfer capability two to eight times better than other materials considered for collector plates. The use of special coatings helps absorb the maximum amount of energy available. Special fiberglass insulation prevents energy from escaping back into the air.

See "Material Specifications" on the back page for the properties of the glazing, special coatings and insulation used in Revere SUN-AID collectors. You'll also find efficiency ratings provided by independent testing laboratories on the back page.

Durability

Revere makes and assembles all the copper parts for its absorber plates, and all the aluminum for its collector casings. The use of high quality materials combined with carefully controlled production and engineering standards ensure uniformly high quality and lasting value in all solar energy collectors manufactured by Revere.

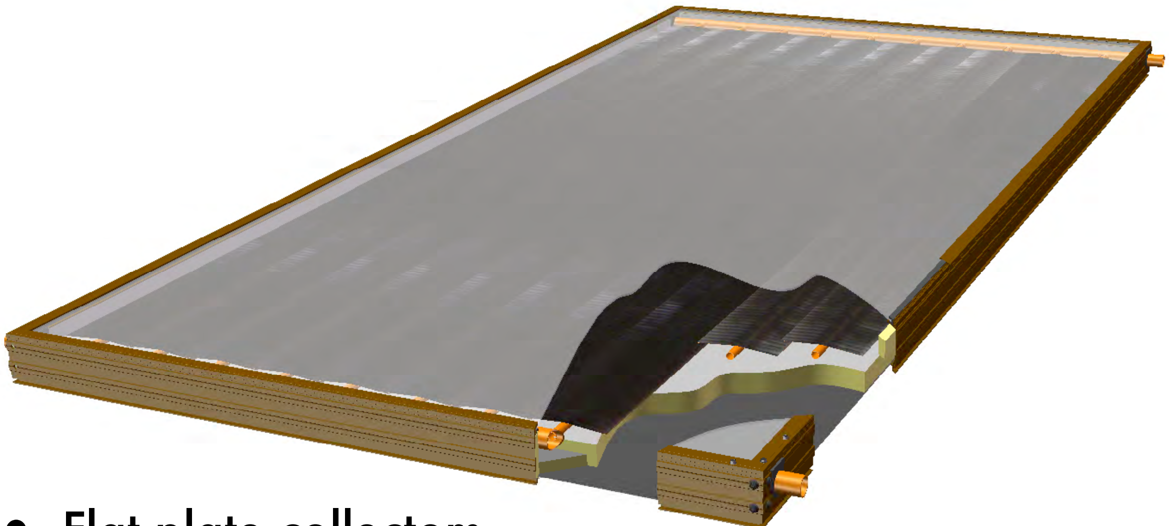
Tested for reliability. The copper in Revere collectors stays strong at the temperatures and pressures encountered in solar water heating systems.

To make sure no leaks show in **your** collectors, Revere pressure-tes. each absorber plate at least twice before the collector leaves the factory.

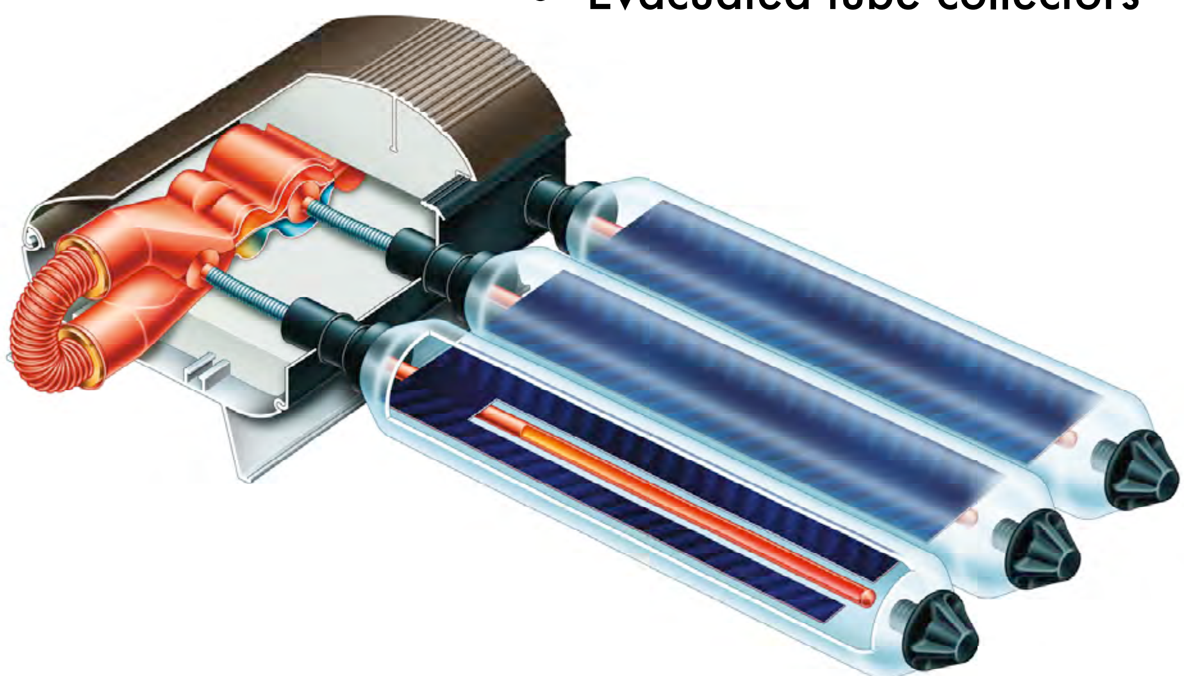
In 1981 we installed our own active solar energy system (6 Revere collectors)

After 28 years this drainback system is still operating fine.

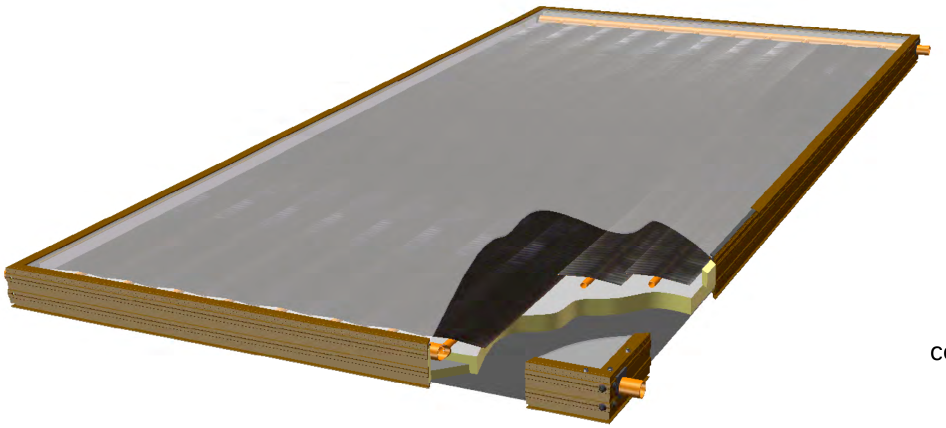
Most modern solar collectors fall into two categories:

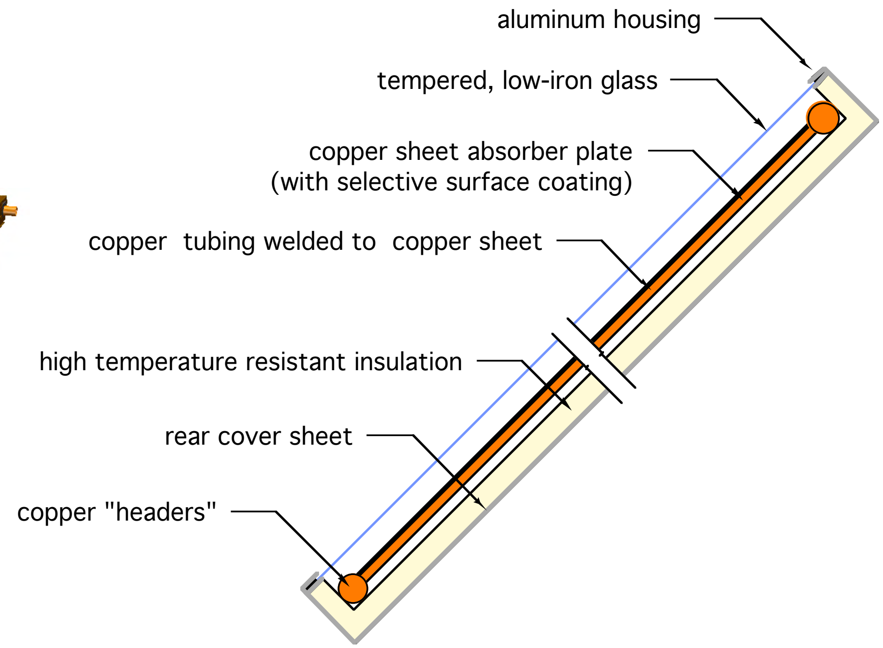


- Flat plate collectors
- Evacuated tube collectors

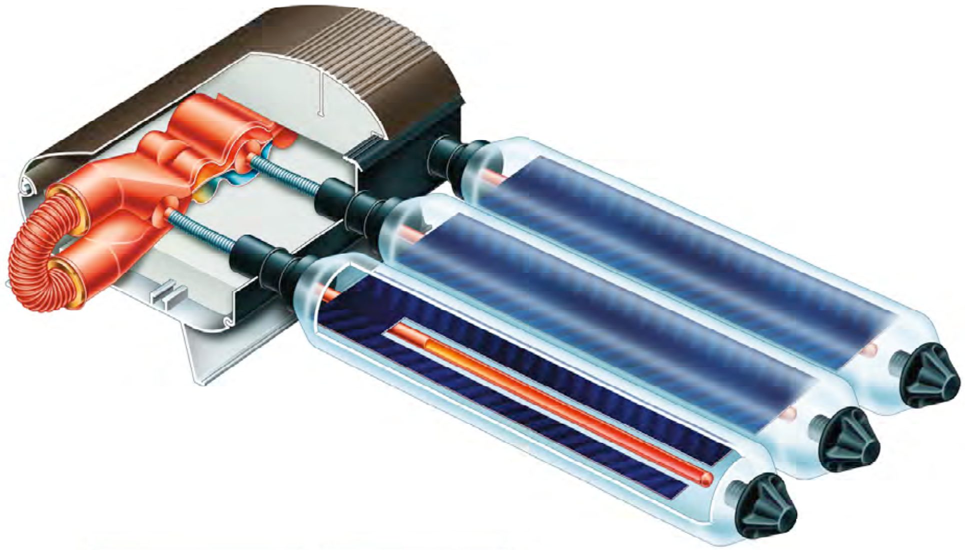


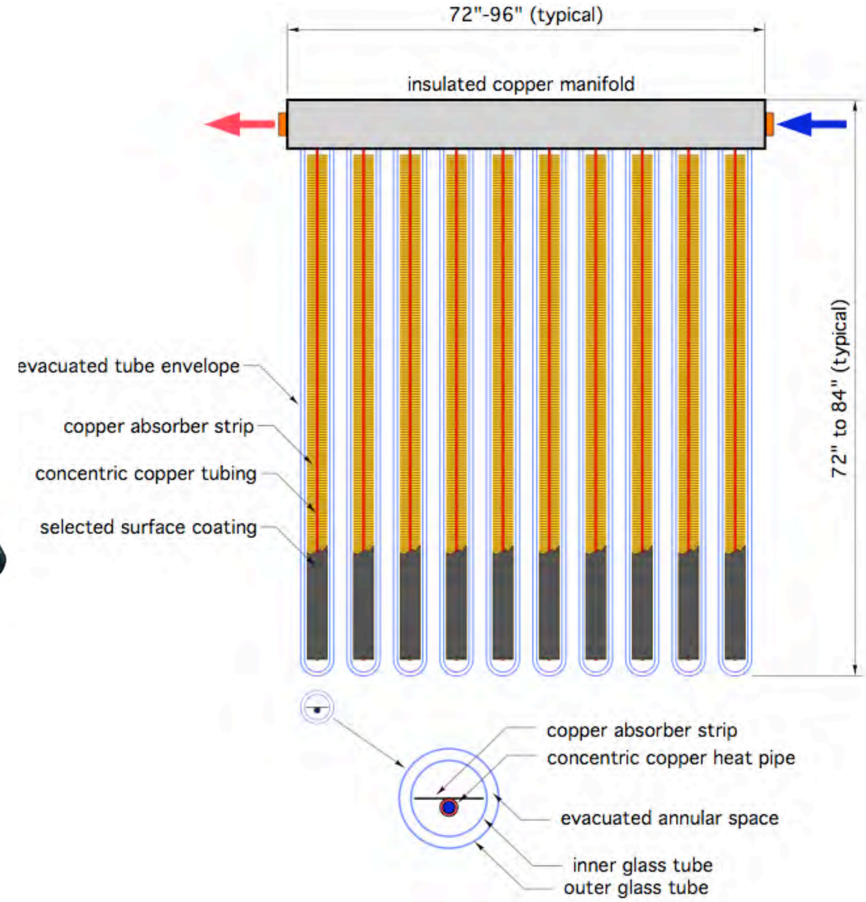
Flat plate collectors:

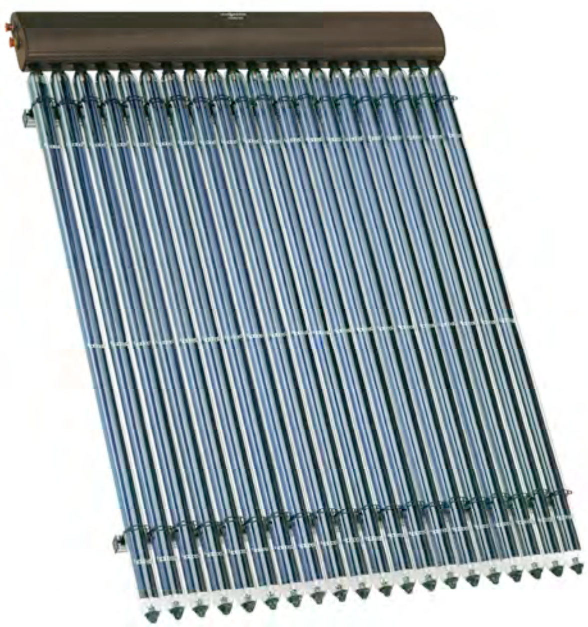




Evacuated tube collectors:







Solar collector testing

- US Testing Procedure:
  - ASHRAE Standard 93-77 “Methods of Testing to Determine the Thermal Performance of Solar Collectors”

- Results published in collector manufacturer’s technical literature.

- Can be depicted graphically: Slope and vertical axis intercept are established through testing

- Collectors with SRCC (Solar Rating & Certification Corporation) OG-100 certification meet standards for federal and state tax credits.

Want to start a war?

Ask those in the solar thermal industry the following question…

Which is better - flat plate collectors or evacuated tube collectors?

The answer depends on both QUANTITATIVE and QUALITATIVE comparisons

QUANTITATIVE factors:

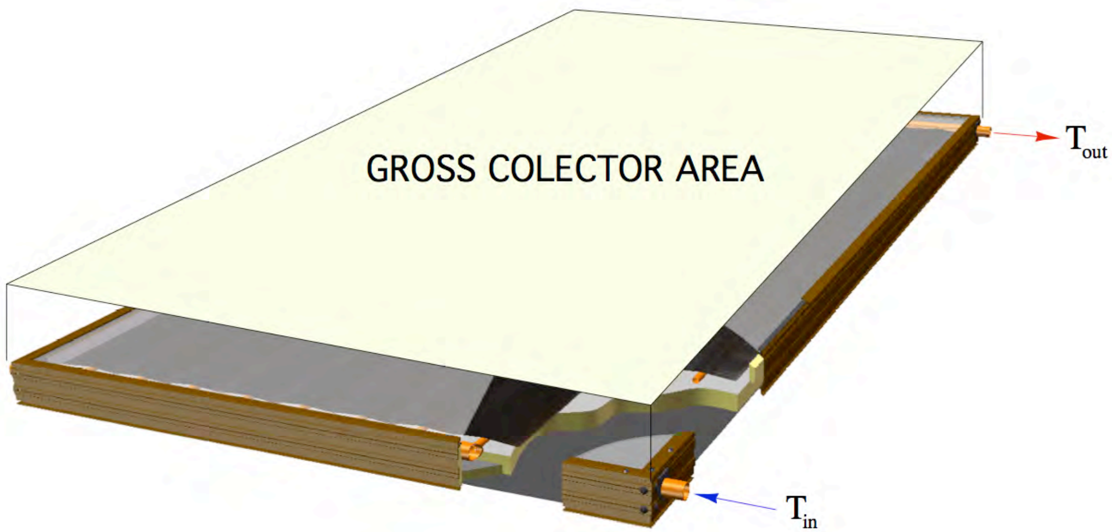
- Efficiency
- Installed cost
- Total energy collected by system during the year

QUALITATIVE factors:

- Appearance
- Installation ease
- Snow shedding ability
- Life expectancy
- Ability to survive extreme weather
- Ability to survive "stagnation" conditions (full solar intensity w/ no flow)

Thermal Efficiency of a solar collector (based on ASHRAE 93-77 standard)

$$\text{Instantaneous collector efficiency} = \frac{\text{thermal output from collector (Btu/hr)}}{\text{solar radiation striking GROSS collector area (Btu/hr)}}$$

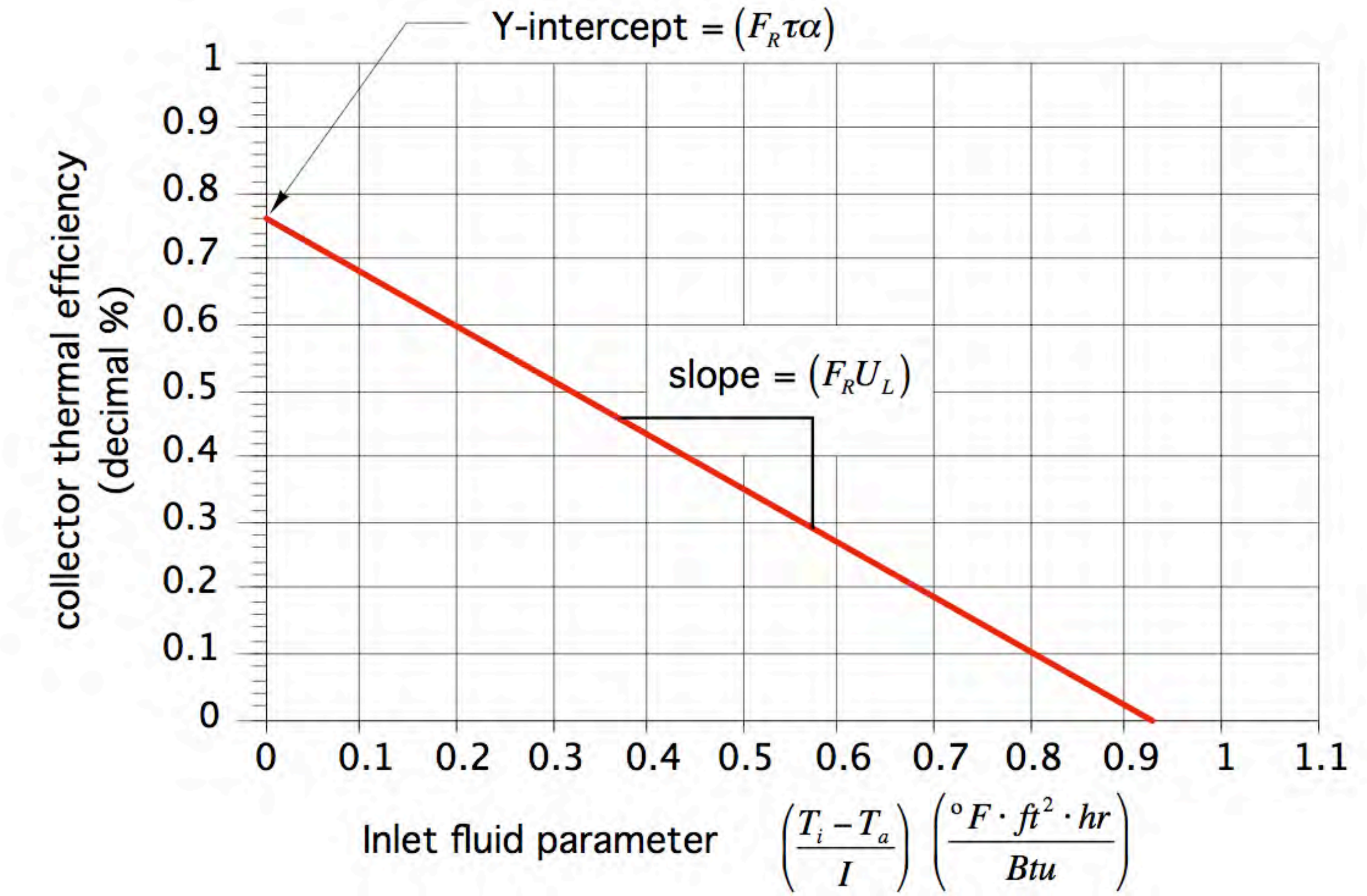


pyronometer

$$\eta_{collector} = \frac{(8.01 \times c \times D) \times f \times (T_{out} - T_{in})}{I \times A_{gross}}$$

$n_{collector}$ = instantaneous collector efficiency (decimal %)
c = specific heat of fluid (Btu/lb/°F)
D = density of fluid (lb/ft^3)
f = flow rate (gallons per minute)
T_{in} = collector inlet temperature (°F)
T_{out}= collector outlet temperature (°F)
I = instantaneous solar radiation intensity in plane of collector (Btu/hr/ft^2) (pyronometer)
A_{gross} = gross collector area (ft^2)

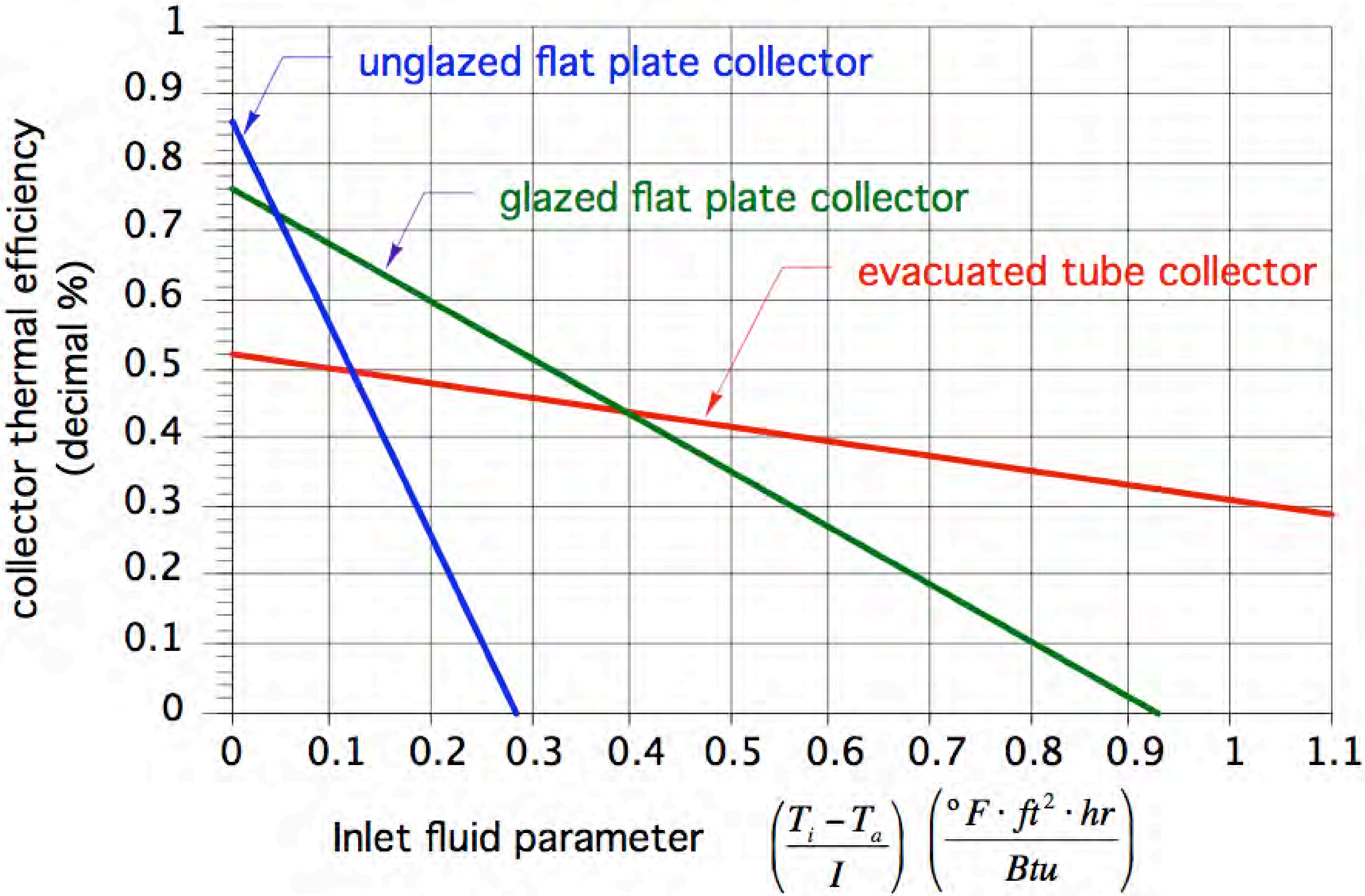
The thermal efficiency of a collector represented as a graph:



$$\eta_{collector} = (F_R \tau\alpha) - (F_R U_L) \times \left[\frac{T_i - T_a}{I}\right]$$

Where:
T_i = inlet fluid temperature to collector (ºF)
T_a = ambient air temperature surrounding collector (ºF)
I = solar radiation intensity incident on collector (Btu/hr/sq. ft.)
Frta = Y-intercept (determined through testing)
FrUL = slope of efficiency line (determined through testing)

Some representative collector efficiency graphs:



Collector efficiency is tested and reported by the SRCC (Solar Rating & Certification Corporation) under standard OG-100.

All information is available for free online at:

http://www.solar-rating.org/ratings/ratings.htm

SOLAR COLLECTOR CERTIFICATION AND RATING

SRCC OG-100

CERTIFIED SOLAR COLLECTOR

SUPPLIER: **Solar Skies Mfg, LLC**
800 Industrial Park, Hwy 28 West
Starbuck, MN 56381 USA

MODEL: Solar Skies SS-40
COLLECTOR TYPE: Glazed Flat-Plate
CERTIFICATION #: 100-2007-039F

COLLECTOR THERMAL PERFORMANCE RATING

Megajoules Per Panel Per Day			
CATEGORY (Ti-Ta)	CLEAR DAY 23 MJ/m²·d	MILDLY CLOUDY 17 MJ/m²·d	CLOUDY DAY 11 MJ/m²·d
A (-5°C)	55	41	28
B (5°C)	50	36	23
C (20°C)	42	29	16
D (50°C)	25	13	3
E (80°C)	10	1	

Thousands of Btu Per Panel Per Day			
CATEGORY (Ti-Ta)	CLEAR DAY 2000 Btu/ft²·d	MILDLY CLOUDY 1500 Btu/ft²·d	CLOUDY DAY 1000 Btu/ft²·d
A (-9°F)	52	39	27
B (9°F)	47	35	22
C (36°F)	40	27	15
D (90°F)	24	13	3
E (144°F)	9	1	

A-Pool Heating (Warm Climate) B-Pool Heating (Cool Climate) C-Water Heating (Warm Climate) D-Water Heating (Cool Climate) E-Air Conditioning

Original Certification Date: October 4, 2007

COLLECTOR SPECIFICATIONS

Gross Area:	3.696	m²	39.78	ft²	Net Aperture Area:	3.481	m²	37.47 ft²
Dry Weight:	69.4	kg	153	lb	Fluid Capacity:	6.1	l	1.6 gal
Test Pressure:	1103	kPa	160	psig				

COLLECTOR MATERIALS

Frame:	Anodized Aluminum
Cover (Outer):	Low Iron Tempered Glass
Cover (Inner):	None
Absorber Material:	Tube - Copper / Plate - Copper Fin
Absorber Coating:	Selective Coating
Insulation (Side):	Polyisocyanurate
Insulation (Back):	Polyisocyanurate

PRESSURE DROP

Flow		ΔP	
ml/s	gpm	Pa	in H_2O

TECHNICAL INFORMATION

Efficiency Equation [NOTE: Based on gross area and (P) = Ti-Ta]

S I Units:	η = 0.691	-3.3960	(P)/I	-0.0197	$(P)^2/I$		
I P Units:	η = 0.691	-0.5985	(P)/I	-0.0019	$(P)^2/I$		

Y Intercept	**Slope**	
0.706	-4.9099	W/m²·°C
0.706	-0.865	Btu/hr·ft²·°F

Incident Angle Modifier [(S) = 1/cos θ - 1, 0°≤ θ ≤60°]

$K_{\alpha\tau}$ = 1.0 -0.1939 (S) -0.0055 $(S)^2$

$K_{\alpha\tau}$ = 1.0 -0.20 (S) (Linear Fit)

Model Tested: 100-2002-001A
Test Fluid: Water
Test Flow Rate: 39 ml/s 0.62 gpm

Collector efficiency is a function of the "inlet fluid parameter"

$$p = \frac{(T_i - T_a)}{I}$$

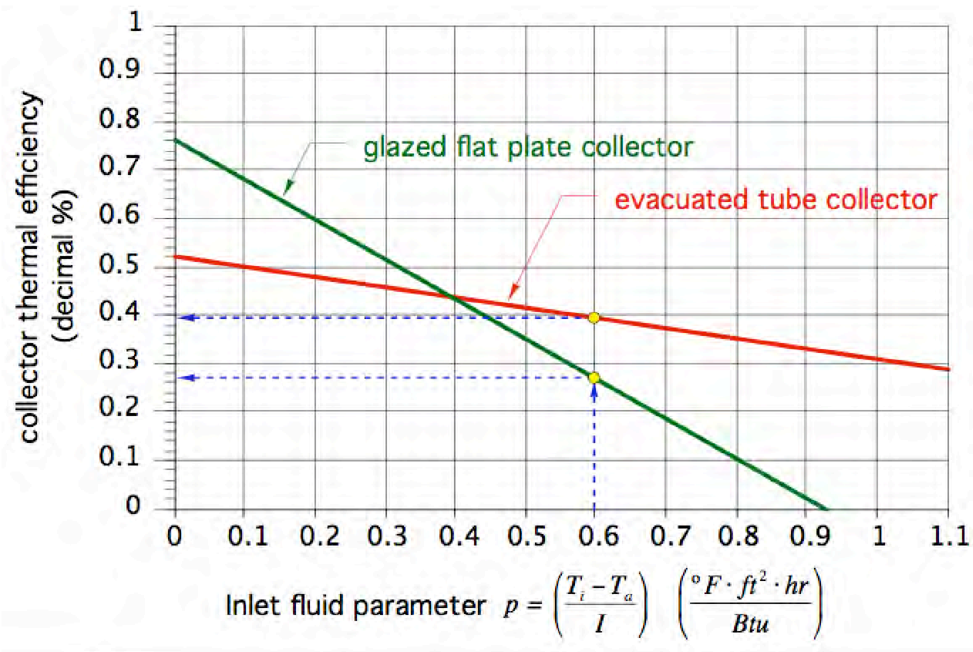
Where:
T_i = inlet fluid temperature to collector (°F)
T_a = ambient air temperature surrounding collector (°F)
I = solar radiation intensity incident on collector (Btu/hr/sq. ft.)

The higher the inlet fluid parameter the more severe the conditions under which the collector operates as it converts solar radiation to useful heat output.

Here's an example: Assume a fin-tube baseboard system provides water at 170 °F to the inlet of both flat plate and evacuated tube collectors having the efficiency shown in figure 5. The outdoor ambient temperature is 20 °F, and the solar radiation incident on the collector is 250 Btu/hr/sq ft (reasonably bright conditions). The inlet fluid parameter is:

$$p = \frac{(T_i - T_a)}{I} = \frac{(170 - 20)}{250} = 0.6$$

The corresponding efficiency of the evacuated tube collector to be 0.40 (40%), while the efficiency of the flat plate collector under the same conditions is only 0.27 (27%).

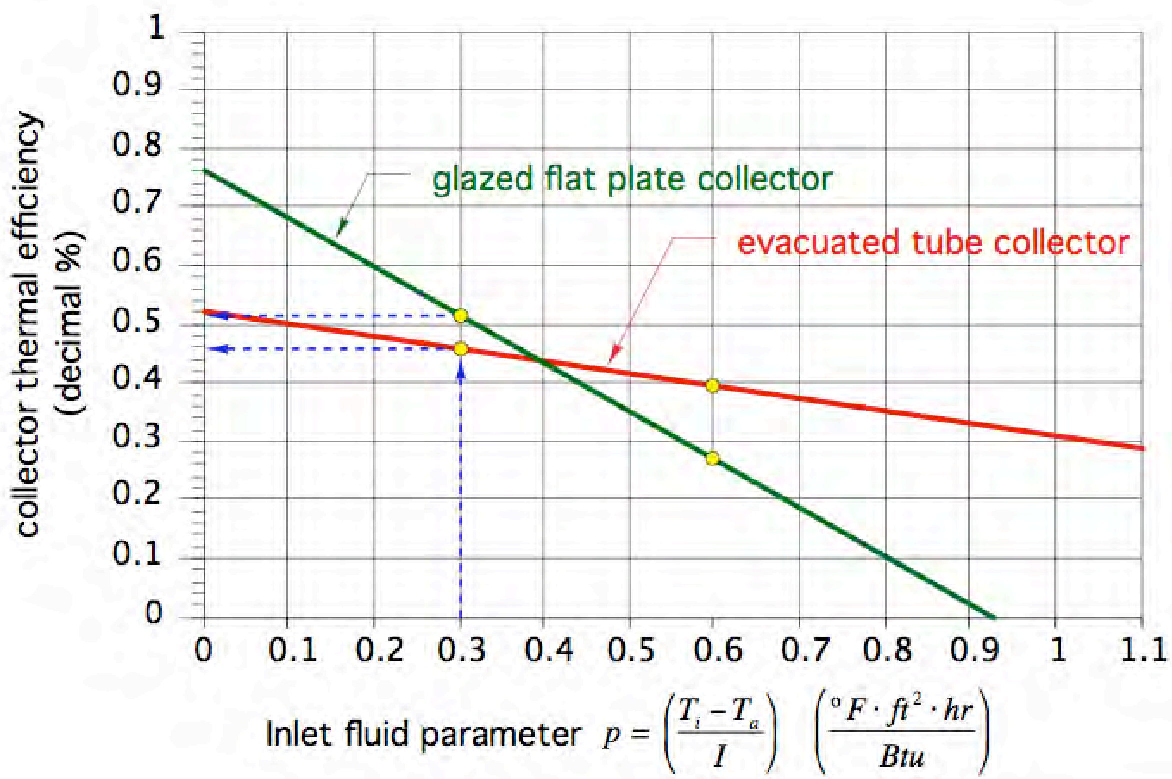


Collector efficiency is a function of the "inlet fluid parameter"

What happens when the two collectors operate within a low temperature system, such as slab-type floor heating? Assume the water temperature supplied to the collectors is now 95 °F and the solar radiation intensity and air temperature remain the same. The inlet fluid parameter is now:

$$p = \frac{(T_i - T_a)}{I} = \frac{(95 - 20)}{250} = 0.3$$

Under these conditions the efficiency of the evacuated tube is 0.46 (46%), while that of the flat plate collector is 0.52 (52%).



Collector Stagnation Temperature:

Collector stagnation occurs when sunlight is incident on the collector, but no fluid moves through it to remove the captured energy.

Every collector will experience stagnation at some point, probably many times.

Reasons for stagnation:

- during installation (prior to completion of piping)
- failure of a controller or a sensor
- Tank reaches maximum temperature setting of controller
- power outage during the day

(How hot can an absorber plate get?)

At stagnation, collector efficiency is zero. $$\eta_{collector} = (F_R\tau\alpha) - (F_R U_L)\left[\frac{T_i - T_a}{I}\right] = 0$$

Ti becomes the stagnation temperature of the absorber plate. $$T_{stagnation} = \left[\frac{(F_R\tau\alpha)}{(F_R U_L)}\right] I + T_a$$

Here's an example for a typical flat plate collector:

$$T_{stagnation} = \left[\frac{(F_R\tau\alpha)}{(F_R U_L)}\right] I + T_a = \left[\frac{0.706}{.865}\right] 317 + 85 = 344^{\circ} F$$

Typical collector slope angles:

- For Solar Water Heating

  Slope = local latitude (from horizontal)

  Slope at least 40 degrees

  in snowfall climates

- For Space Heating

Slope = local latitude + 15 degrees

Solar thermal system design

There are several principles to observe when designing
a solar energy subsystem for DHW or space heating.

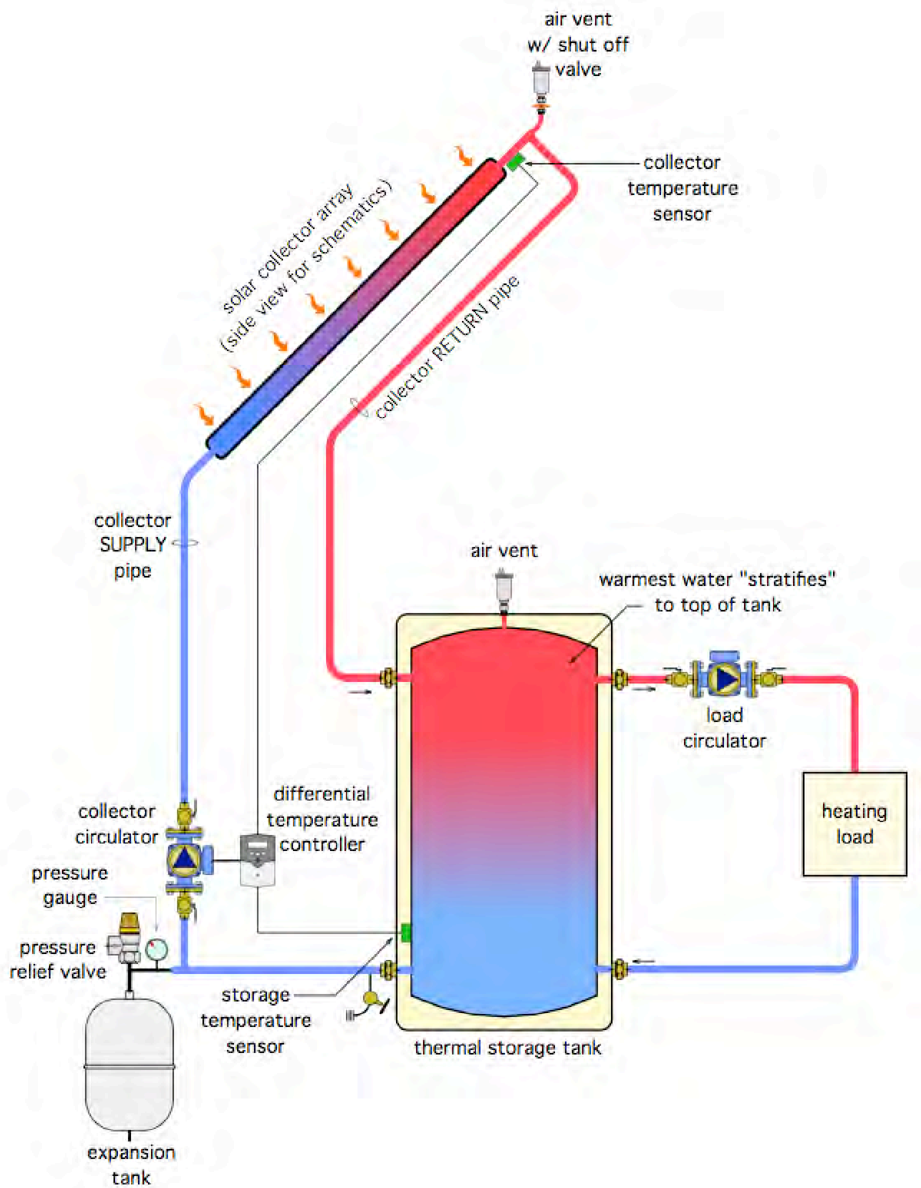
1. The cooler the collector array can operate the lower its thermal losses and thus the higher its efficiency.

2. Conventional energy sources (oil, gas, and electricity) should only be "invoked" when needed by the load (e.g. not converted to and stored as thermal energy).

3. The collector array and all piping outside of heated space must be protected against freezing during non-operational periods.

Watch for how these principles are applied in the designs that follow…

Solar thermal system - basic concept



Source: Caleffi idronics journal

Q: What's the problem with this design?

A. The collectors would be ruined the first time the outdoor temperature *approaches* freezing

Freeze protection must be provided in ALL US and Canadian climates.

Q: What's another the problem with this design?

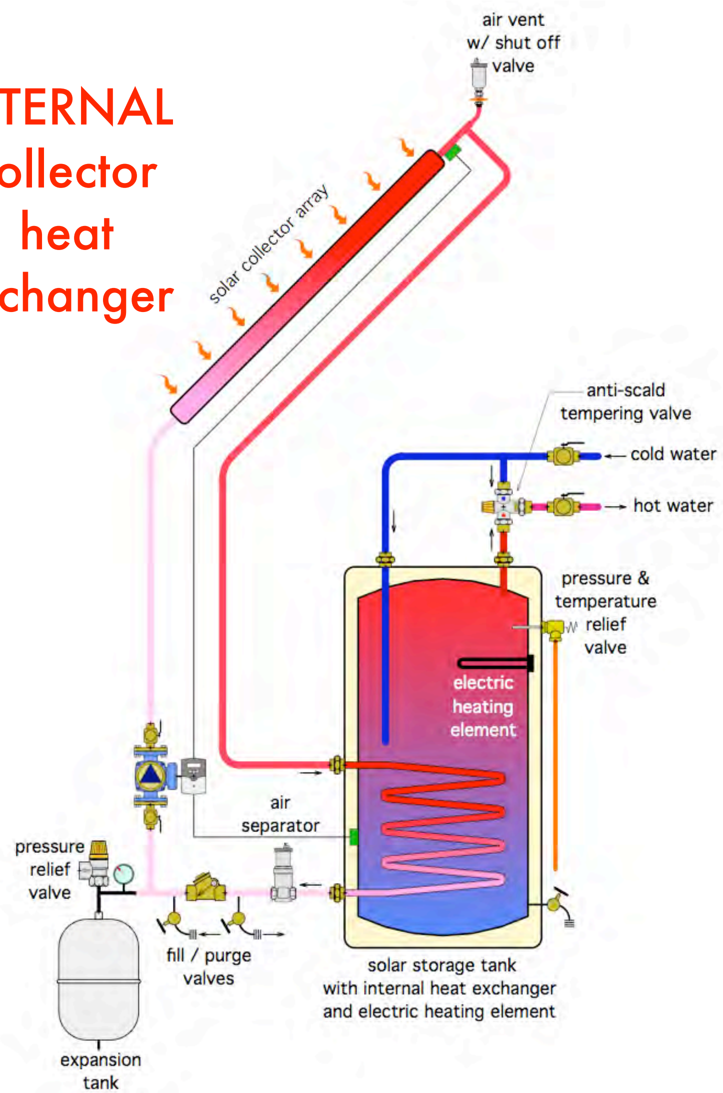
A. The warm fluid in the storage tank will reverse thermosyphon through the collector array at night and loss most of the heat previously stored in tank.

A properly installed check valve prevents this

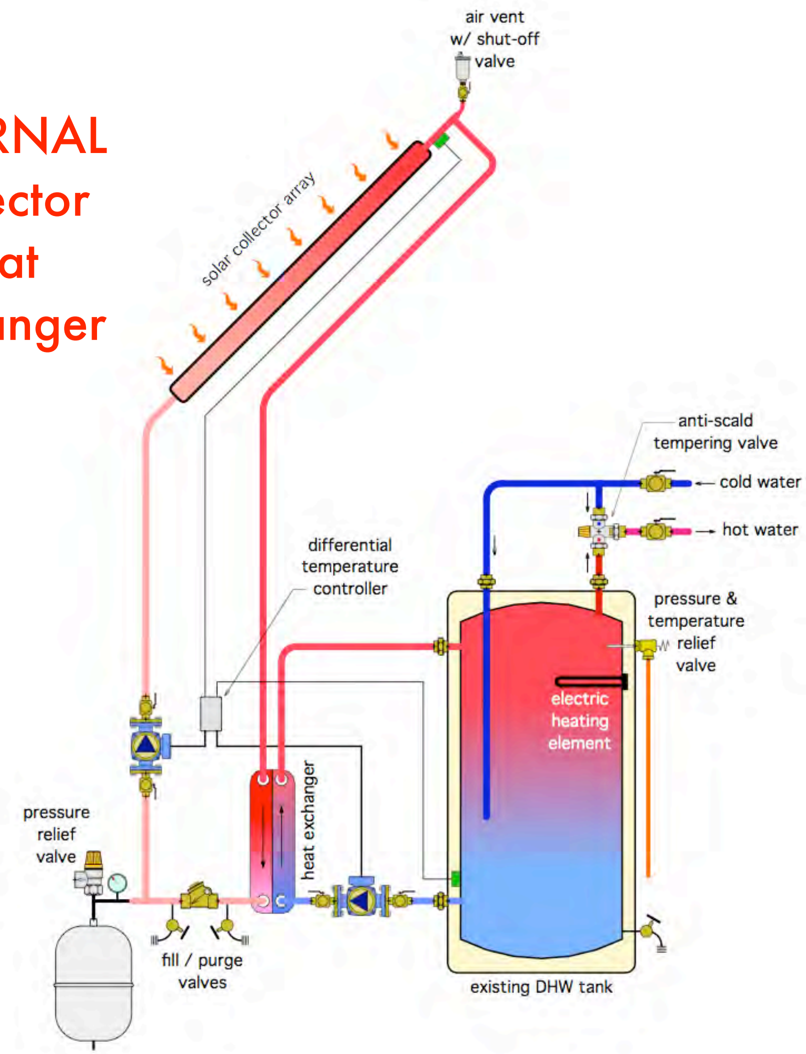
Closed Loop/Antifreeze Systems:

One way to protect the collector array and exposed piping against freezing is to use an antifreeze solution in the collector circuit.

INTERNAL Collector heat exchanger



EXTERNAL Collector heat exchanger



Advantages of closed-loop antifreeze systems:

- Piping between the collectors and storage tank can be installed in virtually any orientation, inside or outside..

- Since the collector loop is filled, and flow rate is relatively low, the collector circulator can be very small.

- In some systems, a collector circulator with a DC motor can be powered directly and at variable speed by a photovoltaic panel (more on this later).

Disadvantages of closed-loop antifreeze systems:

- The temperature differential across the heat exchanger forces the collectors to operate at a higher temperature relative to tank water flowing directly through collectors.

- The glycol solution is subject to thermal breakdown due to stagnation (no flow) conditions under full sun. Many antifreeze-based systems use a "heat dump" to reduce degradation due to stagnation.

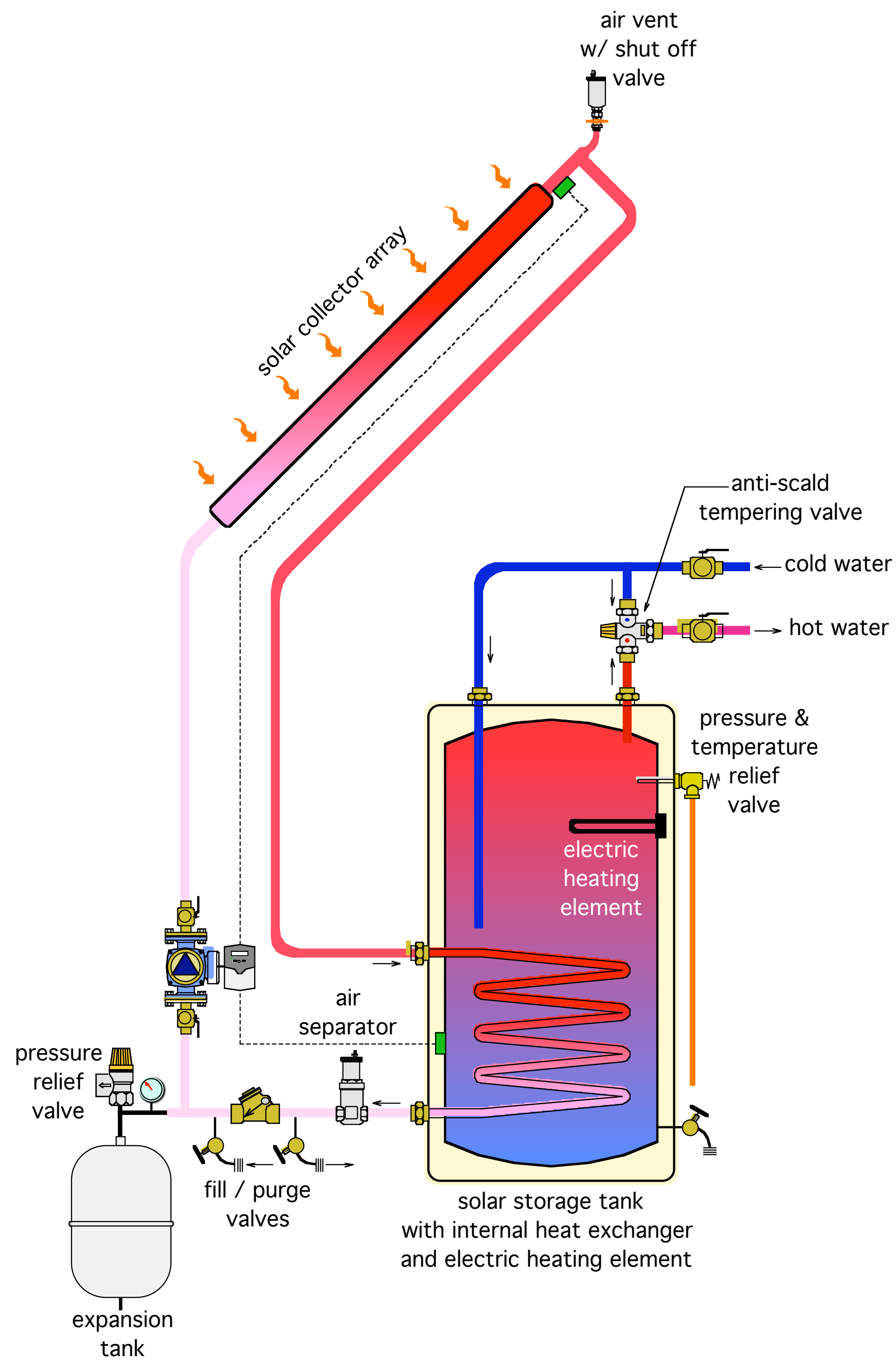
- The glycol solution requires periodic maintenance to prevent it from becoming acidic and corroding the system.

Residential Solar DHW:

Single tank solar DHW system using internal heat exchanger.

Electric heating element serves as Backup.

Tank should be very well insulated to Minimize standby loss (2" urethane minimum)



Source: Caleffi idronics journal

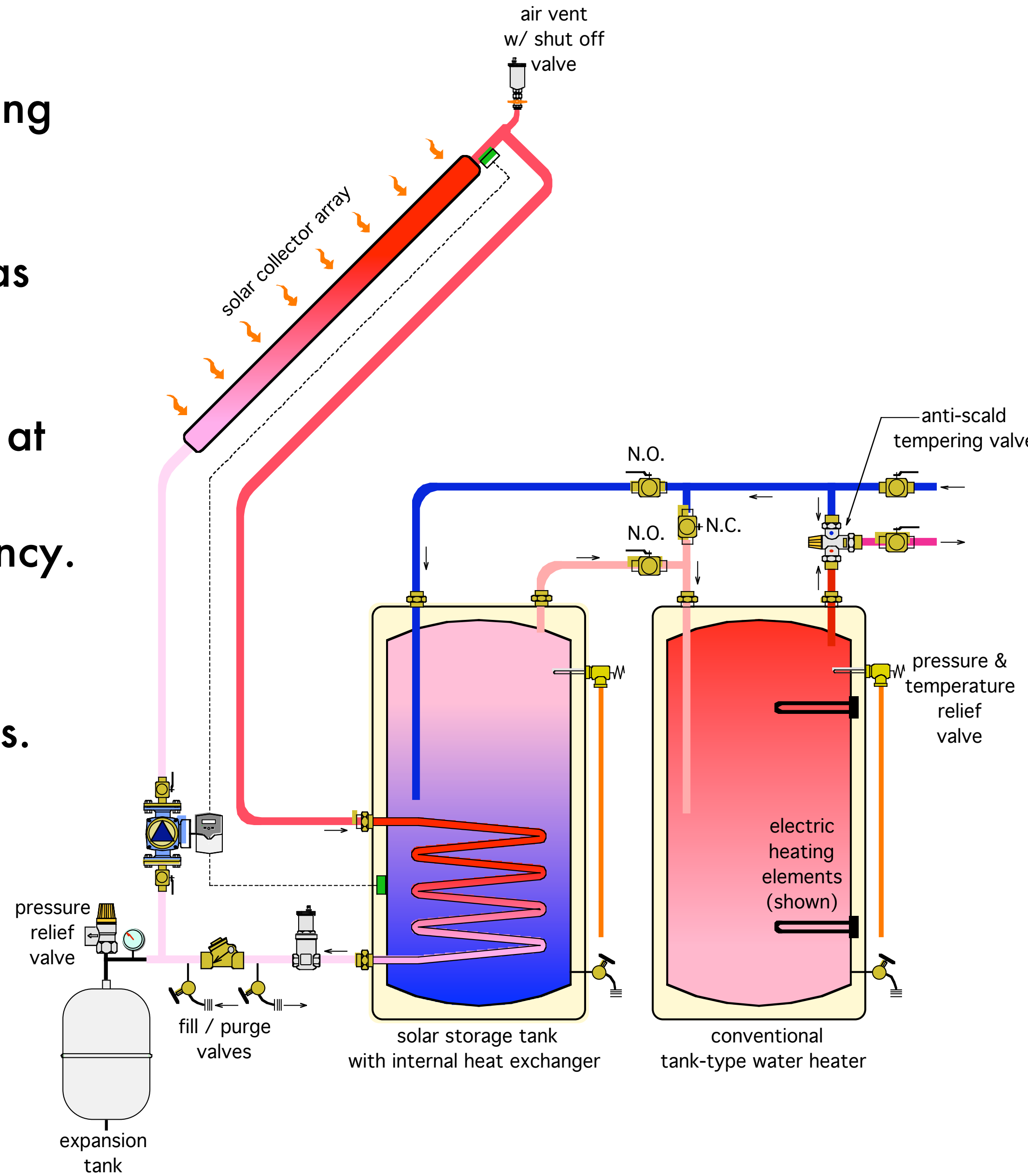
Residential Solar DHW:

Dual tank solar DHW system using internal heat exchanger.

Electric heating element serves as Backup.

Allows solar storage to operate at lowest possible temperature for highest possible collector efficiency.

Higher standby heat loss due to Added surface area of two tanks.



Source: Caleffi idronics journal

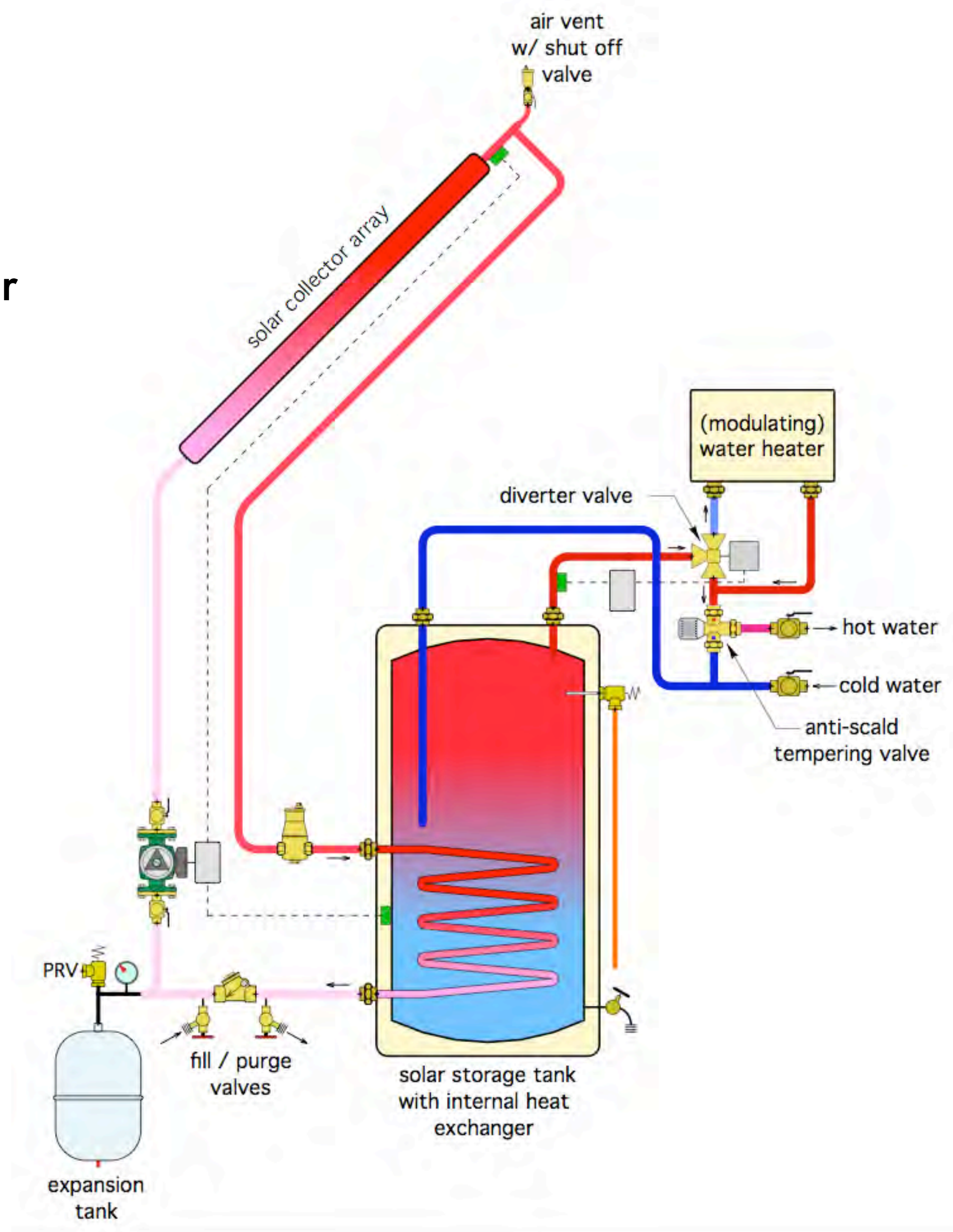
Residential Solar DHW:

Single tank solar DHW system using internal heat exchanger.

"Tankless" instantaneous water heater provides backup when needed. (Must be modulating burner) - verify with manufacturer

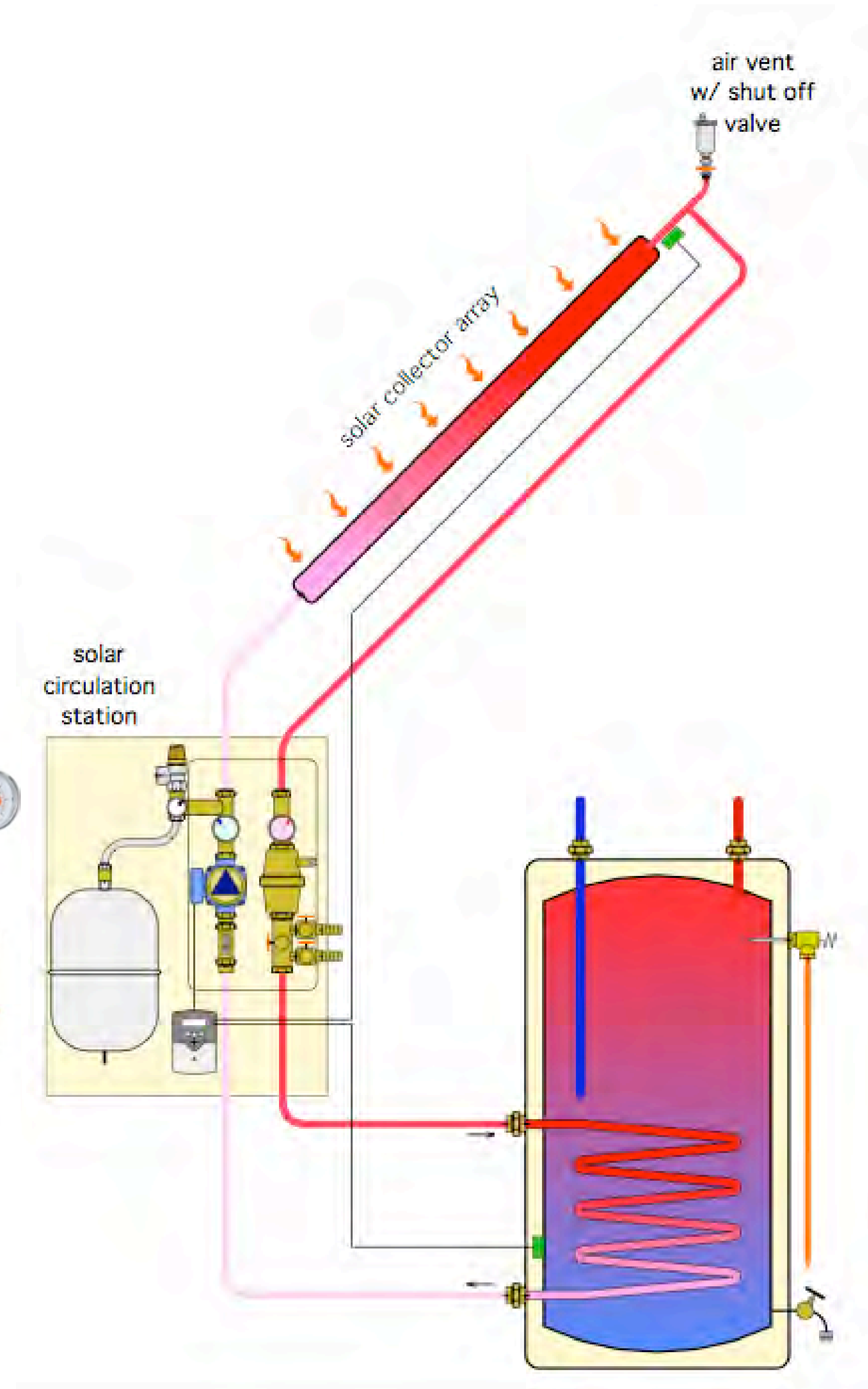
Diverter valve prevents solar heated water from flowing through tankless heater when not necessary.

Lower standby heat loss due to Reduced surface area and "smart" water routing.



Residential Solar DHW:

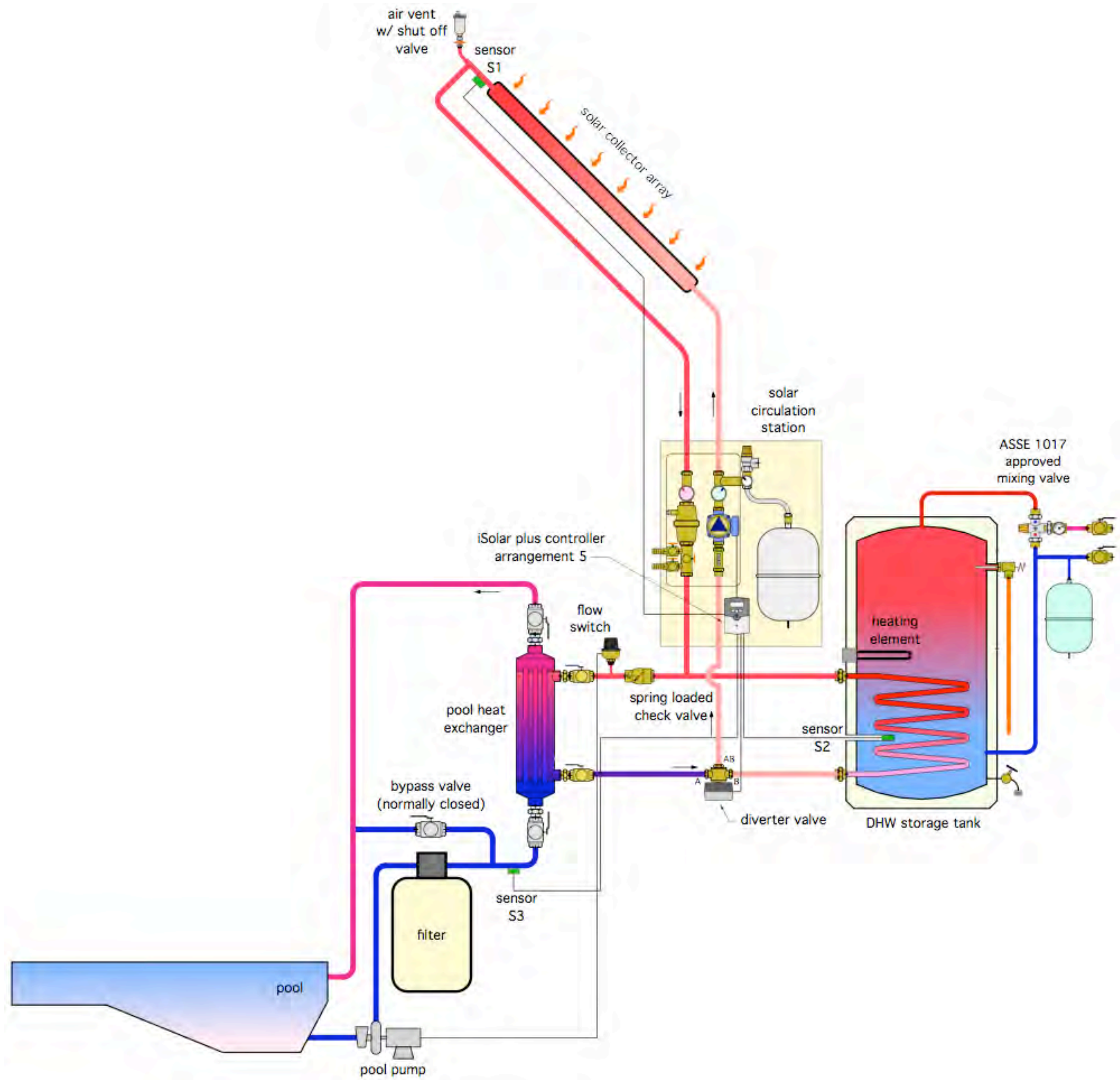
Solar circulation stations are available that consolidate individual components into a single assembly.



Possible "heat dump" arrangement

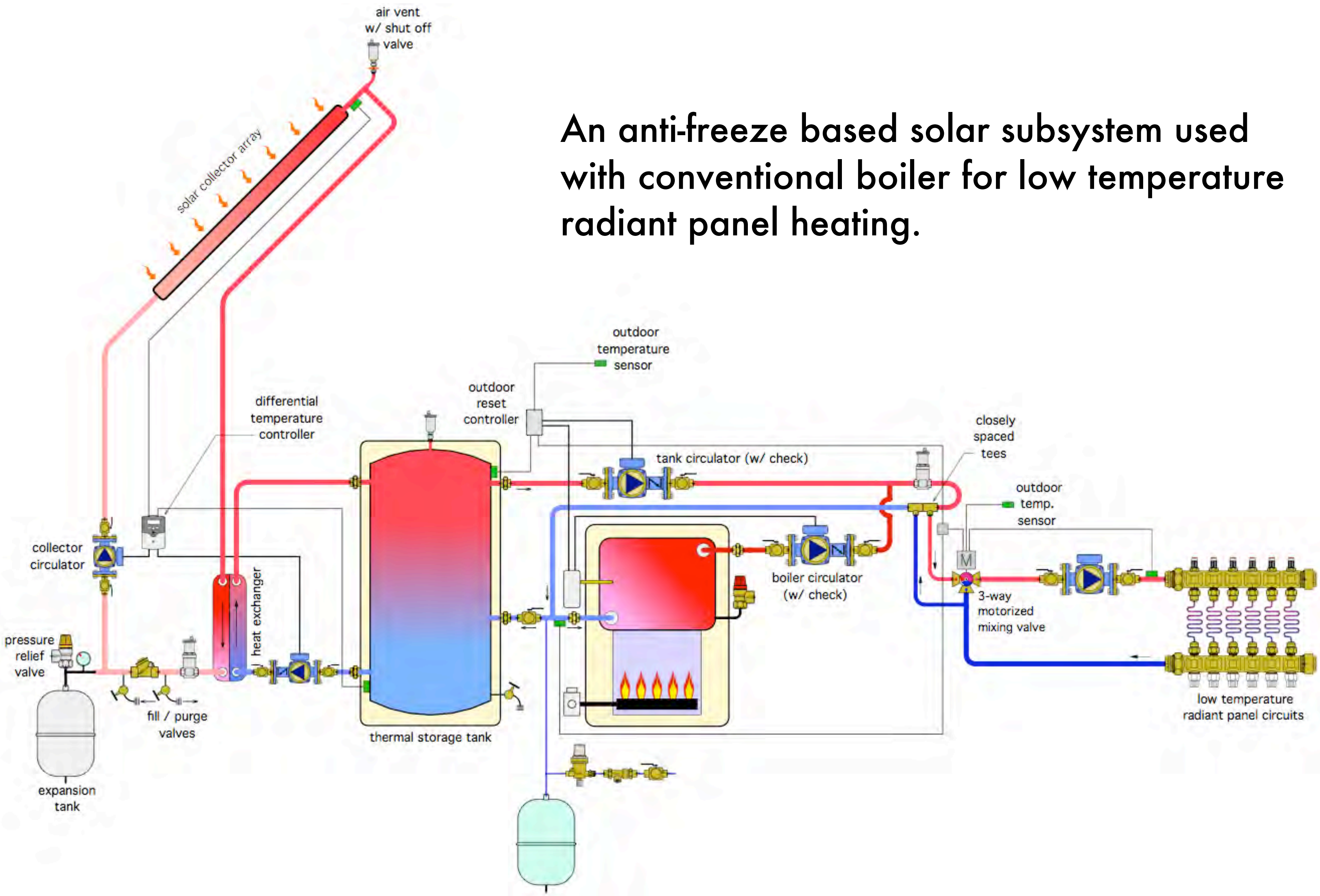
Solar controller brings storage tank to preset upper temperature limit.

Diverter valve then routes solar collector fluid through heat exchanger to heat pool



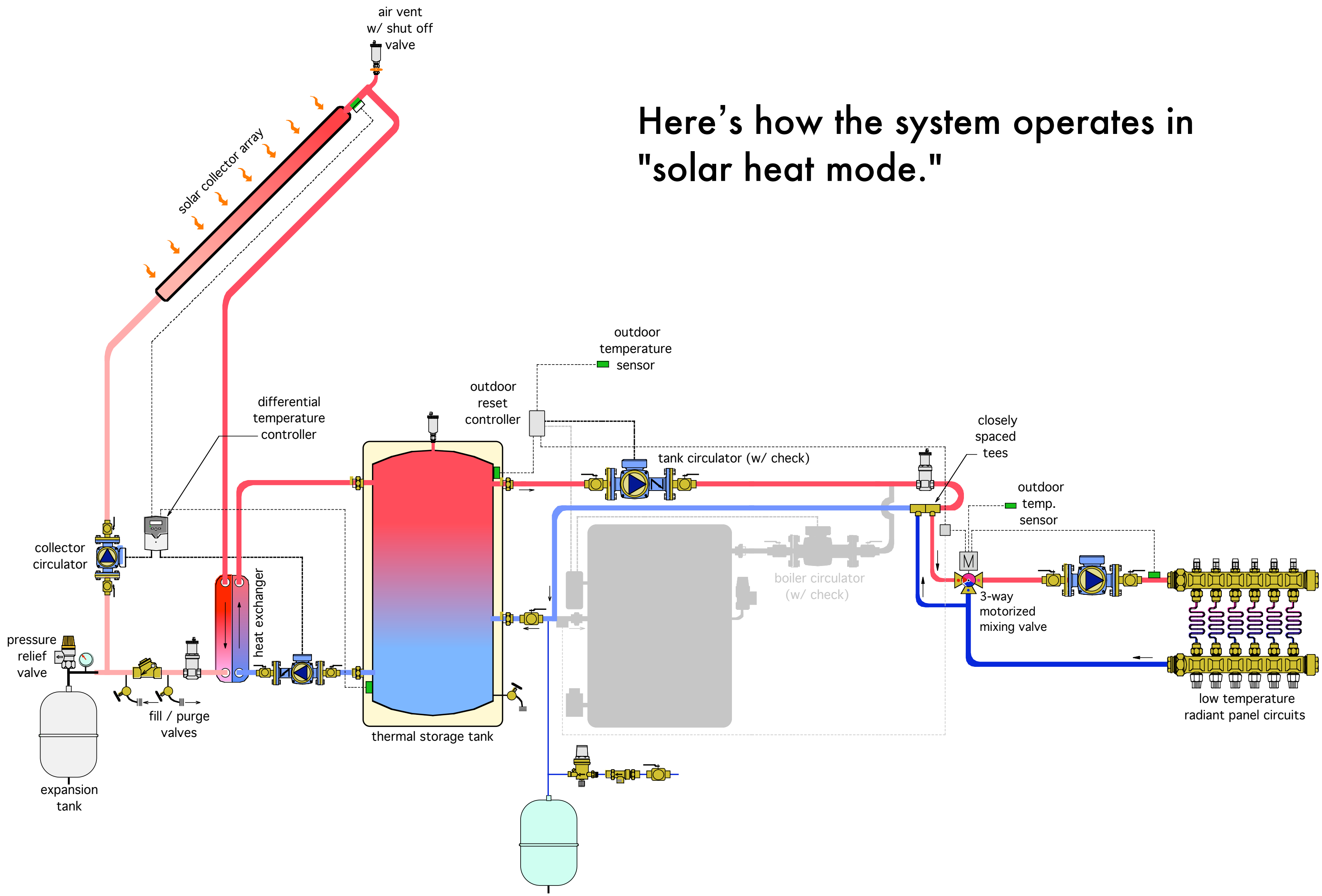
Closed Loop/Antifreeze Systems (space heating only):

An anti-freeze based solar subsystem used with conventional boiler for low temperature radiant panel heating.



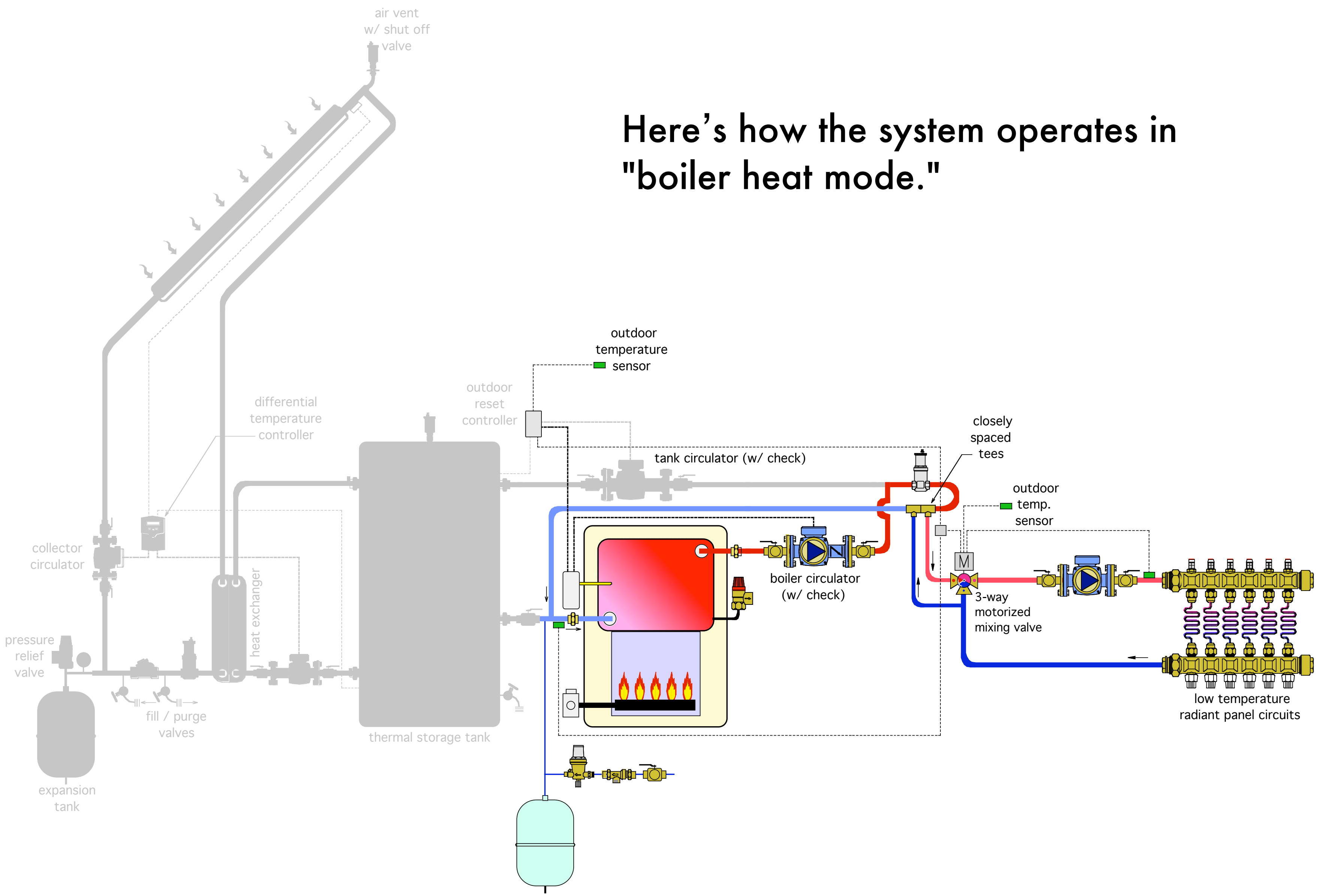
Closed Loop/Antifreeze Systems (space heating only):

Here's how the system operates in "solar heat mode."

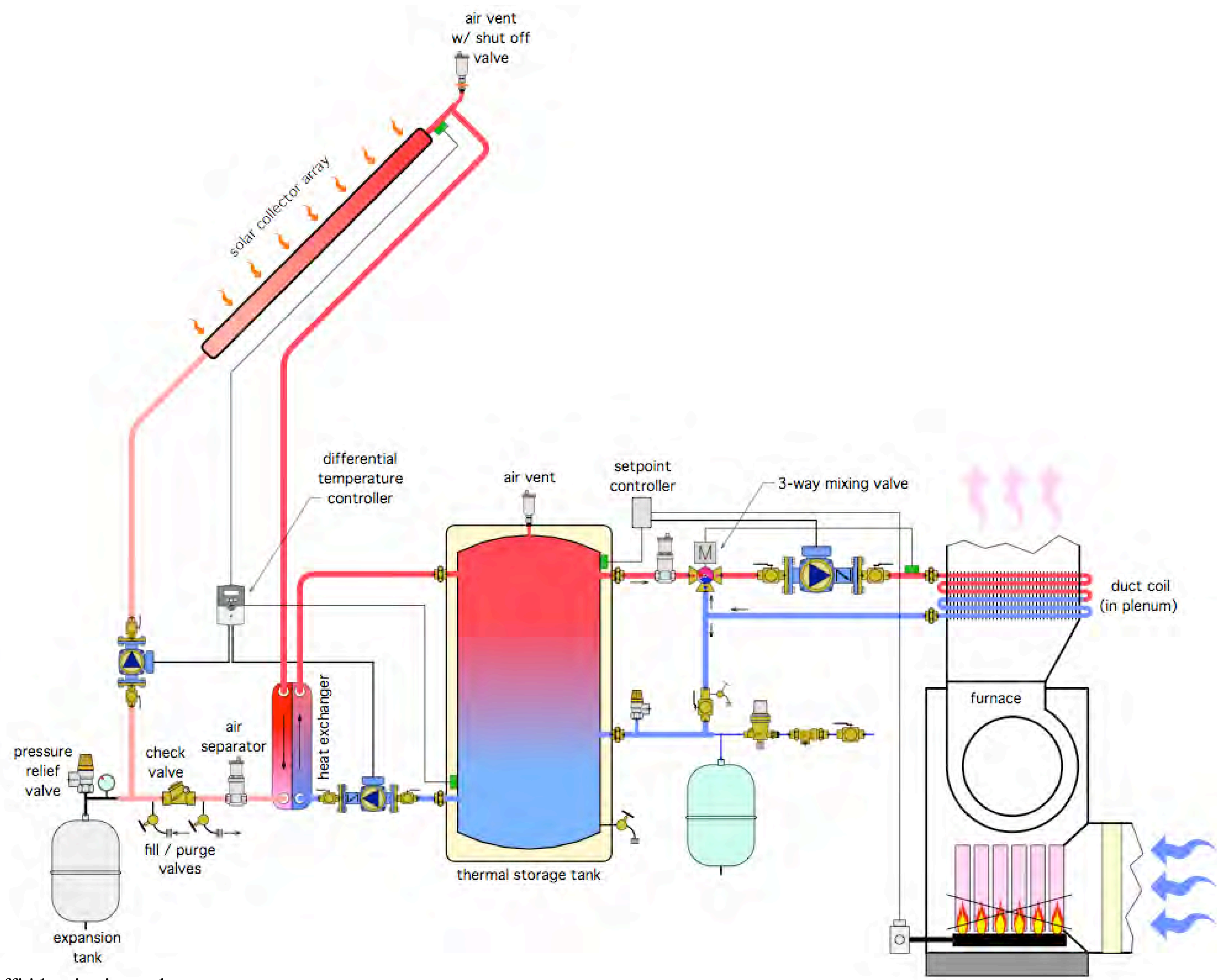


Closed Loop/Antifreeze Systems (space heating only):

Here's how the system operates in "boiler heat mode."



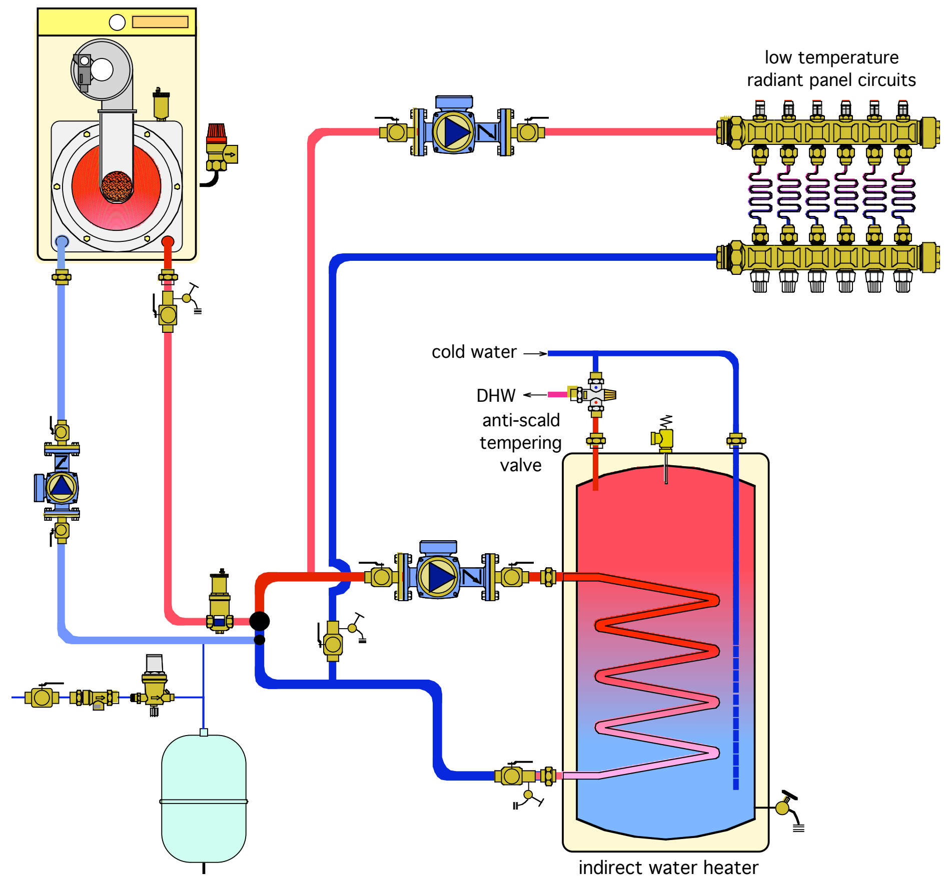
Closed Loop/Antifreeze System: (w/ forced air delivery)



Source: Caleffi idronics journal

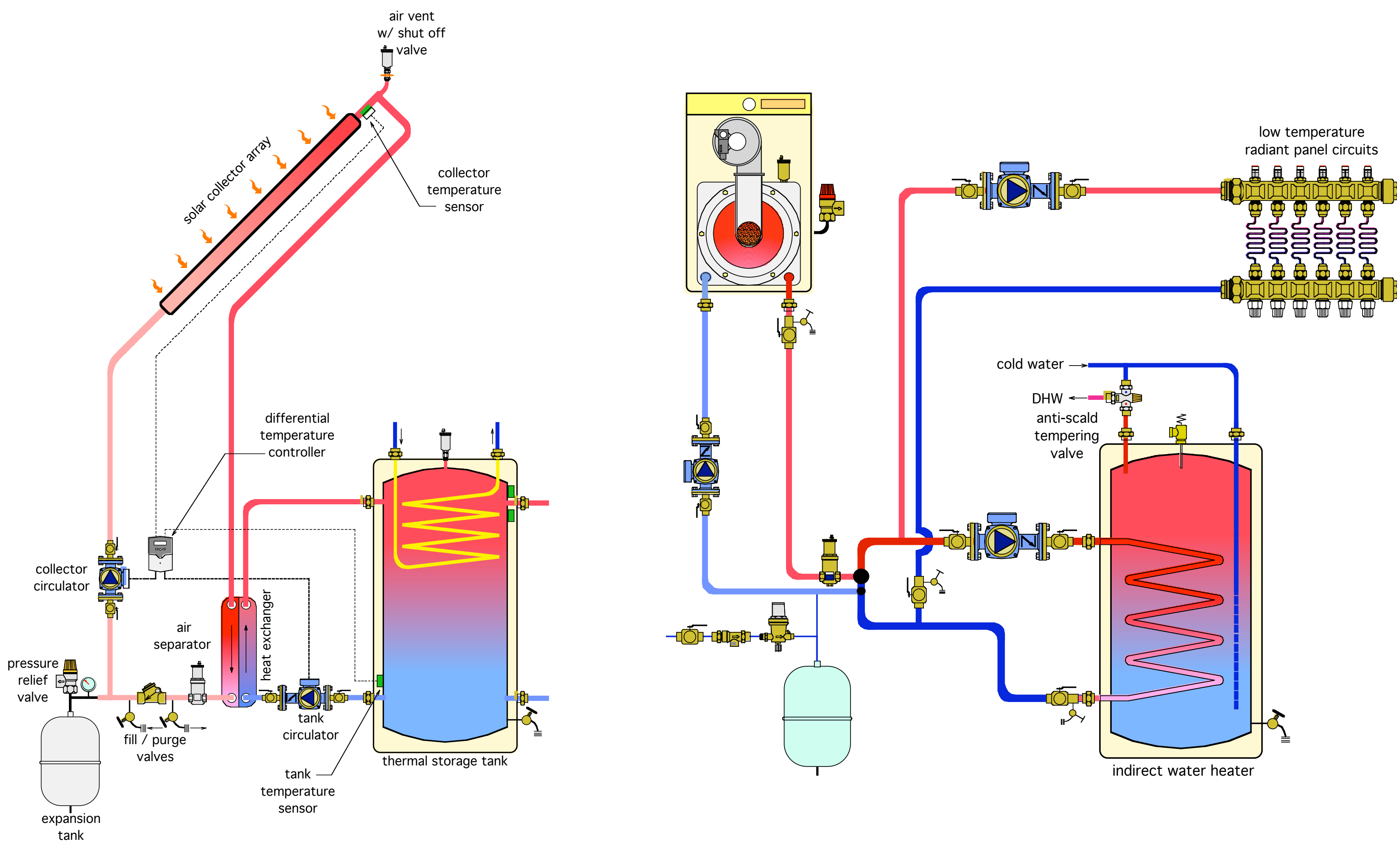
Closed Loop/Antifreeze Systems (space heating & DHW):

A "conventional system" using a mod/con boiler to supply heat and DHW:



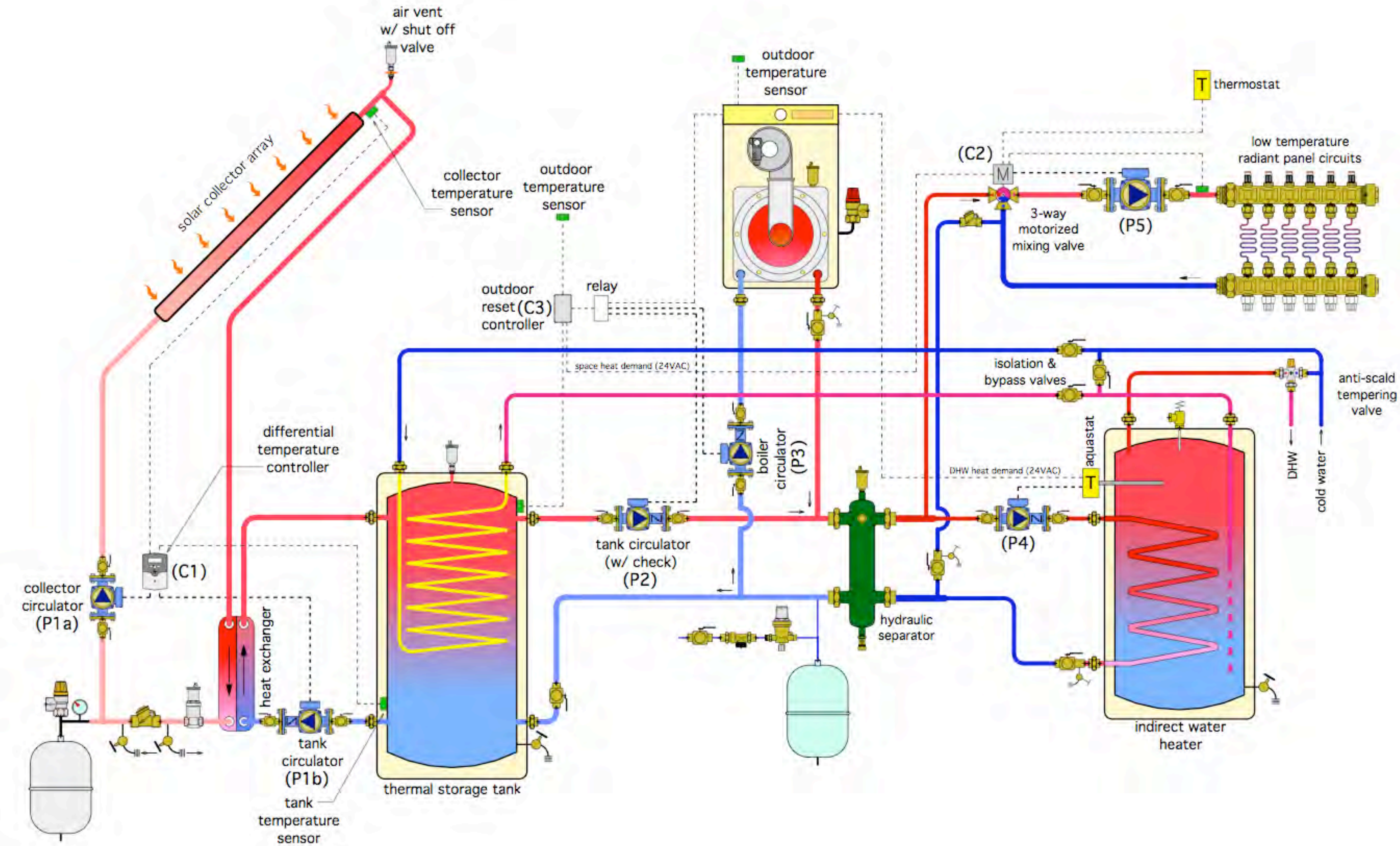
Closed Loop/Antifreeze Systems (space heating & DHW):

Space heating system along side a solar subsystem.



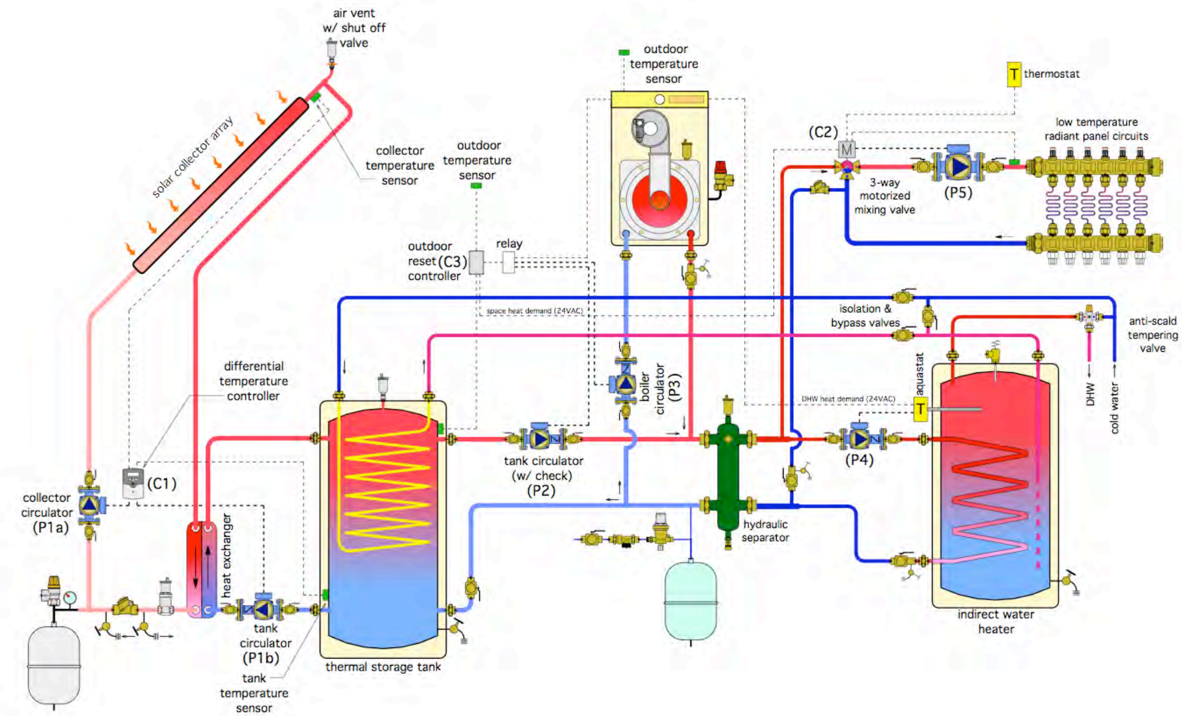
Closed Loop/Antifreeze Systems (space heating & DHW):

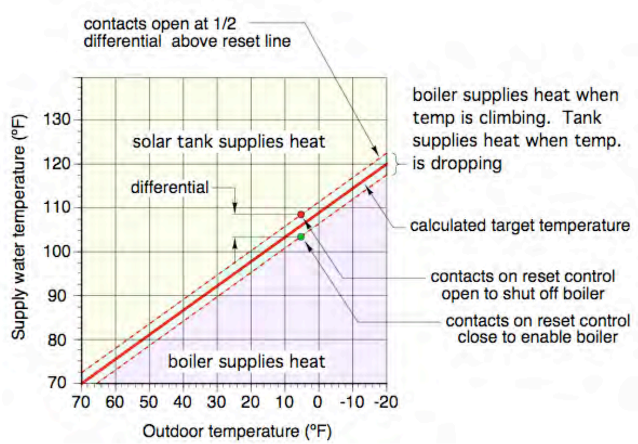
Merging the two systems together - simpler controls



Closed Loop/Antifreeze Systems (space heating & DHW):

Merging the two systems together -simpler controls





CONTROL SEQUENCE:

1. Solar collection is controlled by the differential temperature controller (C1) operating circulators (P1a and P1b). If collectors are warmer than storage tank by 5ºF these circulators operate. If the differential drops to 2ºF or less these circulators are turned off.

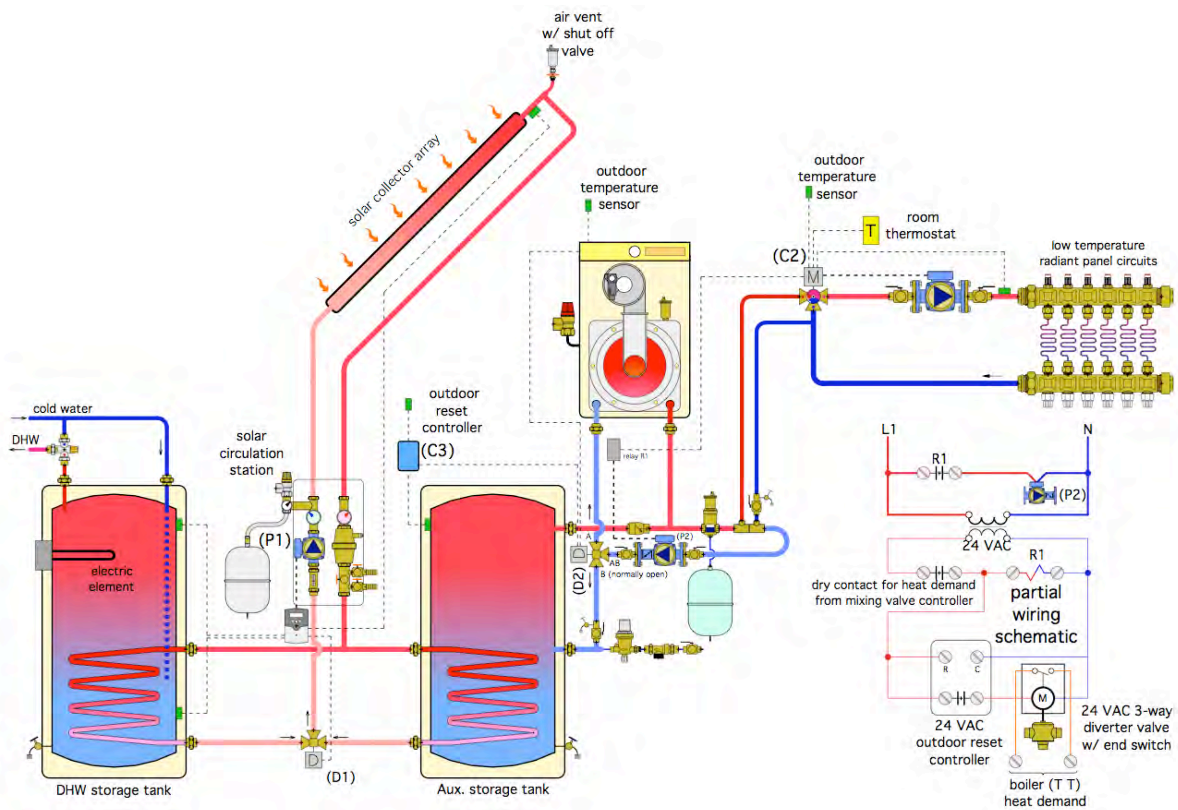
2. Upon a call for space heating, the mixing valve controller (C2) calculates the necessary water supply temperature to the radiant panel circuits. Controller (C2) calls for heating by closing a set of dry contacts sending 24 VAC to power up outdoor reset controller (C3) monitoring temperature at top of solar storage tank. If temperature in storage tank is at or above the calculated target temperature minus half control differential, the normally closed contacts in the relay turn on the tank circulator. If the tank is below this temperature the normally open contact of the relay close to provide a call for space heating and the boiler turns on the boiler circulator (P3). The boiler temperature is controlled by the boiler's internal reset controller.

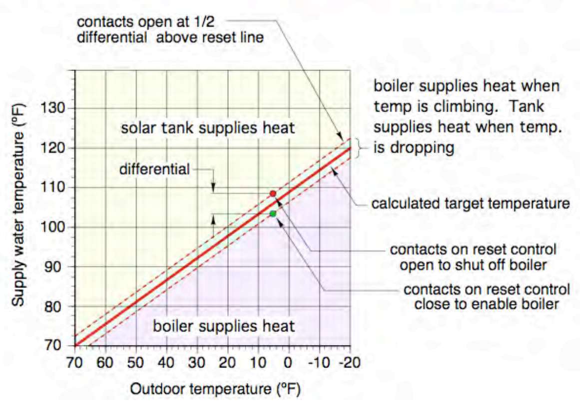
3. If the DHW tank calls for heating, the tank circulator (P2) is turned off, circulator (P4) is turned on, the boiler is turned on (e.g. receive a DHW heating demand), and the boiler circulator (P3) operates. The boiler temperature is controlled based on its setting for DHW mode.

The only limitation of this approach is that solar-sourced energy cannot "top off" the DHW tank through the indirect coil to make up for stand-by loss when there is no DHW draw.

Closed Loop/Antifreeze Systems (space heating & DHW):

DHW is priority - surplus heat dumped to 2nd tank.



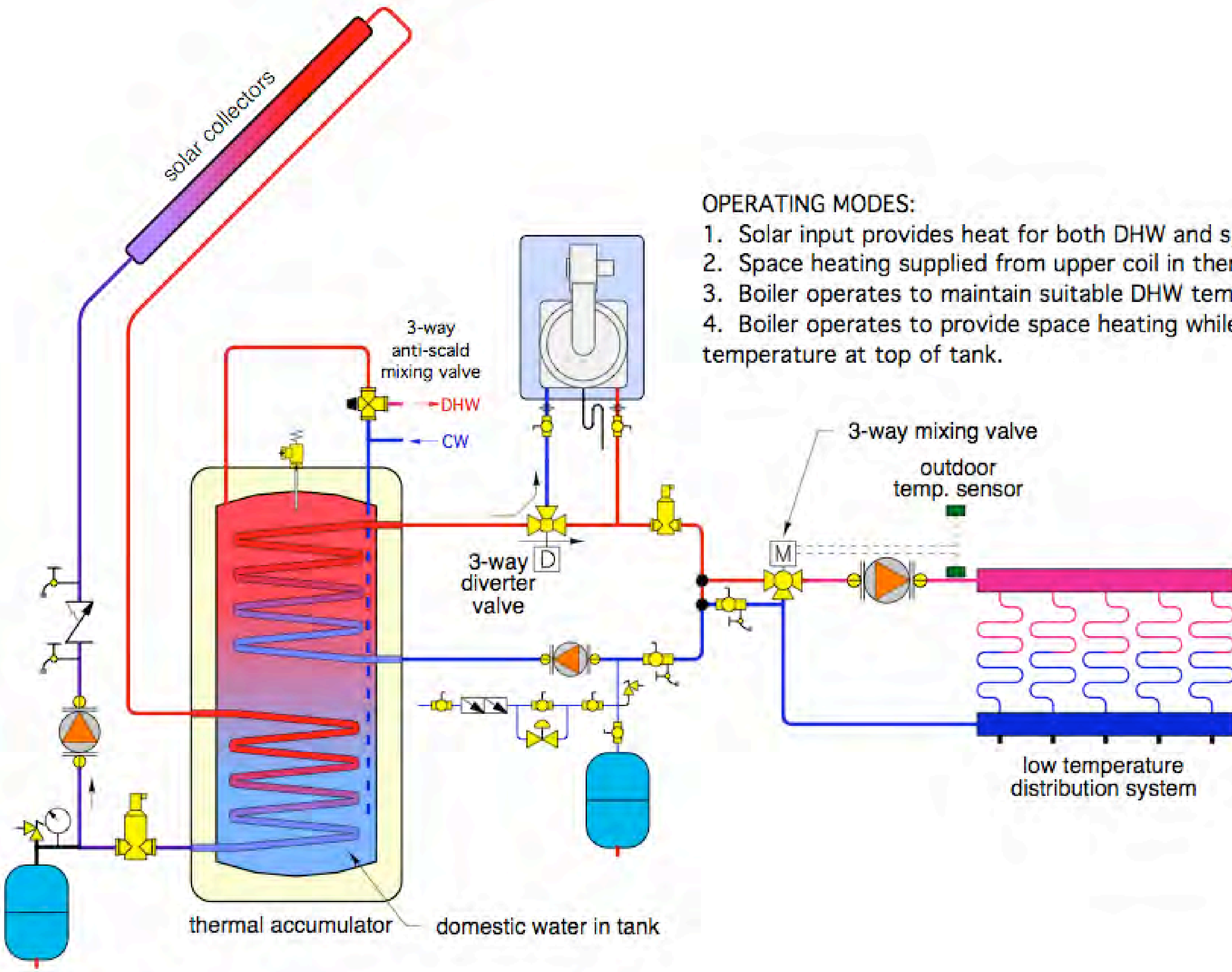


CONTROL SEQUENCE:

1. Solar collection is controlled by the differential temperature controller operating circulator (P1). If collectors are warmer than storage tank by 5ºF the circulator in the solar circulation station operates. If the differential drops to 2ºF or less this circulator is turned off. If the DHW tank temperature exceeds a set limit, the solar controller operates the diverting valve (D1) to send heat to the aux storage tank.

2. Upon a call for space heating, the mixing valve controller (C2) calculates the necessary water supply temperature to the radiant panel circuits. Controller (C2) calls for heat by closing a set of dry contacts sending 24 VAC to power up outdoor reset controller (C3), which monitors temperature at top of Auxiliary storage tank. If temperature in this tank is at or above the calculated target temperature minus half control differential, the normally closed contact in the outdoor reset controller is open, and the diverter valve (D2) is unpowered, routing flow through the auxiliary storage tank. When the temperature in the Auxiliary storage tank drops to *less than* the calculated target temperature minus 1/2 differential, the 24 VAC diverter valve (D2) is powered on sending flow through the boiler. The end switch in the diverter valve closes to provide a dry contact closure to signal a heat demand to the boiler. The boiler fires and operates on its own reset curve.

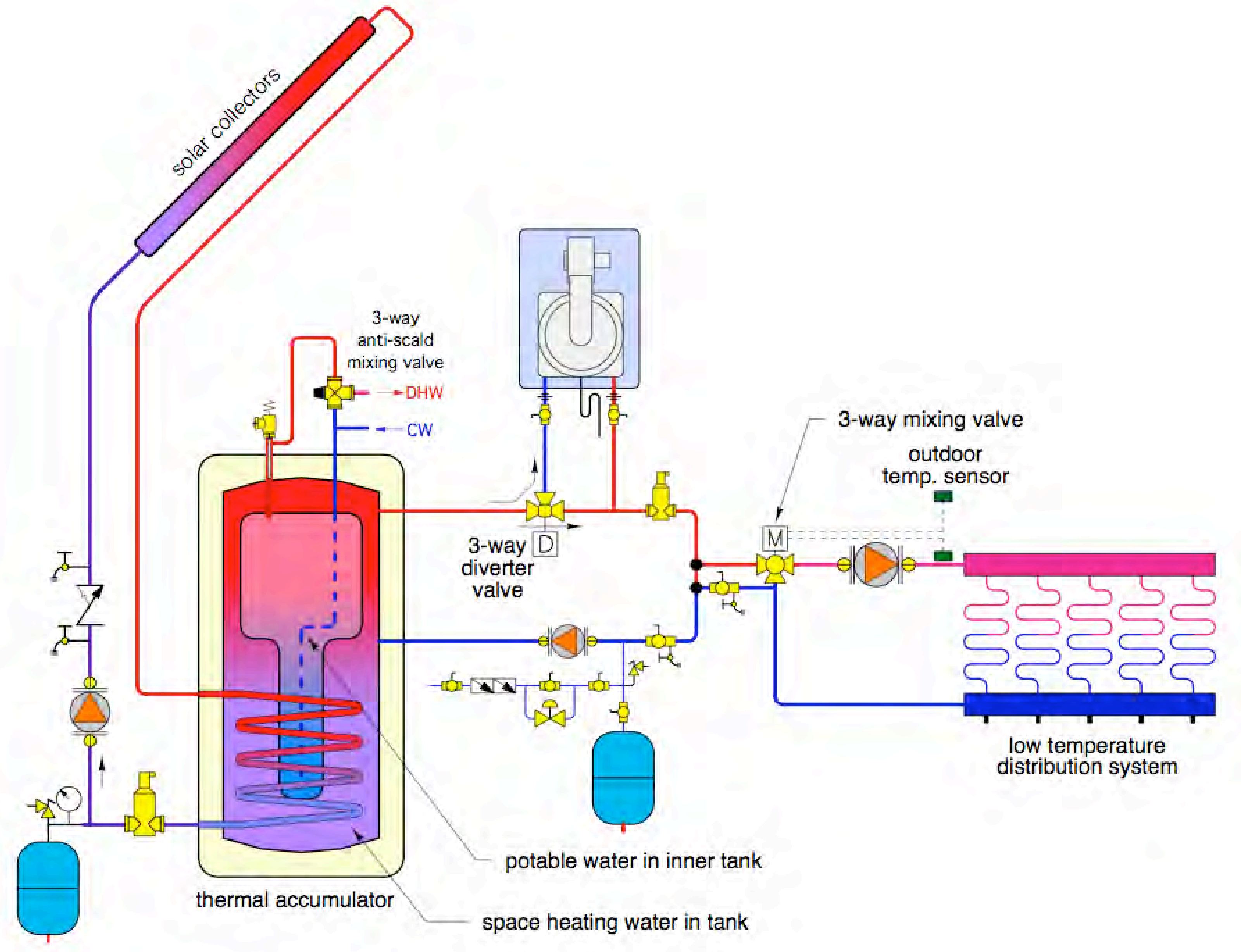
Use of DUAL COIL tank in system for solar DHW and space heating



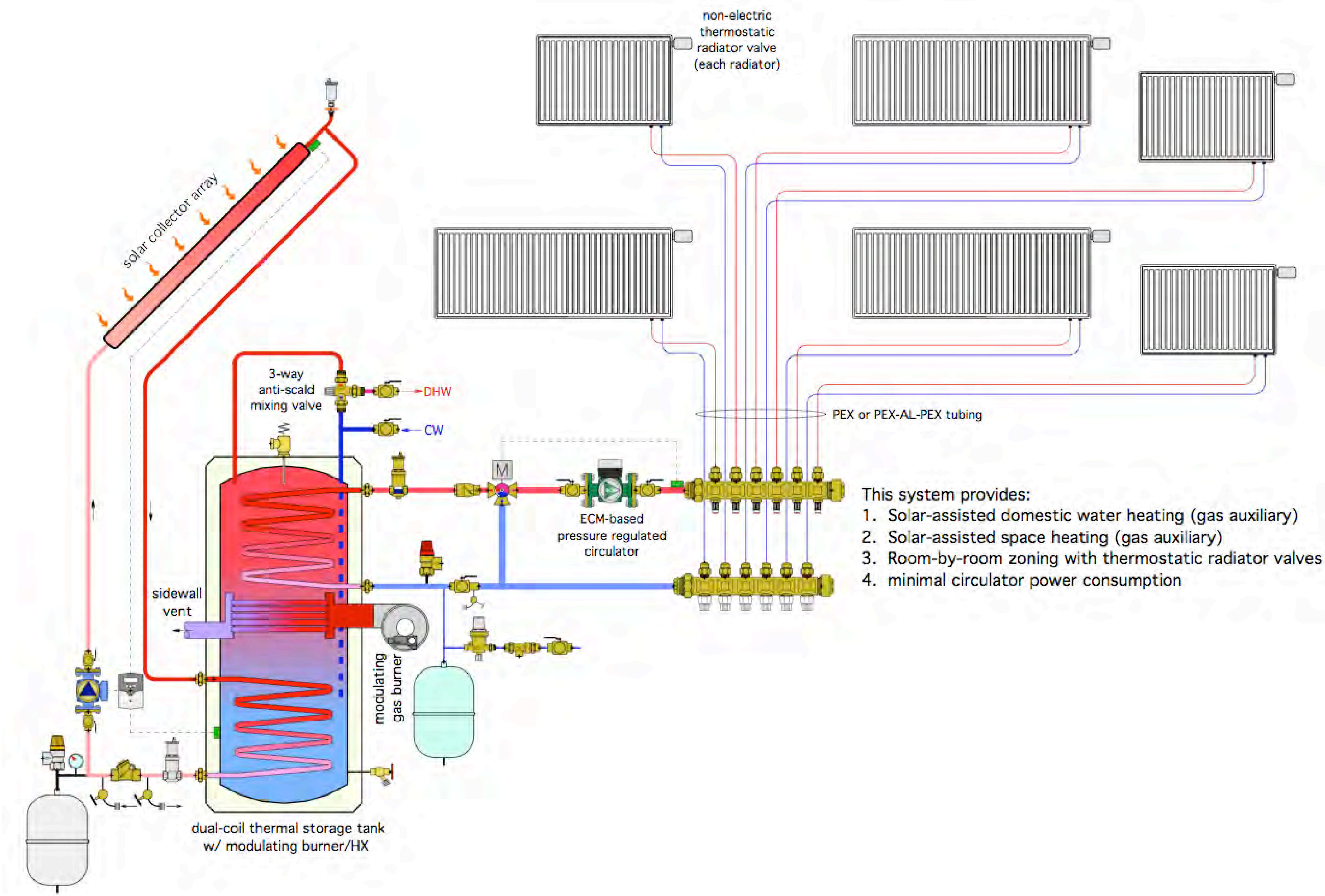
OPERATING MODES:

1. Solar input provides heat for both DHW and space heating.
2. Space heating supplied from upper coil in thermal accumulator.
3. Boiler operates to maintain suitable DHW temp. at top of tank.
4. Boiler operates to provide space heating while also maintaining temperature at top of tank.

Use of TANK-IN-TANK storage system for solar DHW and space heating



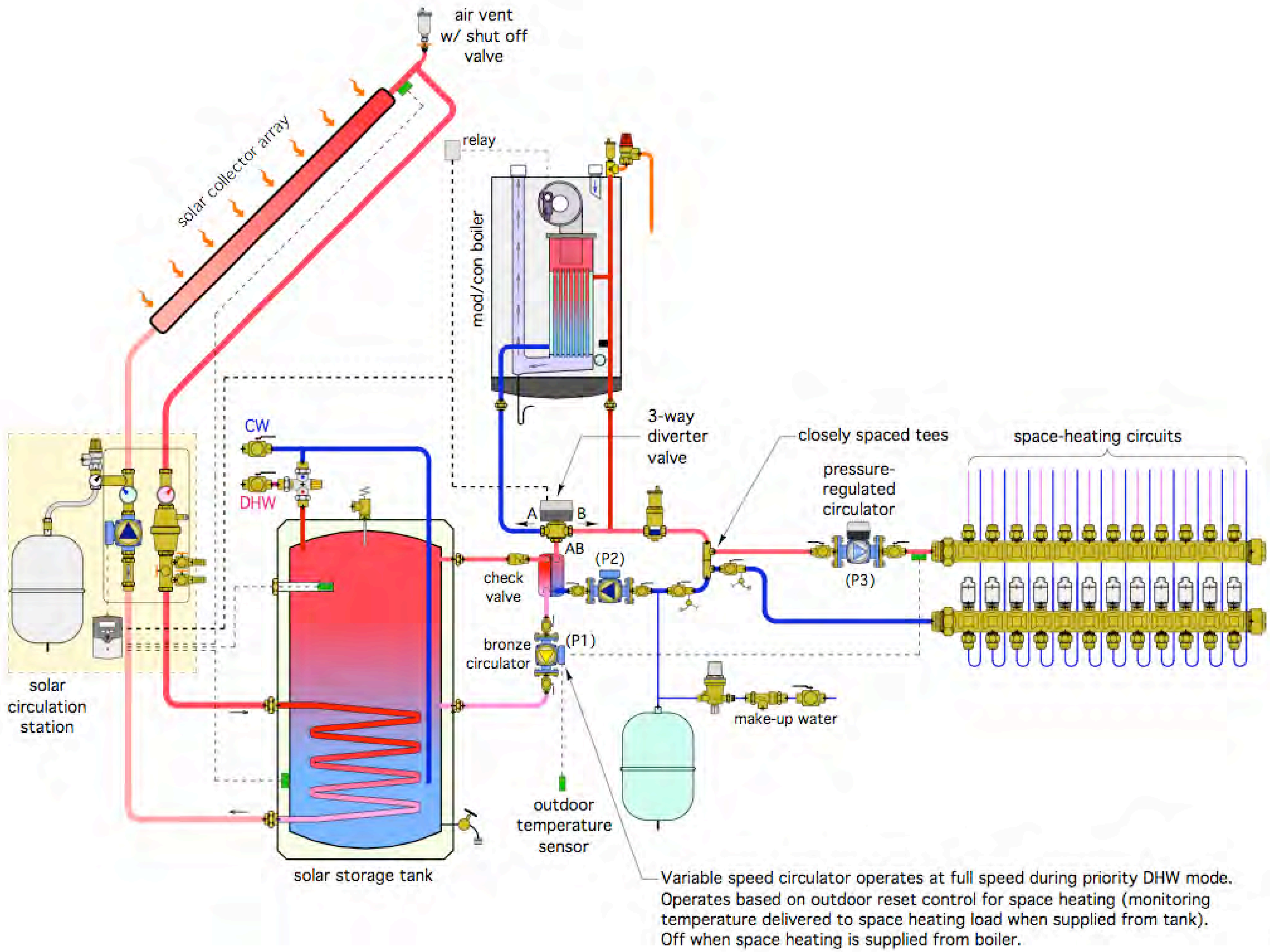
Use of dual coil tank with INTEGRAL BURNER for DHW and space heating



This system provides:

1. Solar-assisted domestic water heating (gas auxiliary)
2. Solar-assisted space heating (gas auxiliary)
3. Room-by-room zoning with thermostatic radiator valves
4. minimal circulator power consumption

Domestic water in storage tank, external heat exchanger for space heating



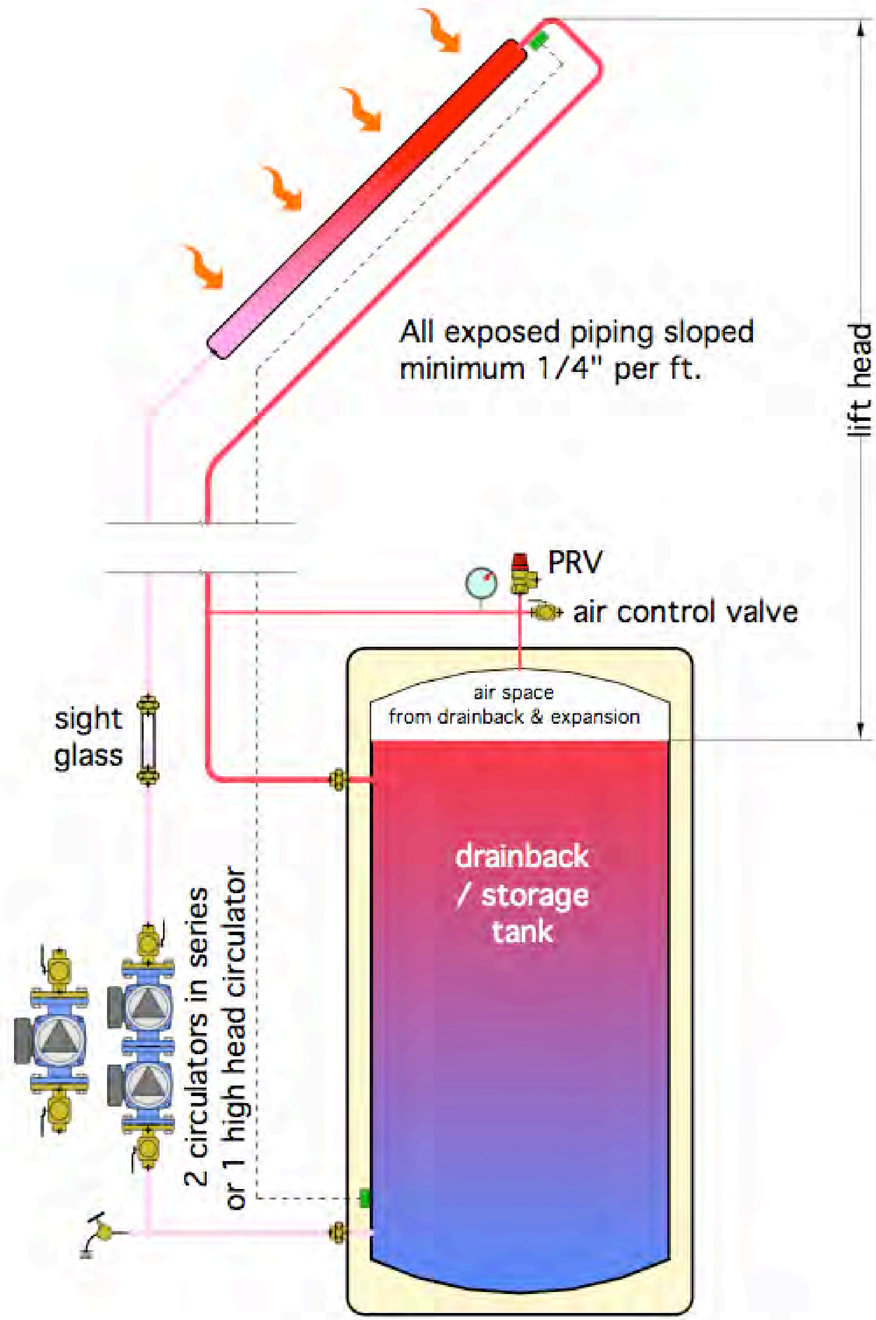
Gravity Drain*back* Systems

An alternative to antifreeze is a direct circulation approach known as ***gravity drainback***.

The water drains from the collectors whenever the solar array pump is off.

The collector circulator in a drainback system must be sized to lift the water to the top of the collector array.

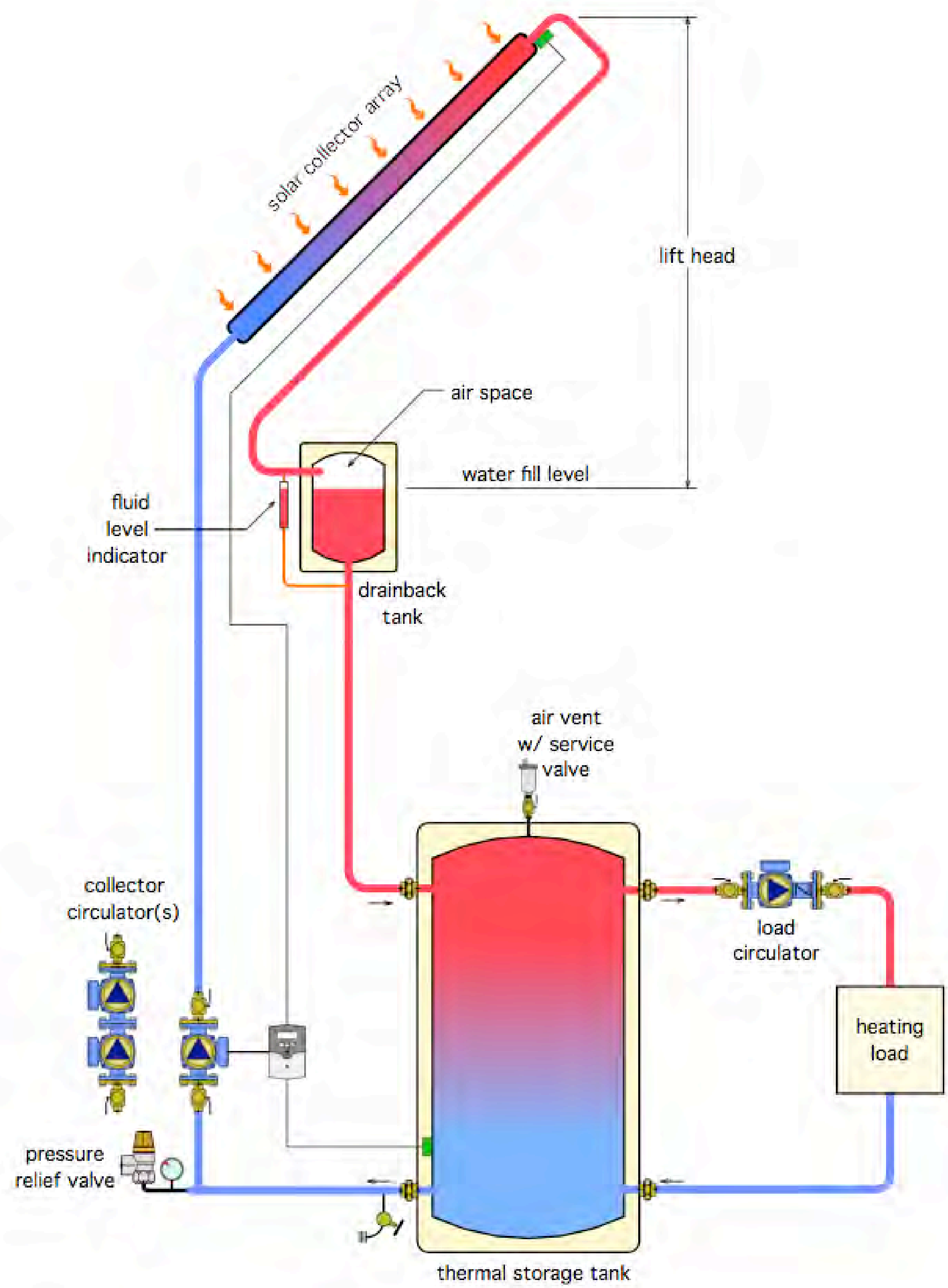
This distance represents “lift head” for the circulator while the supply pipe and collectors are being filled.



Gravity Drain*back* Systems

Another approach is use of a separate drainback tank.

The higher the drainback tank is relative to the top of the collectors, the lower the lift head, and the smaller the pumping power requirement.



Gravity Drainback Systems

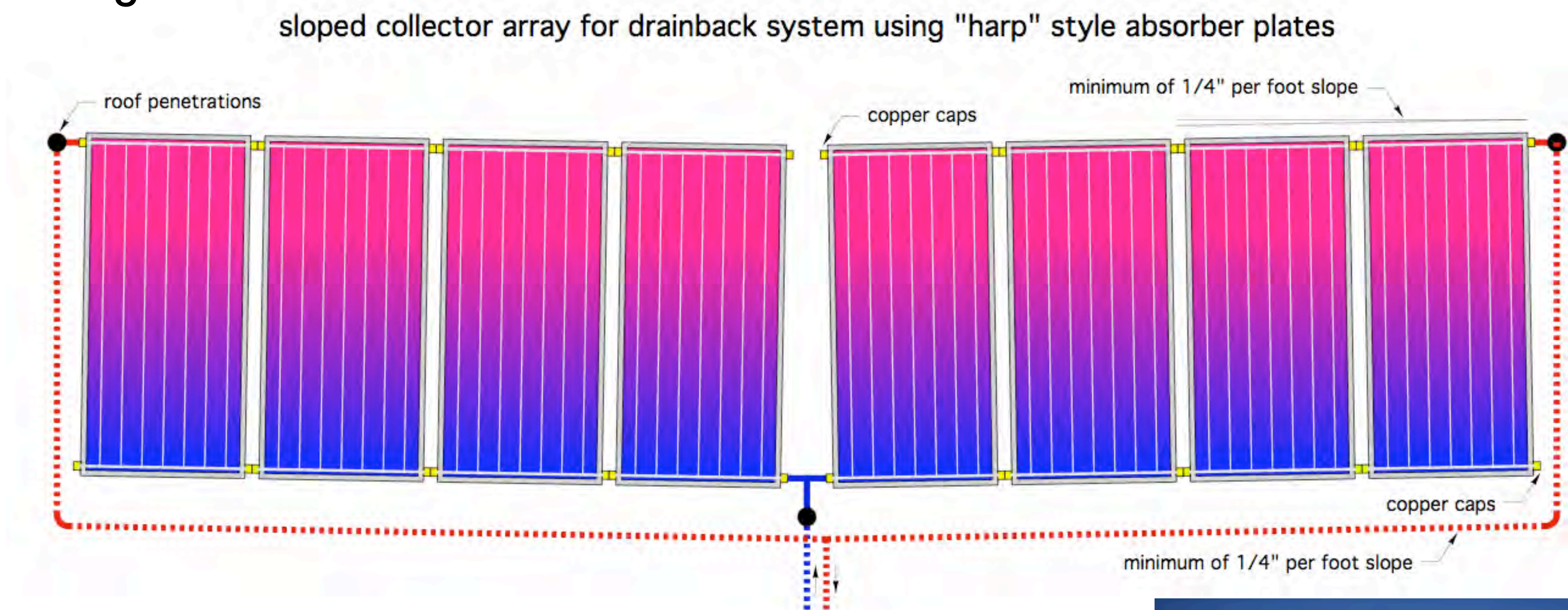
It is absolutely necessary that the collectors and all exposed piping be pitched a minimum of 1/4 inch per foot toward the storage tank for complete drainage.

External header is sloped

Entire collector array is sloped

Gravity Drainback Systems

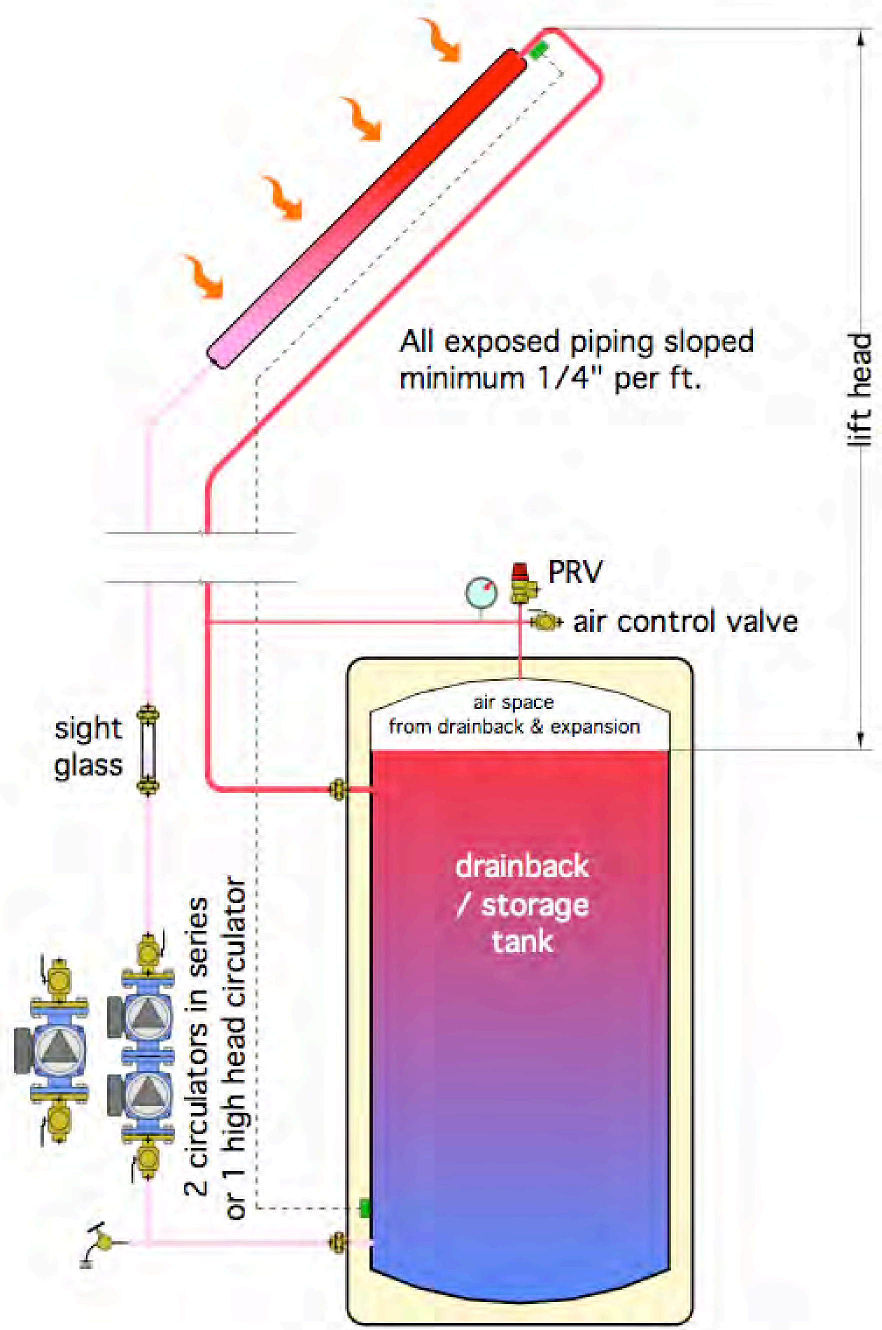
It is absolutely necessary that the collectors and all exposed piping be pitched a minimum of 1/4 inch per foot toward the storage tank for complete drainage.



Gravity Drainback Systems

The return line should be sized for a minimum flow velocity of 2 feet per second at the flow rate present when the water level reaches the top of the collector array.

This allows downward flow to entrain air bubbles and return them to the top of the storage tank.

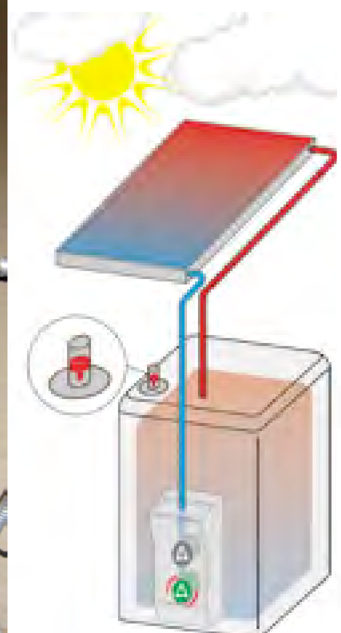
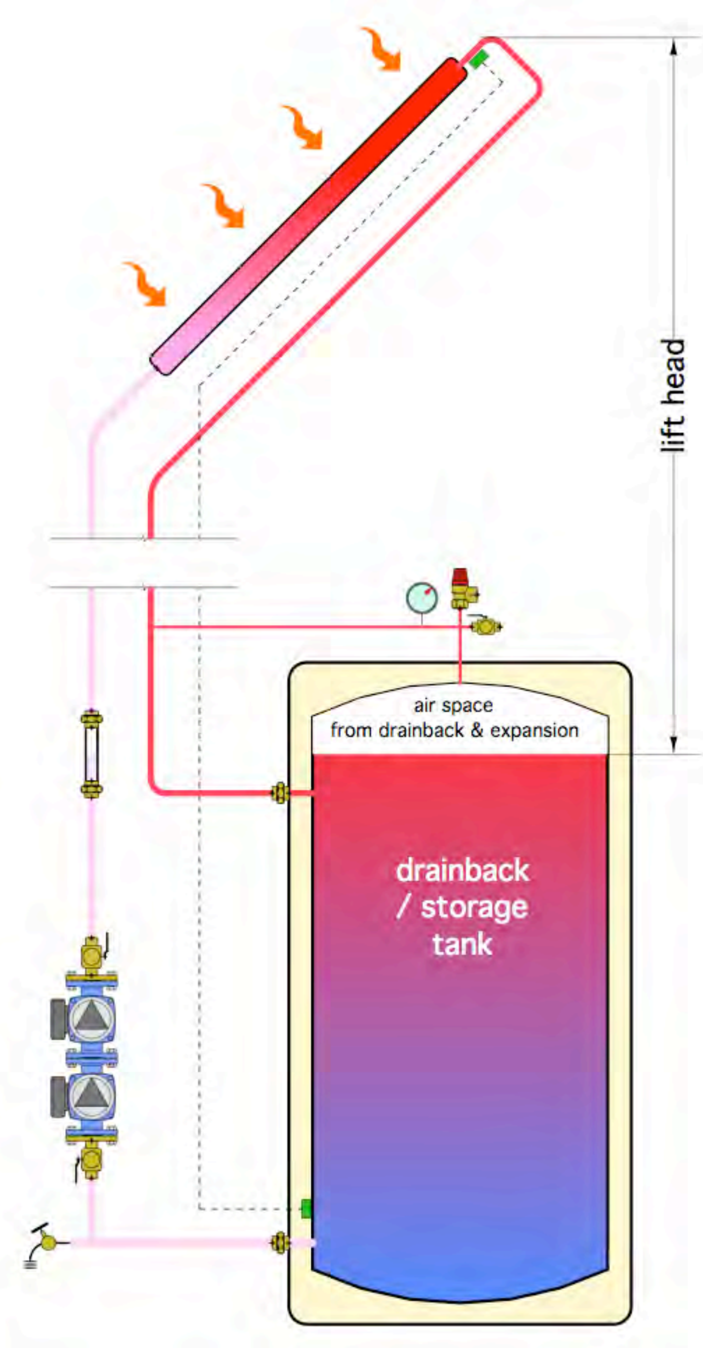


Gravity Drainback Systems

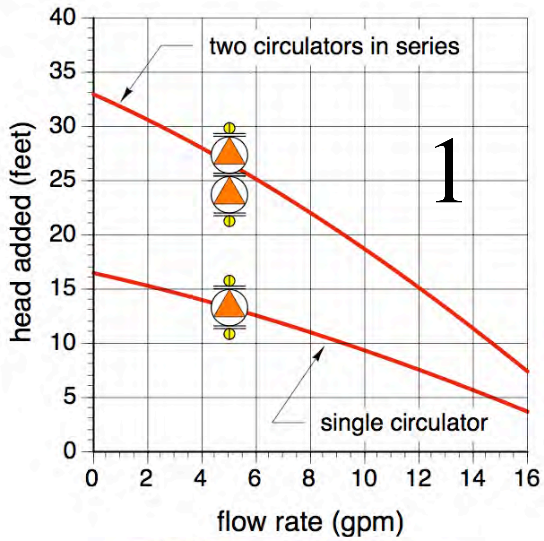
A common technique is to use 2 circulators in series to supply the collector array.

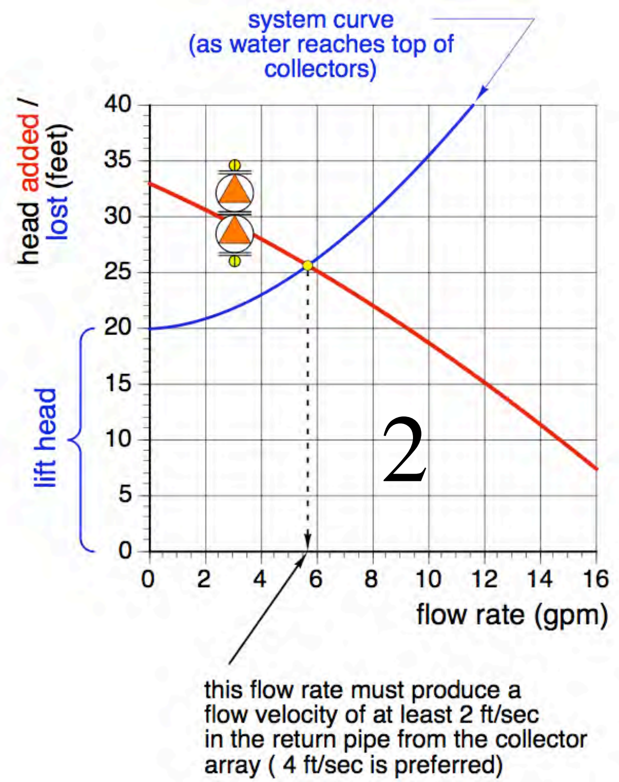
After a 1-3 minute period a siphon is established over the top of the collector loop so that the upper circulator can be turned off to reduce electrical demand.

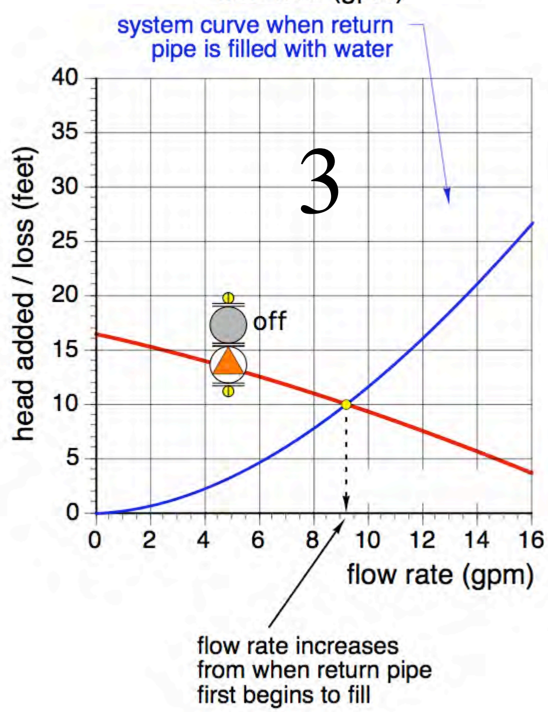


Gravity Drainback Systems (Series circulators)

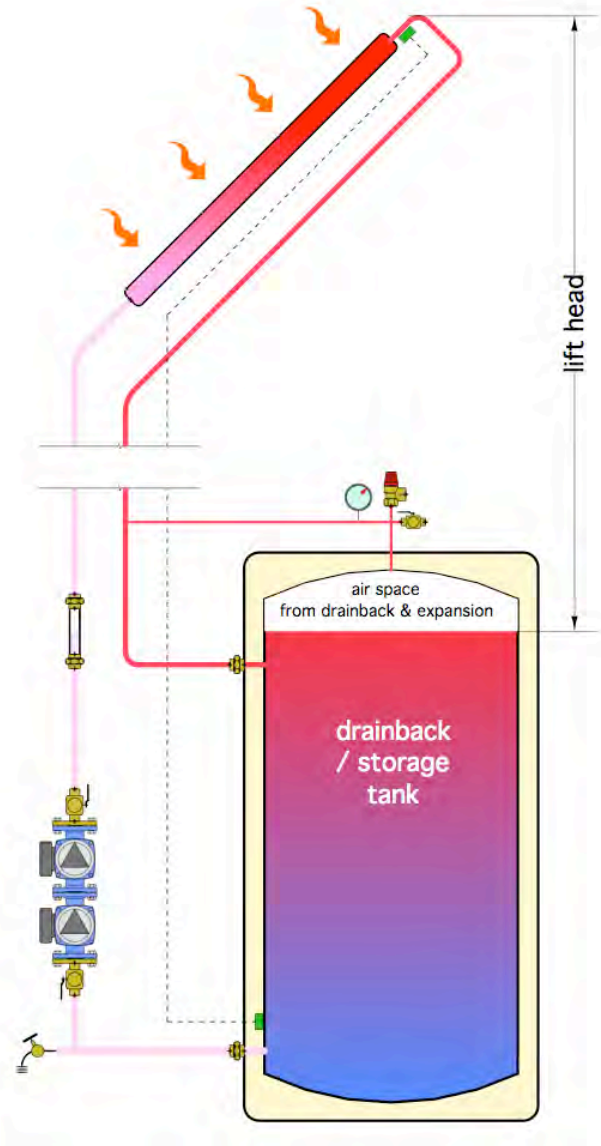






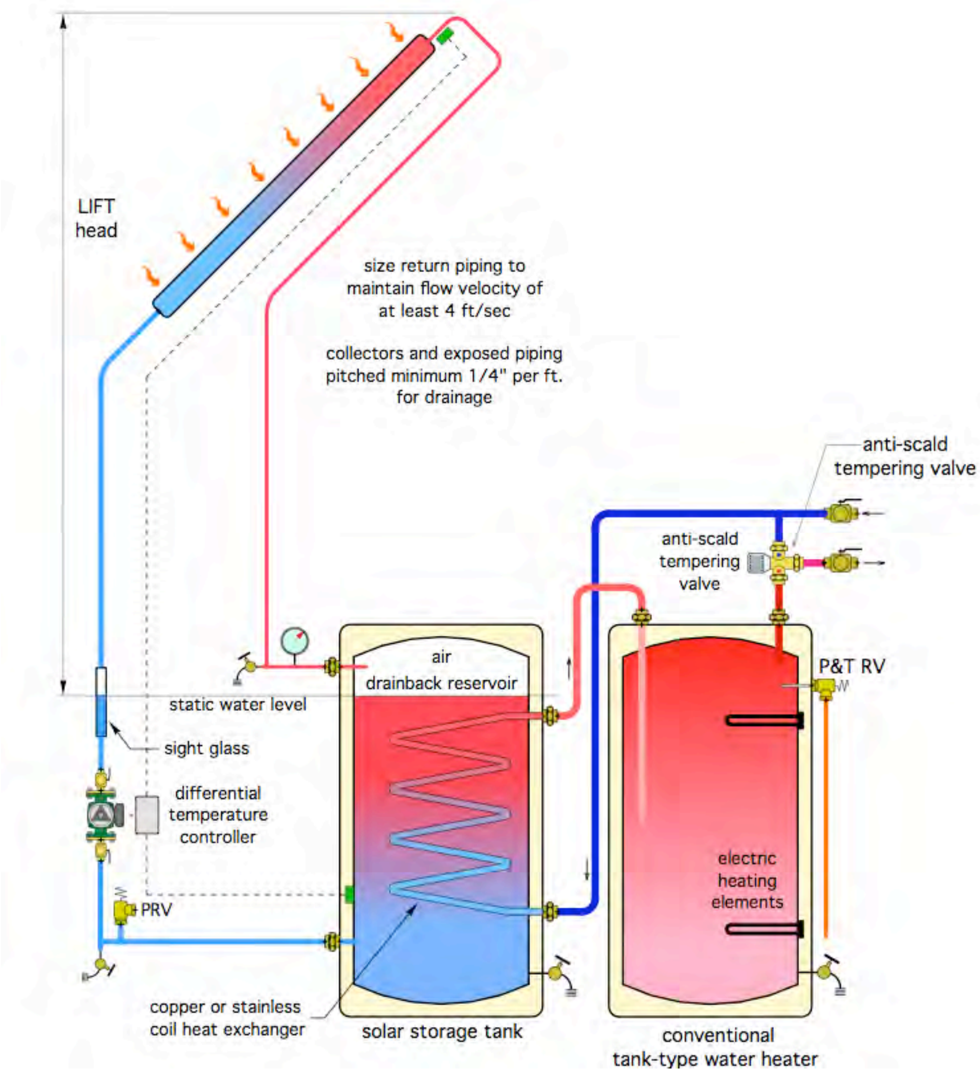
A variable speed circulator
Can also be used:

- Full speed to establish siphon
- Reduce speed to maintain "siphon established" flow

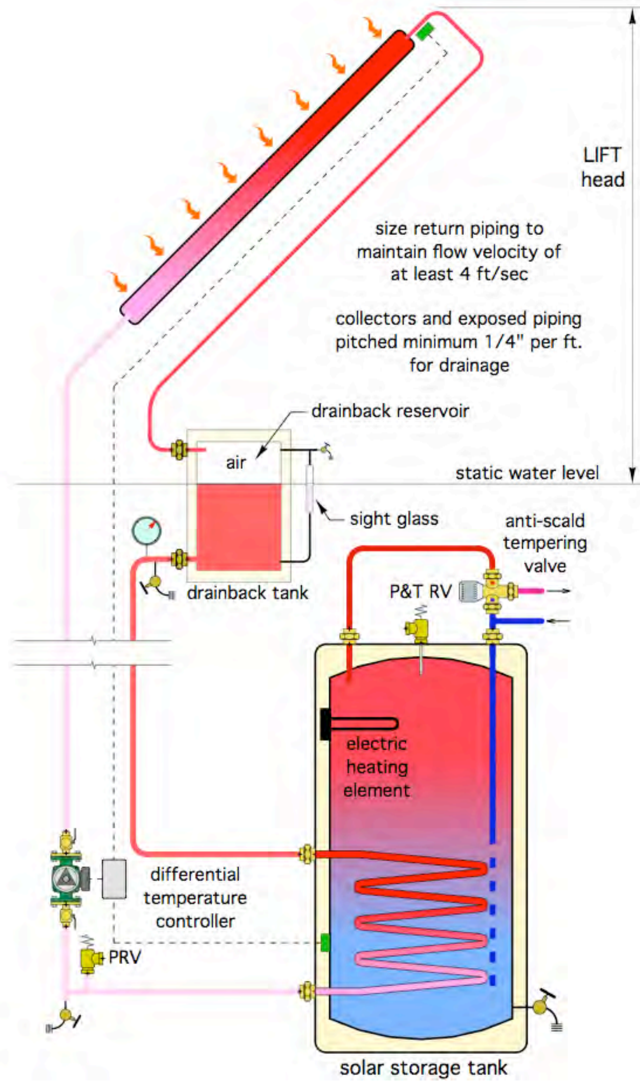


Drainback System for DHW Only

Domestic water coil in drainback tank



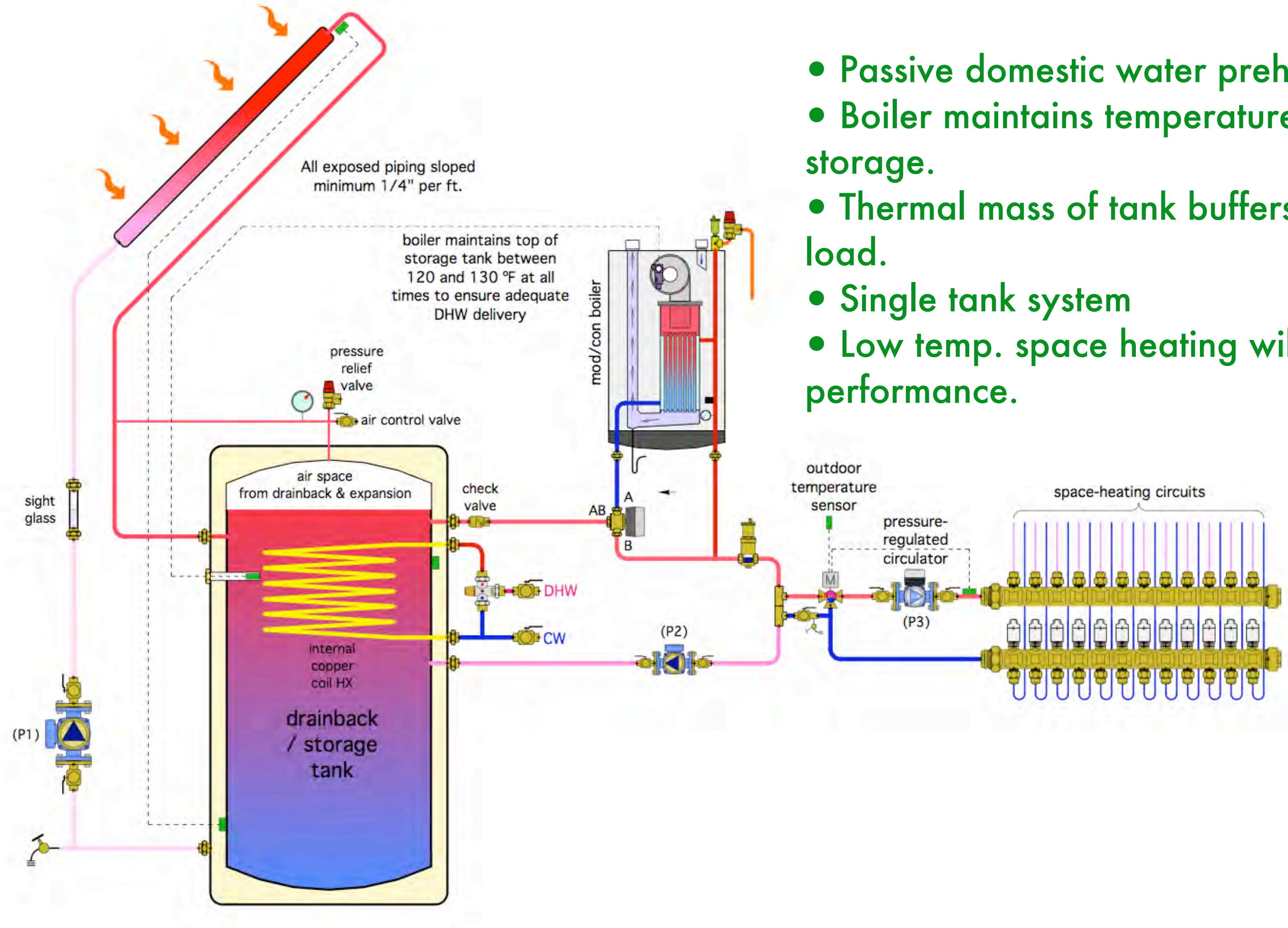
Separate drainback tank and internal coil in solar storage tank



Drainback System for DHW and Space Heating

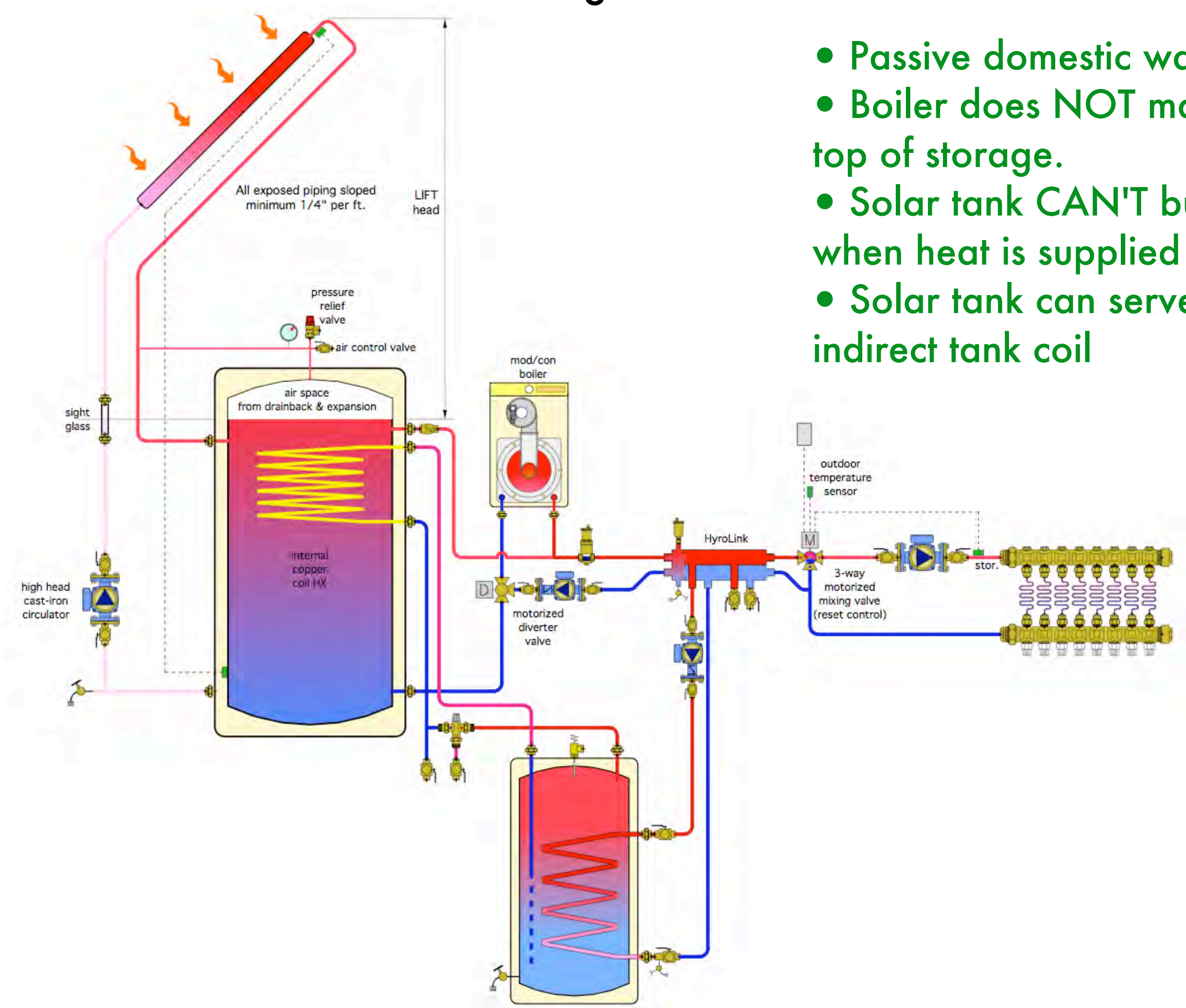
Pressurized gravity drainback system w/ internal coil for domestic water heating. Boiler maintains top of solar storage tank @ suitable temperature for DHW.

- Passive domestic water preheating
- Boiler maintains temperature at top of storage.
- Thermal mass of tank buffers space heating load.
- Single tank system
- Low temp. space heating will improve solar performance.



Drainback System for DHW and Space Heating

Pressurized gravity drainback system w/ *internal* coil for domestic water heating.
Boiler never heats solar storage tank.

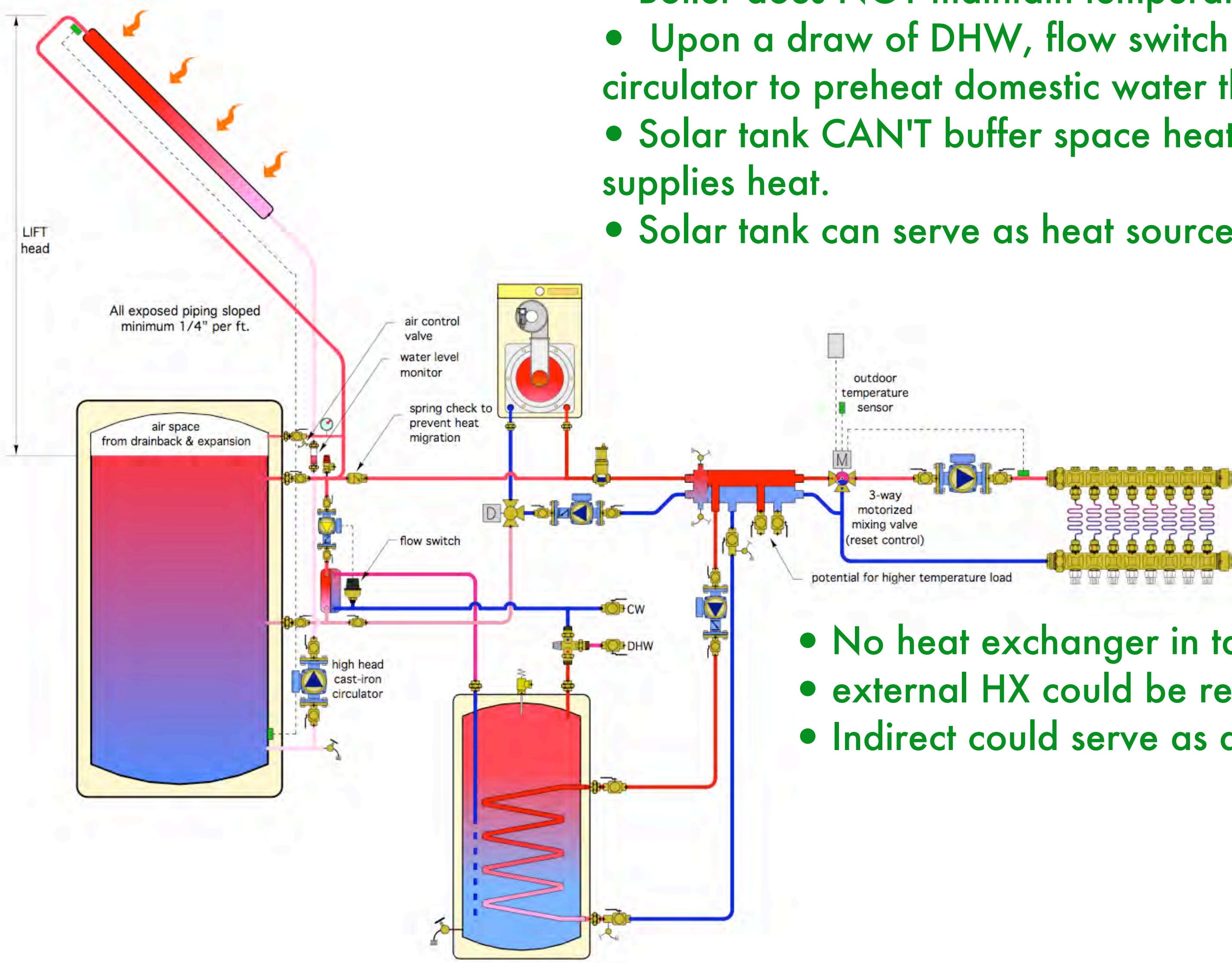


- Passive domestic water preheating
- Boiler does NOT maintain temperature at top of storage.
- Solar tank CAN'T buffer space heating when heat is supplied by boiler.
- Solar tank can serve as heat source to indirect tank coil

Drainback System for DHW and Space Heating

Pressurized gravity drainback system w/ *external plate heat exchanger* for domestic water heating.

- Boiler does NOT maintain temperature of storage.
- Upon a draw of DHW, flow switch turns on small circulator to preheat domestic water through plate HX
- Solar tank CAN'T buffer space heating when boiler supplies heat.
- Solar tank can serve as heat source to indirect tank coil

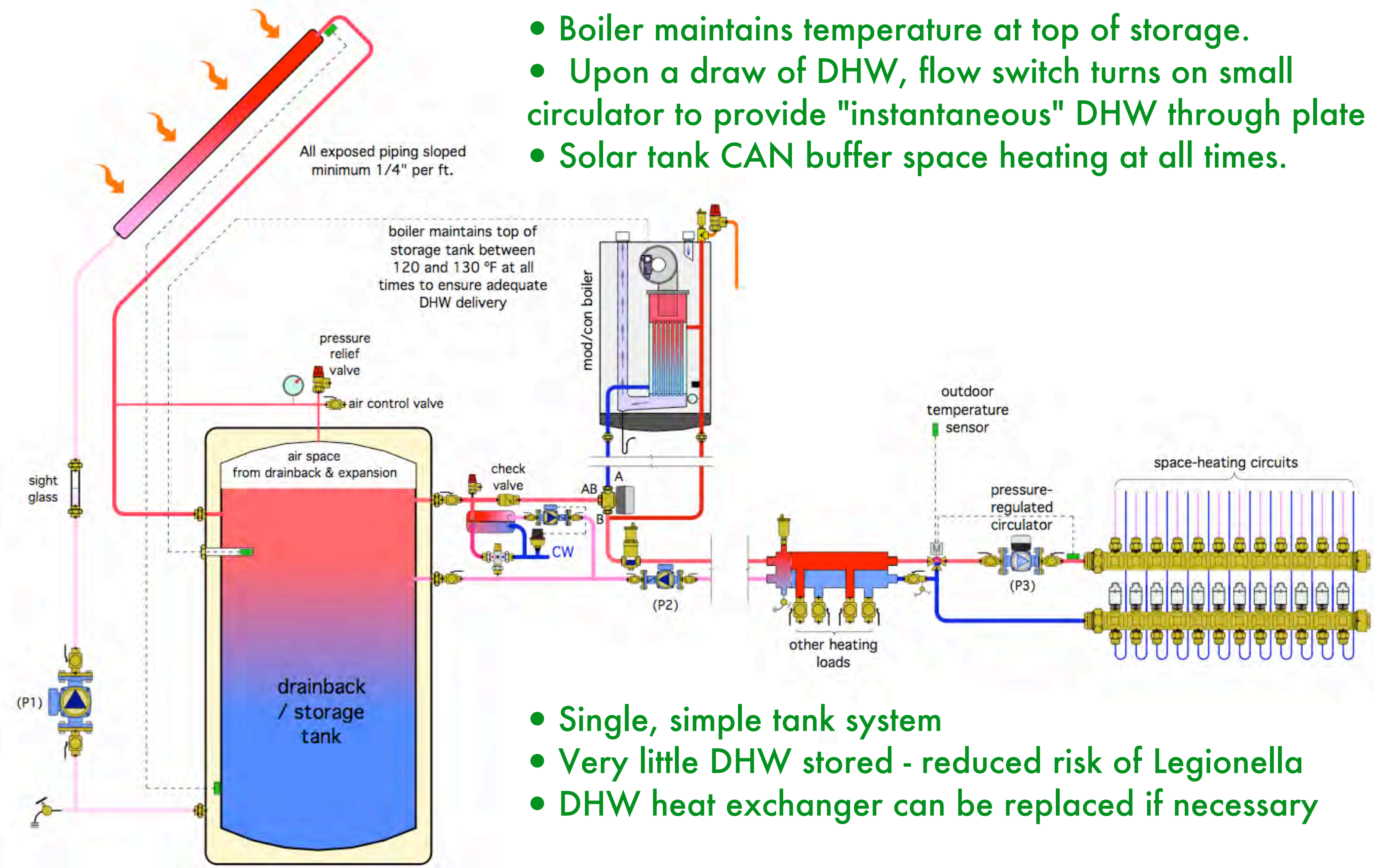


- No heat exchanger in tank.
- external HX could be replaced if necessary
- Indirect could serve as a heat dump

Drainback System for DHW and Space Heating

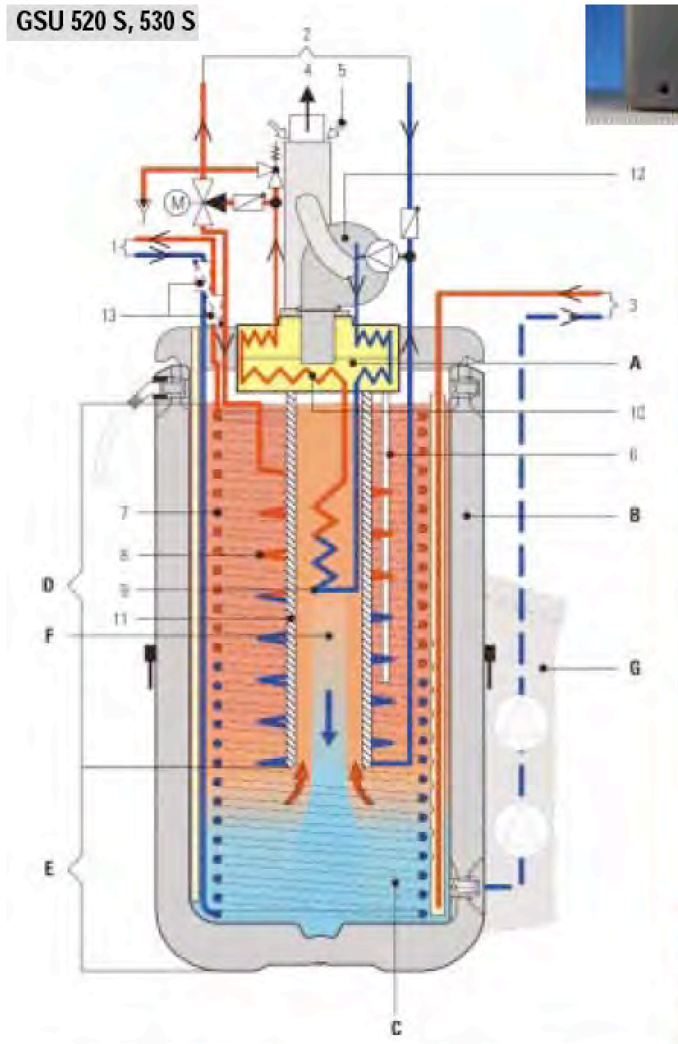
Pressurized gravity drainback system w/ external HX for domestic water heating.

- Boiler maintains temperature at top of storage.
- Upon a draw of DHW, flow switch turns on small circulator to provide "instantaneous" DHW through plate HX
- Solar tank CAN buffer space heating at all times.



- Single, simple tank system
- Very little DHW stored - reduced risk of Legionella
- DHW heat exchanger can be replaced if necessary

European (ROTEX) tank with integral burner and solar heating for DHW and space heating



- A Gas condensing boiler
- B Hot water stratified storage tank
- C Unpressurized storage tank water
- D Active water zone
- E Solar zone
- F Heating support zone
- G Control and pump unit (Accessories)

1. Domestic water
2. heating applications
3. Solaris connection
4. Flue gas
5. Air supply
6. Condensate drain
7. Domestic hot water heat exchanger (stainless steel)
8. Storage tank charging heat exchanger (stainless steel)
9. Solar heating support heat exchanger (stainless steel)
10. Heating heat exchanger
11. Heat insulation sleeve
12. Fan burner
13. Non return valves (accessories)

Software for evaluation solar system performance and economic viability

RET Screen: Developed by Natural Resources Canada, RETScreen is powerful simulation software that can be used to study the technical and economic feasibility of active solar energy systems. It's available as a *free* download from www.RETscreen.net

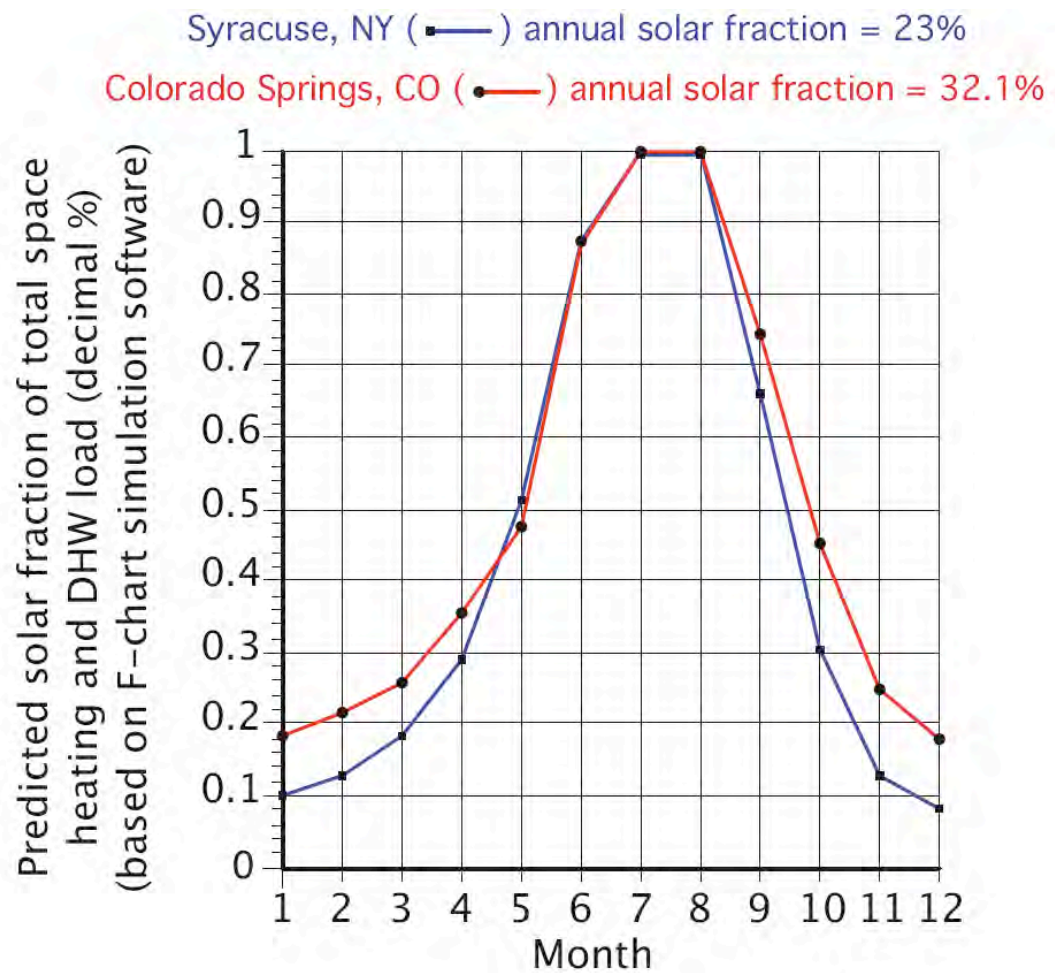
F-Chart: The software is the latest version of a method for predicting solar system performance and economic viability. It was developed at the University of Wisconsin, and has been used in the solar industry for over three decades. It's available from: www.fchart.com

Tsol: Developed and primarily used in Europe, Tsol is simulation software for active solar thermal systems. It is available in both "express" and "professional" versions from http://www.valentin.de/.

SolarPro IP: Developed as a tool for active solar system design and simulation based on hour-by-hour calculations. This version is set up for traditional North American units, and has weather data for 239 US locations. It's available from Maui Solar www.mauisolarsoftware.com

Knowing how to integrate solar energy collection with conventional hydronic heating is a valuable asset to hydronic professionals.

Predicted performance of combined solar space heating & DHW system sizing using F-chart:



Assumptions:

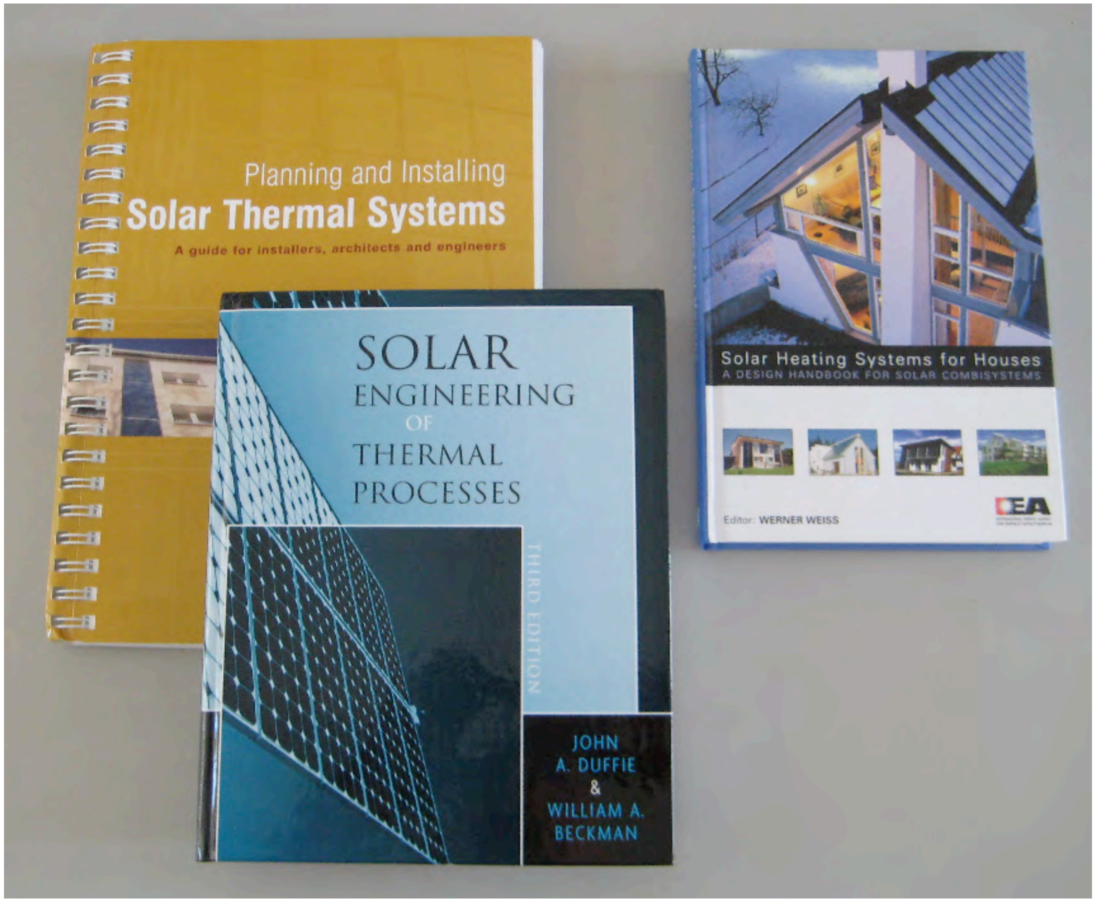
112 gross square feet of flat plate collectors (Frta=0.76, Frul = 0.825)
Collectors are sloped at 60° and face directly south
300 gallon storage tank
Low temperature floor heating delivery system
Coil in top of storage tank for DHW

Technical books on active solar system design:

Planning & Installing Solar Thermal Systems
By German section of the International Solar Energy Society
2006, Stylus Publishers, ISBN 1-84407-125-1 (English version)
Available at: www.hydronicpros.com

Solar Engineering of Thermal Processes, 3rd Edition
By Duffie and Beckman
2006, Wiley,
ISBN 0-471-69867-9

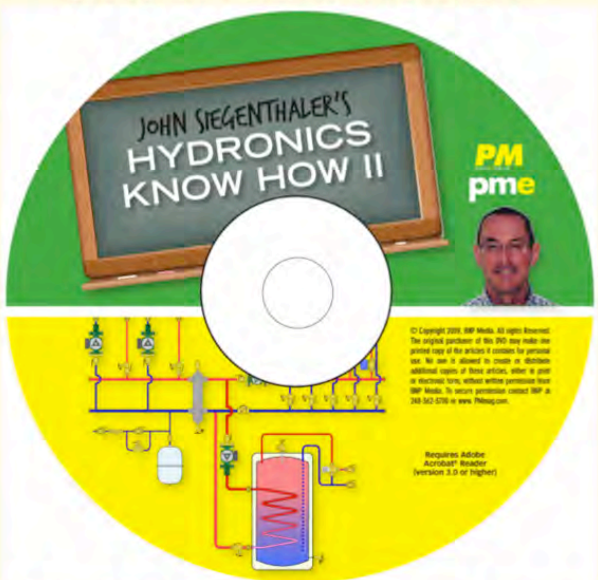
Solar Heating Systems for Houses
A design handbook
for solar combisystems
By Werner Weiss
2006, Stylus Publishers,
ISBN 1-902916-46-8
Available at:
www.hydronicpros.com



Thank you for attending this session.

Thanks also to Co-op Power for the invitation to participate in the Sustainable Energy Summit.

Just Released!



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