The electrical wattage needed by the circulator is:

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

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.

With good design it's possible to achieve distribution efficiencies > 3000 Btu/hr/watt

<u>This will become increasingly important in low energy and net zero buildings...</u>

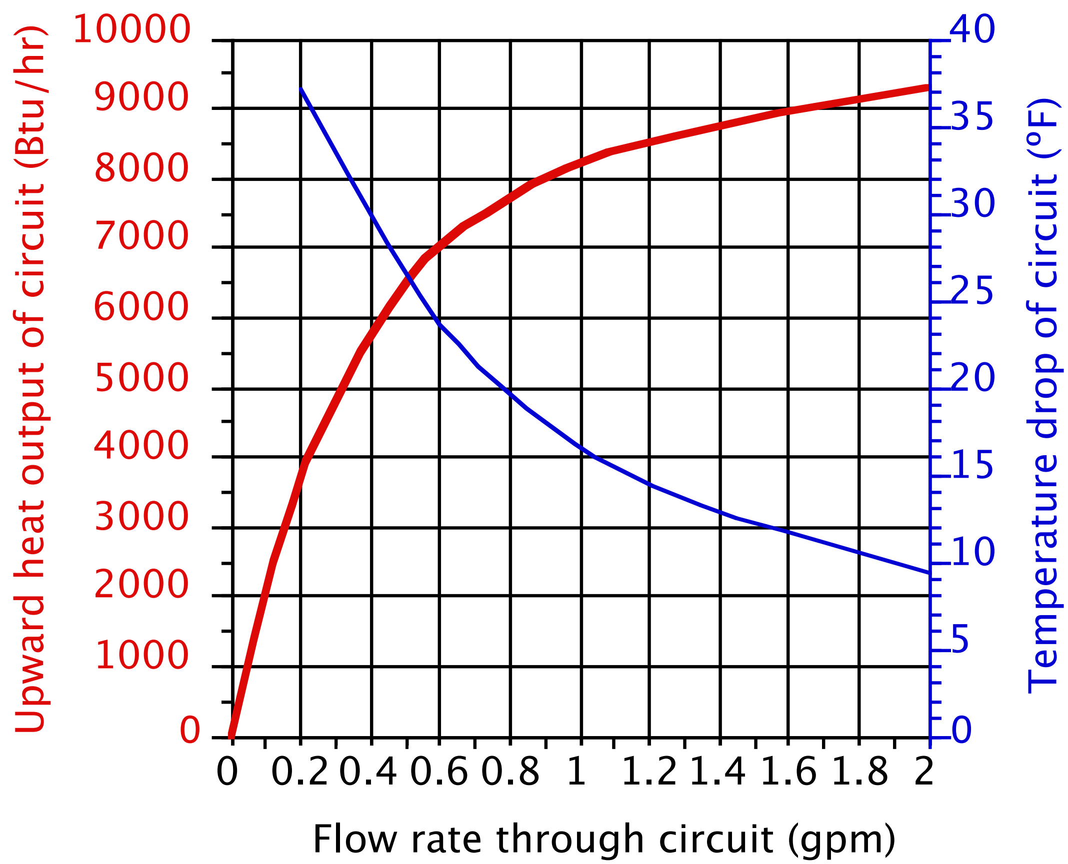
Other factors to Consider…

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).

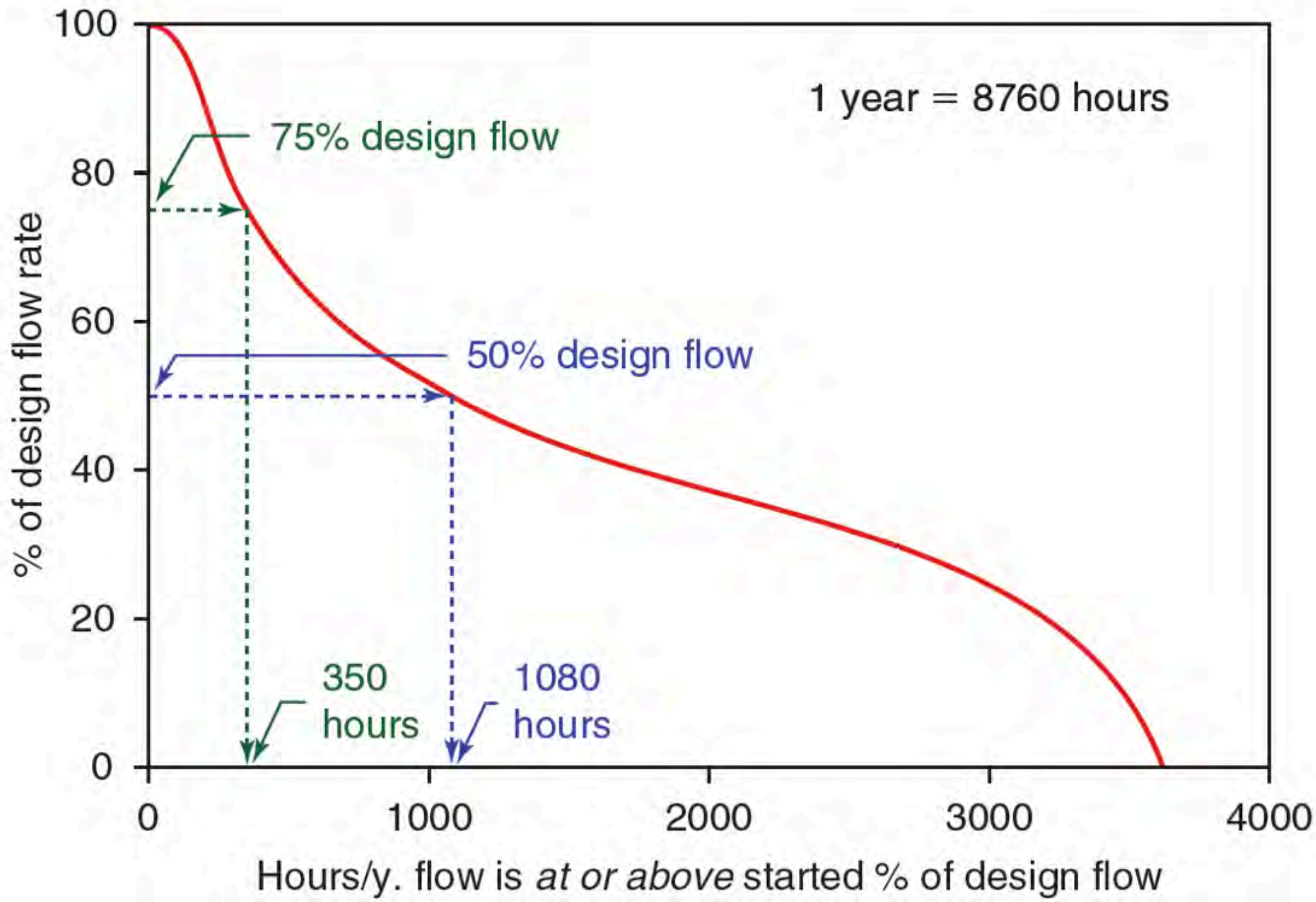
At 50 percent of design flow rate heat output is about 89 percent of design output.

Implication...

If the heat emitters are 11% or more oversized, the system could likely still deliver design load output at 50% or less of its current flow rate.

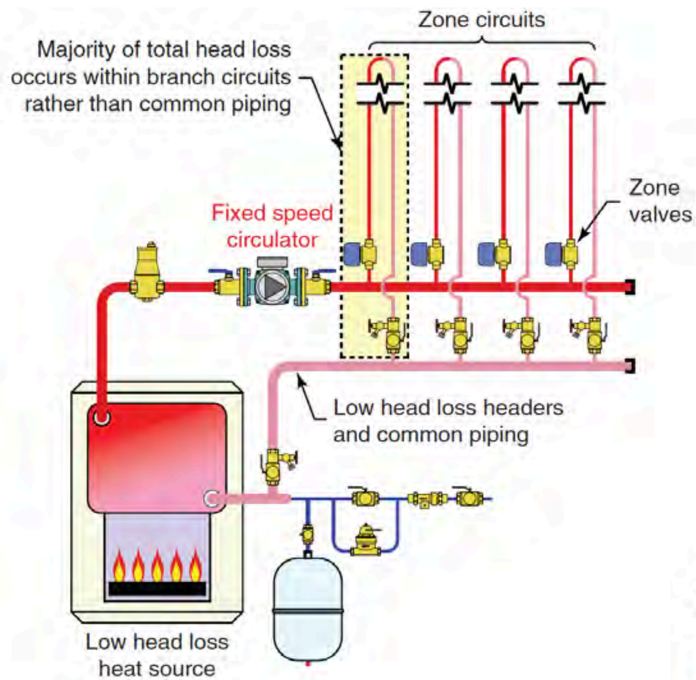


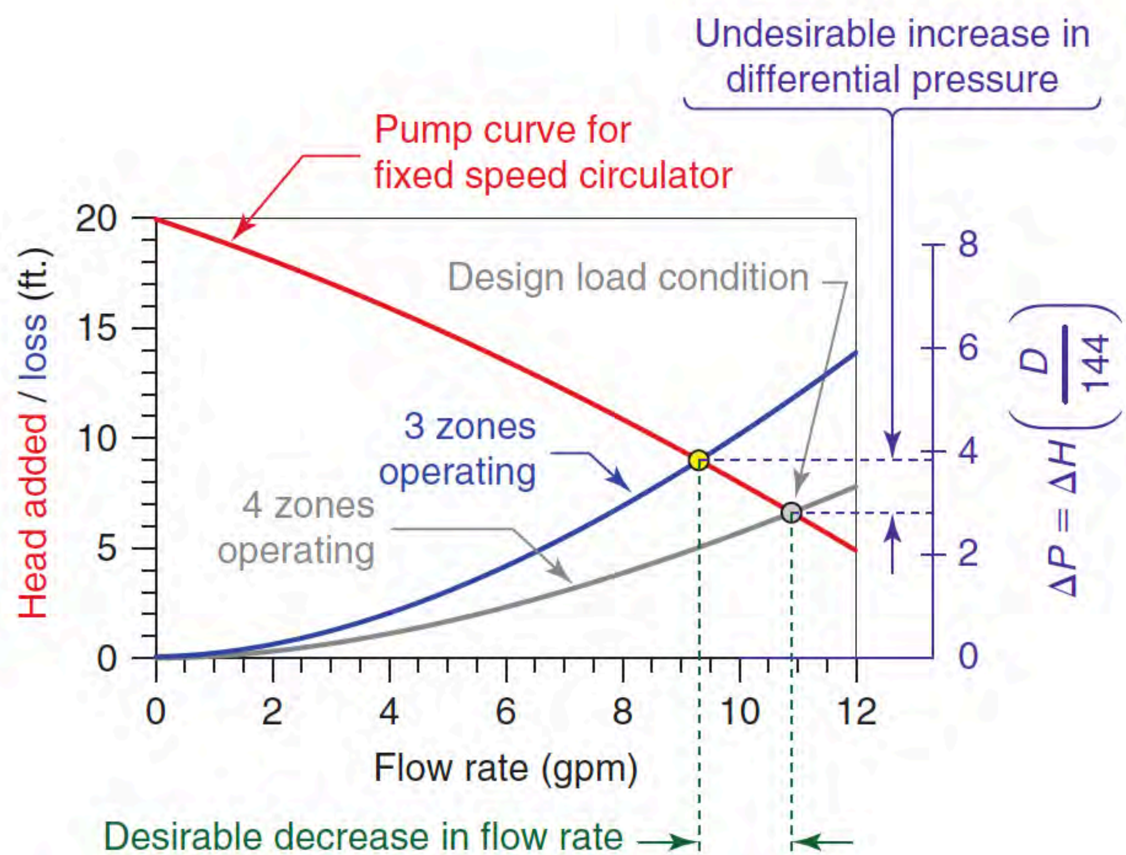
This graph shows the relationship between system flow rate vs. operating hours for a typical Northern climate.



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

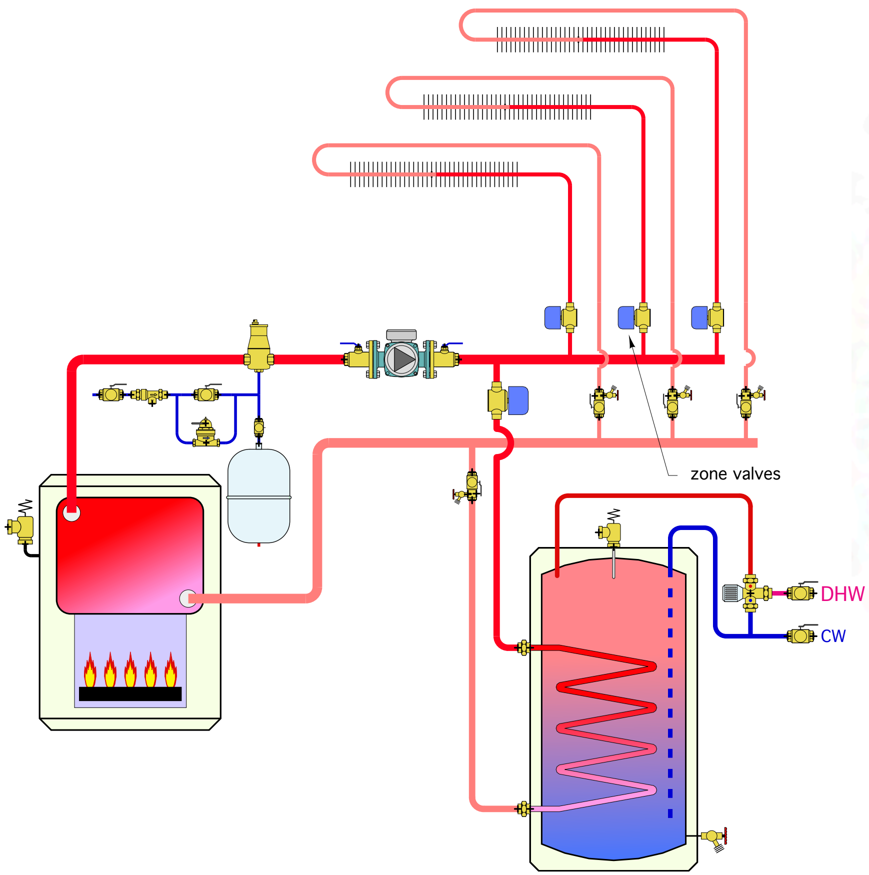
What happens when a zone valve closes?

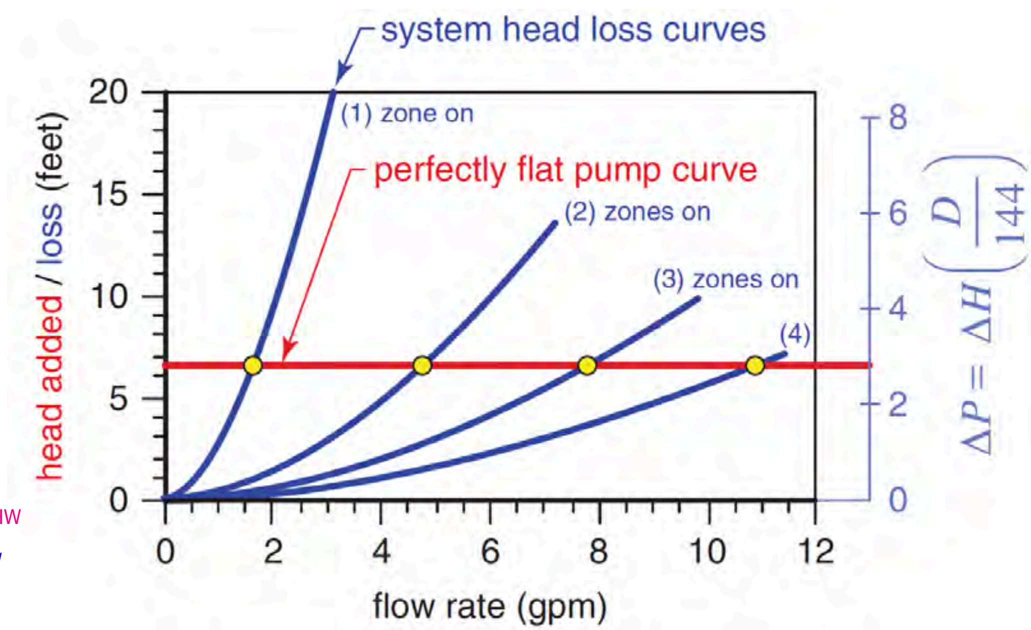




What would be the **ideal** pump curve for a hydronic system using valve based zoning?

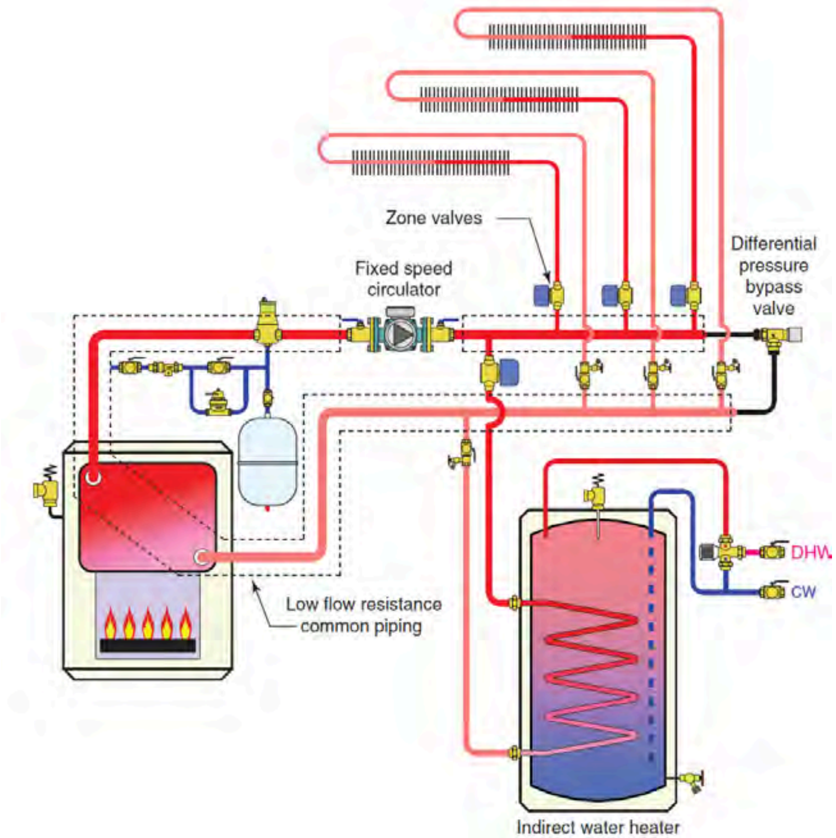
Answer: a perfectly flat pump curve

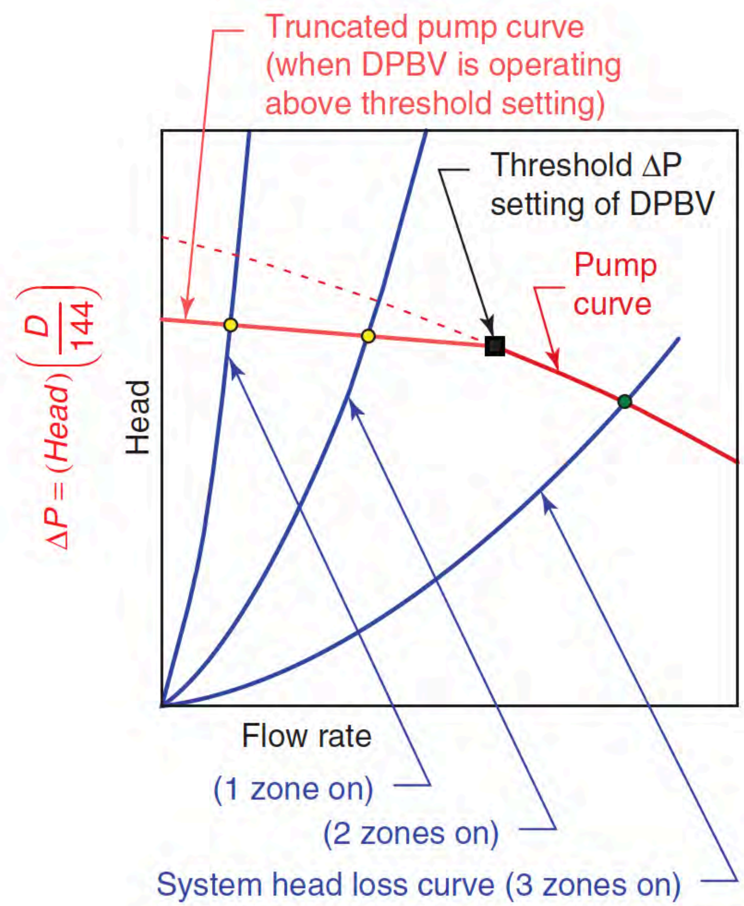




A perfectly flat pump curve would all steady flow rate in every zone circuit, regardless of which other zones are on.

Approximating a flat pump curve with ΔP bypass valve

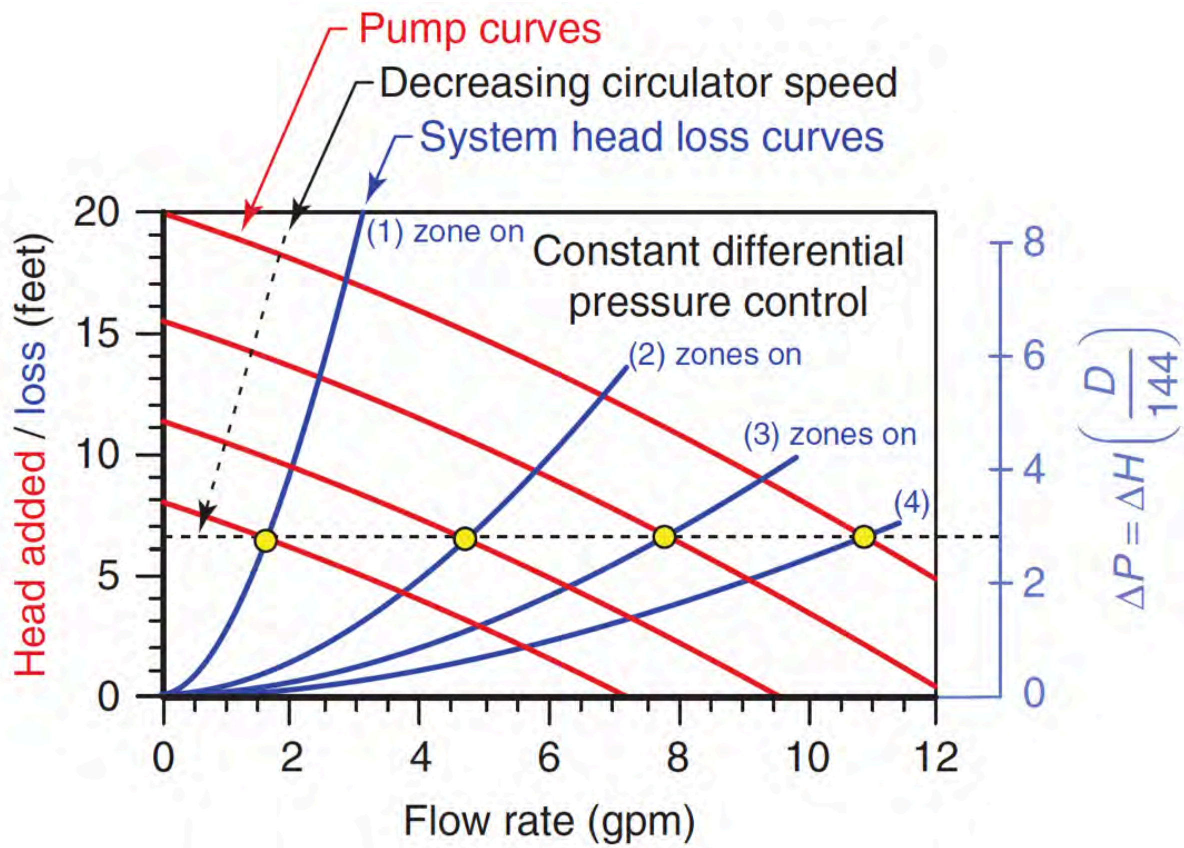




A ΔP bypass valve helps limit changes in differential pressure, but does so "parasitically" by throttling away head energy

Approximating a flat pump curve with ΔP bypass valve

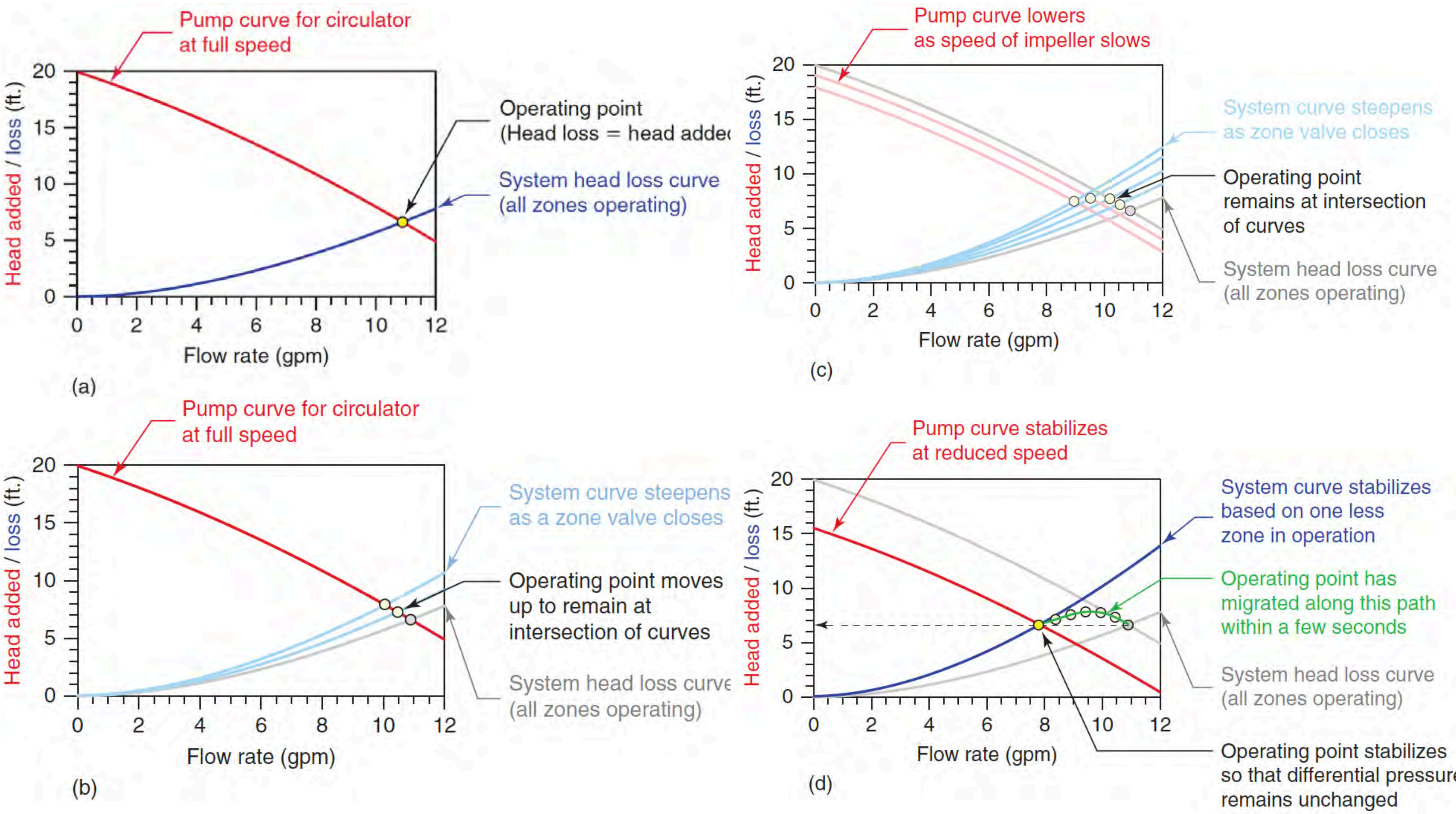
By varying the speed of the circulator it is possible to produce the same "net" effect as would be produced by a perfectly flat pump curve.



This is called

CONSTANT DIFFERENTIAL PRESSURE CONTROL

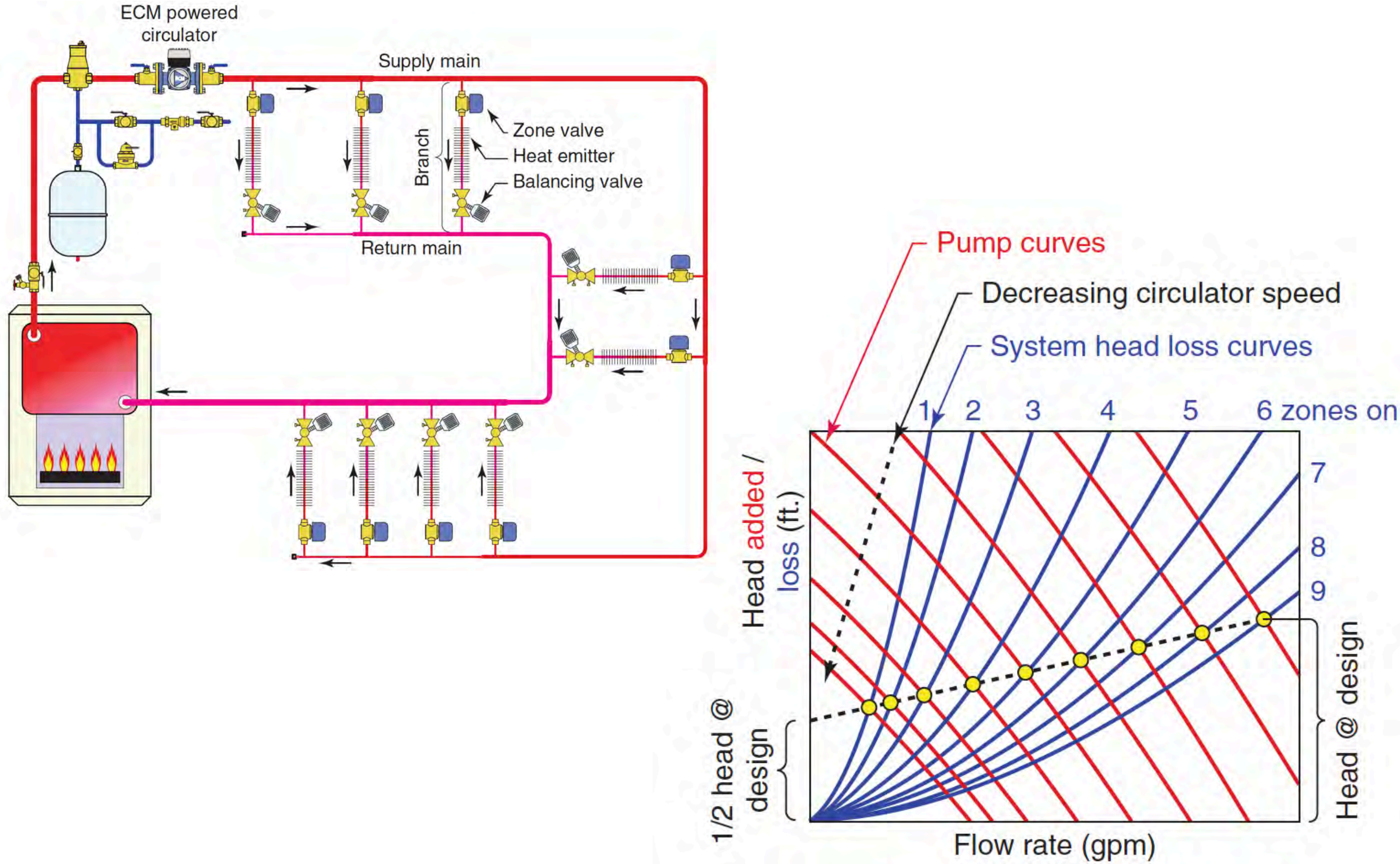
Constant differential pressure control



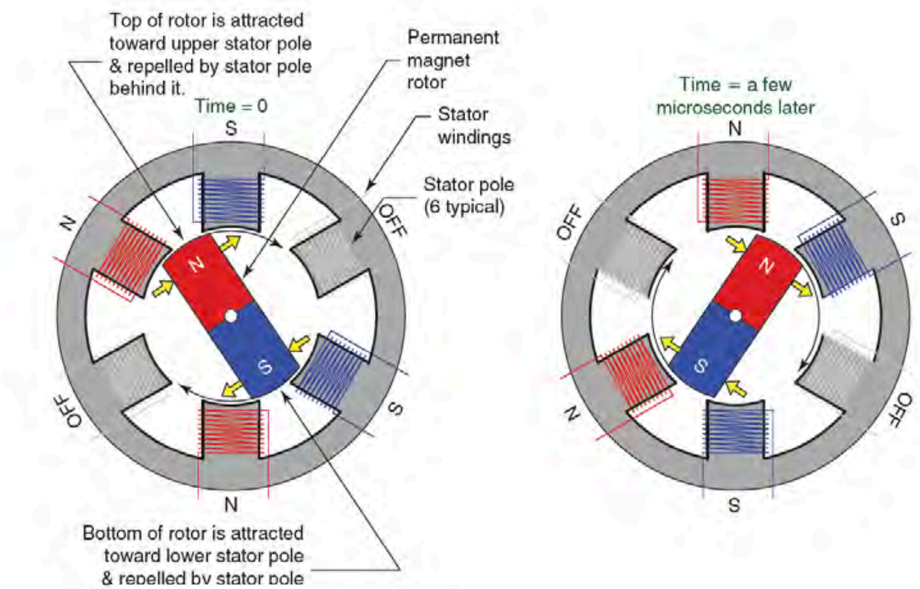
This is all regulated by P.I.D. control

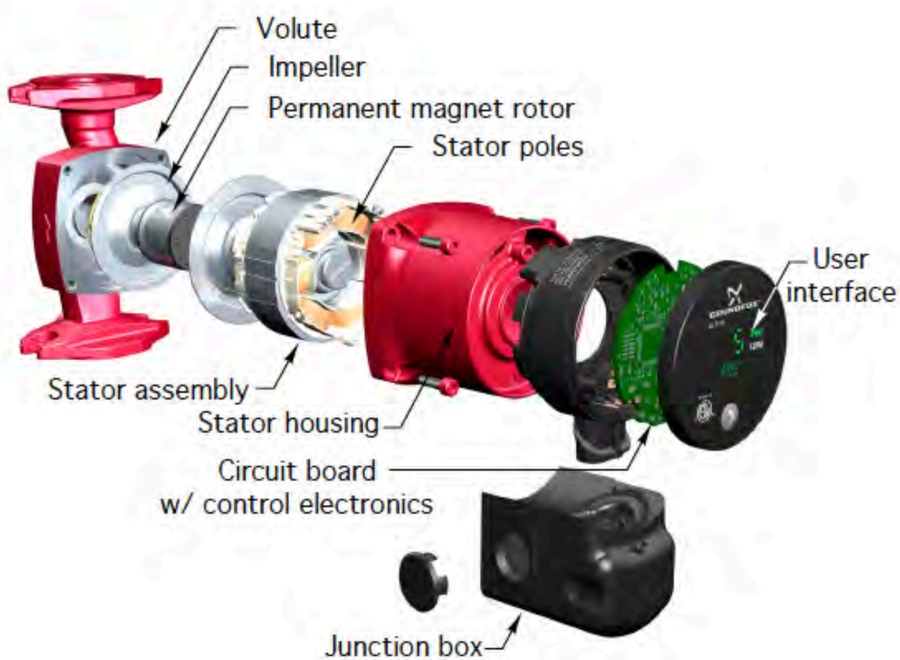
PROPORTIONAL DIFFERENTIAL PRESSURE CONTROL

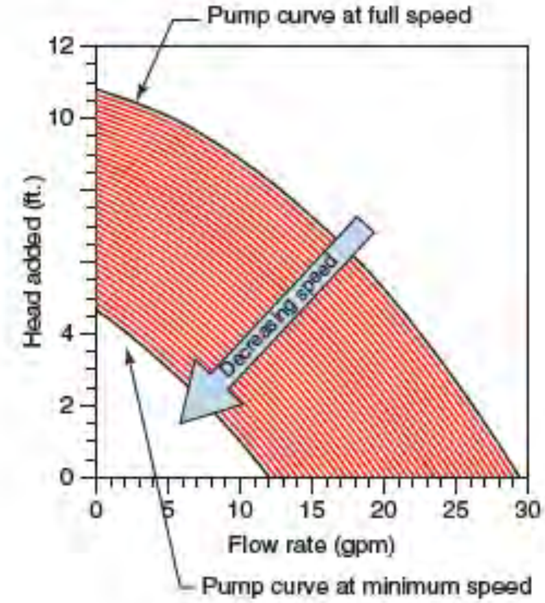
This method is best for systems where the heat source and/or “mains” piping leading to the load circuits dissipate a substantial portion of the circulator head.



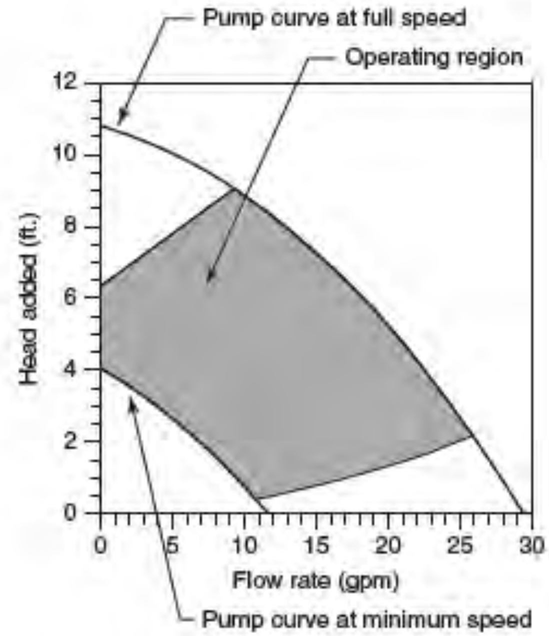
How does a ECM Circulator work?







(a)



(b)

Small ECM circulators now available in North America

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

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

Bell & Gossett ECOCIRC, Provides manual adjustable speed setting (VARIO model), and proportional differential pressure (AUTO model). 5-60 watt electrical input.

Taco Bumblebee Temperature based speed control. 9-42 watts electrical input

Armstrong COMPASS Provides constant and proportional differential pressure and three fixed speed settings. 3-45watt electrical input.

Circulators

high efficiency ECM Circulators

Larger ECM circulators now available in US

Grundfos MAGNA

Taco Viridian

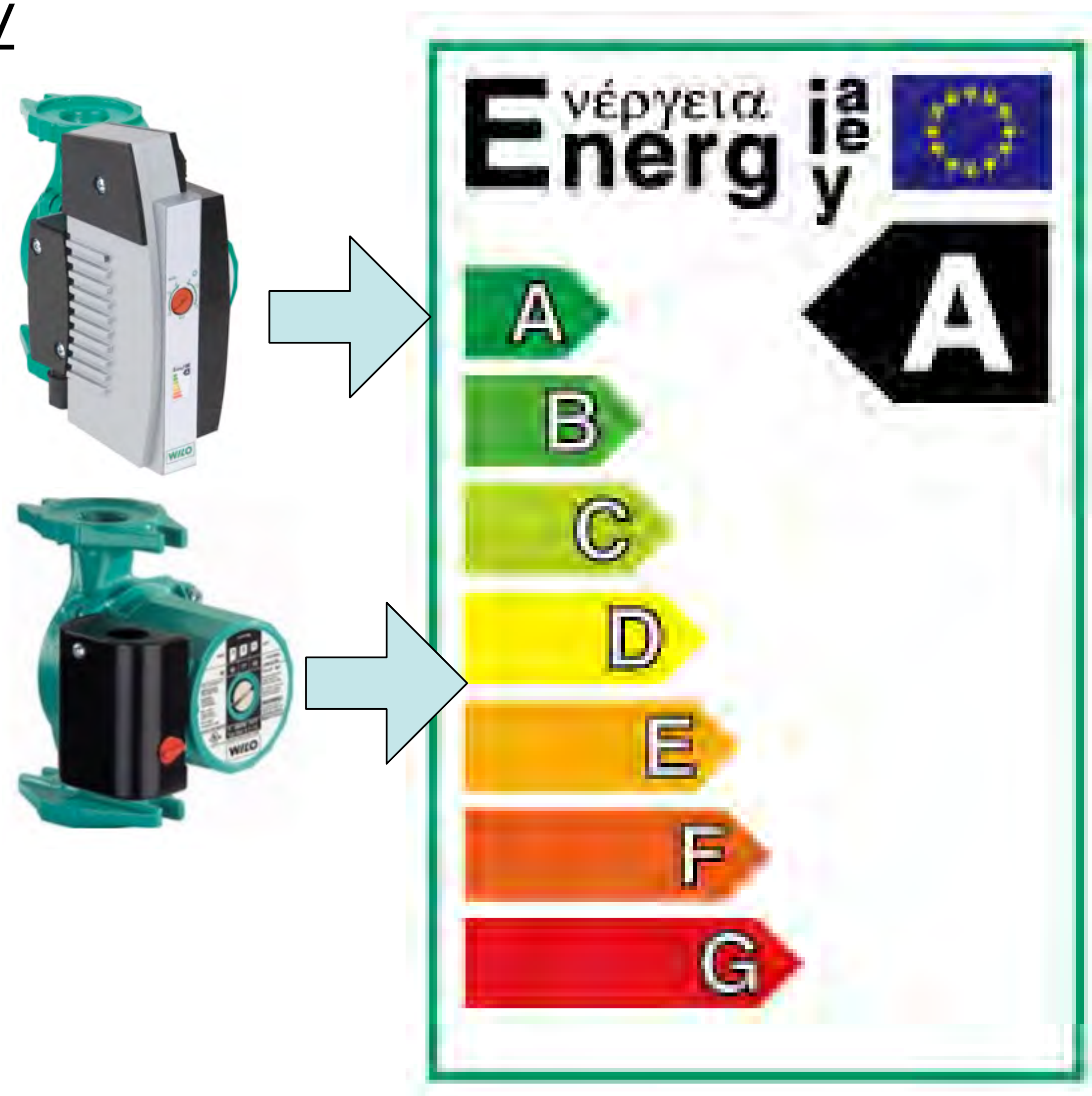
Heads to 45 feet,
flows to 345 gpm
power inputs to 1600 watts

Wilo STRATOS circulators

B&G ECO XL

Current European circulator rating system

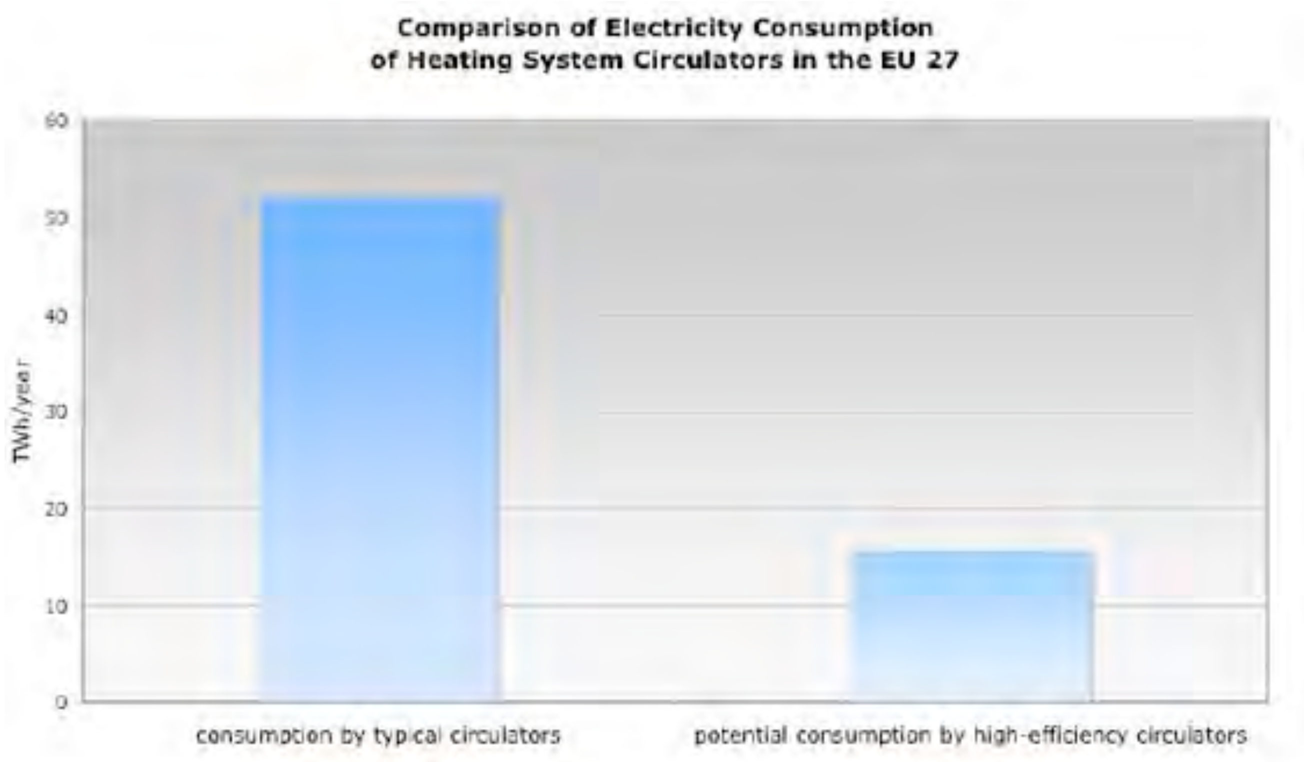
<u>All these circulators rated "A" on the energy labeling system from Europump (European Association of Pump Manufacturers).</u>



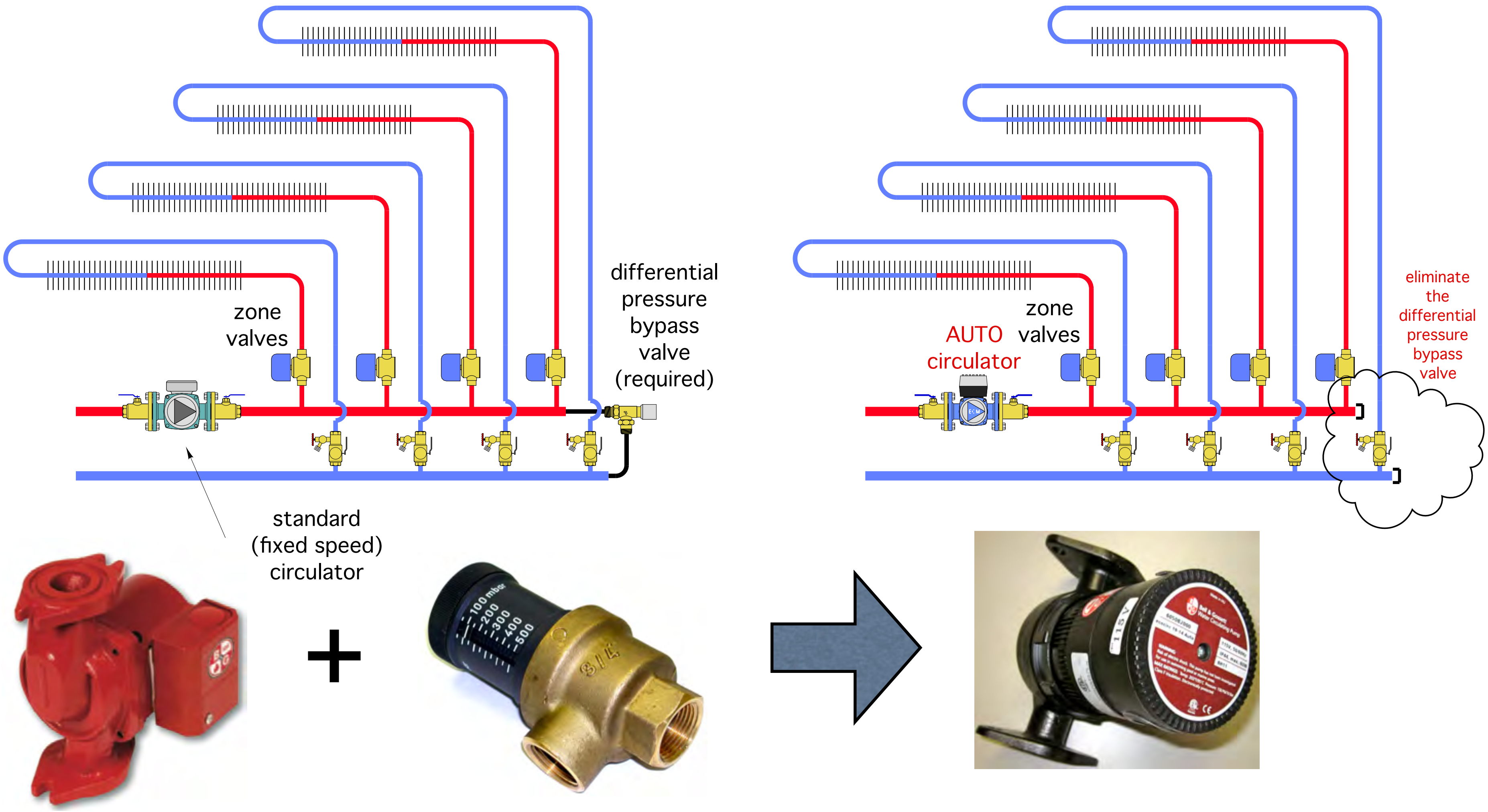
Single or multi-speed wet-rotor circulators like those commonly used in North America would be rated "D" or "E" on this scale.

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.



Fixed speed circulator vs. ΔP valve versus variable speed pressure regulated circulator



Zoning with valves and a fixed speed circulator requires a differential pressure bypass valve.

Zoning with valves and an AUTO circulator eliminates need (and cost) of a differential pressure bypass valve.

A real price comparison...

All prices taken for same internet-based supplier (April 2013)

B&G NRF-22
circulator

+

B&G ΔP
bypass valve

vs.

B&G AUTO
circulator

$85.95

$61.95

$147.90

$169.95

Can you install this valve (with adapter fittings) and labor for

$22.05?

This comparison ignores the saving in electrical energy associated with the AUTO circulator

A real price comparison...

Energy savings comparison

Conventional zone circulator operating 3000 hours per year in area where electricity costs $0.13/kwhr.

$$(80watt)\left(\frac{3000hr}{yr}\right)\left(\frac{1kwhr}{1000whr}\right)\left(\frac{\$0.13}{kwhr}\right)=\frac{\$31.2}{yr}$$

Based on European modeling, an ECM circulator operating with proportional differential pressure control reduces electrical consumption by about 60% comparison to a conventional wet rotor circulator of same max curve performance.

$$savings=(0.6)\$31.20=\$18.72/yr$$

Simple payback on higher cost of AUTO versus NFR22: $84.00/$18.72 = **4.5 years**

Payback on higher cost of AUTO versus NFR22 assuming 5% per year inflation on cost of electricity = **4.0 years**

B&G AUTO 19-14

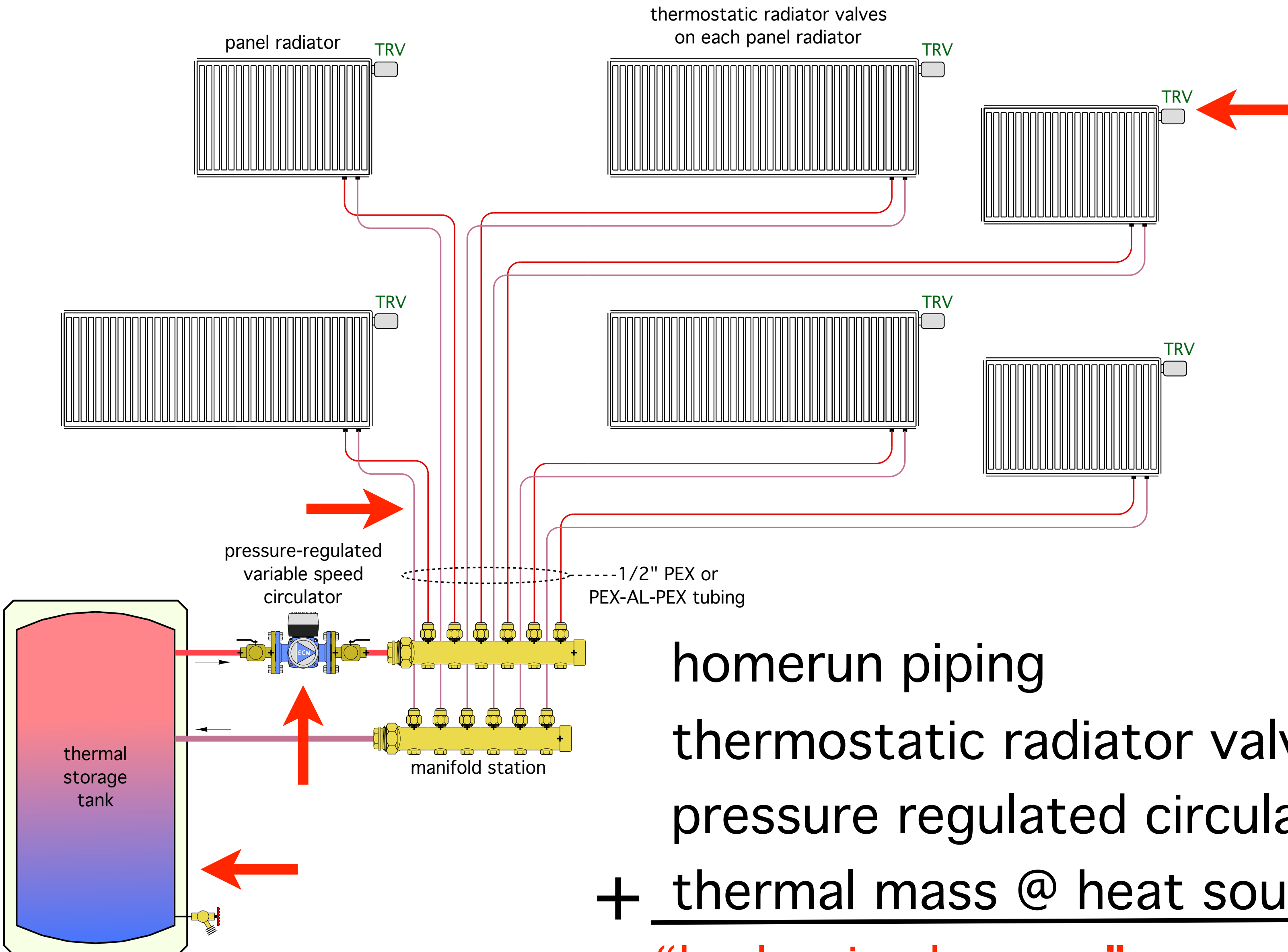
$169.95

B&G NRF-22 circulator

$85.95

cost difference $84.00

Supplying a homerun distribution system...



homerun piping

thermostatic radiator valves

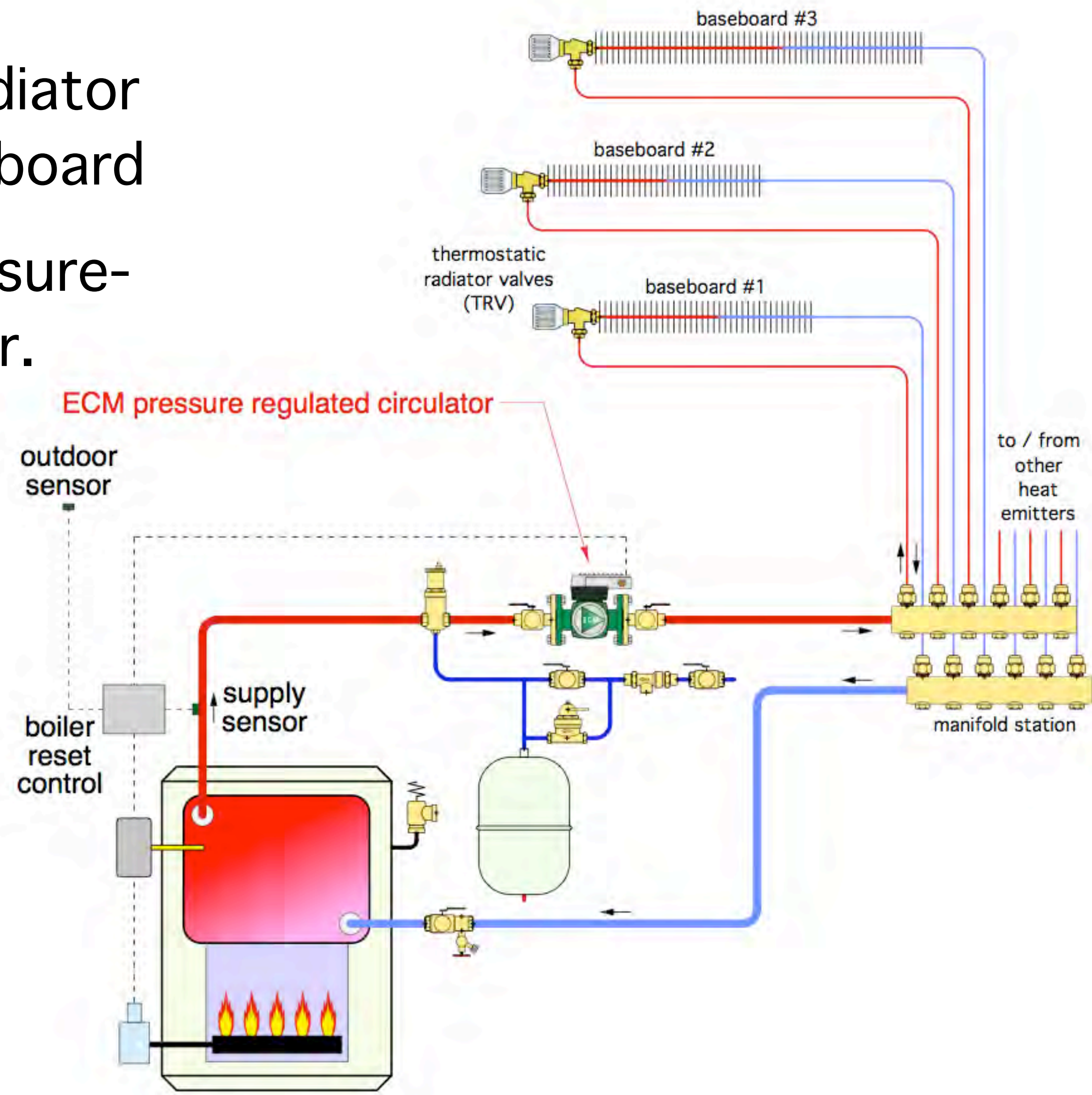
pressure regulated circulator

\+ thermal mass @ heat source

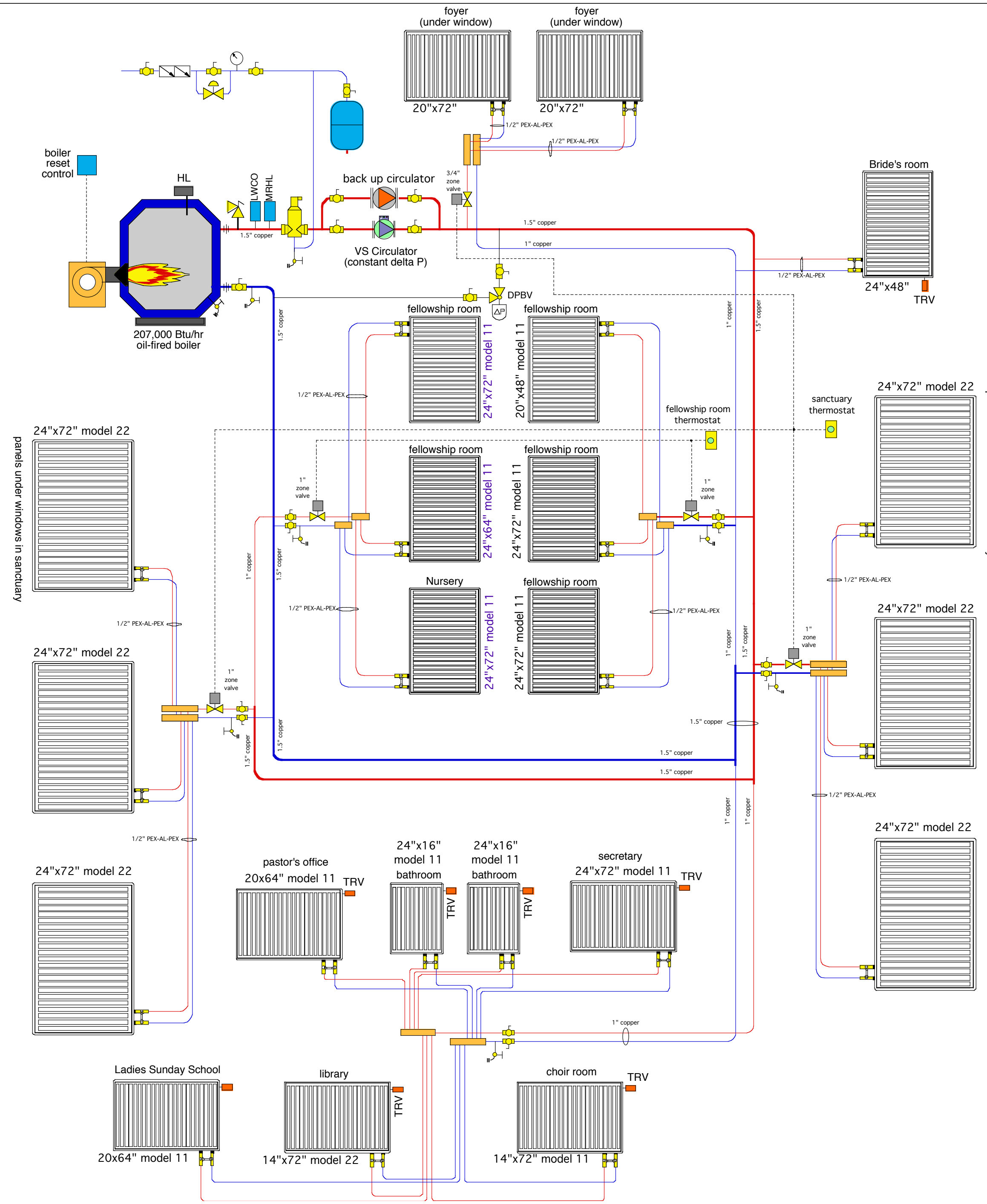
“hydronics heaven”

The modern way to install fin-tube baseboard:

- Thermostatic radiator valve on each baseboard
- ECM-based pressure-regulated circulator.



Examples of systems using pressure regulated circulators

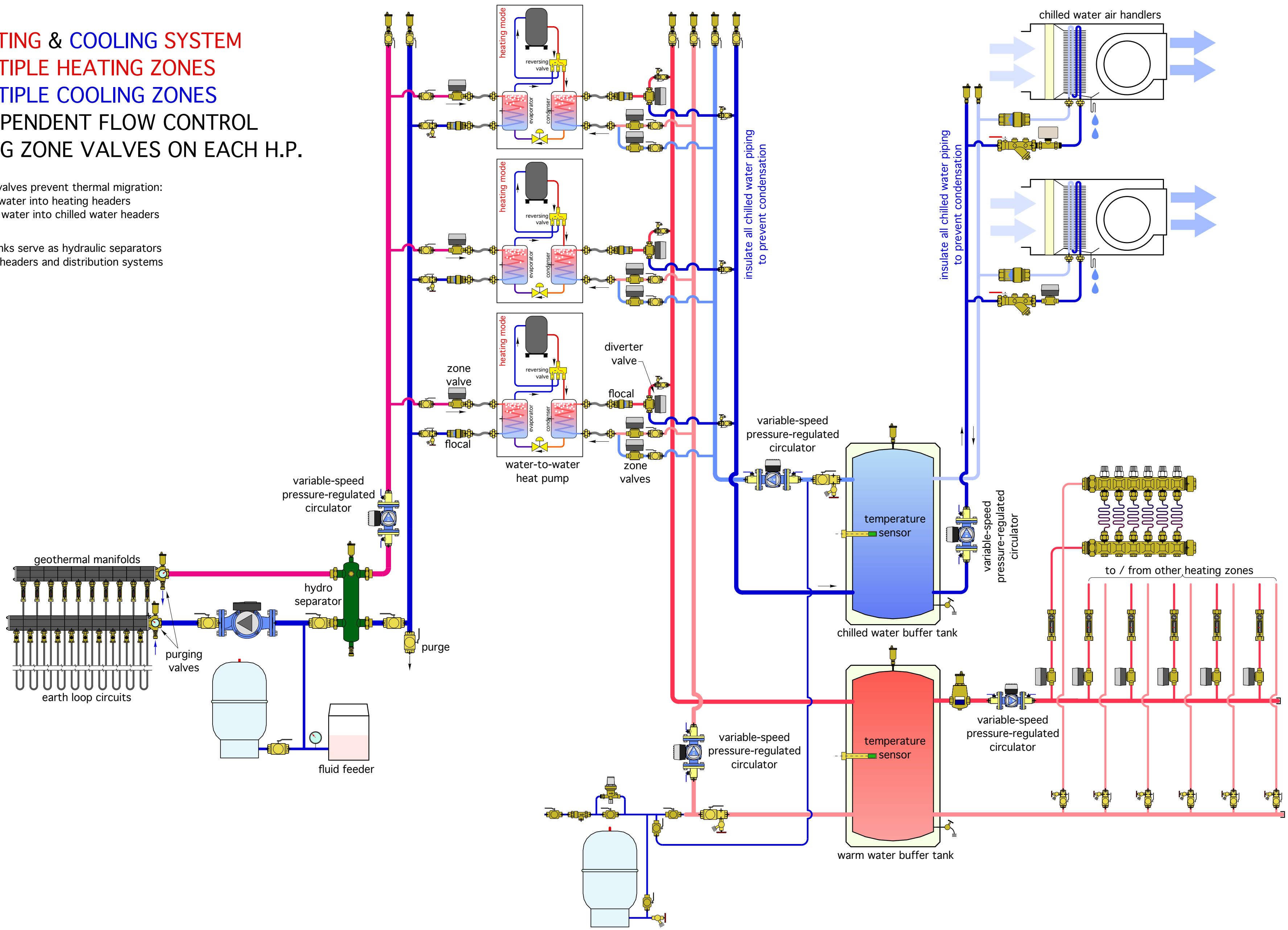


Examples of systems using pressure regulated circulators

HEATING & COOLING SYSTEM
MULTIPLE HEATING ZONES
MULTIPLE COOLING ZONES
INDEPENDENT FLOW CONTROL
USING ZONE VALVES ON EACH H.P.

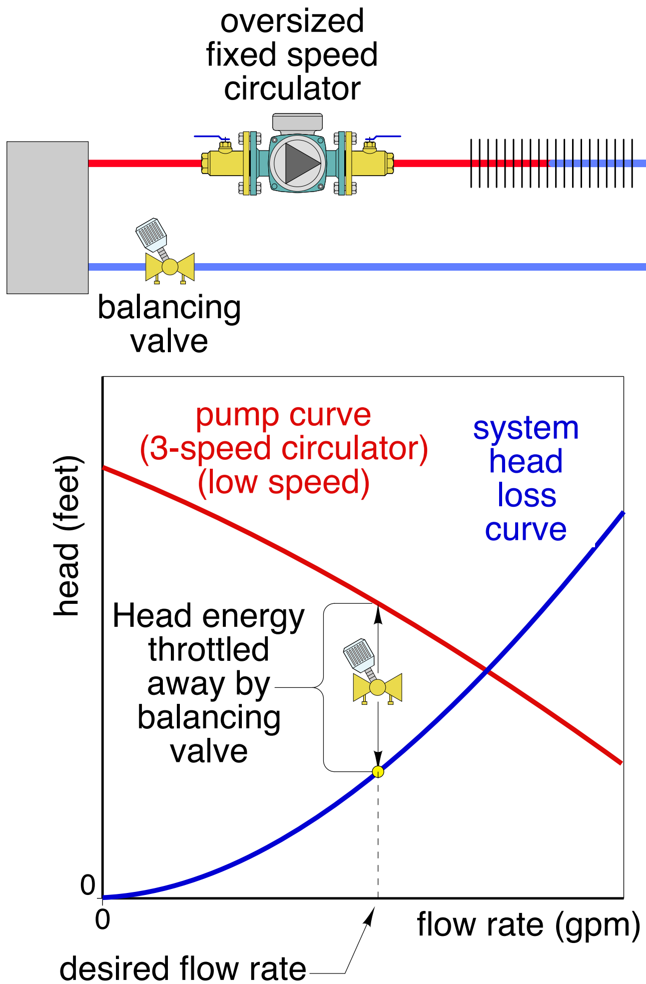
Diverter valves prevent thermal migration:
• chilled water into heating headers
• heated water into chilled water headers

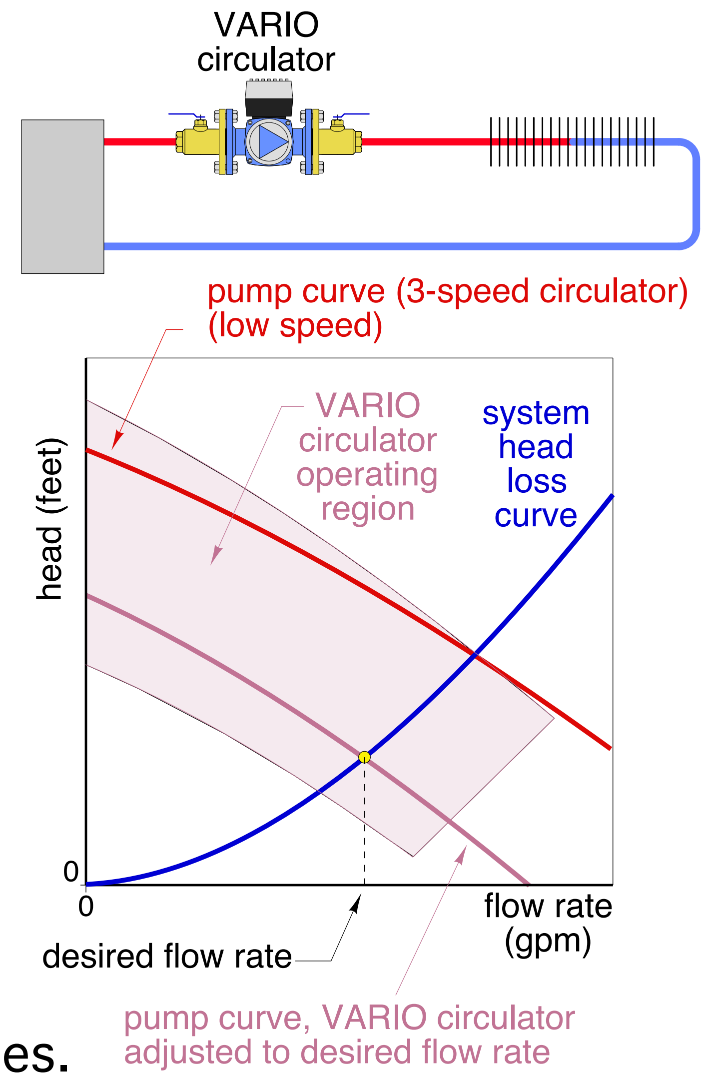
Buffer tanks serve as hydraulic separators between headers and distribution systems



Adjust circulator speed - not a “balancing” valve

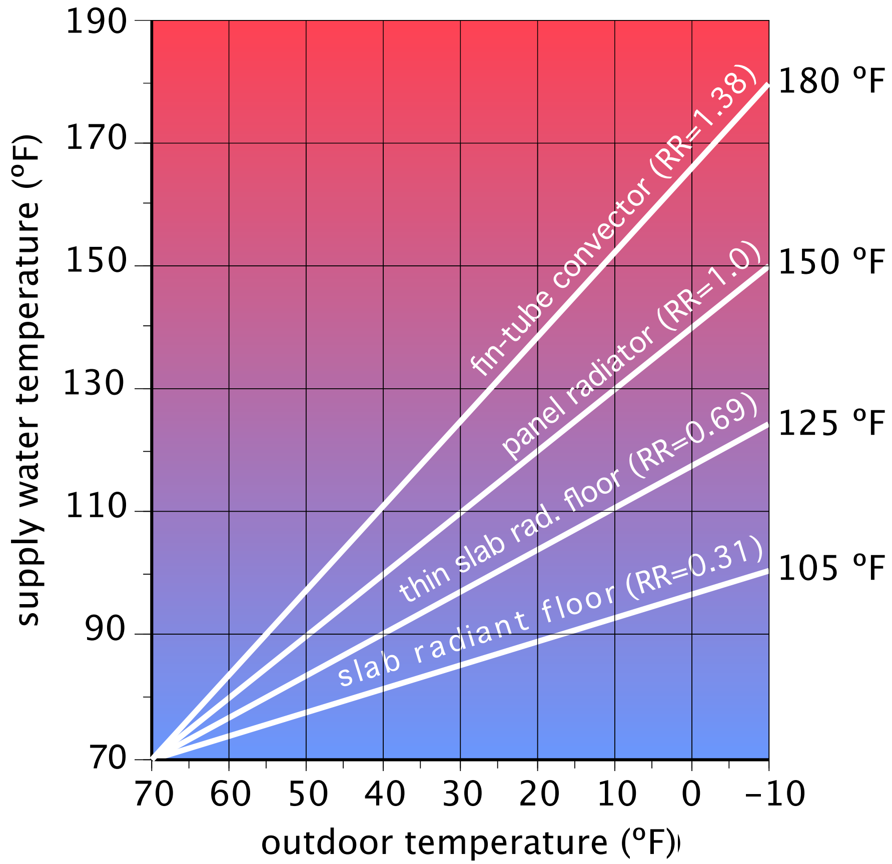
Concept: It’s wasteful to install a circulator with greater hydraulic power than required, and “throttle” away some of this head with a balancing valve.





This is especially beneficial in small zones.

Outdoor Reset Control: Theory & Implementation



Outdoor Reset Control Theory

• An ideal heating system would continually adjust its rate of heat delivery to match the heat loss of a building.

• This allow inside air temperature to remain constant regardless of outside conditions.

• Outdoor reset control was developed with this objective in mind.

• An outdoor reset controller measures outdoor air temperature then calculates what water temperature should be supplied to the distribution system based on that outdoor temperature.

• This calculated temperature is called the **target** supply temperature.

• The target supply temperature is continually updated through repeated calculations so it's always valid for the current outside conditions.

• Outdoor reset controllers also operate devices such as the system's heat source, or a mixing device to "steer" the water temperature supplied to the system toward the calculated target value.

Outdoor Reset Control Theory

Outdoor reset control is based on two basic heat transfer principles:

- Principle #1: The rate of building heat loss is proportional to the difference between inside and outside air temperatures.

Imagine a building with a design heat loss of 80,000 Btu/hr when the inside air temperature is 70ºF., and the outside air temperature is -10 ºF. This building's heat loss coefficient (UA) is:

$$UA_{building} = \frac{80{,}000\,Btu/hr}{[70-(-10)]^{\circ}F} = \frac{80{,}000\,Btu/hr}{80^{\circ}F} = 1000\,\frac{Btu}{hr \bullet {}^{\circ}F}$$

A formula can be written based on the heat loss coefficient that allows the building's heat loss to be calculated for any indoor and outdoor temperature:

$$Heat\ \ loss = 1000 \times \left(T_{indoor} - T_{outdoor}\right)$$

Outdoor Reset Control Theory

- Principle #2: The rate of heat output from a hydronic heat emitter is approximately proportional to the difference between the supply water temperature and the inside air temperature.

Imagine that the building above was equipped with a radiant floor heating system that could release the design load of 80,000 Btu/hr when supplied with 110 ºF water. Note that the difference in temperature between the water and inside air is 40 ºF. under these conditions. The heat output coefficient of the heating system is:

$$heat\ output\ coefficient = \frac{80{,}000\,Btu\,/\,hr}{[110-70]^{\circ}F} == \frac{80{,}000\,Btu\,/\,hr}{40^{\circ}F} = 2000\,\frac{Btu}{hr \bullet^{\circ} F}$$

$$system\ heat\ output = 2000 \times \left(T_{\sup ply} - T_{indoor}\right)$$

Outdoor Reset Control Theory

$$Heat\ loss = 1000 \times \left(T_{indoor} - T_{outdoor}\right)$$

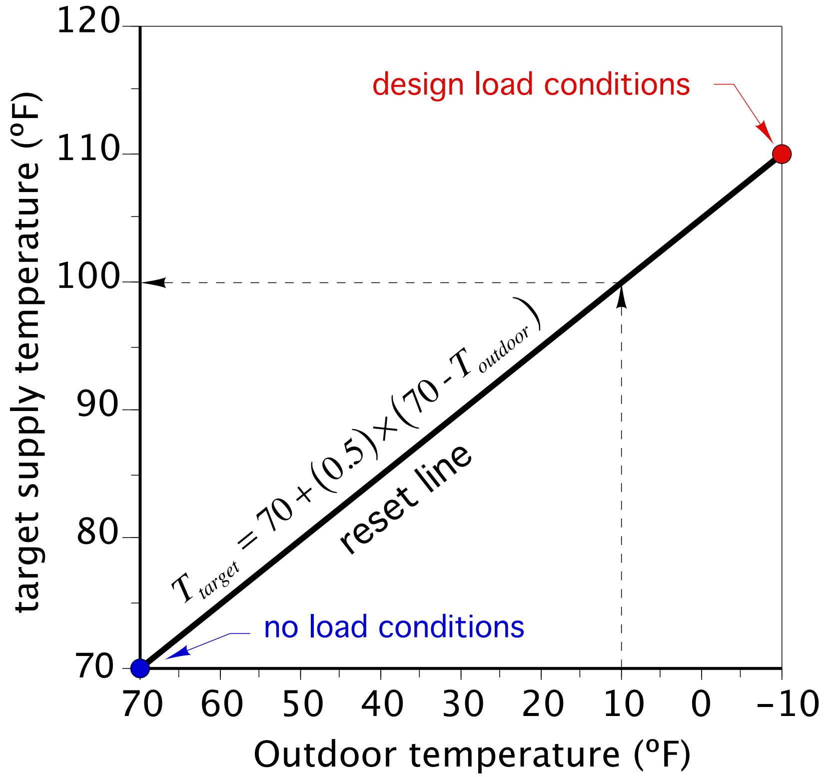
$$system\ heat\ output = 2000 \times \left(T_{\sup ply} - T_{indoor}\right)$$

Combining these two equations yields:

$$T_{supply} = T_{indoor} + \left(\frac{1000}{2000}\right) \times \left(T_{indoor} - T_{outdoor}\right)$$

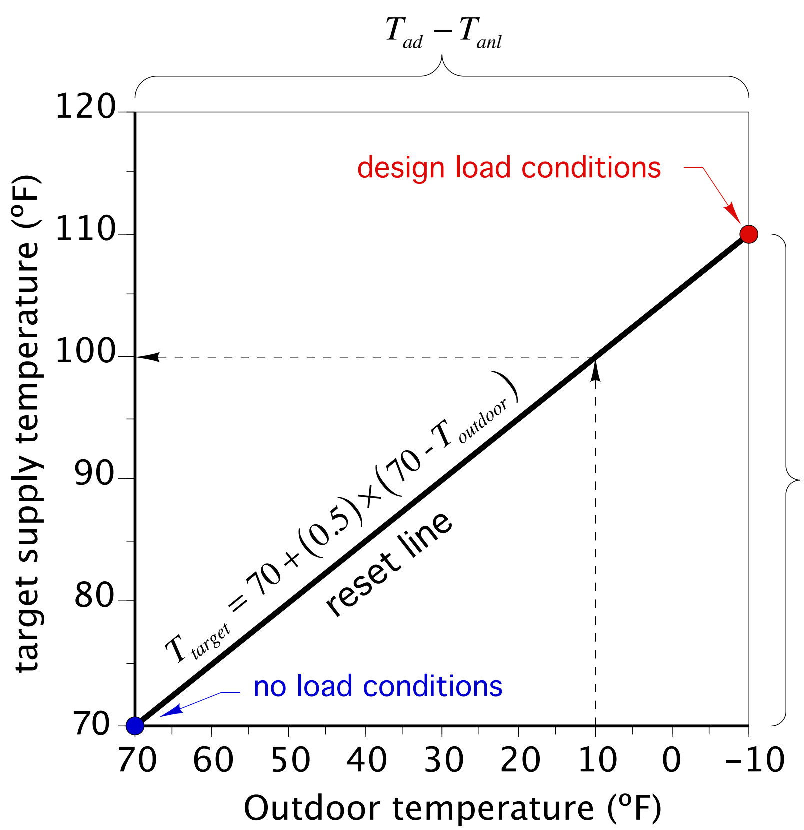
$$T_{supply} = T_{indoor} + (0.5) \times \left(T_{indoor} - T_{outdoor}\right)$$

If the indoor temperature is set to 70ºF, and this equation is plotted, the following graph is created:



Outdoor Reset Control Theory

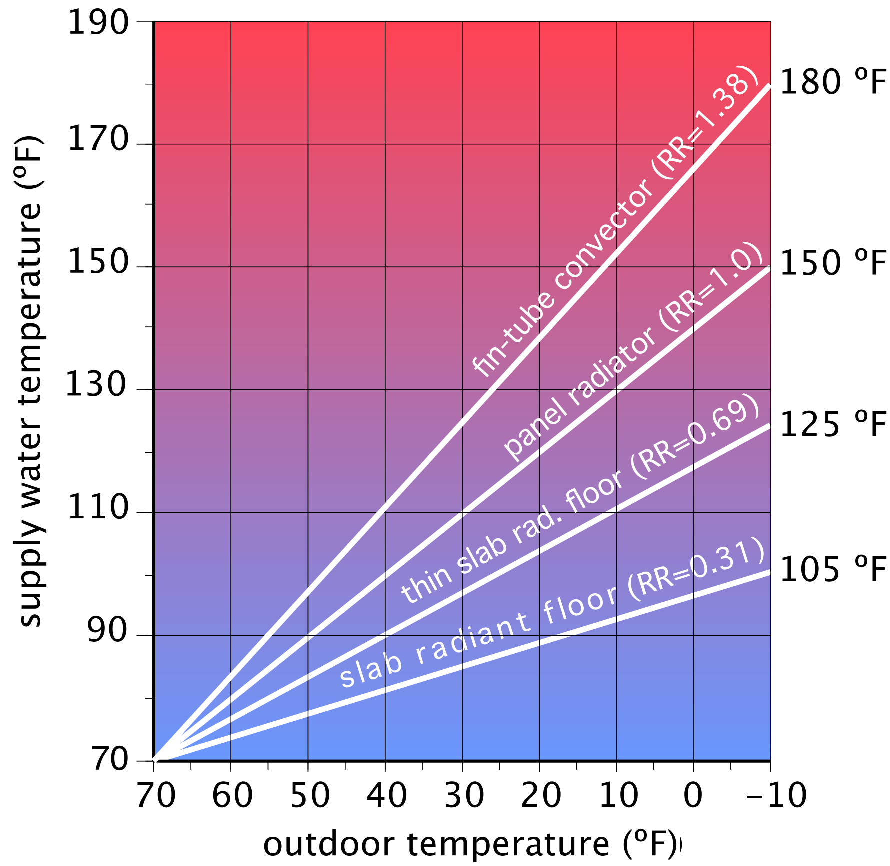
The slope of the reset line is called the “reset ratio”



$$RR = \frac{T_{wd} - T_{wnl}}{T_{ad} - T_{anl}} = \frac{110 - 70}{70 - (-10)} = \frac{40}{80} = 0.5$$

$$T_{target} = 70 + (0.5) \times (70 - T_{outdoor})$$

The reset ratio can be adjusted to match the combined effect of building heat loss and heat output of the distribution system.

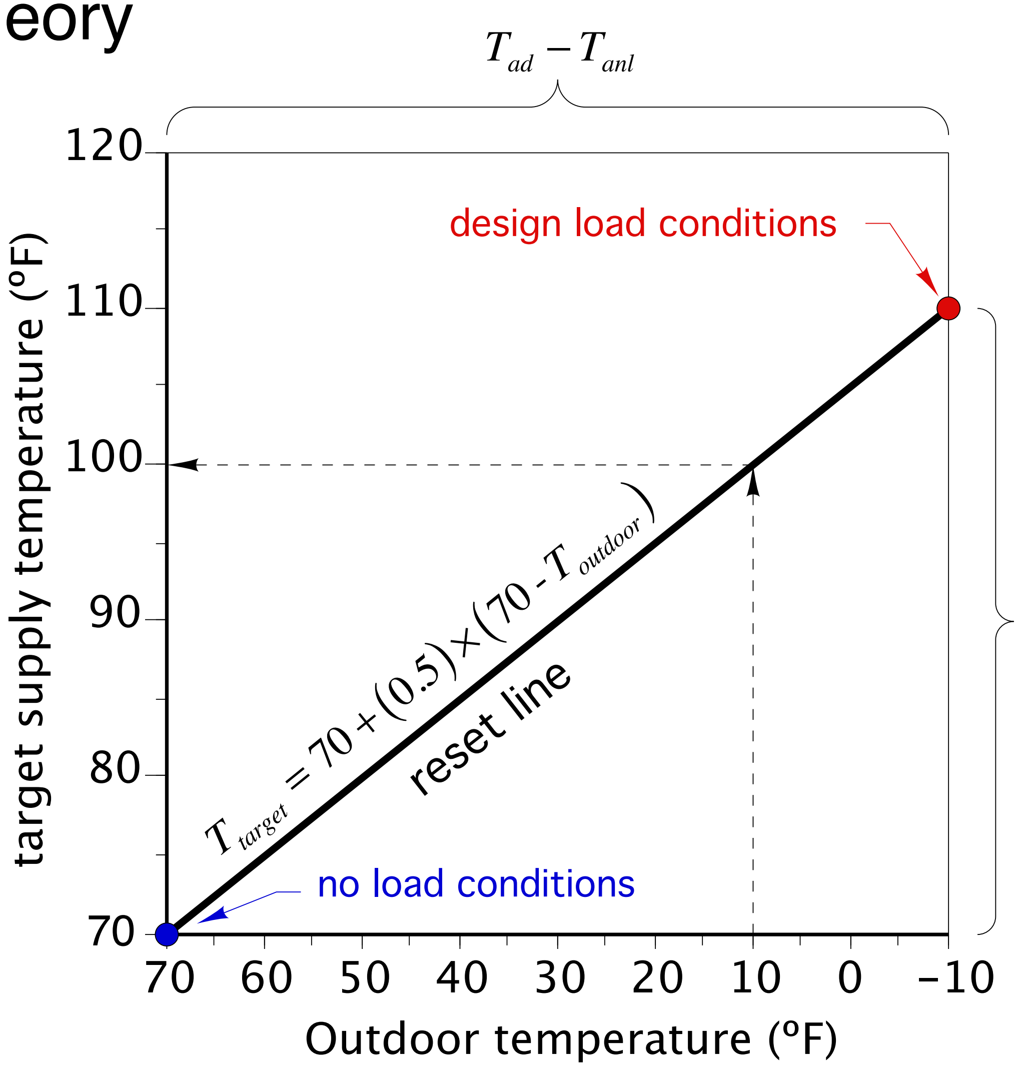


Outdoor Reset Control Theory

The reset ratio is calculated by taking the change in supply water temperature, and dividing by the corresponding change in outdoor air temperature.

$$RR = \frac{T_{wd} - T_{wnl}}{T_{ad} - T_{anl}} = \frac{110 - 70}{70 - (-10)} = \frac{40}{80} = 0.5$$

$$T_{target} = 70 + (0.5) \times (70 - T_{outdoor})$$



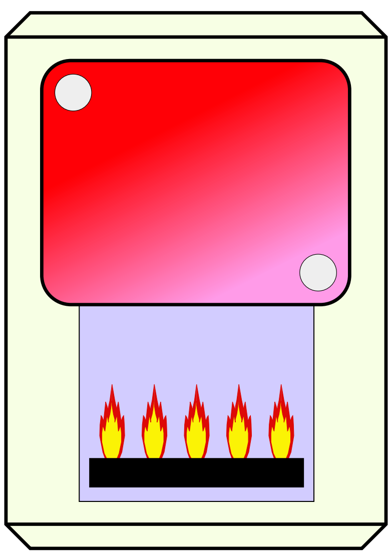
$$RR = \frac{T_{wd} - T_{wnl}}{T_{ad} - T_{anl}} = \frac{110 - 70}{70 - (-10)} = \frac{40}{80} = 0.5$$

$$T_{target} = 70 + (0.5) \times (70 - T_{outdoor})$$

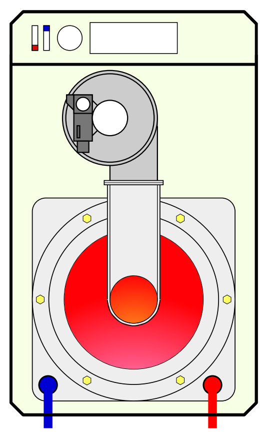
Outdoor Reset Control Theory

Outdoor reset control can be implemented two ways:

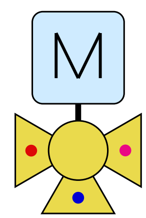
1. Controlling the temperature leaving a on/off heat source (a.k.a. “boiler reset control”)
2. Controlling the temperature leaving a modulating heat source (a.k.a. “boiler reset control”)
3. Controlling the temperature supplied to the distribution system using a mixing device (a.k.a. “mixing reset control”)



on/off heat source



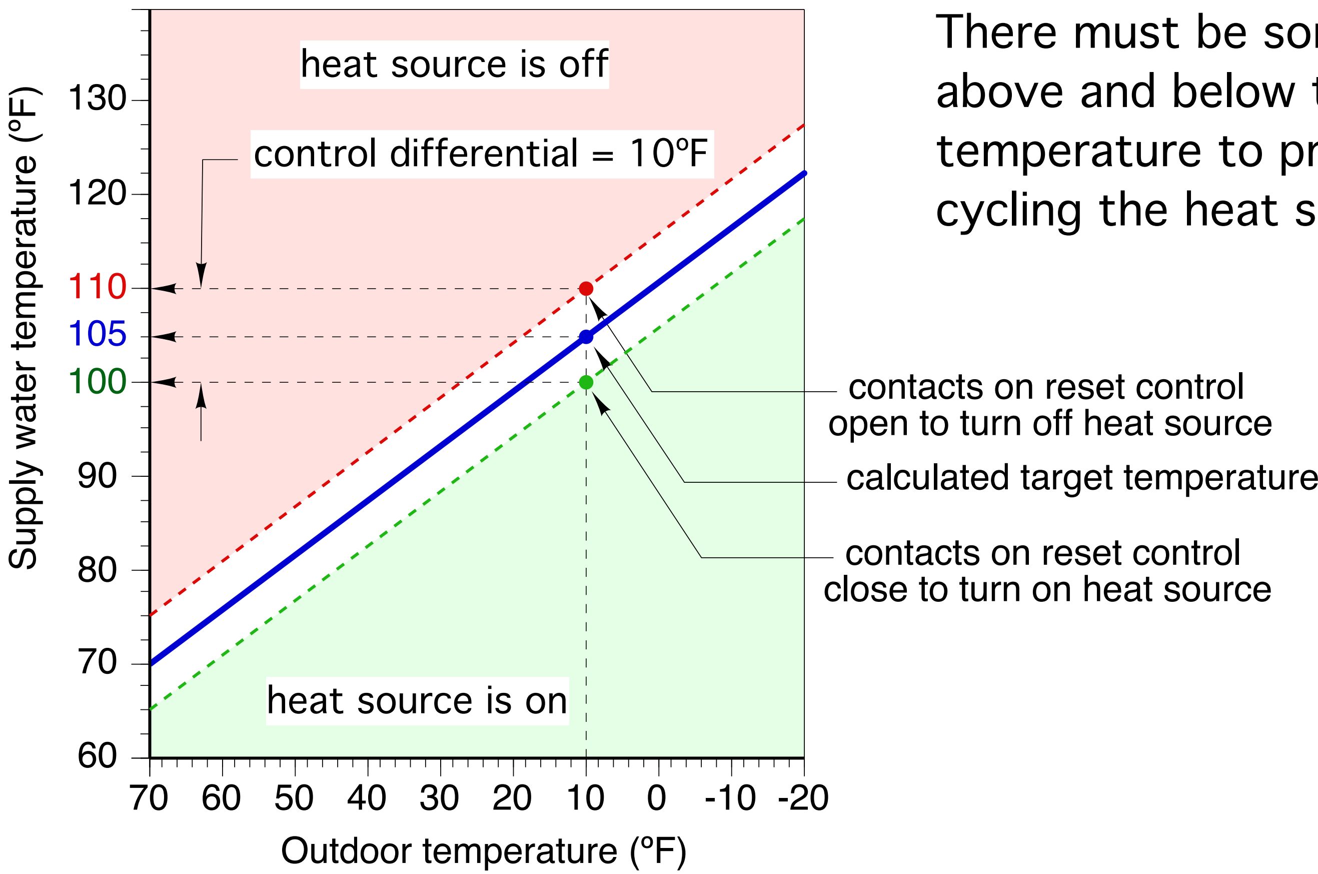
modulating heat source



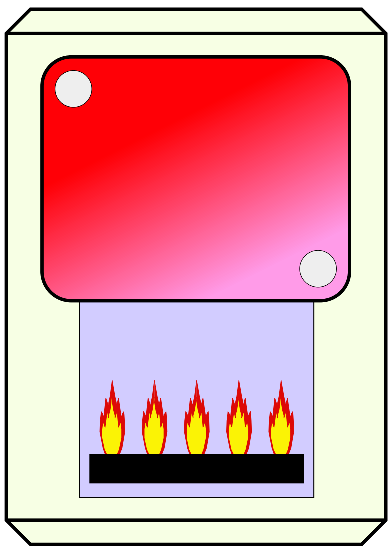
mixing device

Outdoor Reset Control Theory

1. Controlling the temperature leaving a on/off heat source
(a.k.a. “boiler reset control”)



There must be some differential, above and below the target temperature to prevent short cycling the heat source.

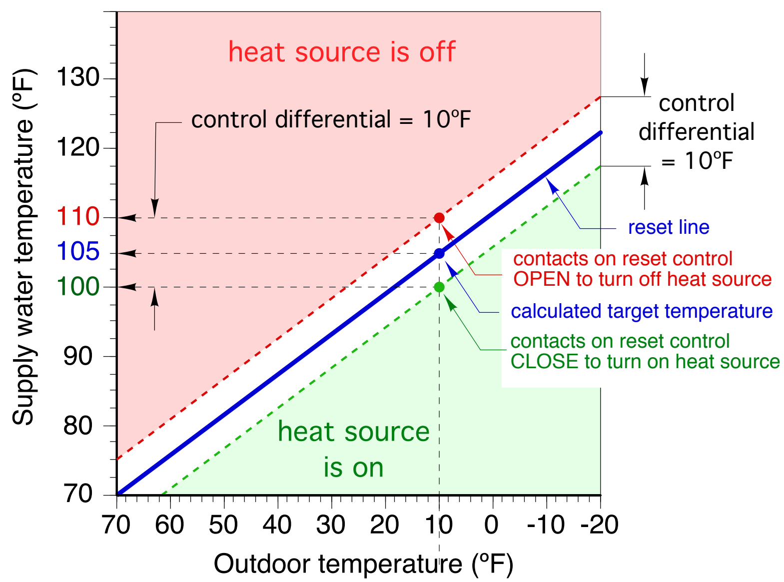


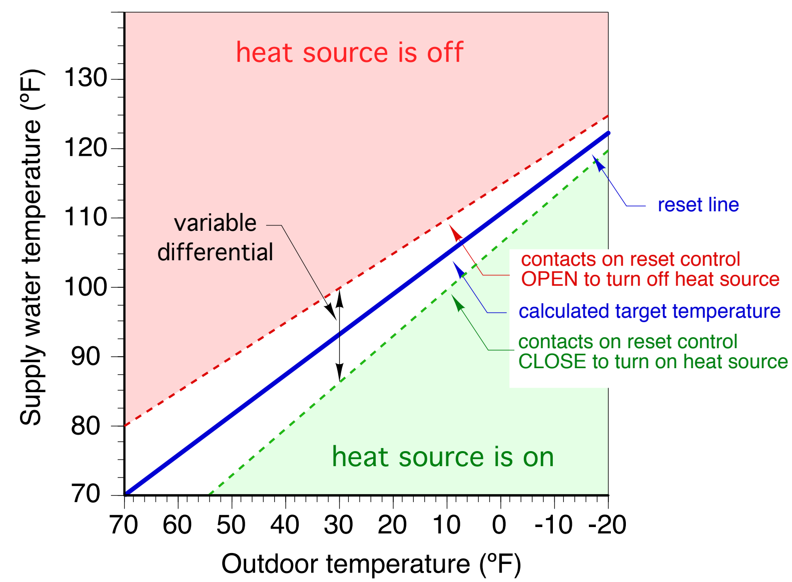
on/off heat source

Outdoor Reset Control Theory

1. Controlling the temperature leaving a on/off heat source (a.k.a. “boiler reset control”)

There must be some differential, above and below the target temperature to prevent short cycling the heat source.



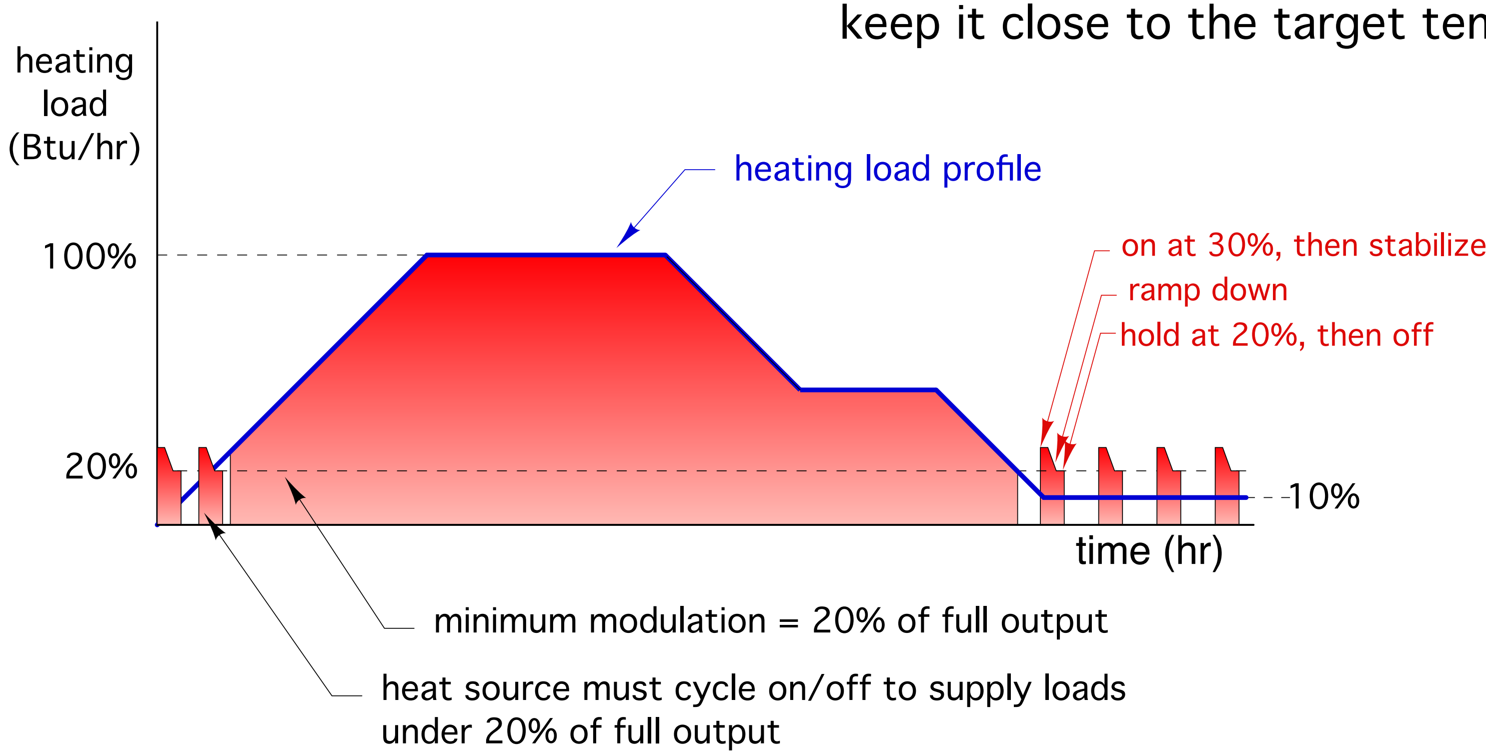


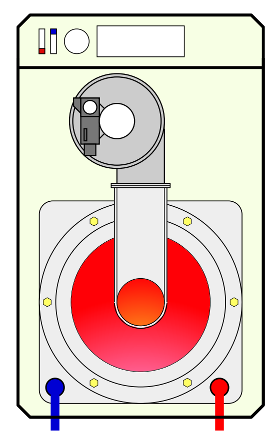
Outdoor Reset Control Theory

2. Controlling the temperature leaving a modulating heat source (a.k.a. "boiler reset control")

Most modulating heat sources have an internal outdoor reset controller.

They modulate the burner and continually monitor the supply temperature, trying to keep it close to the target temperature.

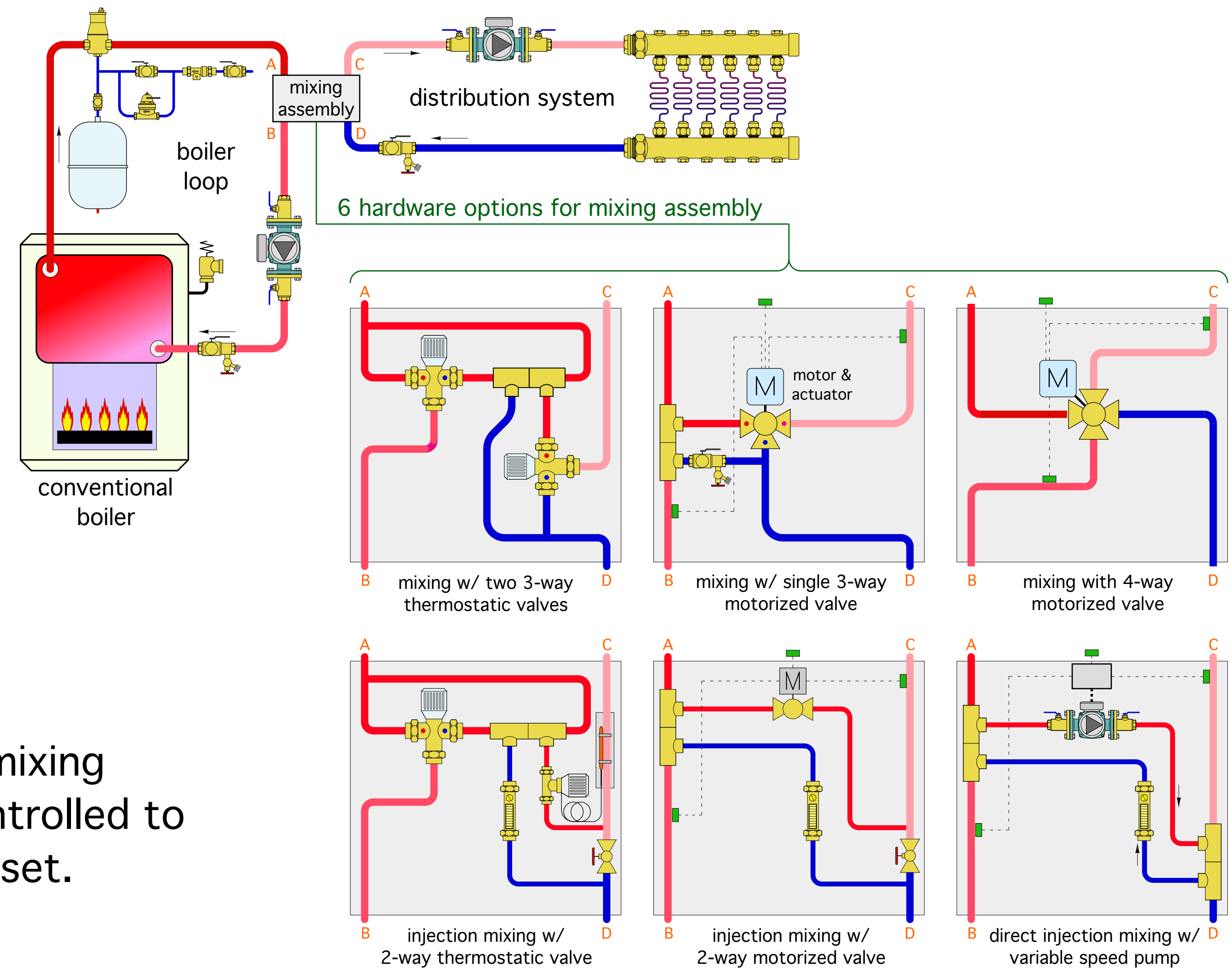




modulating heat source

Outdoor Reset Control Theory

3. Controlling the temperature supplied to the distribution system using a mixing device (a.k.a. “mixing reset control”)



A wide variety of mixing devices can by controlled to provide outdoor reset.

Outdoor Reset Control Theory

3. Controlling the temperature supplied to the distribution system using a mixing device (a.k.a. "mixing reset control")

A wide variety of mixing devices can by controlled to provide outdoor reset.