Hydronics for High Efficiency Biomass Boilers

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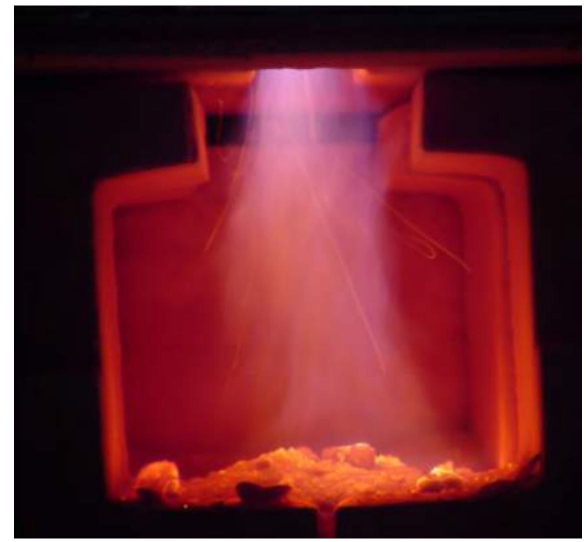

presented by:

John Siegenthaler, P.E.
Appropriate Designs
Holland Patent, NY
www.hydronicpros.com

AIA approved course: BIOMASS2014
7.0 LU credits

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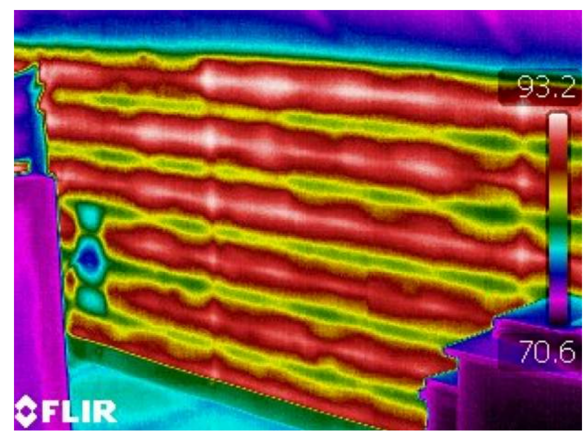
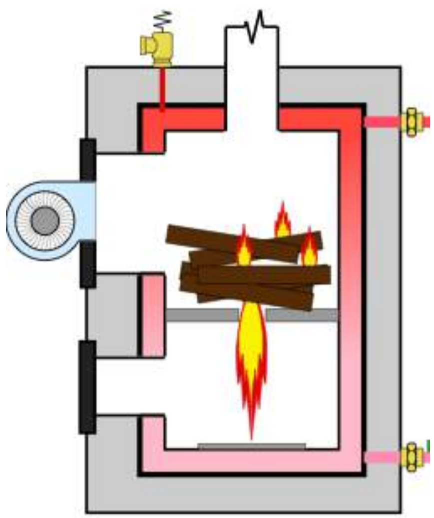


Hydronics for High Efficiency Biomass Boilers

Today's Agenda:

- Short break at 10 AM
- Lunch: noon - 12:30
- Short break at 2:30
- ***Out of here by 9:00 PM***

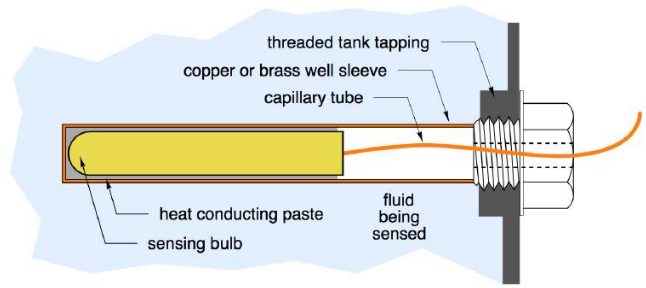


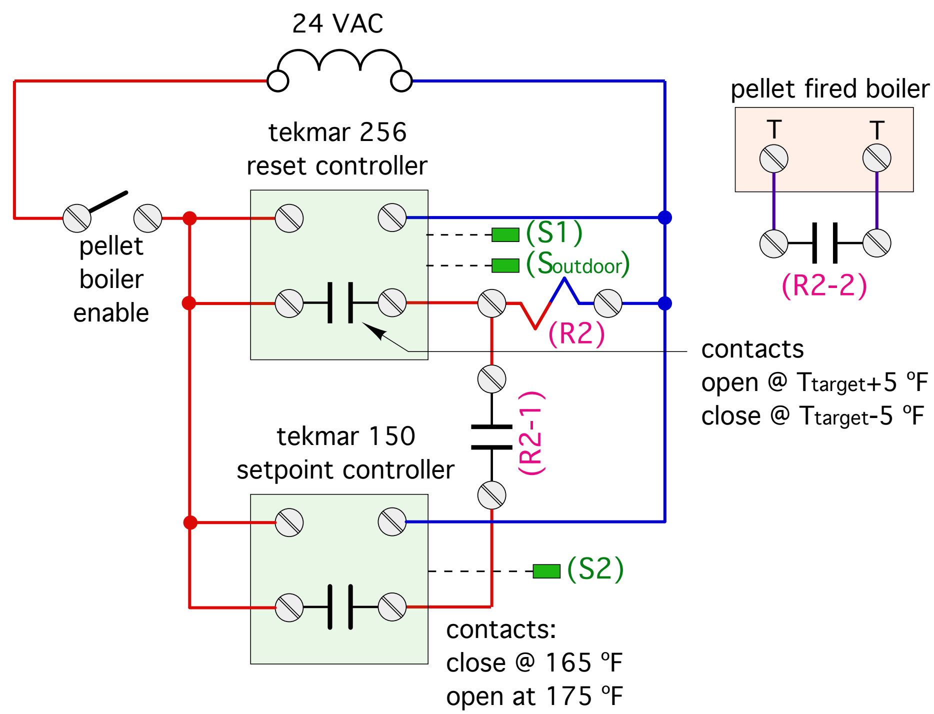
wood-gasification boiler

Hydronics for High Efficiency Biomass Boilers

Today's Topics:

- The importance of hydronics to renewable energy
- Wood as a heating fuel
- Wood gasification boilers
- Pellet-fired boilers
- Thermal storage options
- Preventing “negative energy flow”
- Boiler protection options
- Low temperature hydronic heat emitters
- Instantaneous domestic water heating
- Thermal storage control concepts
- Sizing biomass boilers & thermal storage
- System examples
- Renewable Heat NY program





Hydronics for High Efficiency Biomass Boilers

Get the PDF of all the slides at:
https://www.nyserda.ny.gov/-/media/Files/EERP/Renewables/Biomass/biomass-hydronics-training.pdf

Just "google" *Renewable Heat NY* & scroll down:

On-Site Training

Hydronics for High Efficiency Biomass Boilers

This full day design-focused workshop examines best practices for combining modern, high efficiency wood-fired boilers with hydronic distribution systems. It covers the operating characteristics of wood-gasification boilers, pellet-fired boilers, and wood-chip boilers and the latest hydronic heating technology that can complement these high efficiency heat sources. The hydronic topics covered include low temperature heat emitters, high efficiency circulators, modern control techniques, and options for water-based thermal storage.

Presentation Slides

- Hydronics for High Efficiency Biomass Boilers [PDF]

New York State Energy Research & Development Authority

"Hydronics for High Efficiency Biomass Boilers"
BIOMASS2014

John Siegenthaler

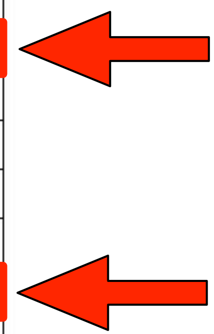
7 AIA LU credits

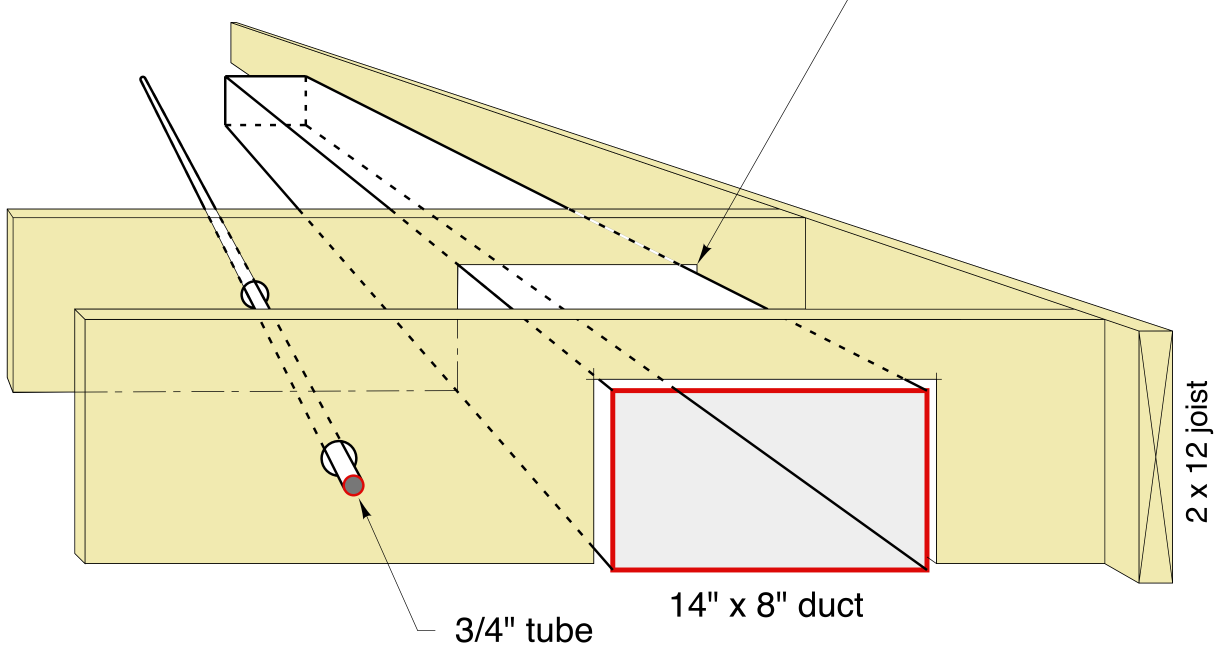
Water vs. air: It's hardly fair...

courtesy of Dan Foley

Water is vastly superior to air for conveying heat

Material	Specific heat (Btu/lb/°F)	Density* (lb/ft³)	Heat capacity (Btu/ft³/°F)
Water	1.00	62.4	62.4
Concrete	0.21	140	29.4
Steel	0.12	489	58.7
Wood (fir)	0.65	27	17.6
Ice	0.49	57.5	28.2
Air	0.24	0.074	0.018
Gypsum	0.26	78	20.3
Sand	0.1	94.6	9.5
Alcohol	0.68	49.3	33.5



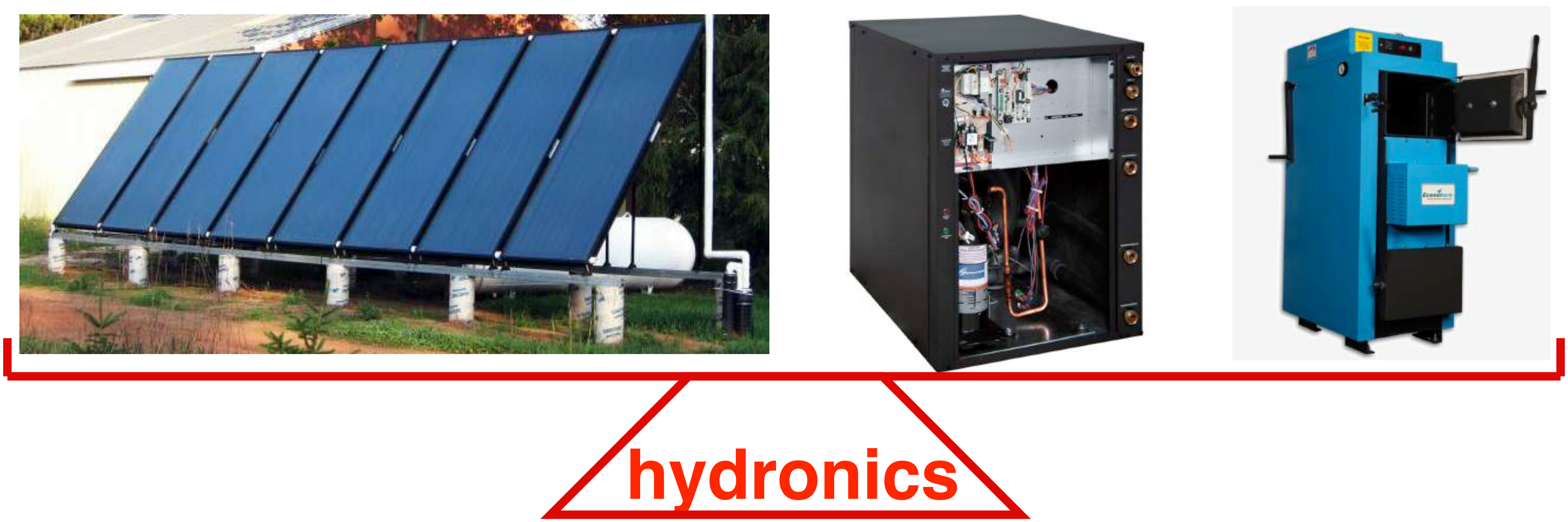


$$\frac{62.4}{0.018} = 3467 \approx 3500$$

A given volume of water can absorb almost 3500 times as much heat as the same volume of air, when both undergo the same temperature change

Hydronics & Renewable Energy

Modern hydronics is the "glue" holding together many thermally-based renewable energy systems.



Regardless of what solar collector, geothermal heat pump, or wood-fired boiler is selected, if the distribution system, controls, and heat emitters are not properly matched, that system will not perform well.

Why hydronics enhances renewable heat sources

- Superior comfort
- Low temp. operation (high heat source efficiency)
- Very high distribution efficiency
- Thermal storage potential
- Easy integration with conventional heat sources
- Minimally invasive retrofitting
- Potential for thermal metering (ASTM E44 coming 2018)

Firewood needs to be dry!

20% moisture maximum *INTERNAL* moisture content

Source: Richard Gibbs

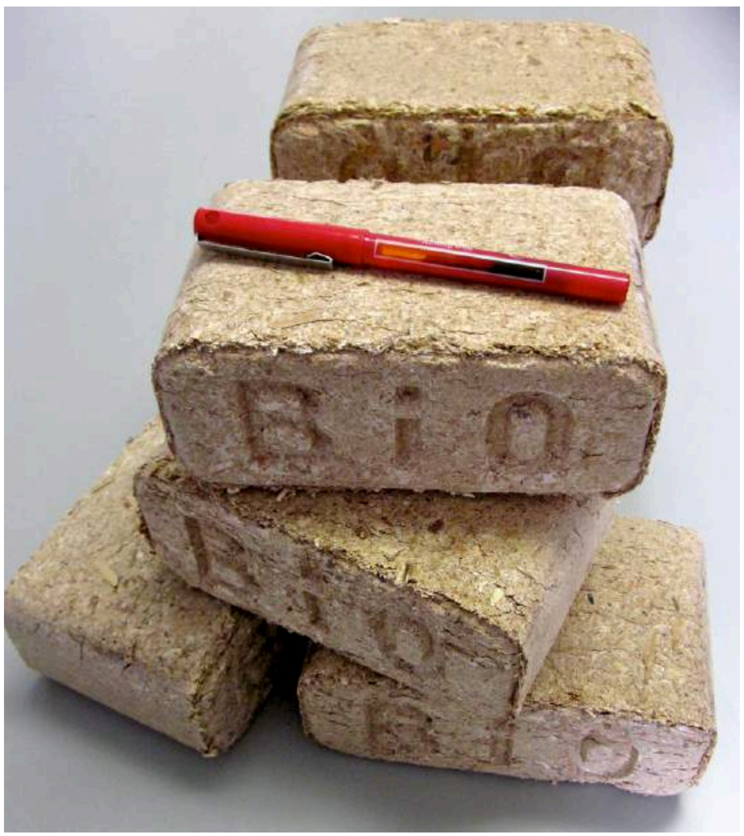
Split open several pieces of firewood from the pile to check internal moisture %

end grain
moisture = 7.9%

split open internal
moisture = 16.0%

Pellets & other "densified" wood fuel

Wood pellets
7600 to 8400 Btu/lb



Wood briquettes
about
8000 Btu/lb

PFI GRADED FUEL — Pellet Fuels Institute

PFI Densified Fuel Grade: Premium

Grade Requirements:
Reg. #1234

Bulk Density:	40–46 lbs/ft^3
Diameter:	.230–.285 in/5.84–7.25 mm
Durability:	≥96.5
Fines:	≤0.50%
Ash Content (as received):	≤1%
Length:	≤1% >1.5 in.
Moisture:	≤8.0%
Chlorides:	≤300 ppm

Manufacturers Guaranteed Analysis:

Type of Material:	Softwood fiber
Additives:	2.0% corn oil by weight
Minimum Higher Heating Value (as received):	8,000 BTU
Other Manufacturers Guarantees:	

Approved Auditing Agency Logo
Displayed Here

 For more information, please visit the PFI website at www.pelletheat.org.

PELLET FUELS INSTITUTE www.pelletheat.org

Pellet Production

New England Wood Pellet plant, Utica, NY

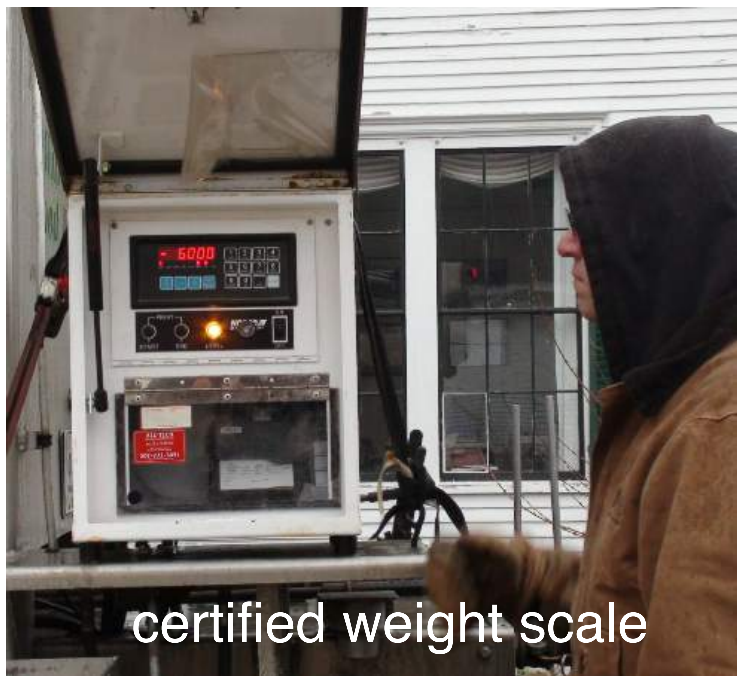
pellets emerge from mill
at about 190 °F

Bulk Pellet Delivery

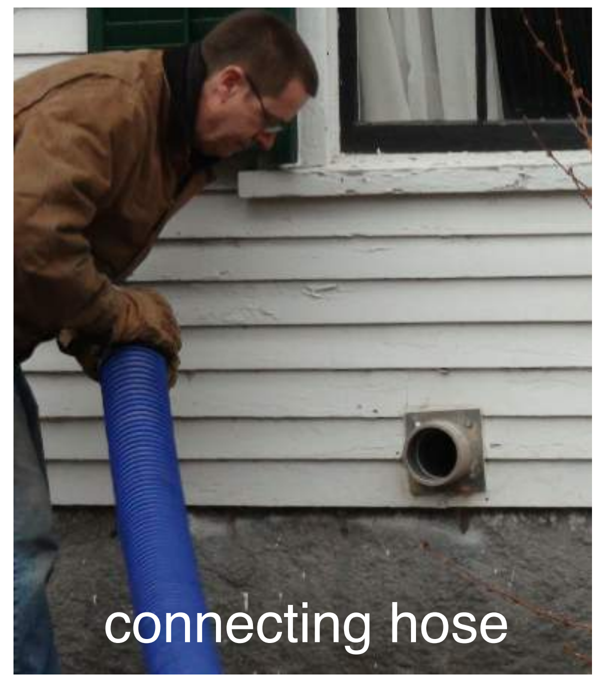
Images courtesy of Maine Energy Systems

Filling truck

preparing hose



certified weight scale



connecting hose

Wood as a heating fuel

Higher heating value (HHV) = theoretical heat available from 0% moisture content wood, burned with stoichiometric air/fuel ratio, and including recovery of latent heat (condensation and cooling of water vapor produced during combustion.

$HHV_{0\%mc}$ = 8660 Btu/lb

Higher heating value (HHV) as function of moisture content

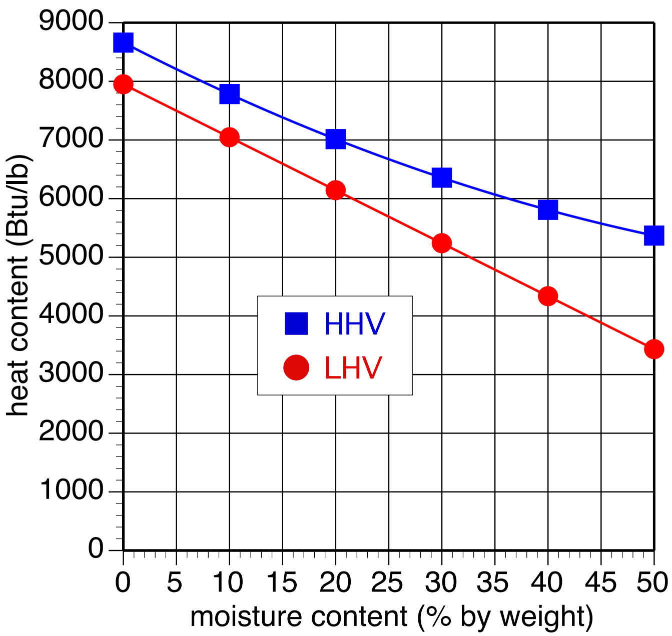
$$HHV_{BTU/lb} = 8660(1 - 0.010766w + 0.00006333w^2)$$

w = moisture content (%)

Lower heating value of wood does *not* include the latent heat associated with water vapor produced as the wood is burned.

$$LHV_{BTU/lb} = 7950 - 90.34w$$

w = moisture content (%)



Wood as a heating fuel

Thus, wood with 20% moisture content, typical of firewood that's been keep under cover and air dried for at least nine months, is approximately:

$$HHV_{BTU/lb} = 8660[1 - 0.010766(20) + 0.00006333(20)^2] = 7015\frac{Btu}{lb}$$

$$LHV_{BTU/lb} = 7950 - 90.34(20) = 6143\frac{Btu}{lb}$$

When comparing boiler efficiencies, be sure to determine if they are based on HHV or LHV of wood.

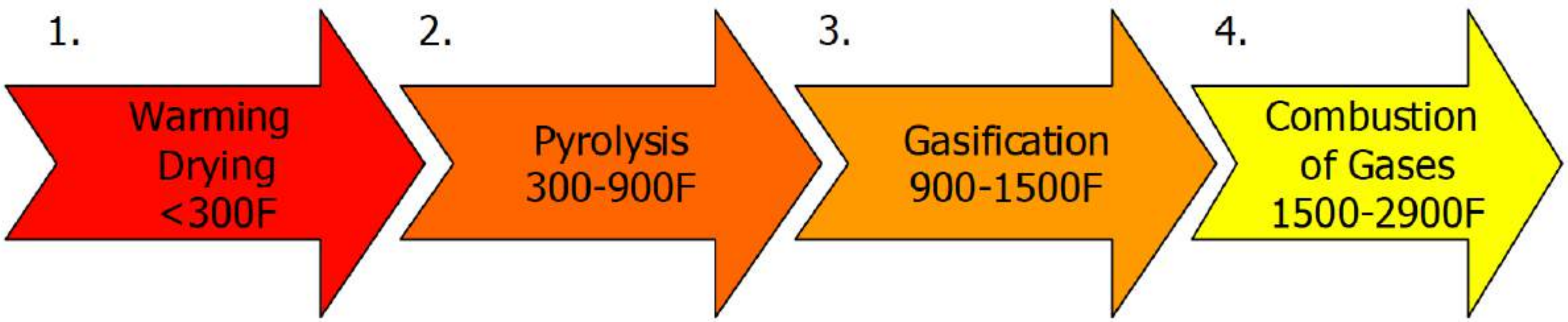
Example (assuming 20% mc wood):

A boiler rated at 70% thermal efficiency based on HHV will yield (0.70)(7015) = **4911 Btu/lb useable output**

A boiler rated at 80% thermal efficiency based on LHV will yield (0.80)(6143) = **4914 Btu/lb useable output**

Almost identical useful heat output, but two different "paths of arrival" (e.g. efficiencies based on HHV vs. LHV).

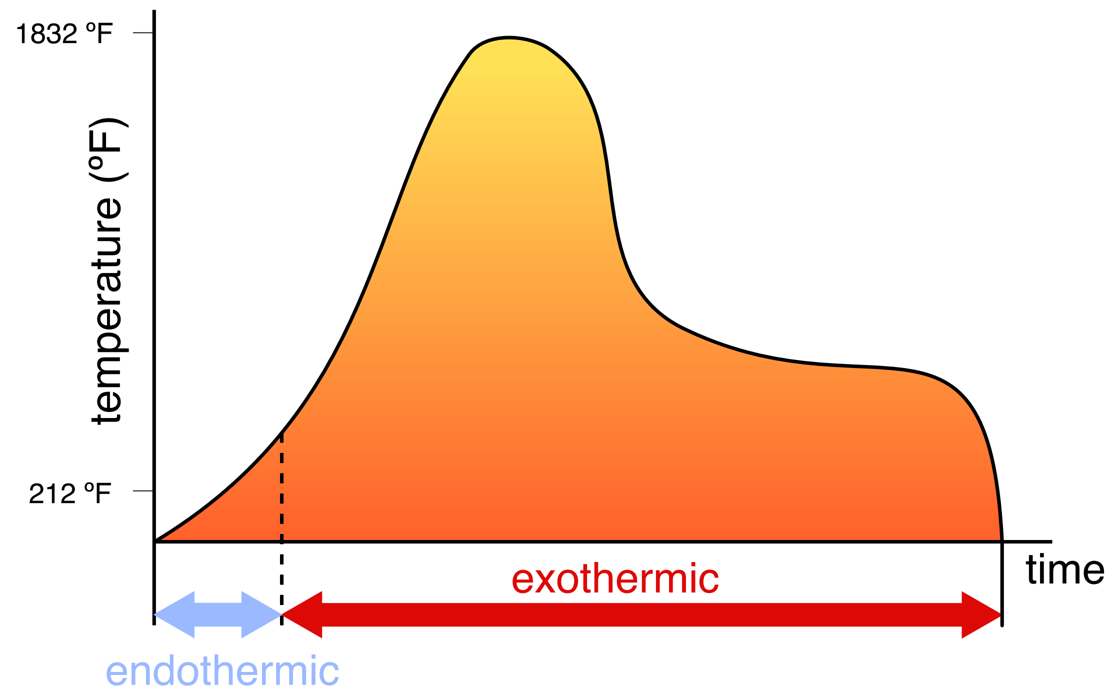
Combustion phases



1. Water evaporating from wood

2 Volatilization & chemical composition change of compounds in the wood, low oxygen levels (gasification)

3. combustion of high temperature gases, usually with excess oxygen



Wood as a heating fuel

Electric Resistance Heat	____cents / Kwhr x 2.93 = ____ $/MMBtu
Heat Pump	(____cents / Kwhr x 2.93) / (____average COP) = ____ $/MMBtu
#2 Fuel Oil	(____ $ / gallon x 7.14) / (___ AFUE (decimal)) = ____ $/MMBtu
Propane	(____ $ / gallon x 10.9) / (___ AFUE (decimal)) = ____ $/MMBtu
Natural Gas	(____ $/ therm x 10) / (___ AFUE (decimal)) = ____ $/MMBtu
Firewood*	(____ $ / face chord x 0.149) / (___ ave. efficiency (decimal)) = ____ $/MMBtu
Wood Pellets	(____ $ / ton x 0.06098) / (___ ave. efficiency (decimal)) = ____ $/MMBtu
Bituminous coal	(____ $ / ton x 0.03268) / (___ ave. efficiency (decimal)) = ____ $/MMBtu
Shelled Corn **	(____ $ / bushel x 2.551) / (___ ave. efficiency (decimal)) = ____ $/MMBtu

* Assumes a 50/50 mix of maple and beech dried to 20% moisture content.
Price is for 4 ft x 8 ft x 16 inch face chord split and delivered.

** Assumes 15% moisture content

- #2 fuel oil: 138,500 Btu/gallon
- Waste oil: 125,000 Btu/gallon
- Natural gas: about 1030 Btu/ cubic foot
- Propane: 92,500 Btu per gallon
- Electricity: 3413 Btu/ kilowatt-hour
- Hard coal (anthracite): 26,000,000 Btu/ton

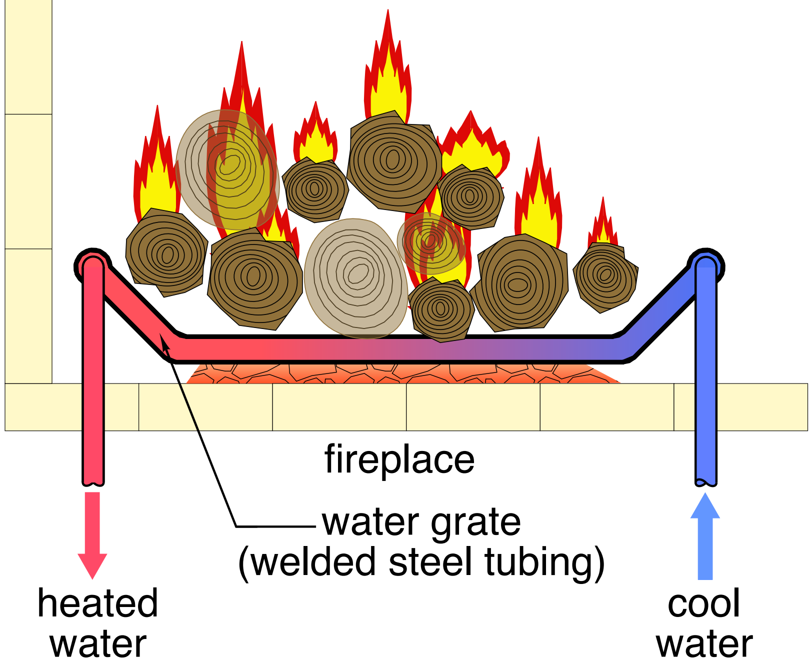
Wood as a heating fuel

Fuel	Calculation	Result
Electric Resistance Heat	12 cents / Kwhr x 2.93	= 35.16 $/MMBtu
Heat Pump	12 cents / Kwhr x 2.93 ÷ 2.9 average COP	= 12.12 $/MMBtu
#2 Fuel Oil	3.35 $ / gallon x 7.14 ÷ 0.86 AFUE (decimal)	= 27.81 $/MMBtu
Propane	2.76 $ / gallon x 10.9 ÷ 0.92 AFUE (decimal)	= 32.7 $/MMBtu
Natural Gas	1.42 $/ therm x 10 ÷ 0.92 AFUE (decimal)	= 15.53 $/MMBtu
Firewood*	70 $ / face chord x 0.149 ÷ 0.65 ave. efficiency (decimal)	= 16.05 $/MMBtu
Wood Pellets	250 $ / ton x 0.06098 ÷ 0.75 ave. efficiency (decimal)	= 20.32 $/MMBtu
Bituminous coal	____ $ / ton x 0.03268 ÷ ___ ave. efficiency (decimal)	= ____ $/MMBtu
Shelled Corn **	____ $ / bushel x 2.551 ÷ ___ ave. efficiency (decimal)	= ____ $/MMBtu

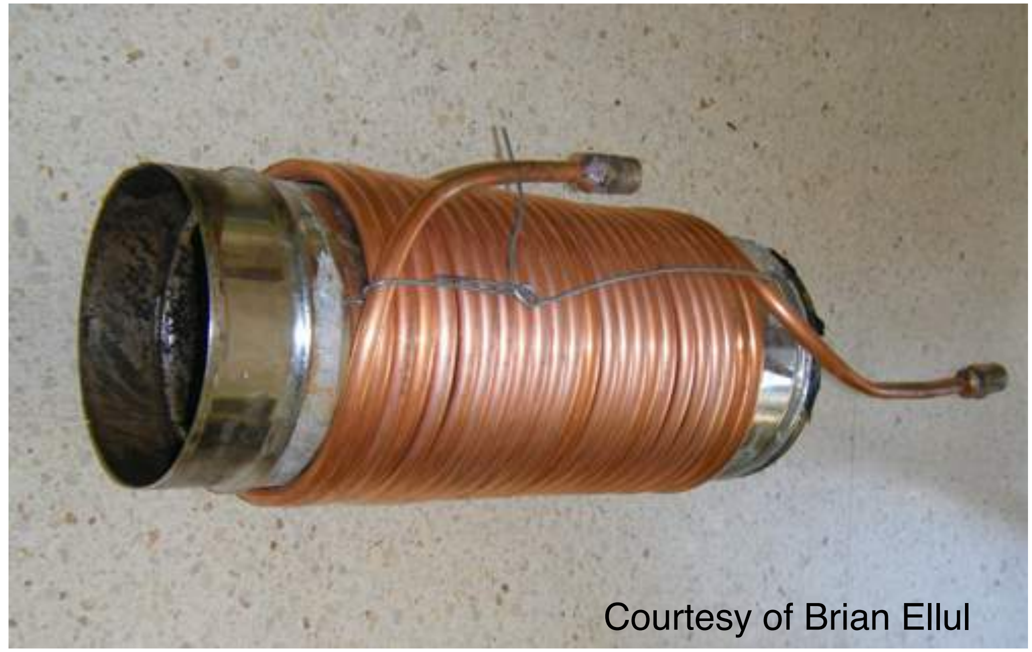
Prices used are from NYSERDA website, western region for fuel oil price, statewide average through 11/17 on electricity price

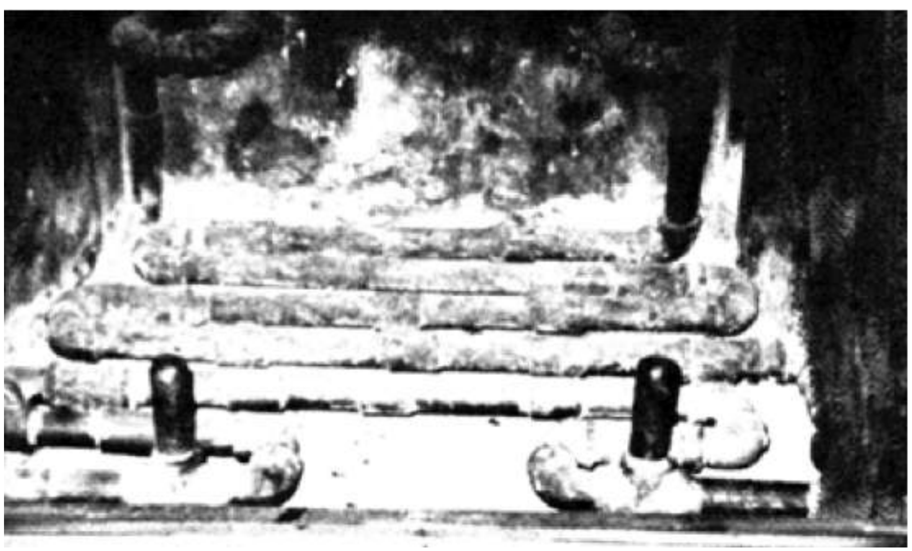
NYSERDA suggests using the 3 year average price of competing fuels when making comparisons.

Early attempts at matching wood & hydronics



water jacket for stove pipe flue





The problems:

1. Safety
2. Creosote formation
3. Scaling/corrosion/stress

Outdoor wood-fired hydronic heaters

Some progress, but issues remain...




The problems:

1. Low thermal efficiency ≤ 40%
2. Creosote formation
3. High particulate emissions
4. Poor underground piping practices

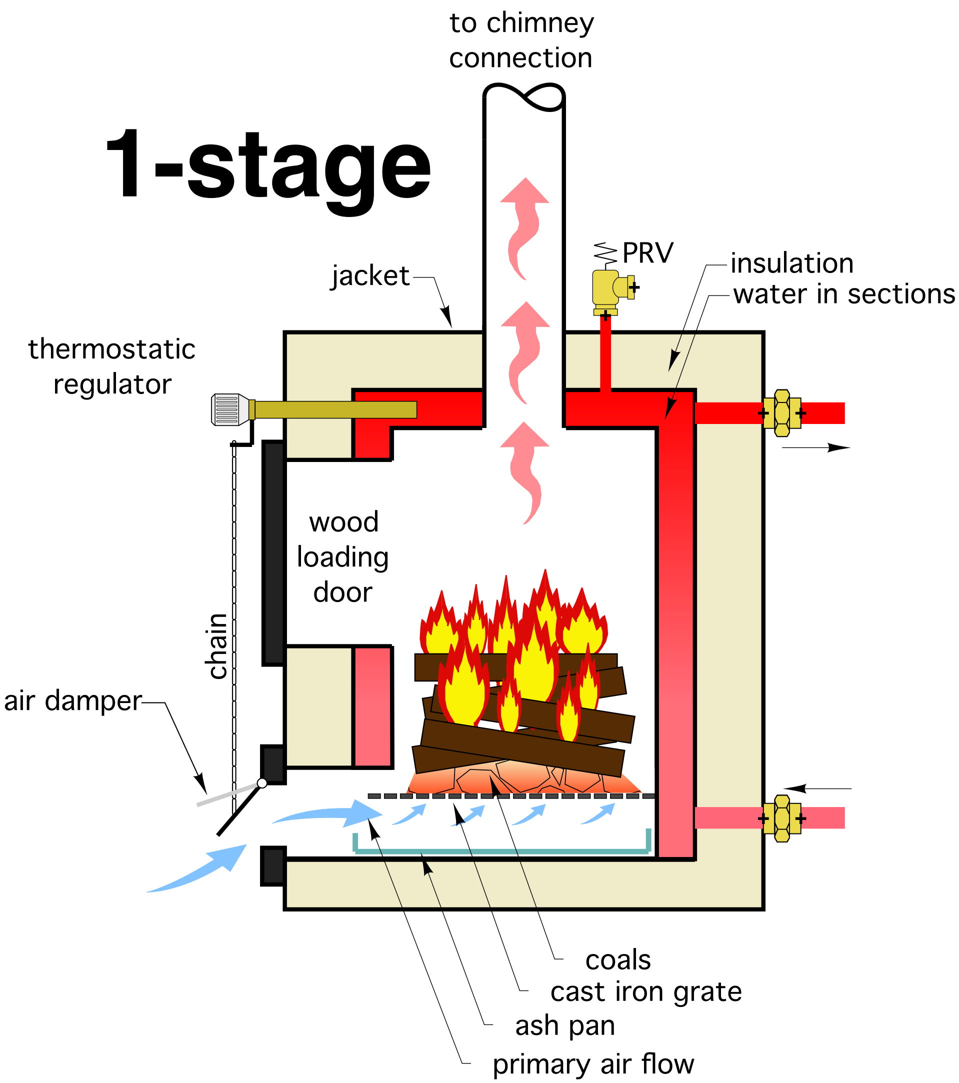
In NY state, read NYSDEC part 247

http://www.dec.ny.gov/regs/71720.html

100’ property line setback & min. 18’ chimney

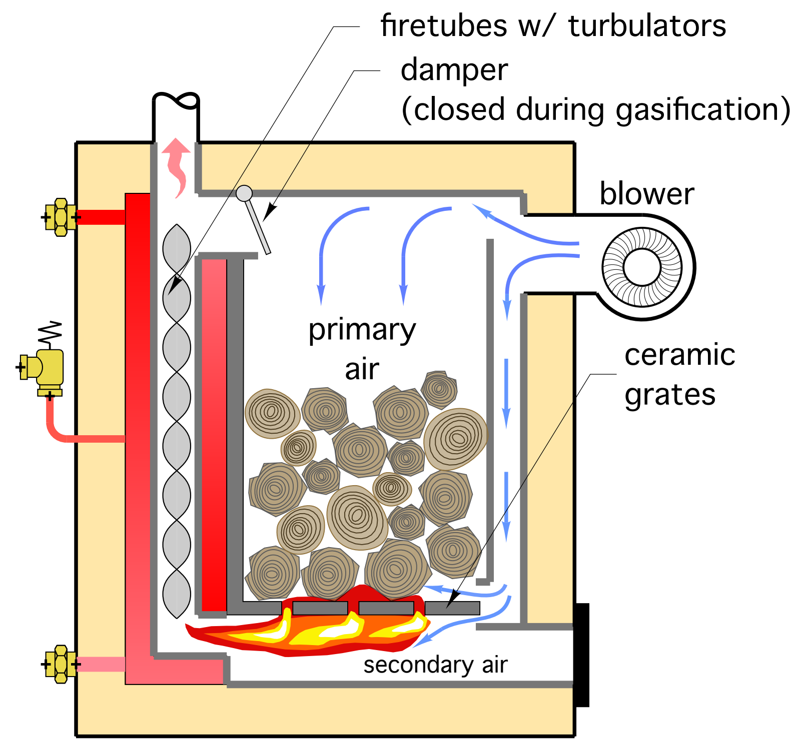
Cordwood gasification boilers

1-stage



• 1-stage combustion
• Thermal efficiency 40-60%
• significant ash & "clinker" residue

2-stage (gasification)



• 2-stage combustion
• Thermal efficiency (high load/steady state) 80-85%
• Very little ash or "clinker" residue
• Available for inside or outside placement

Cordwood gasification boilers

- 2-stage combustion
- Thermal efficiency 80-85% (@high load,steady state)
- Very little ash or “clinker” residue
- Available for inside or outside placement

image courtesy of Econoburn

For highest efficiency...

- **Burn Hot & Burn fast**

Heat output often exceeds heating load

Storage is needed

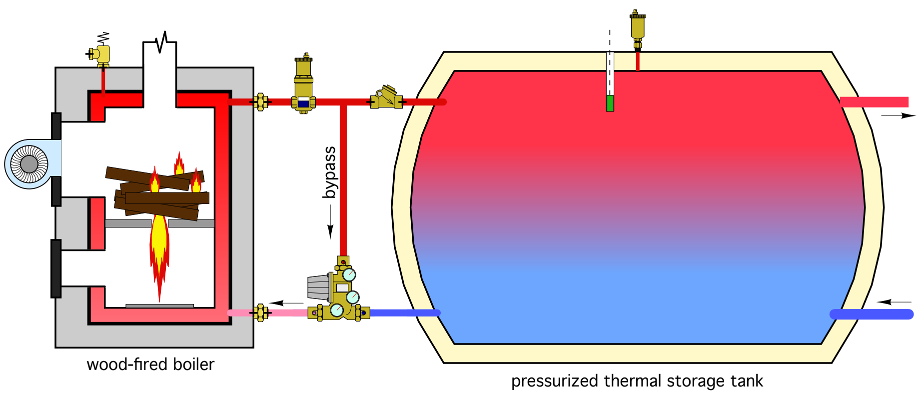


image courtesy of New Horizon Corp.

image courtesy of Tarm Biomass

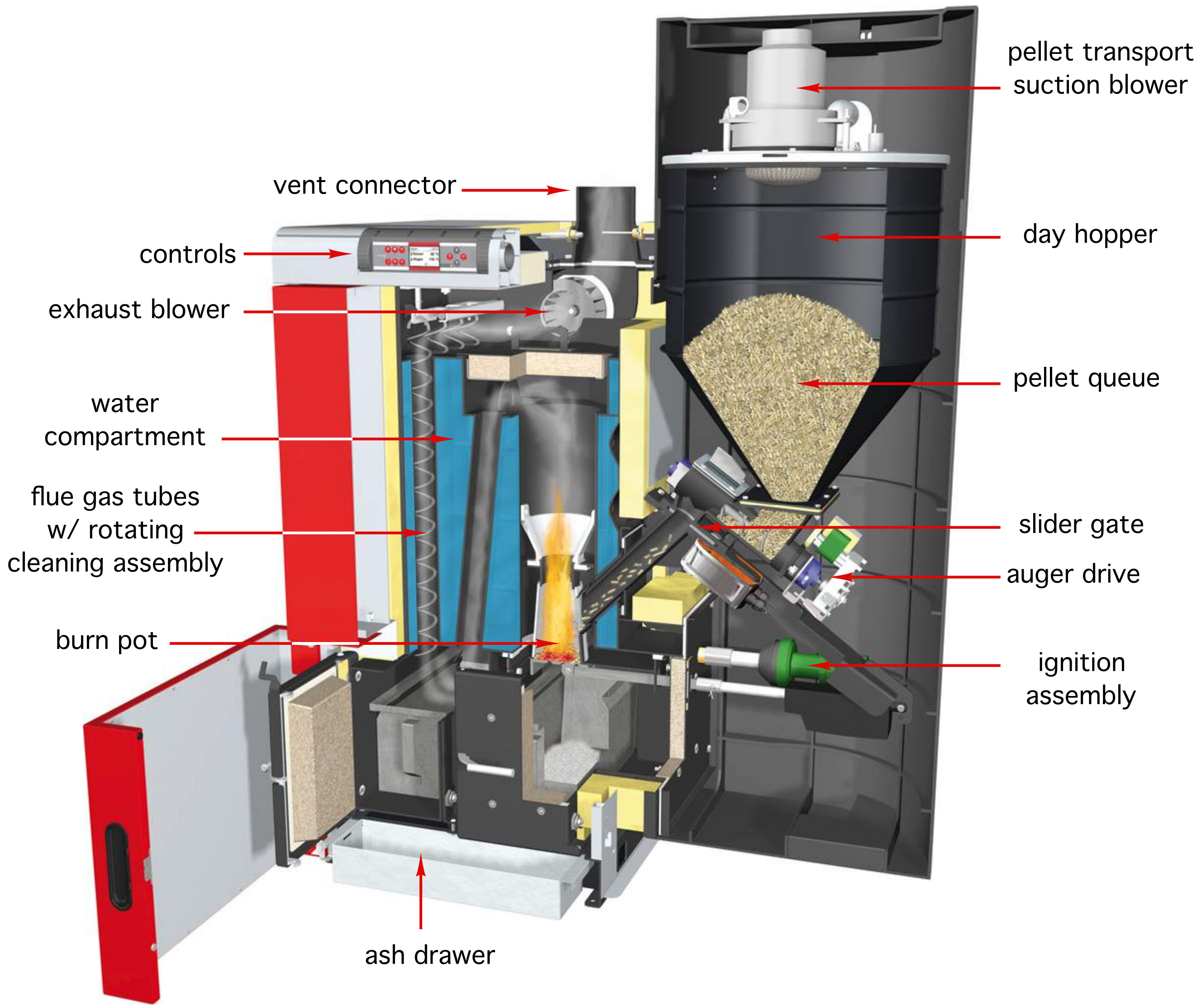
Cordwood gasification boilers

secondary combustion in lower chamber

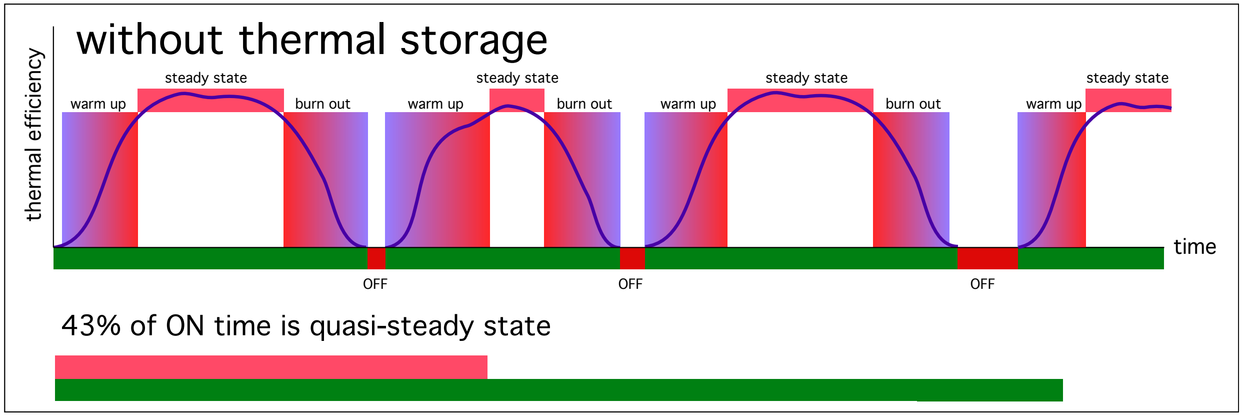
video courtesy of Econoburn

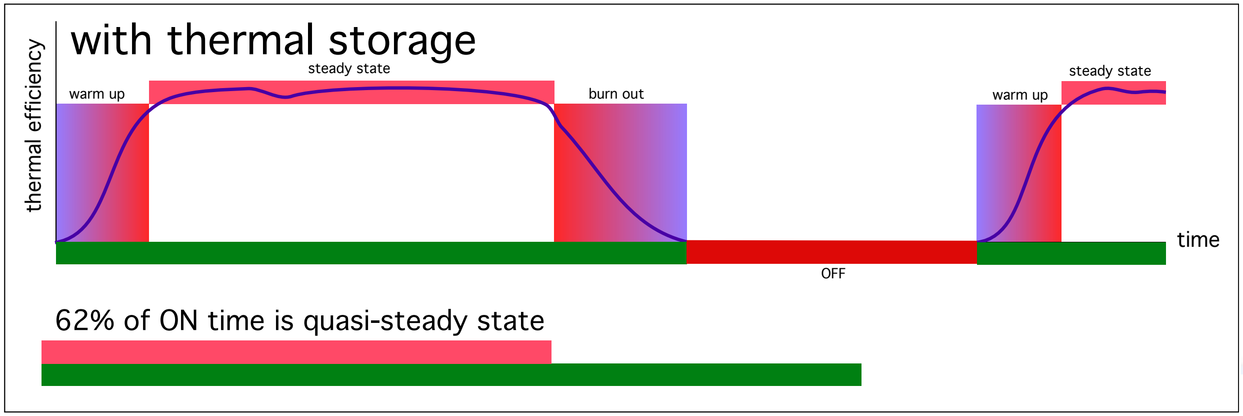
Modern Pellet-fired Boilers

image courtesy of Tarm Biomass

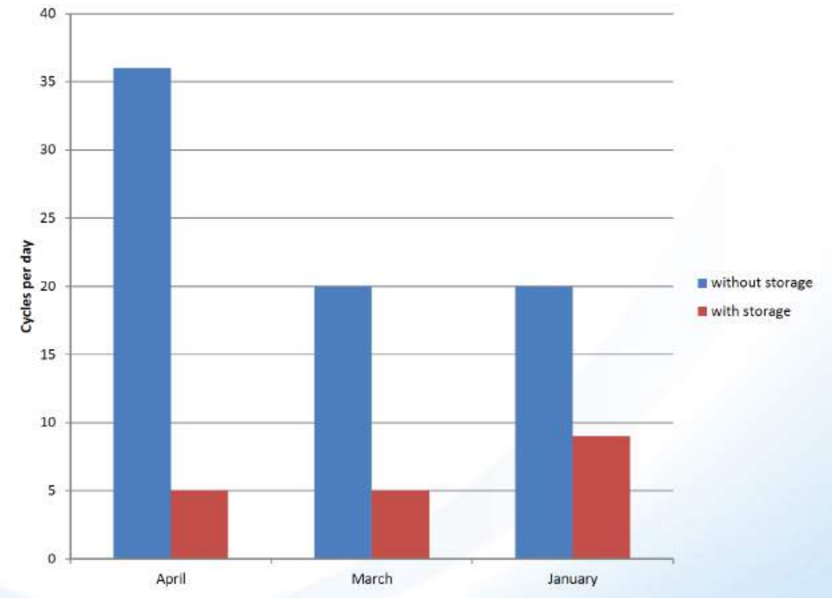


Pellet boilers attain their highest thermal efficiency, and lowest emissions, when **operated for long (multiple hour) burn cycles.**





25 kW (85,300 btu/hr) rated pellet boiler supplying a heating load profile typical of an upstate NY house, with and without a 119 gallon thermal storage tank as part of the system.



Brookhaven National Laboratory & Dr. Thomas Butcher

Suggested design objective: 3 hour run / start

Pellet Outgassing

Research from Clarkson University

Monitoring of Carbon Monoxide Off-Gassing in Wood Pellet Storage in the Northeastern US

http://www.nyserda.ny.gov/-/media/Files/Publications/Research/Biomass-Solar-Wind/Monitoring-CO-Off-gassing.pdf

Due to concerns over CO outgassing, Renewable Heat NY does not allow indoor pellet storage.

Conclusions of Clarkson research

The results of this initial study demonstrate that there is off-gassing of sufficient CO from stored pellets to represent a hazard that needs to be adequately addressed. Although no concentrations that would directly produce significant short-term extreme effects in healthy adults, **concentrations above the levels set as exposure guidelines in both homes and in occupational settings were clearly exceeded.**

outdoor pellet storage bin by Ehrhart Energy

Pellet Outgassing *Update on the Clarkson research:*

energy&fuels Article
pubs.acs.org/EF

Continuous Ozonolysis Process To Produce Non-CO Off-Gassing Wood Pellets

Mohammad Arifur Rahman,[†] Stefania Squizzato,[†] Richard Luscombe-Mills,[‡] Patrick Curran,[§] and Philip K. Hopke[*,†]

http://pubs.acs.org/doi/10.1021/acs.energyfuels.7b01093

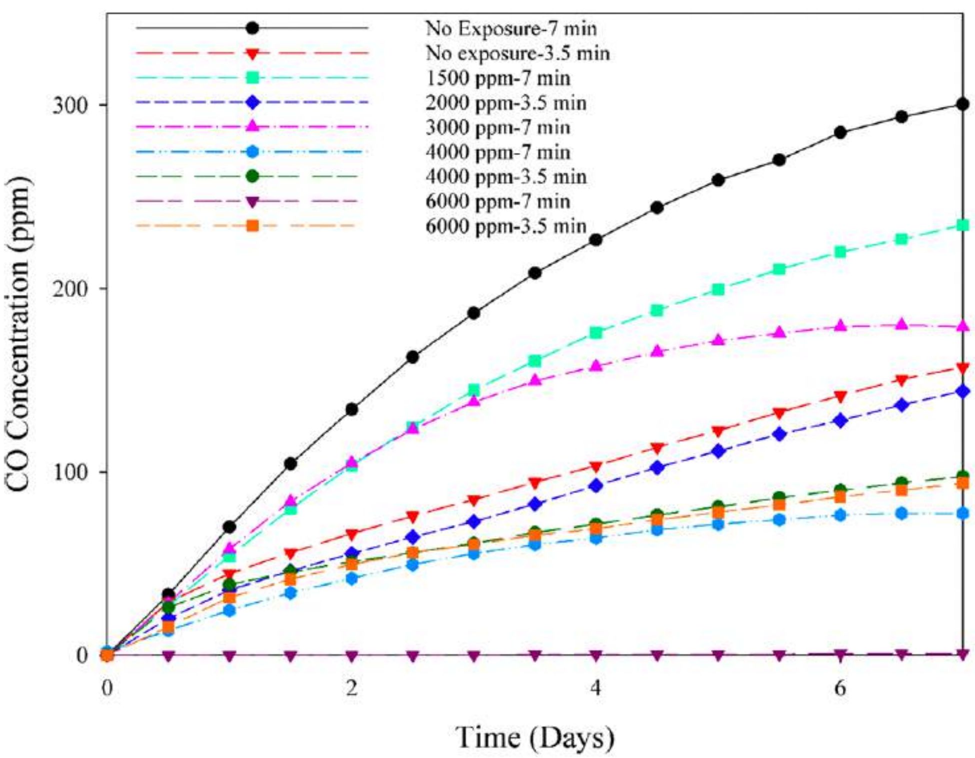


Figure 2. CO off-gas emission of wood fiber exposed at different ozone concentrations in a continuous process.

■ CONCLUSION

In this work, the reaction kinetics were measured for the passivation of reactive hydrocarbons in wood fiber in a continuous auger. The continuous ozonolysis reaction was observed to follow pseudo-first-order reaction kinetics. In the laboratory experiments, CO production was eliminated with a dose of approximately 0.032 g of O3/kg of fiber to be passivated. In the industrial-scale process, it was possible to passivate fiber with only 0.000 64 g of O3/kg of fiber. The pellets produced in the industrial trial showed that their fuel properties were not different from ordinary pellets. **Thus, ozonolysis of wood fiber can be used to commercially produce low-CO or essentially CO-free pellets.**

Pellet storage silos

image courtesy of Ehrhart Energy

image courtesy of Tarm Biomass

Pneumatic pellet receiver at base of silo

Supports weight of pellet column in silo, while allowing loose pellets under hood to be entrained in air flow.

images courtesy of Karl Longnecker

image courtesy of Tarm Biomass

30 ton pellet silo on load cells

“Energy Box” systems

image courtesy of Ehrhart Energy

Manufactured “Energy Box”
storage and boiler

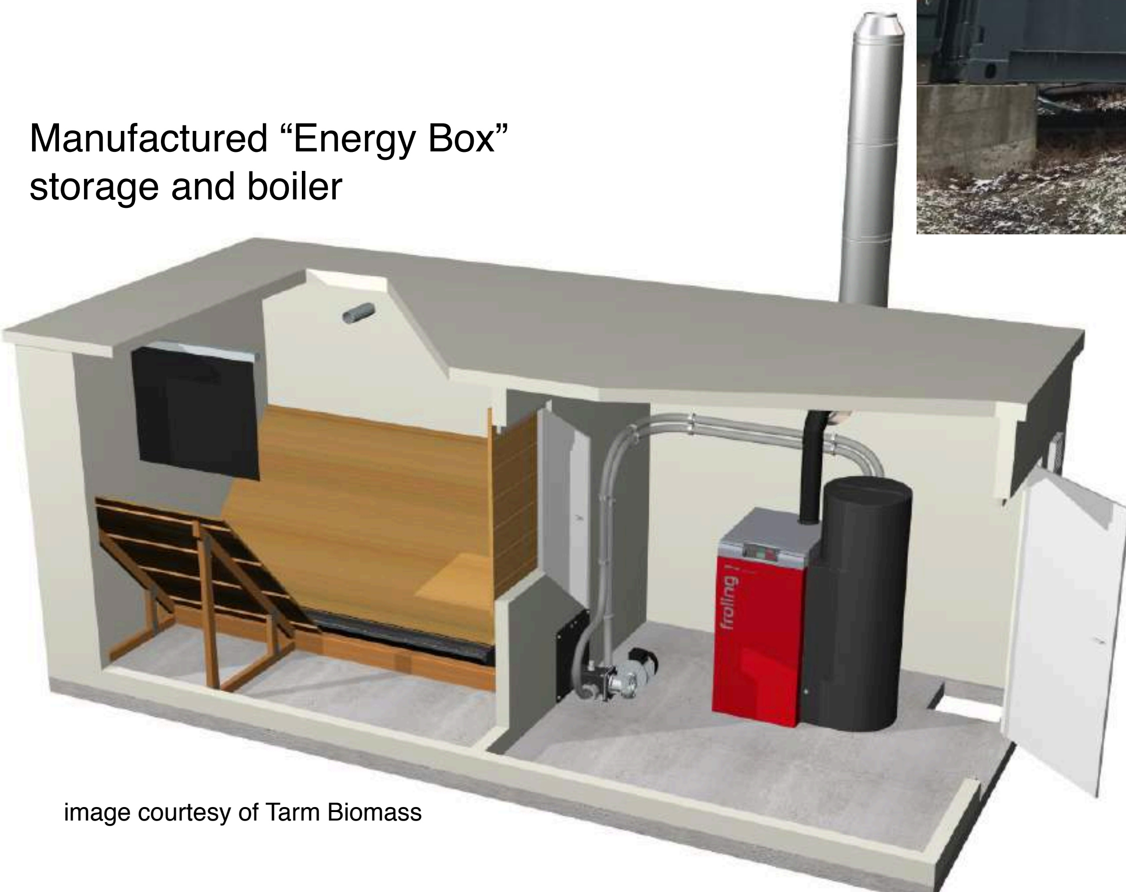
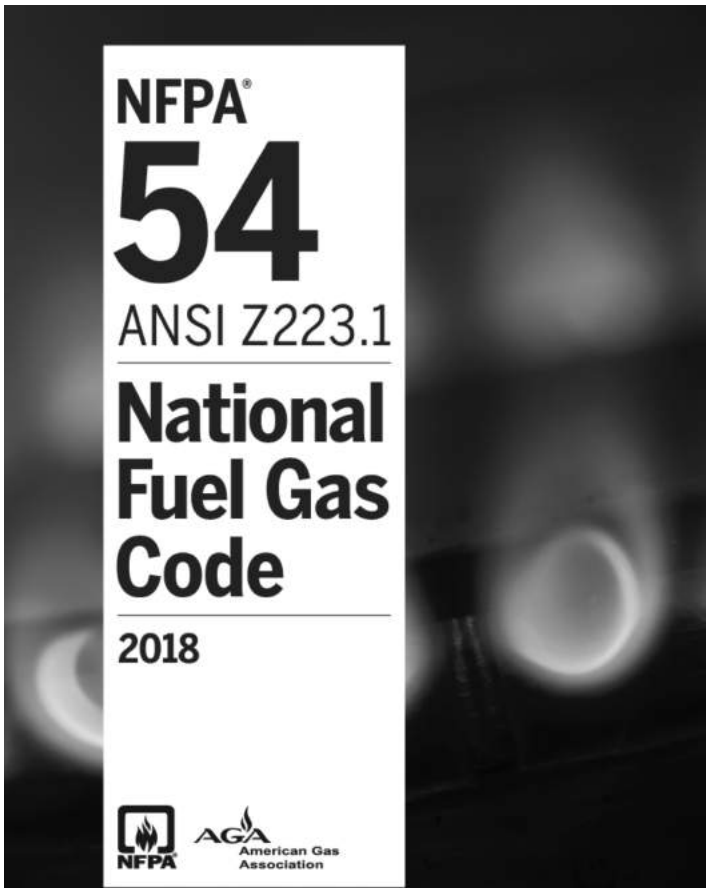


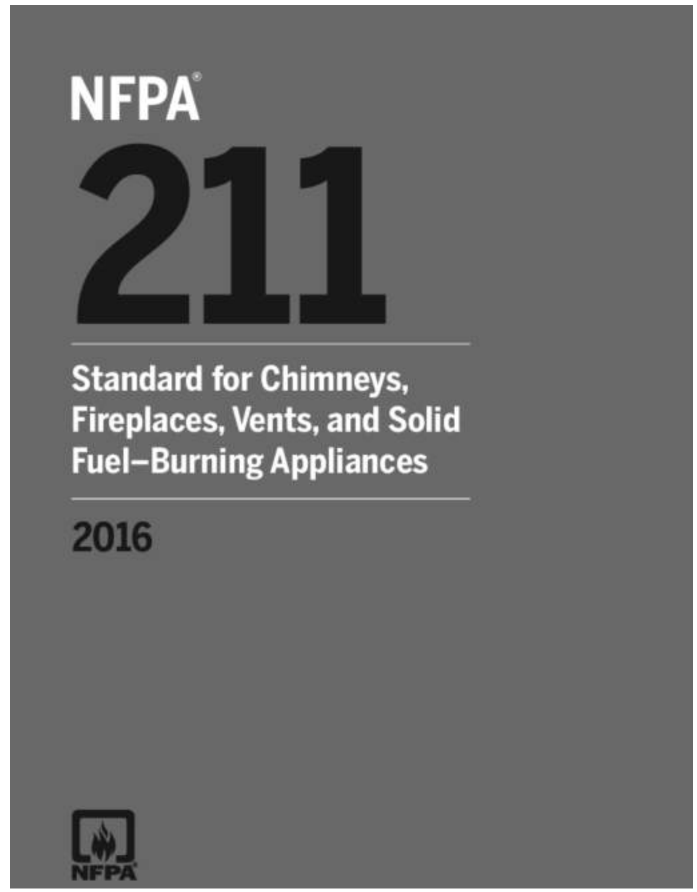
image courtesy of Tarm Biomass

Boiler Venting

NFPA 54 / National Fuel Gas Code (2018), and NFPA 211 (2016) are general references.

Much of the NYS Mechanical code dealing with chimneys & venting is based on these standards.





Free online access: http://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards

Chimneys

Chimneys for pellet and cordwood gasification boilers

Class A "all fuel" chimney (UL103-HT) 1000 °F continuous, 2100 °F, 10 minute. (stainless inner & outer wall, insulated) is recommended by most boiler manufacturers. (NFPA 211)

Opinions vary on the practicality of side wall venting: *Most biomass boiler manufacturers don't recommend side wall venting.*

Image source: Hart & Cooley

Image source: Selkirk

Some available products:

http://www.olympiachimney.com/ventis-class-a-all-fuel-chimney-pipe

http://www.selkirkcorp.com/~/media/selkirk/reference-documents/common/file/product-literature/chimney/ultratemp-514/brochure--all-fuel-chimney-buyers-guide-mbafcbg.pdf

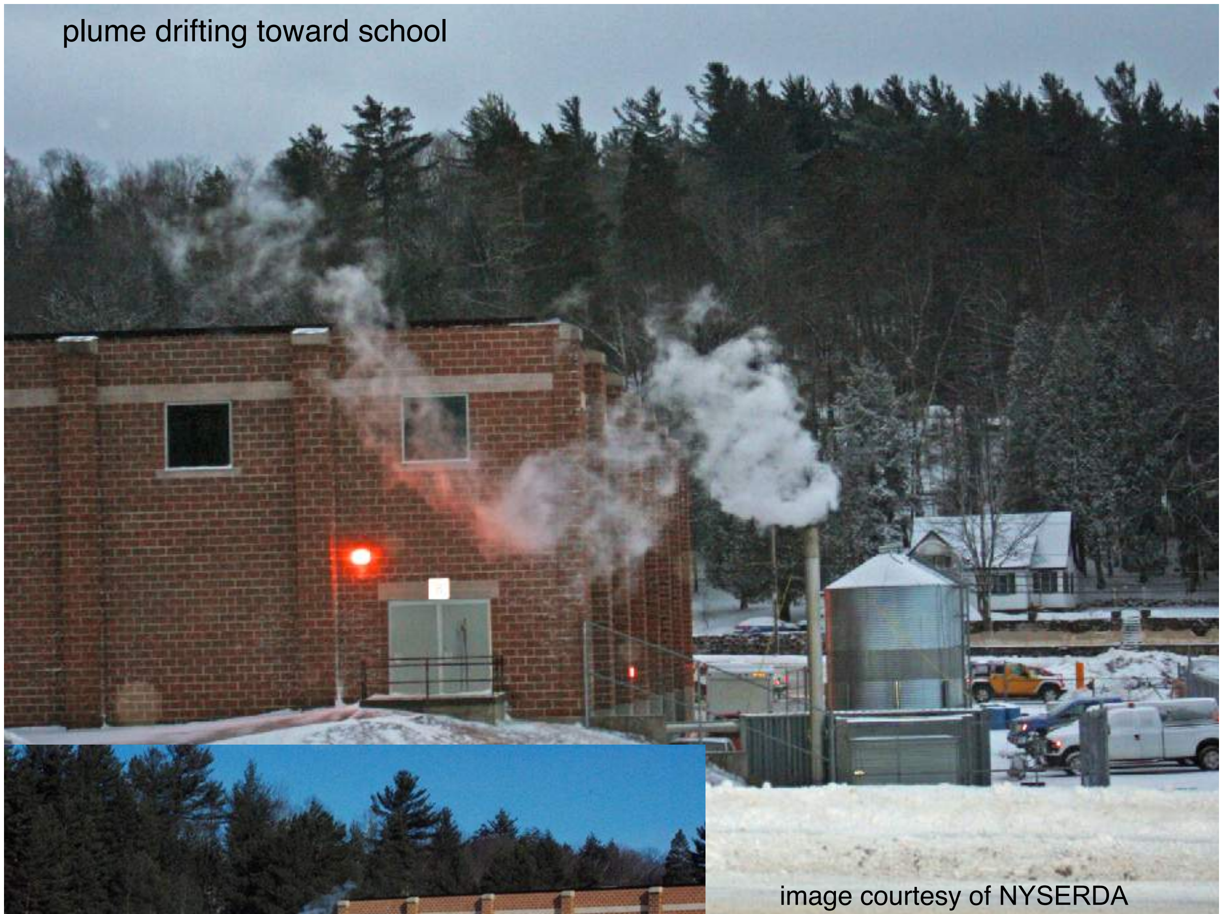
http://www.duravent.com/Product.aspx?hProduct=1

http://www.hartandcooley.com/files/assets/files/1371500382_HartandCooley_TLC_Catalog_0613.pdf

Image source: Simpson Duravent

Chimneys for biomass boilers

For commercial buildings, stack heights should be consistent with good engineering practice to minimize the wake effects caused by buildings or terrain on emissions. (see www.epa.gov/ttn/scram/guidance_permit.htm for some EPA documents on good engineering stack height and modeling).



plume drifting toward school

image courtesy of NYSERDA

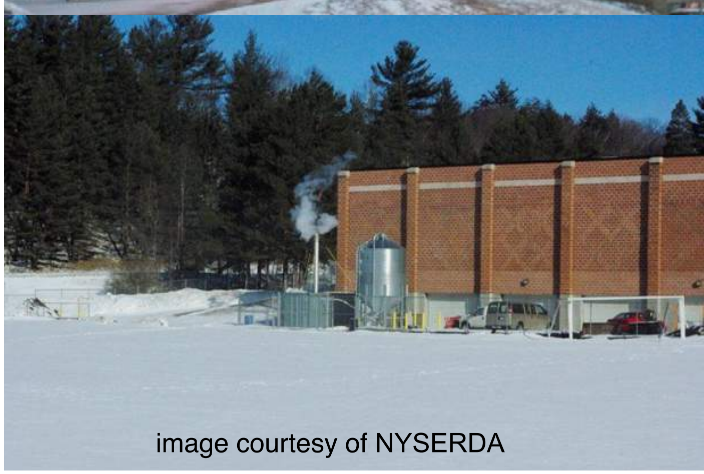


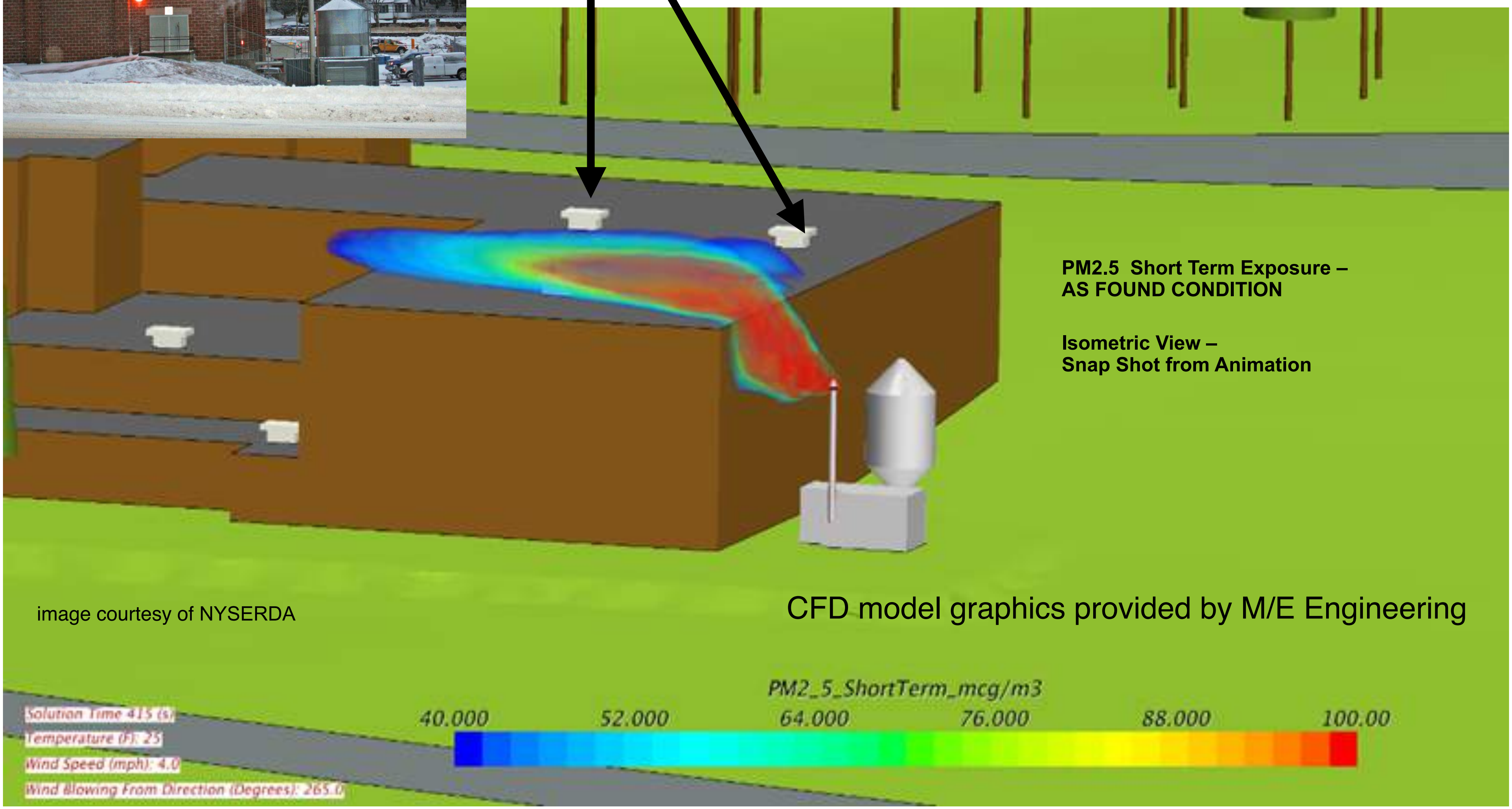
image courtesy of NYSERDA

Good entrainment of plume

Computational fluid dynamics (CFD) modeling in chimney wake relative to building(s).

plume drifting toward school

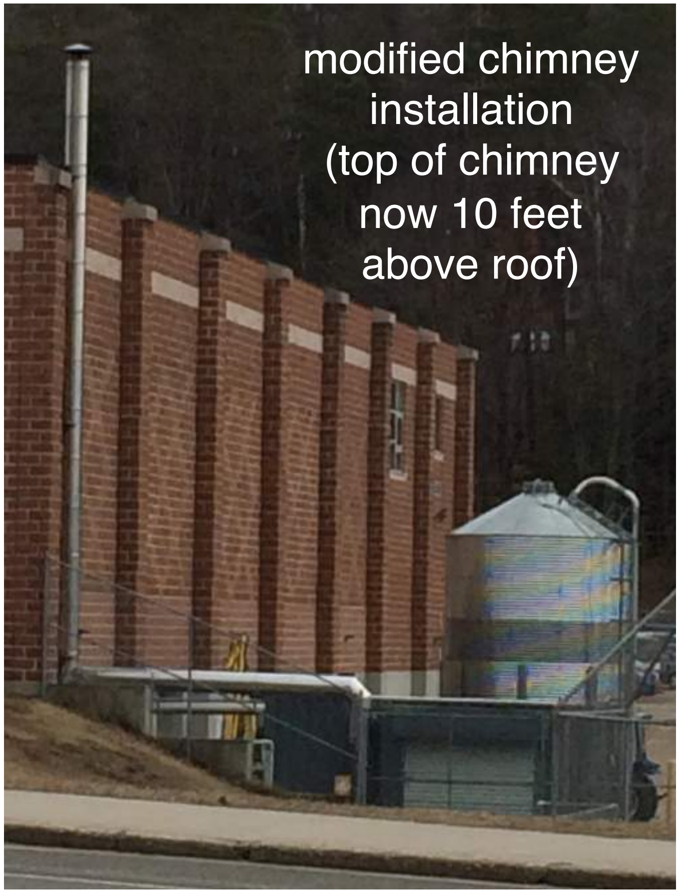
image courtesy of NYSERDA



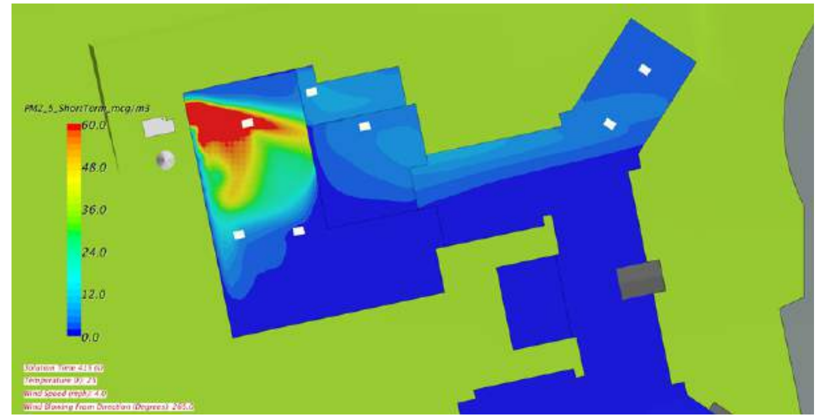
CFD model graphics provided by M/E Engineering

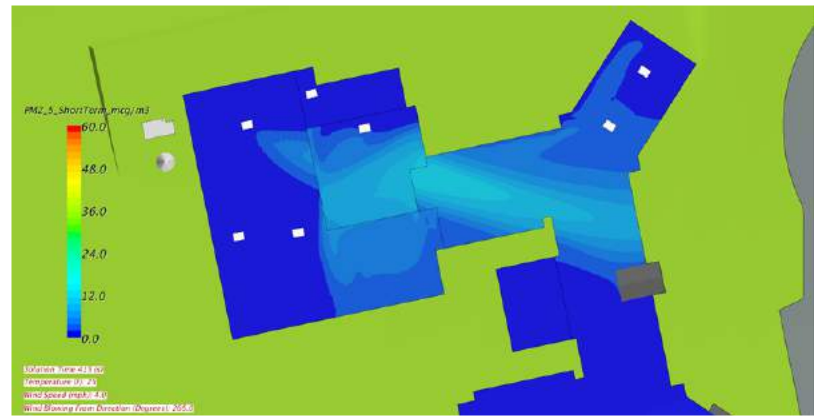
Lesson learned

image courtesy of NYSERDA

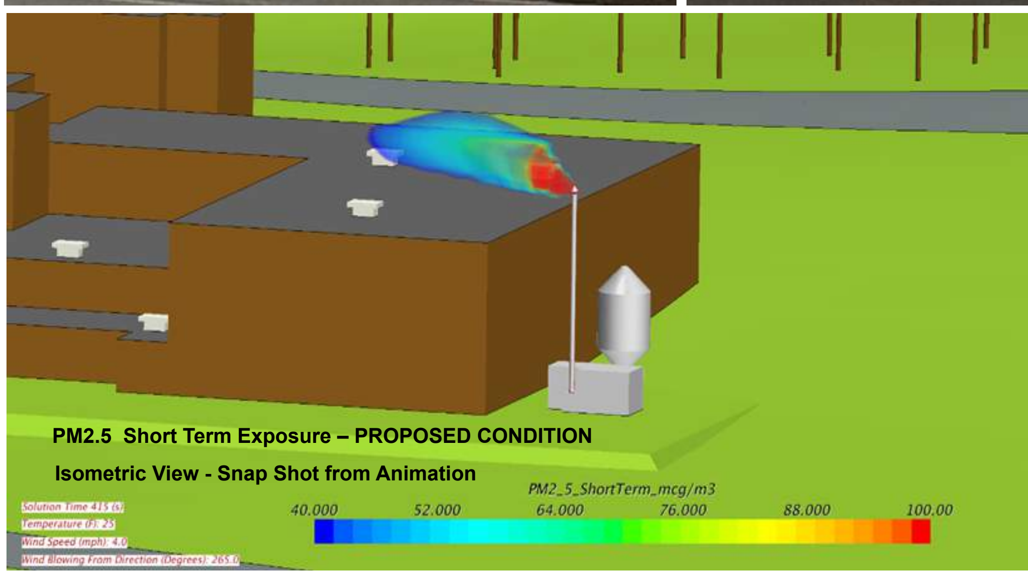


PM2.5 Short Term Exposure – AS FOUND CONDITION





PM2.5 Short Term Exposure – PROPOSED CONDITION



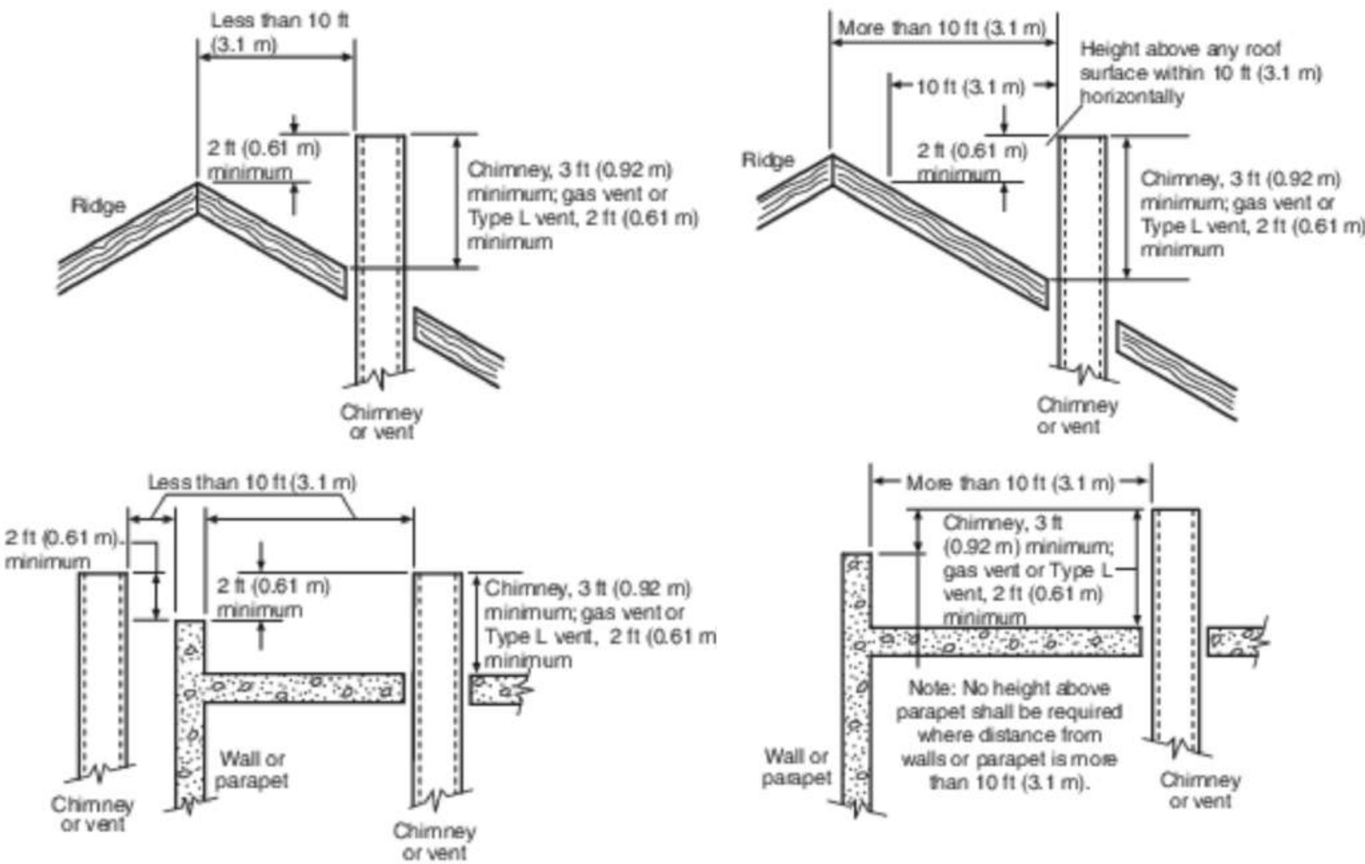
CFD model graphics provided by M/E Engineering

Code requirements on chimneys

1. Top of chimney min. 2 feet above anything within 10 foot radius, and at least 2 feet higher than ridge, wall or parapet if within 10 feet of ridge, wall, or parapet. (503.5.4), NFPA 211

2. Top of chimney min. 3 feet above where it penetrates the roof. (503.5.4), NFPA 211

3. Cannot connect a vent from a solid fuel appliance to same flue serving a gas-fired appliance (503.5.7.1)



chimney <10 ft from roof ridge   chimney >10 ft from roof ridge

Check with boiler manufacturer on *minimum* chimney heights.

Most biomass boilers have draft inducing

Situation: Boiler starts up (draft fan on) but little if any draft established in cold chimney.

Exterior masonry chimney are the worst due to large / cold thermal mass.

Causes: Temporary POSITIVE pressure in vent connector piping.

Leads to: Leakage of flue gases and fly ash between joints in vent connector piping, boiler air intake, barometric damper.

This chimney was, at one time, venting both an oil-fired boiler and a pellet boiler.

A violation of NYS Mechanical code, section 801.11

The fix. UL-103 HT chimney for pellet boiler

Exterior masonry chimneys have minimum allowable combustion appliance input ratings depending on climate

54-112 NATIONAL FUEL GAS CODE ANSI Z223.1

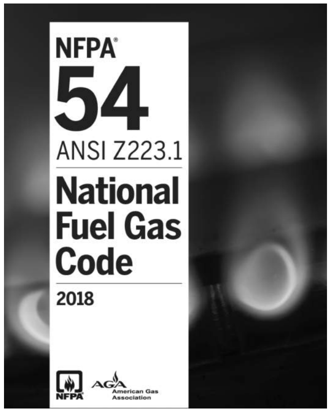
Table 13.2(g) Exterior Masonry Chimney

Number of Appliances:	Two or More
Appliance Type:	NAT + NAT
Appliance Vent Connection:	Type B Double-Wall Connector

Minimum Allowable Input Rating of Space-Heating Appliance in Thousands of Btu per Hour								
Vent Height *H* (ft)	Internal Area of Chimney (in.^{2})							
	12	19	28	38	50	63	78	113
	Local 99% winter design temperature: 37°F or greater							
6	0	0	0	0	0	0	0	NA
8	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
15	NA	0	0	0	0	0	0	0
20	NA	NA	NA	NA	NA	184	0	0
30	NA	NA	NA	NA	NA	393	334	0
50	NA	NA	NA	NA	NA	NA	NA	579
100	NA	NA	NA	NA	NA	NA	NA	NA
	Local 99% winter design temperature: 27°F to 36°F							
6	0	0	68	NA	NA	180	212	NA
8	0	0	82	NA	NA	187	214	263
10	0	51	NA	NA	NA	201	225	265
15	NA	NA	NA	NA	NA	253	274	305
20	NA	NA	NA	NA	NA	307	330	362
30	NA	NA	NA	NA	NA	NA	445	485
50	NA	NA	NA	NA	NA	NA	NA	763
100	NA	NA	NA	NA	NA	NA	NA	NA
	Local 99% winter design temperature: 17°F to 26°F							
6	NA	NA	NA	NA	NA	NA	NA	NA
8	NA	NA	NA	NA	NA	NA	264	352
10	NA	NA	NA	NA	NA	NA	278	358
15	NA	NA	NA	NA	NA	NA	331	398
20	NA	NA	NA	NA	NA	NA	387	457
30	NA	NA	NA	NA	NA	NA	NA	581
50	NA	NA	NA	NA	NA	NA	NA	862
100	NA	NA	NA	NA	NA	NA	NA	NA
	Local 99% winter design temperature: 5°F to 16°F							
6	NA	NA	NA	NA	NA	NA	NA	NA
8	NA	NA	NA	NA	NA	NA	NA	NA
10	NA	NA	NA	NA	NA	NA	NA	430
15	NA	NA	NA	NA	NA	NA	NA	485
20	NA	NA	NA	NA	NA	NA	NA	547
30	NA	NA	NA	NA	NA	NA	NA	682
50	NA	NA	NA	NA	NA	NA	NA	NA
100	NA	NA	NA	NA	NA	NA	NA	NA
	Local 99% winter design temperature: 4°F or lower Not recommended for any vent configurations							

For SI units, 1 in. = 25.4 mm, 1 in.^{2} = 645 mm^2, 1 ft = 0.305 m, 1000 Btu/hr = 0.293 kW, °C = (°F - 32)/1.8.

Note: See Figure F.2.4 for a map showing local 99 percent winter design temperatures in the United States.



Lining existing masonry chimneys with sealed ***stainless steel*** liners.

image courtesy of Interphase Energy LLC

stainless steel rigid liner pipe joined with stainless steel pop rivets

pre-insulated stainless steel liner

images courtesy of Olympia Chimney

Always brace chimneys on metal roofs subject to snow slides

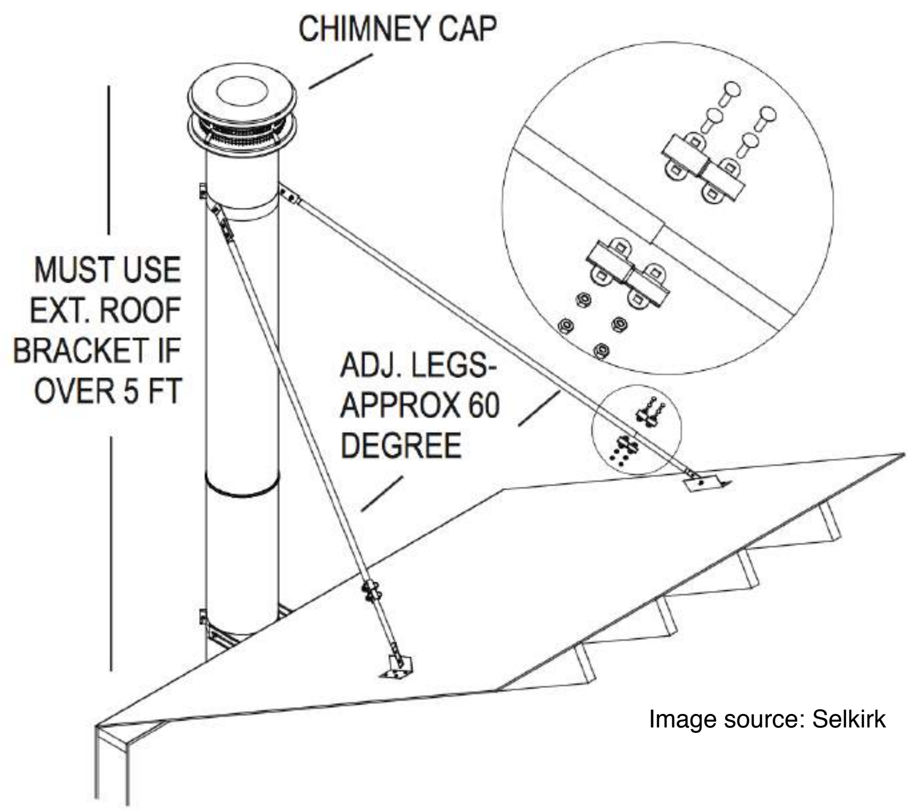
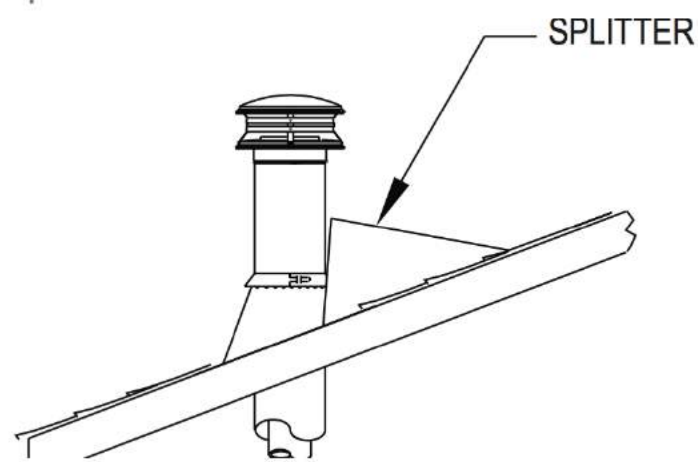


Image source: Selkirk



Vent connectors

General NFPA requirements for vent connectors:

- Horizontal length of vent connector from solid fuel appliance to chimney not more the 50% of chimney height above the connector.

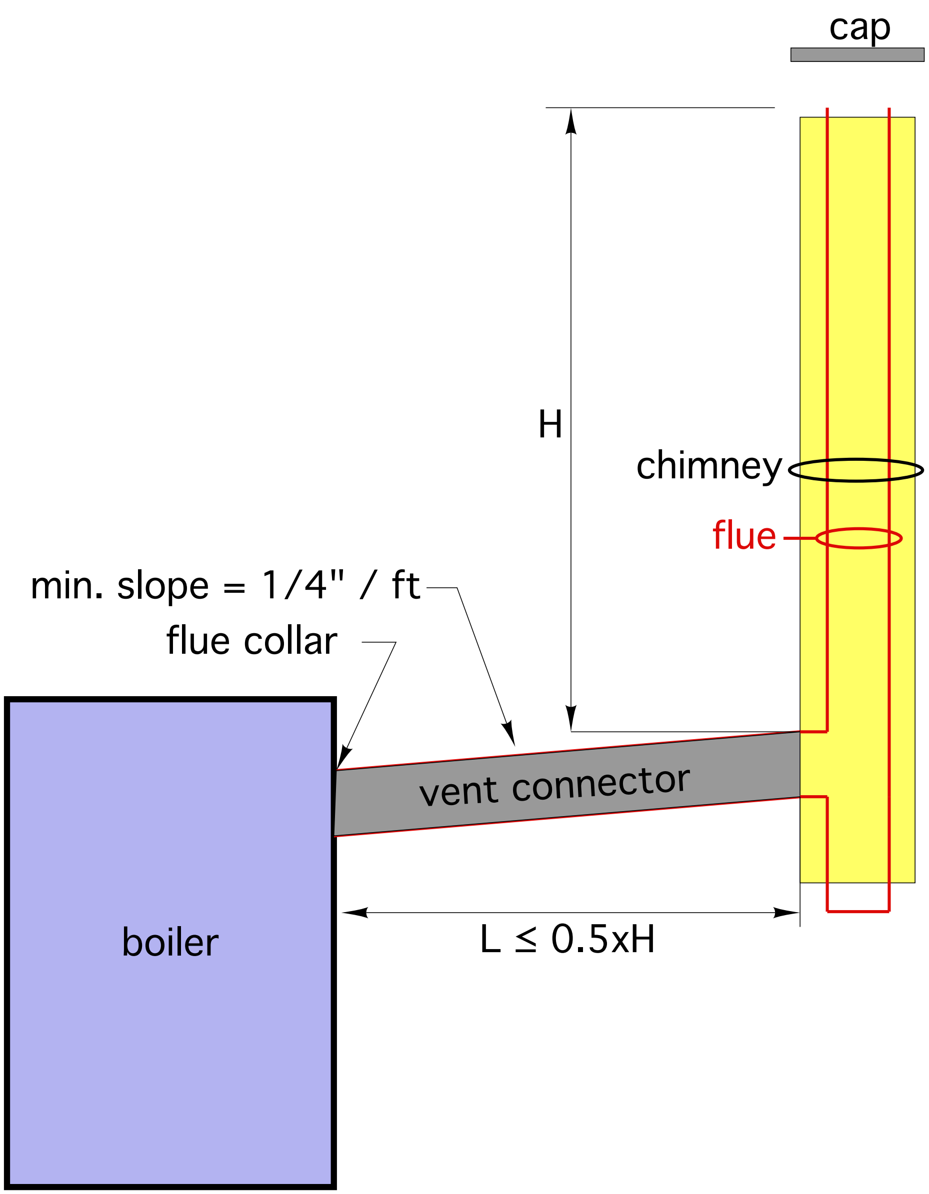
- Cross sectional area of flue for ***interior chimney*** (below roof line) not more than 3x appliance vent connector cross sectional area.

- If one or more walls of chimney exposed (below roof line) the cross sectional area of flue not more than 2x appliance vent connector cross sectional area.

- Minimum upward slope of vent connector = 1/4” per foot.

- Minimum clearance to combustibles for single wall vent connector = 18 inches (there are ways to reduce this clearance with shielding).

- Minimum clearance to combustibles for double wall vent connector = 6 inches.



NYS code allows solid fuel appliances to be vented through 24 gauge (minimum thickness) galvanized steel piping.

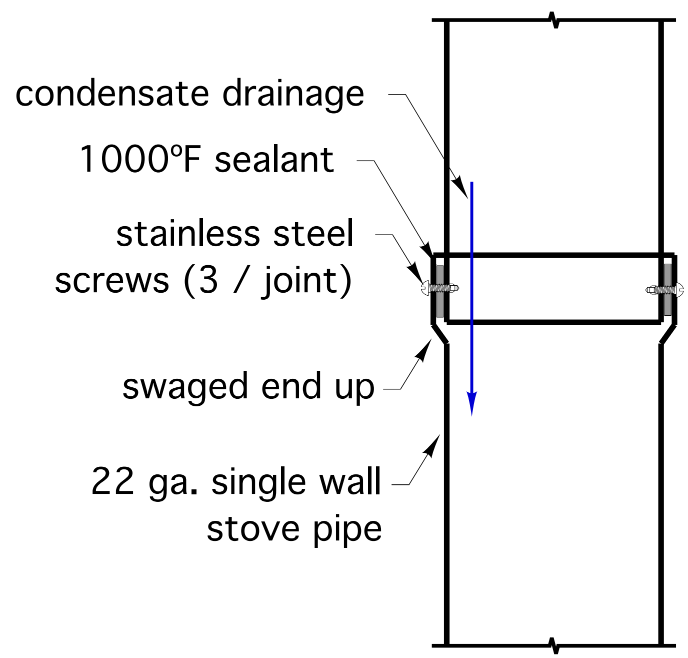
Recommendation is to **avoid use of galvanized steel connectors** due to potential leakage of ash and flue gas at seams.

RTV silicone. Will eventually separate from galvanized pipe

Single wall welded seam stovepipe (**22 gauge**) can be used.

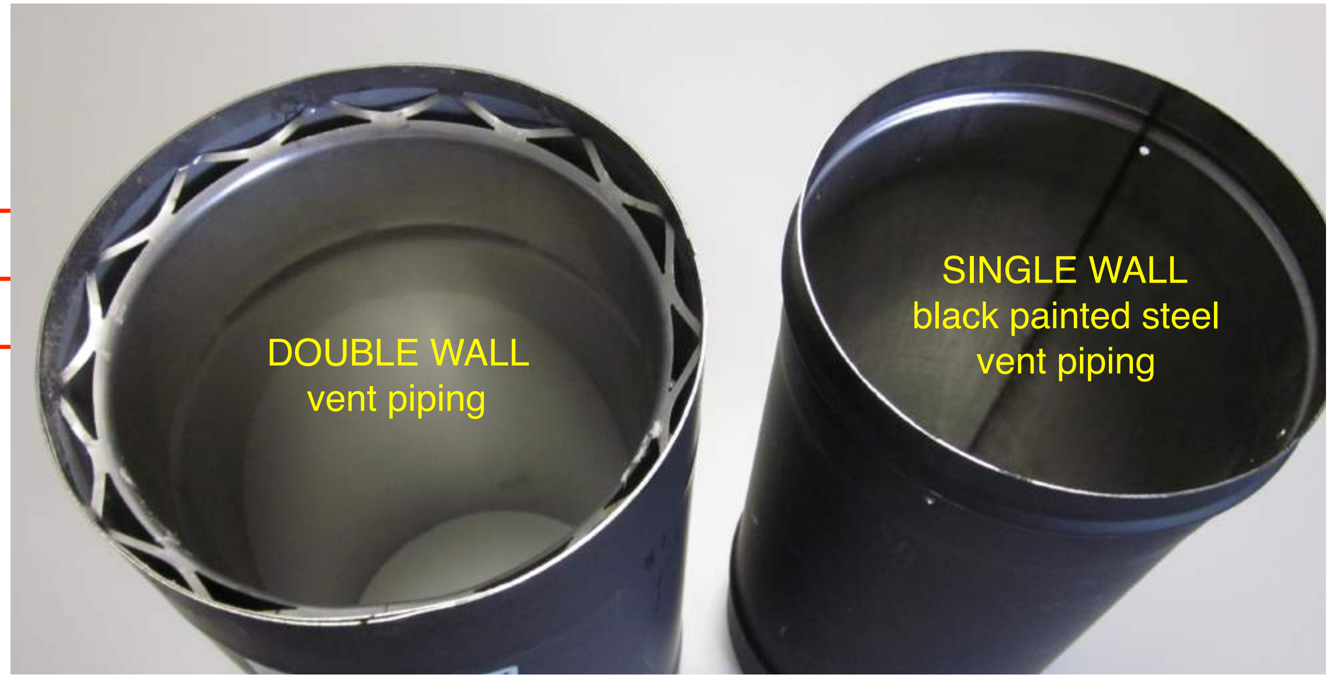
• **Seal joints with high temperature (1000 ºF rated) black silicone sealant**

• Always join pipe so that any interior condensate, moving down pipe, remains in pipe.



• Secure all joints in **single wall vent** connector piping with ***<u>stainless steel sheet metal screws.</u>***

Double Wall vent connector piping allows 6” clearance to combustibles and lower surface temperature.



- Inner wall remains at higher temperature, resulting is less creosote potential.
- Outer wall remains at lower temperature, resulting in safer installation.
- Both single and double wall pipe should be *installed in proper direction* (see arrow on pipe).
- Outer wall of section should be mechanically joined with 3 screws (usually provided with pipe)

Unsealed seams in vent connector piping can leak flue gas and ash

Draft Regulation

Pellet boilers and cordwood gasification boilers are designed for ***regulated*** negative pressure in vent connector

Froling pellet boilers: Draft at flue connector to be -.05 to -.1 “water column (WC) range.

Econoburn cordwood boilers: Draft at flue connector in the -0.02" to -0.05” WC range.

Maine Energy Systems pellet boilers: Draft at flue connector in the -0.02" to -0.04"WC range.

From Froling cordwood gasification boiler manual

⚠ CAUTION

ADJUSTMENT OF THE FLUE DRAFT HIGHER THAN 0.12 INCHES WATER COLUMN (30 Pa) COULD CAUSE A FIRE TO BURN OUT OF CONTROL AND AN UNSAFE CONDITION!

- Maximum permitted setting: 0.12 inches WC (30 Pa)
  Ideal setting: 0.04 inches WC (10 Pa)

Description		S3 Turbo	
		30	50
Flue gas temperature at nominal load	°C	170	170
	°F	340	340
Flue gas temperature at partial load	°C	110	110
	°F	230	230
Flue gas mass flow at nominal load	kg/h	76	122
	lb/h	167	270
Flue gas mass flow at partial load	kg/h	43	65
	lb/h	95	143
Required feed pressure at nominal load	Pa	8	8
	in WC	0.03	0.03
Maximum permissible feed pressure	Pa	30	30
	in WC	0.12	0.12
Flue pipe diameter	mm	150	150
	inches	6	6

<u>Any boiler vented to a chimney requires draft regulation.</u>

Draft regulators **limit how much negative pressure the venting system can create** (relative to atmospheric pressure).

<u>Excessively negative vent pressure (up to 10X normal) will draw too much air through the boiler's combustion system, resulting in:</u>

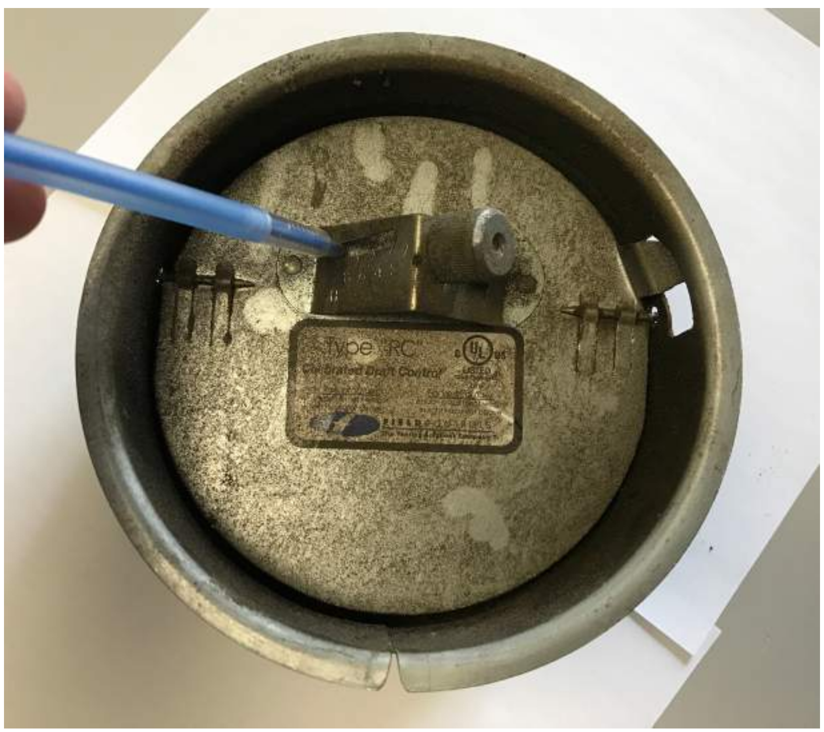
- Wasted heat up the flue
- Potential for uncontrolled combustion rate

adjustable weight

The weight on the damper blade is adjusted to determine the negative pressure at which the blade moves

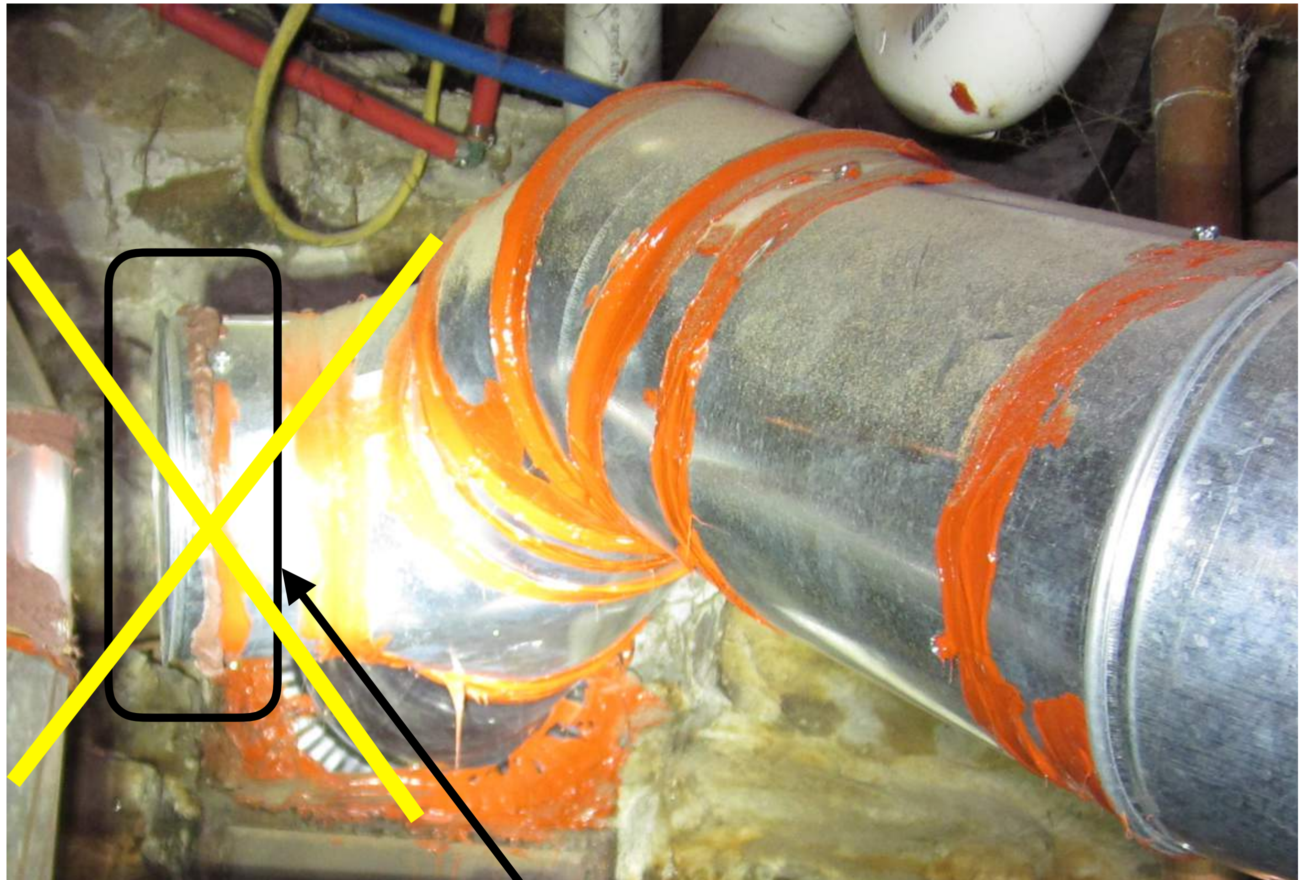
Flue gas and ash leakage at barometric dampers

Standard barometric dampers cannot seal against positive pressure inside venting system



The solution is NOT to omit the draft regulator…

Pellet boiler stack - galvanized pipe - no draft regulator



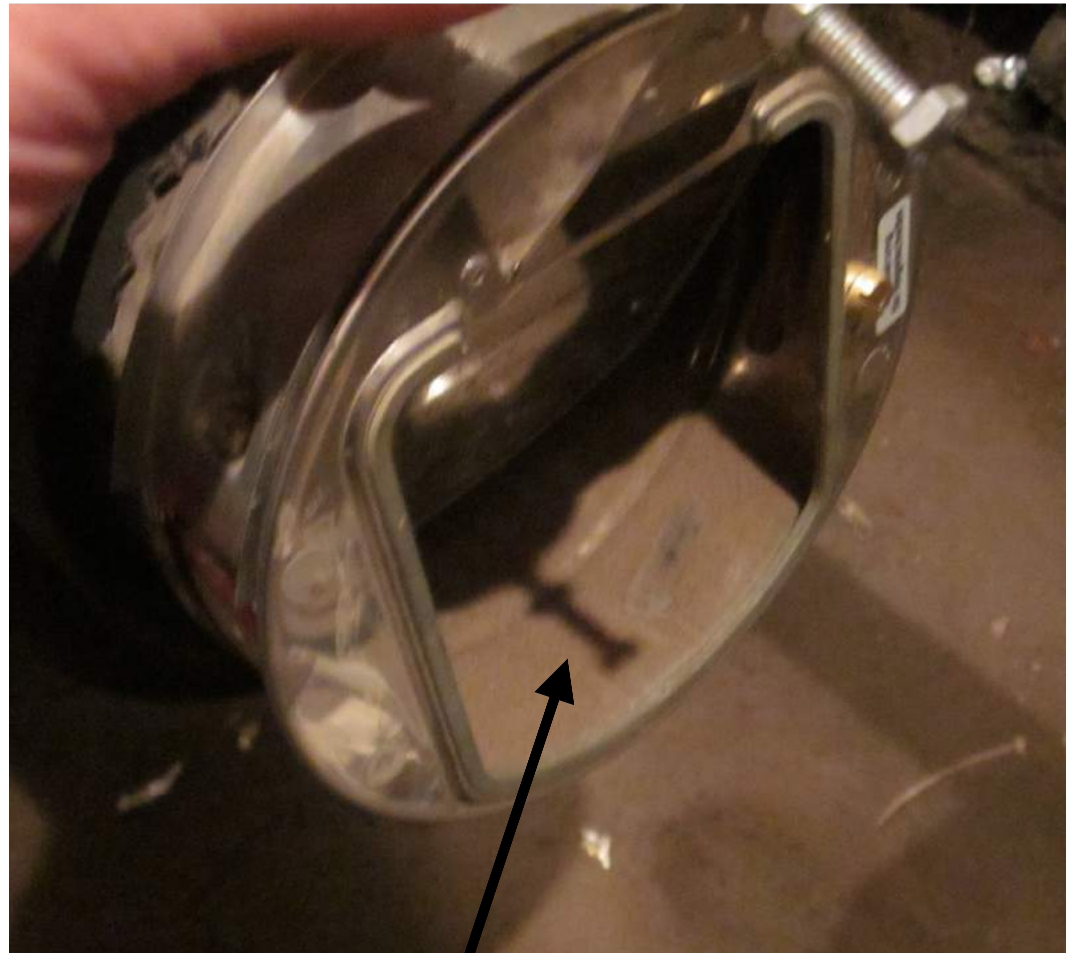
Standard barometric damper was removed and opening sealed because of ash and flue gas leakage.

Solution is ***positive pressure sealing draft regulators***

gasketed openings

European approach using **draft regulator** (not a barometric damper) that seals against back pressure.

Postive pressure sealing draft regulator installed on pellet boiler



outside of damper relatively clean

some fly ash present inside damper

Positive pressure sealing damper available in US

S280 Tigex® 150 Draft Stabilizer

Stainless steel design fights soot, moisture, and corrosive chemicals. Gas tight 1100°C superwool seal ensures no leakage of exhaust fumes, and quiet function - the damper flap opens and closes quietly during operation as there are no metal parts hitting each other. Easy to install. Self-cleaning door axel. Incredible quality - the top of the line!

Tigex® 150 Draft Stabilizer

Adapter for round flue pipe

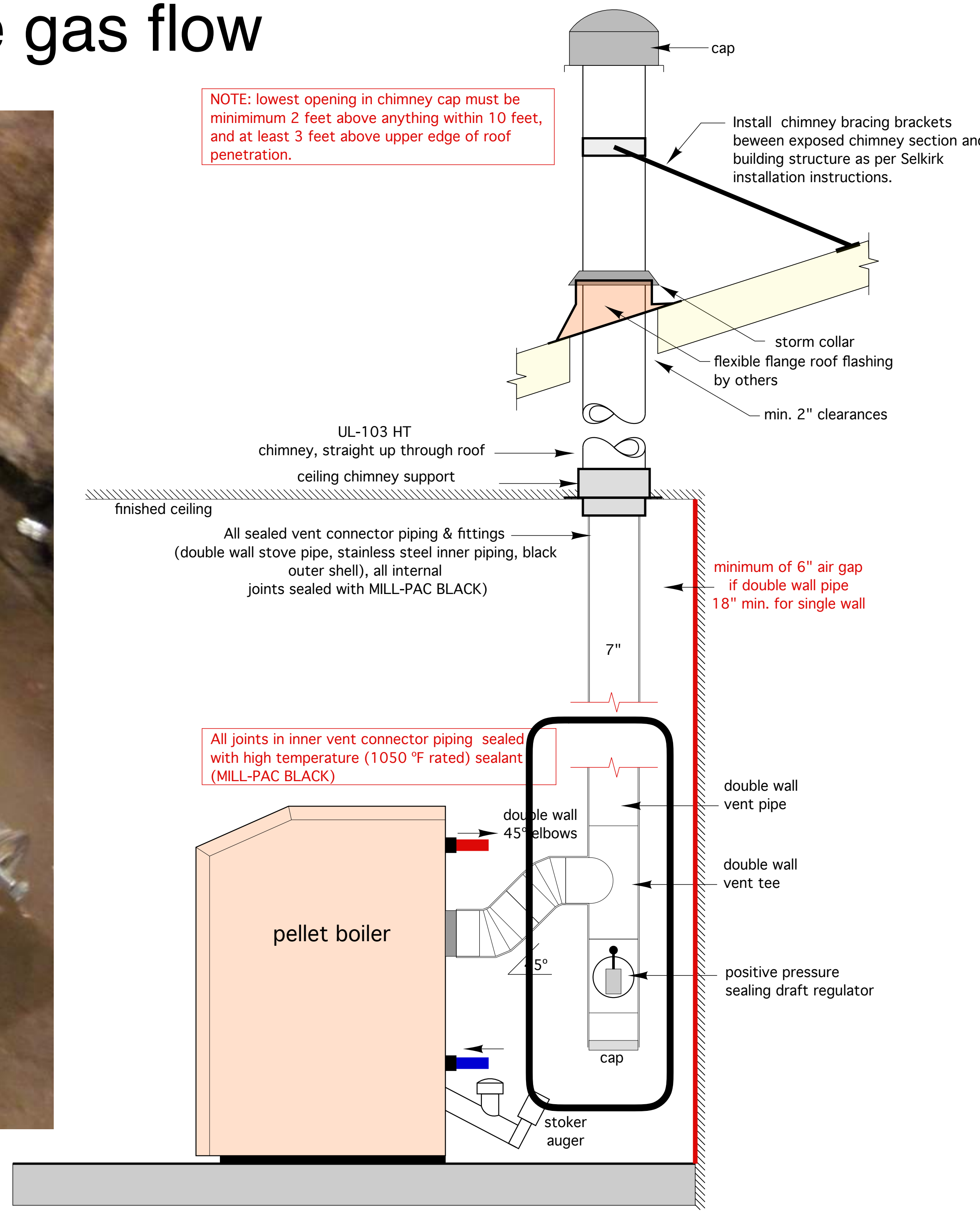
Finish Color		*Description*
Stainless	*Black*	
S280	*S280-2*	*Tigex® 150 Draft Stabilizer*
S280-130	*S280-132*	*Adapter for 5" round flue pipe*
S280-150	*S280-152*	*Adapter for 6" round flue pipe*
S280-180	*S280-182*	*Adapter for 7" round flue pipe*
S280-200	*S280-202*	*Adapter for 8" round flue pipe*

http://www.westwoodproducts.com

1-800-442-1630

This damper is not currently UL listed. we're working it….

Draft regulator below flue gas flow

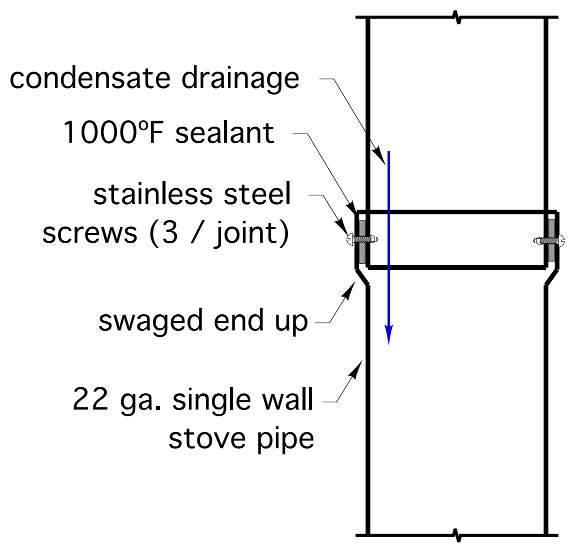


BOILER VENTING

Single wall vent connector piping

Do not use galvanized vent piping on wood-fired or pellet-fired boilers

Example: Selkirk Saf-T Pipe (black painted steel or **stainless steel**) 22 ga., no seams, built for sealed joints and wood-fired appliances.



- Use positive pressure sealing black vent connector piping on wood or pellet fired boilers with induced draft blowers.
- **Install in direction indicated by manf. (allow any condensate to run back to boiler)**
- **Secure all joints with stainless steel sheet metal screws.**
- **Seal joints with high temperature (1000 °F rated) black silicone sealant**

Air Supply to Boiler

Combustion air supply

When boiler room draws air from OUTSIDE:

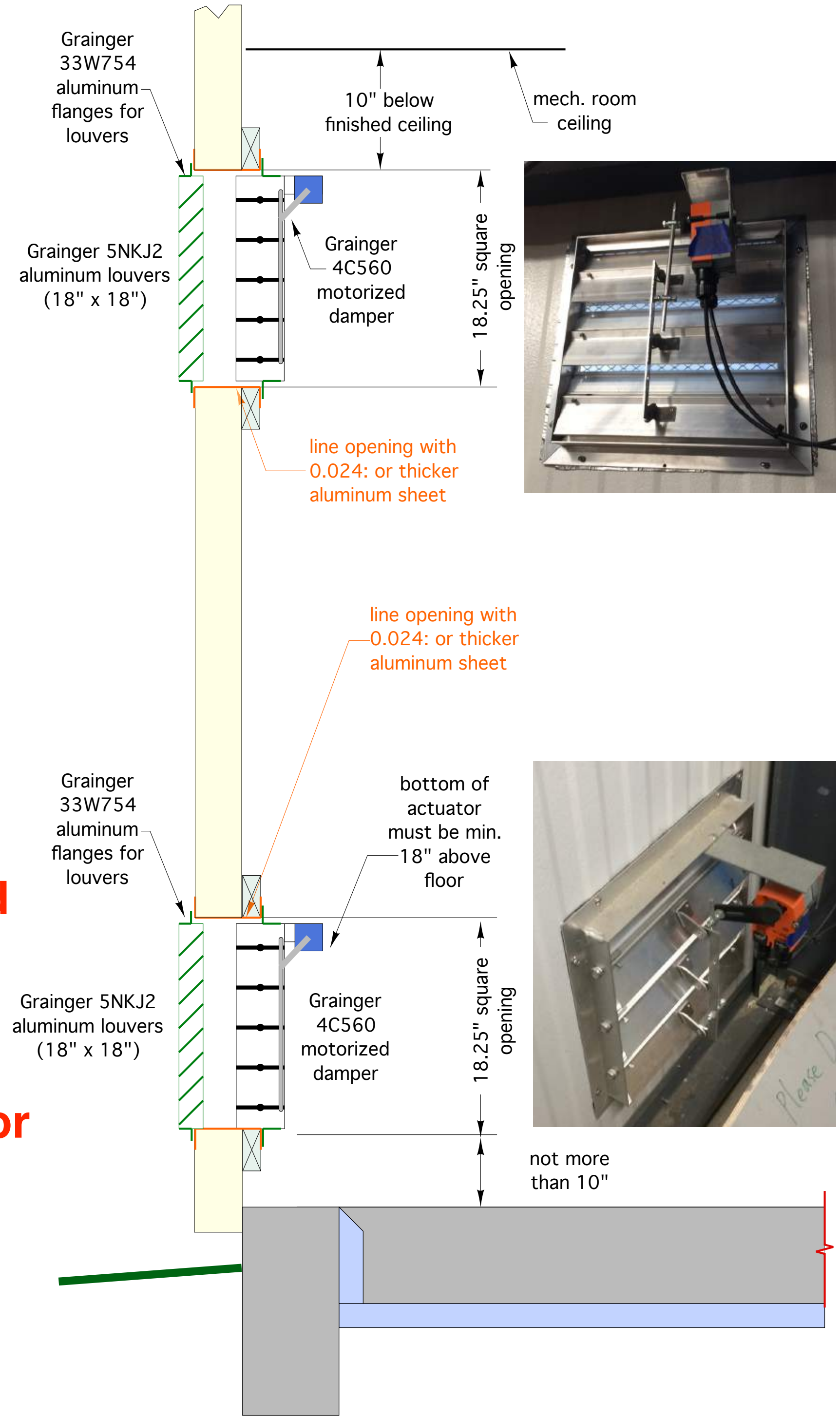
NFPA 54/2018, National Fuel Gas Code:
If air comes directly from outside, **and two openings are used:** 1 in^2 free area per 4000 Btu/hr of fuel input rating of all appliances in the space.

NFPA 54/2018, National Fuel Gas Code:
If air comes directly from outside, **and one opening (within 12” of ceiling) is used**: 1 in^2 free area per 3000 Btu/hr of fuel input rating of all appliances in the space, and not less than sum of cross section areas of all vent connectors in the space.

For wood louvers:
Free area =
opening area / 0.25

For metal louvers:
Free area =
opening area / 0.75

If motorized louvers are used they must be verified prior to burner operation.

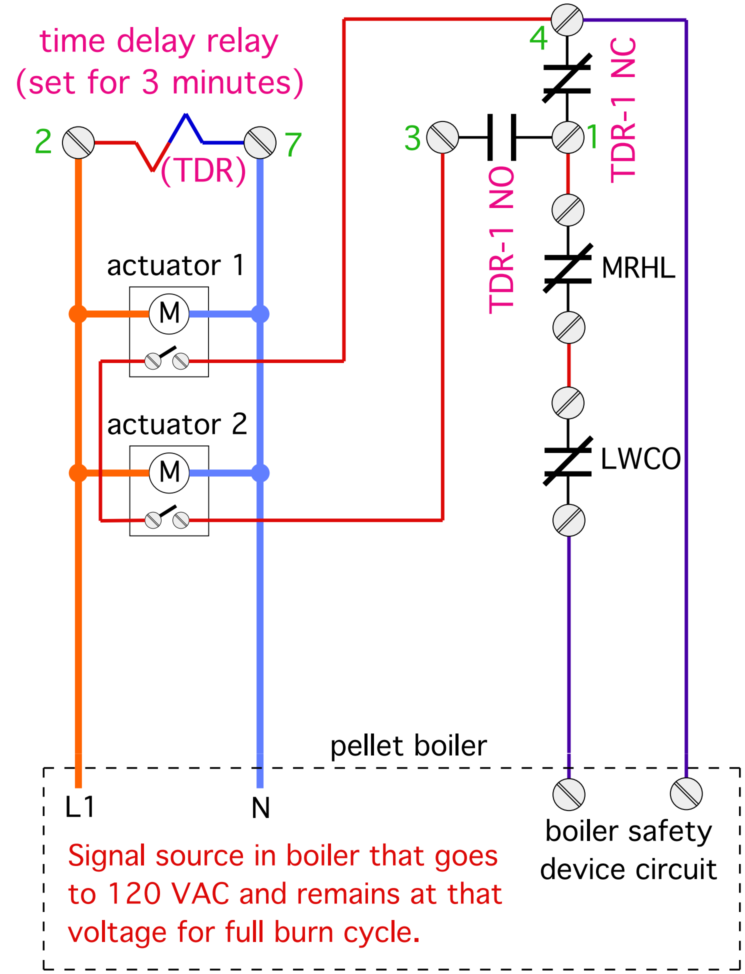


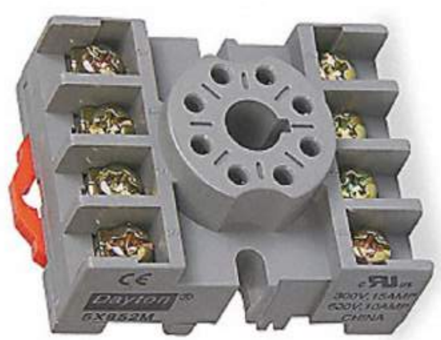
Boiler room ventilation air

The actuators must keep the dampers open whenever combustion is occurring.

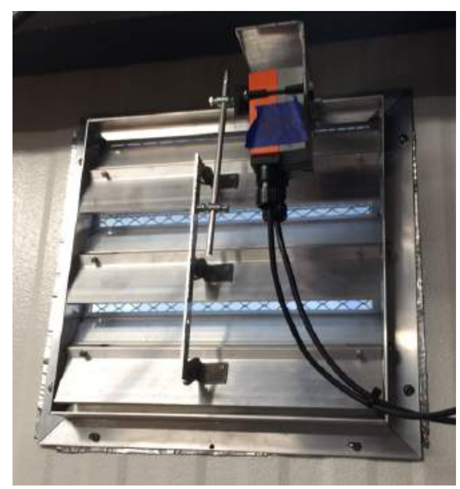
This must be verified by end switches in each damper actuator.

This circuit allows a nominal 2 minute time delay for the dampers to open and verify, or else if opens the boiler safety circuit for shut down.





Grainger 23NU95 time delay relay
(can be set for 3-300 seconds)
in Grainger 5X852 socket



Thermal storage options

Why is thermal storage needed?

• Output from some biomass boilers (especially from wood gasification boilers) is often higher than current heating load. Excess heat needs to be temporarily "parked" in storage.

• Allows the heating system to meet intermittent loads without firing the boiler, improving performance and longevity.

• Prevents boiler short cycling during partial load conditions, (for both biomass and auxiliary boiler). **Cleaner burning / higher efficiency**

• Prevents thermal shock to boiler by tempering the return water at start-up.

• Supplements boiler output during a period of high demand.

• May act as a heat sink for residual heat during power outage.

• Able to capture residual heat at boiler shut-down.

• Can also provide mass to stabilize domestic hot water production.

• With proper piping, tank can serve as hydraulic separator in multiple circulator systems.

• Can provide thermal storage for solar thermal input.

Water-based thermal storage options

1. unpressurized tanks
2. pressurized tanks

courtesy of Hydroflex

courtesy of American Solartechnics

courtesy of AHONA

Open (unpressurized) buffer tanks

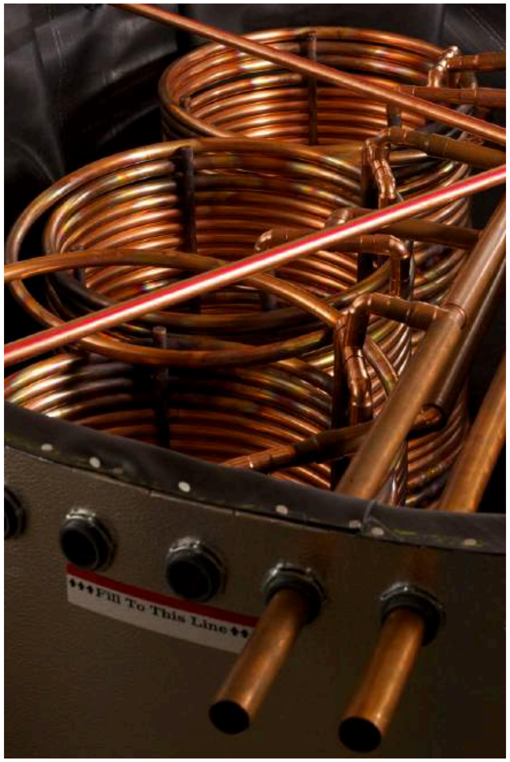
Considerations:

- Water will evaporate - water level must be monitored
- Air space above water accommodates water expansion
- Many open tanks are “knock down” construction and are assembled on site
- Typically lower cost ($/gallon) than pressurized tanks
- Requires one or more heat exchangers to interface with boiler or distribution system
- May require water treatment to control biological slime growth (use Fernox)
- Must use stainless steel or bronze circulators to handle open system water

courtesy of American Solartechnics

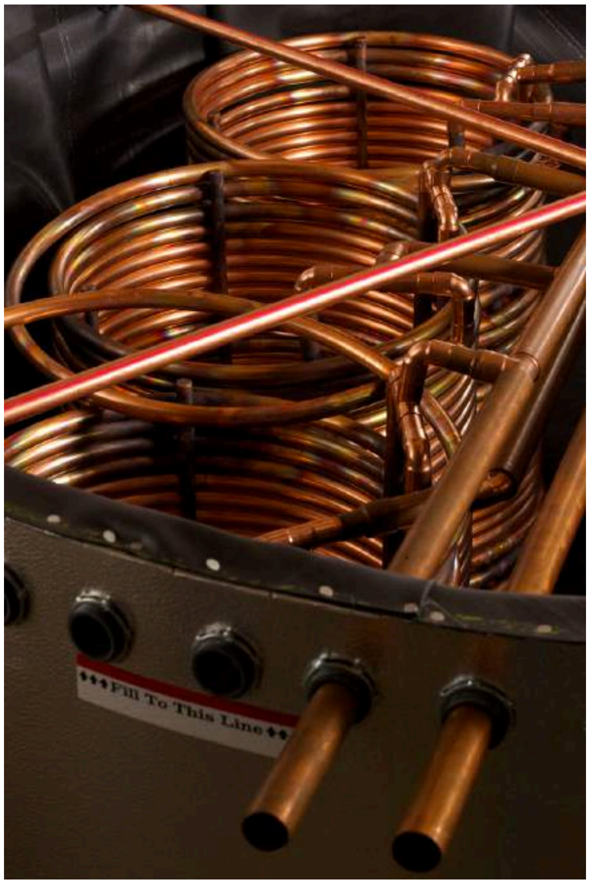
courtesy of Hydroflex

Open (unpressurized) buffer tanks

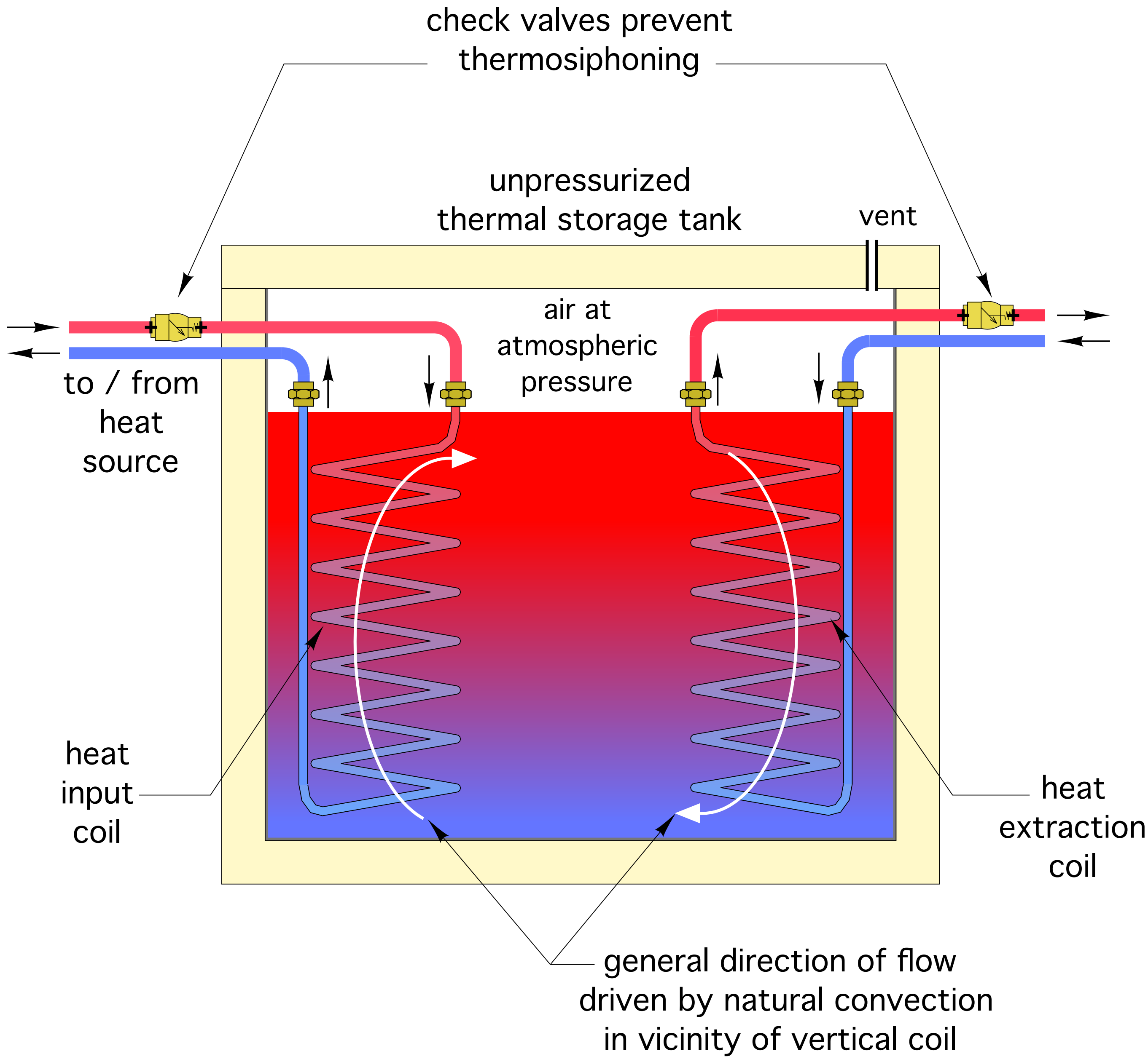


images courtesy of Hydroflex

- Flow direction should produce counterflow heat exchange
- Use check valves to prevent thermosiphoning



courtesy of Hydroflex



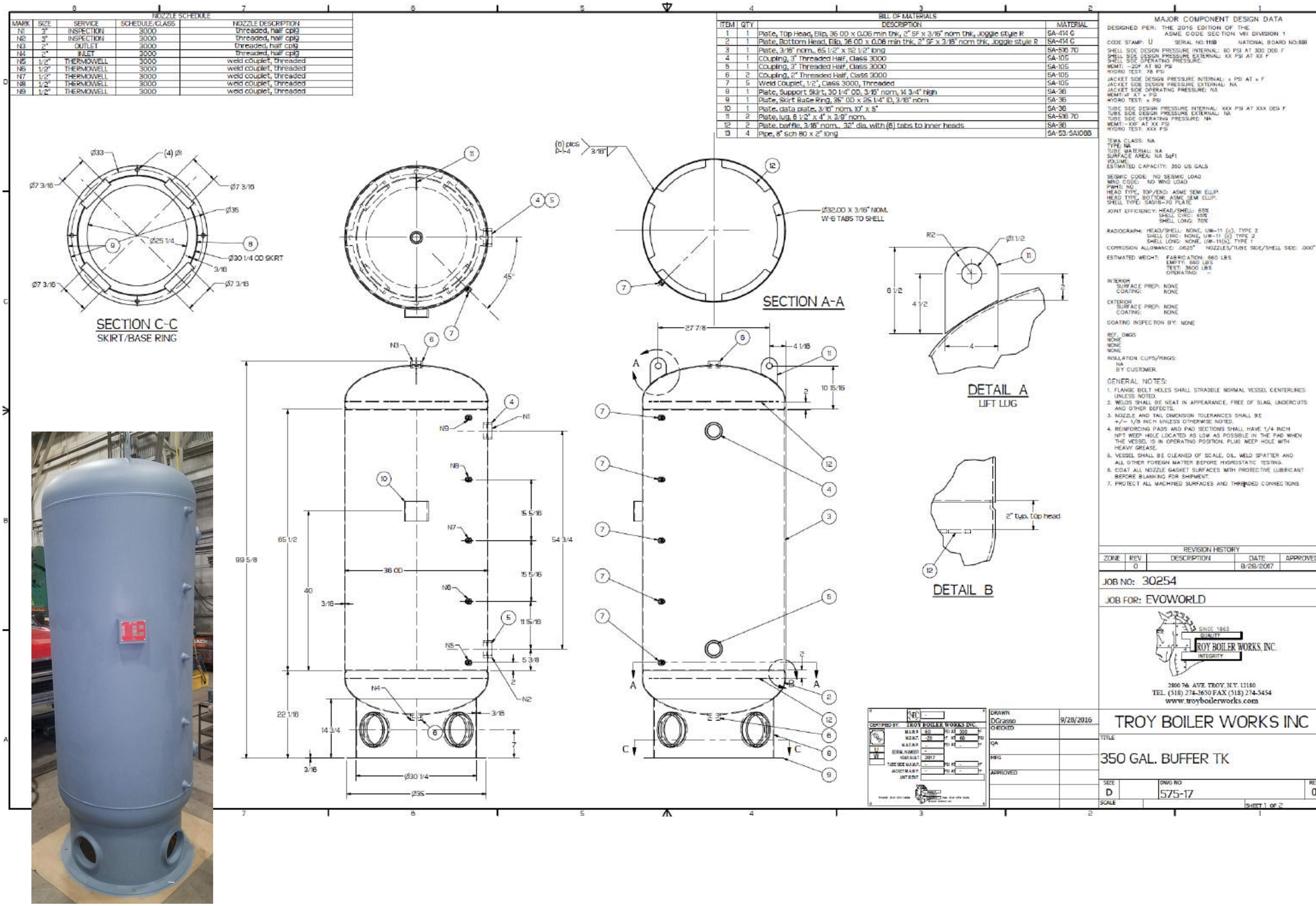
Closed/pressurized thermal storage tanks

courtesy of Caleffi North America

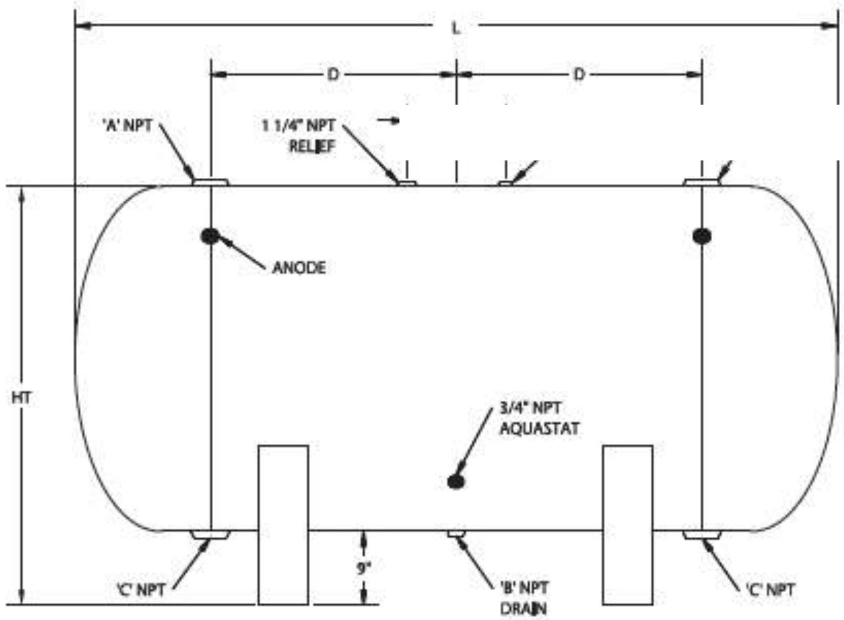
courtesy of Hydronic Specialty Supply

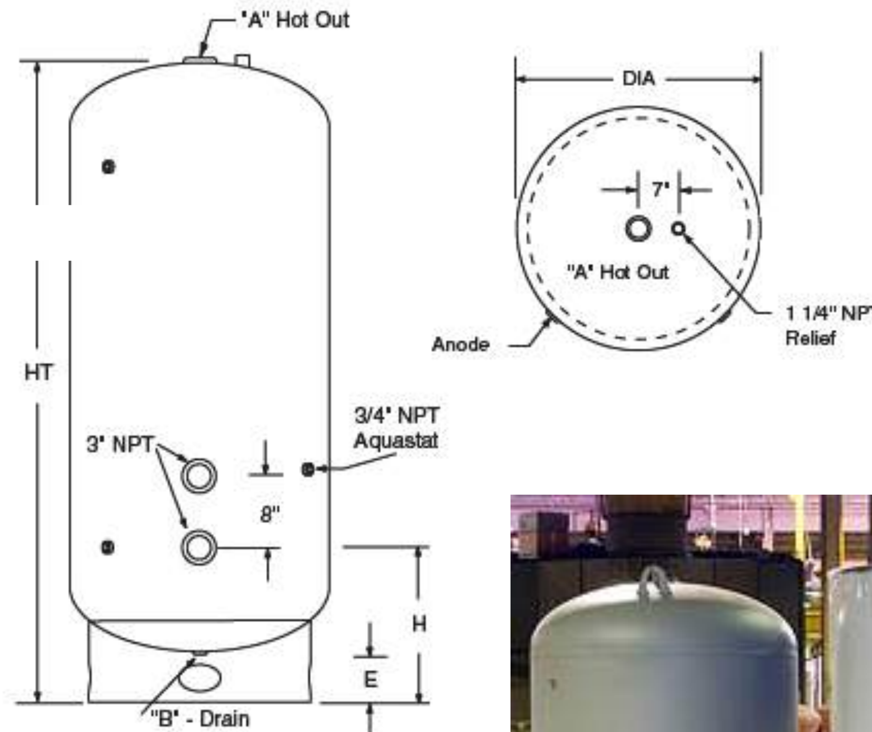
courtesy of Troy Boiler Works

Shop drawing of ASME thermal storage tanks



Large ASME (section VIII) certified storage tanks intended for **domestic water heating** are not necessarily a good choice for thermal storage in hydronic systems .





source: www.nilesst.com

The connections are usually not in the right locations, or of the size needed for hydronic systems (and good temperature stratification).

Examples of medium capacity ASME thermal storage tanks

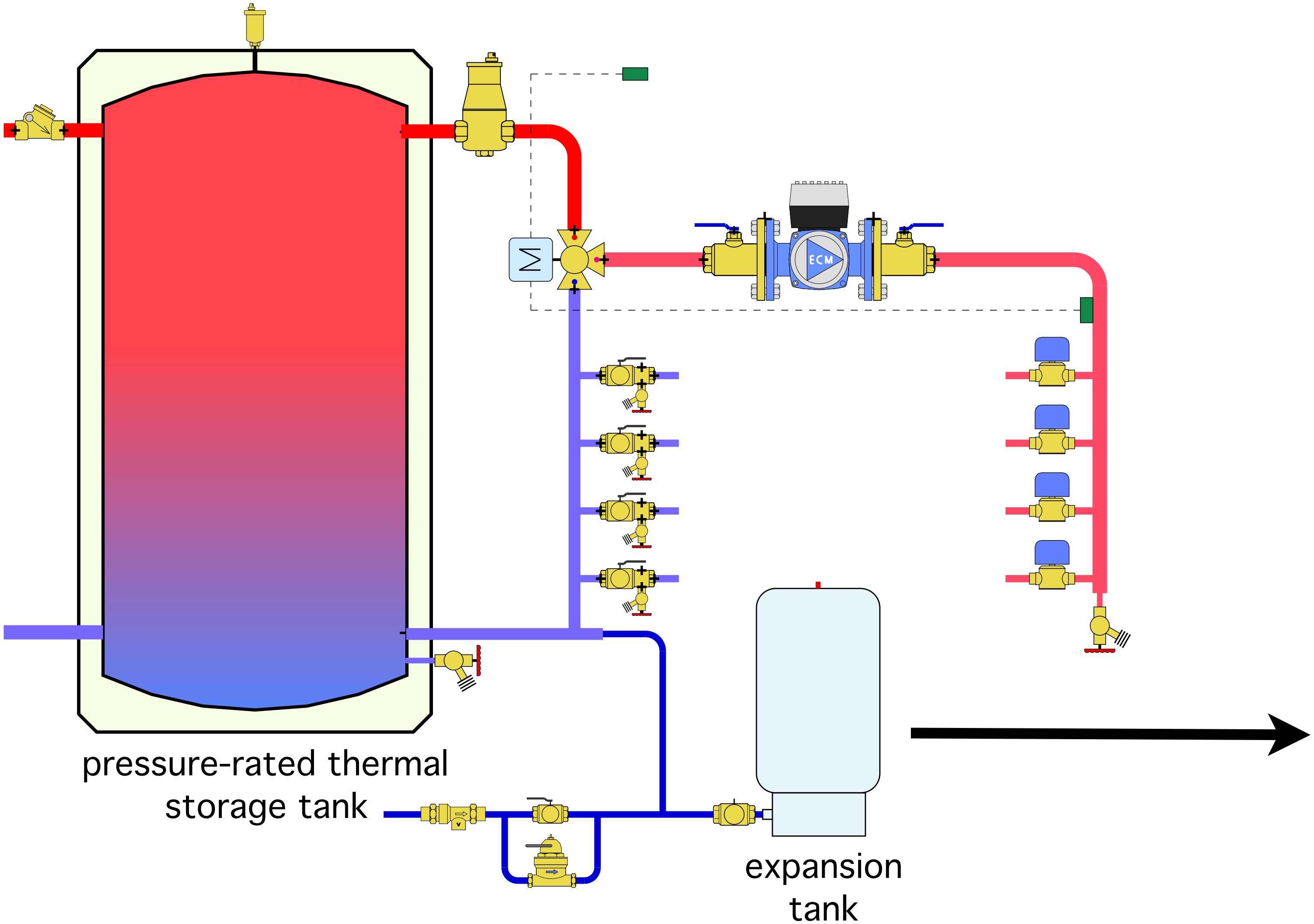
Hydronic Specialty Supply
210 gallon, ASME
flat top & bottom

With 4+” of Spray polyurethane insulation + intumescent coating

Hydronic Specialty Supply
360 gallon, ASME
flat top & bottom

All thermal storage tanks needs good insulation


Large pressurized storage requires larger expansion tanks



courtesy of Amtrol

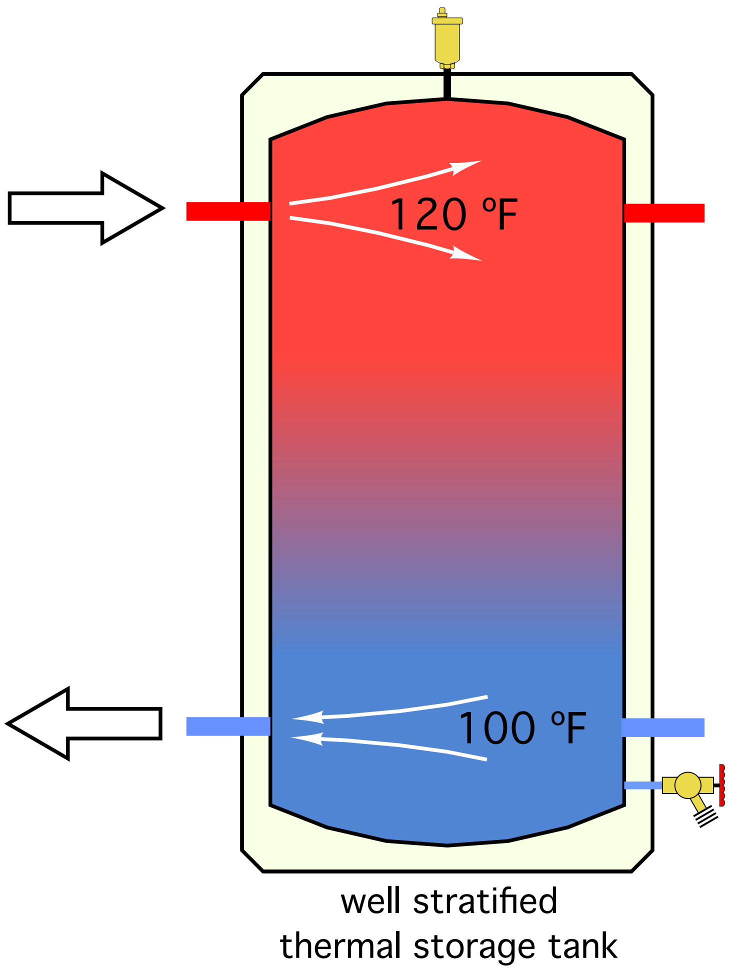
First pass estimate:

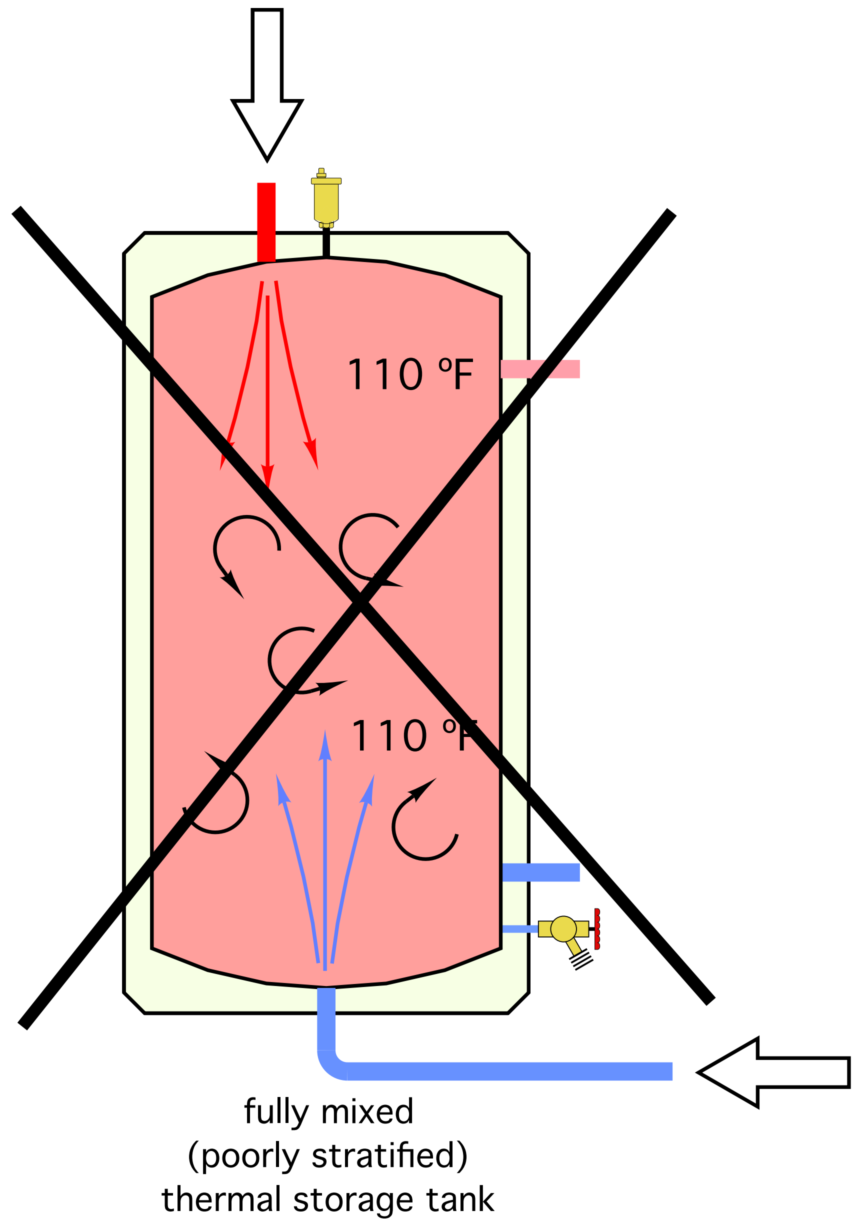
Expansion tank volume = 10% of thermal storage volume.

Free online sizing tool: **http://www.calefactio.com/tank-sizing?heating**

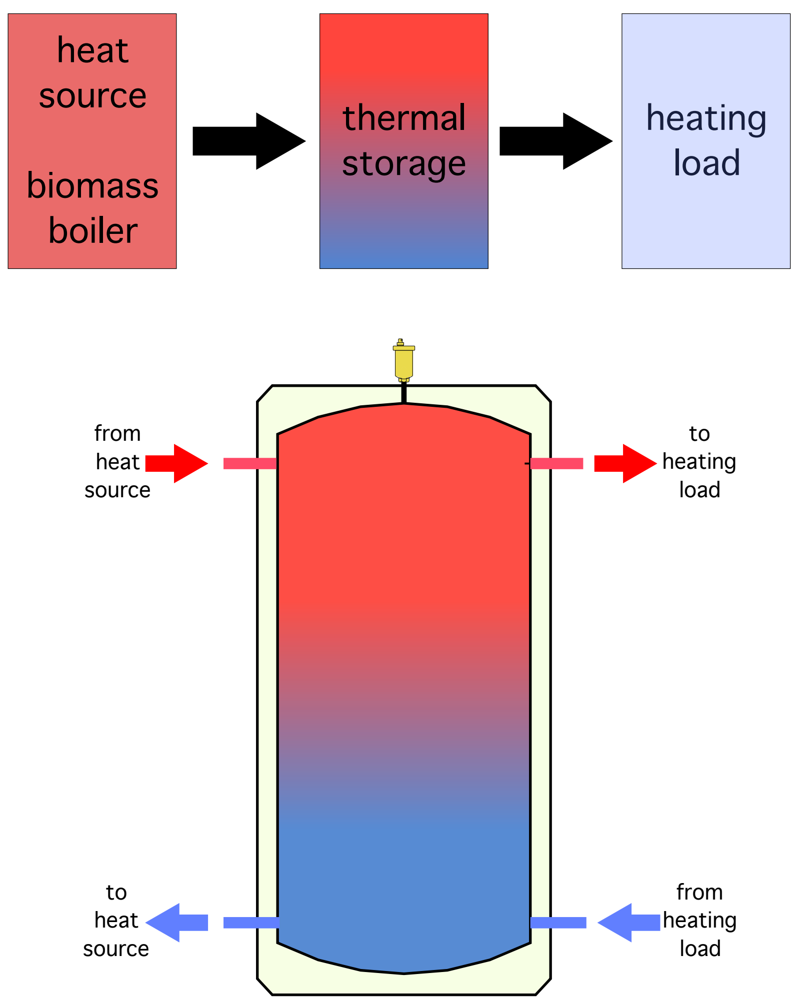
Stratification in thermal storage is DESIREABLE

Good temperature stratification preserves the "**quality**" (Exergy)of the heat available from the tank.

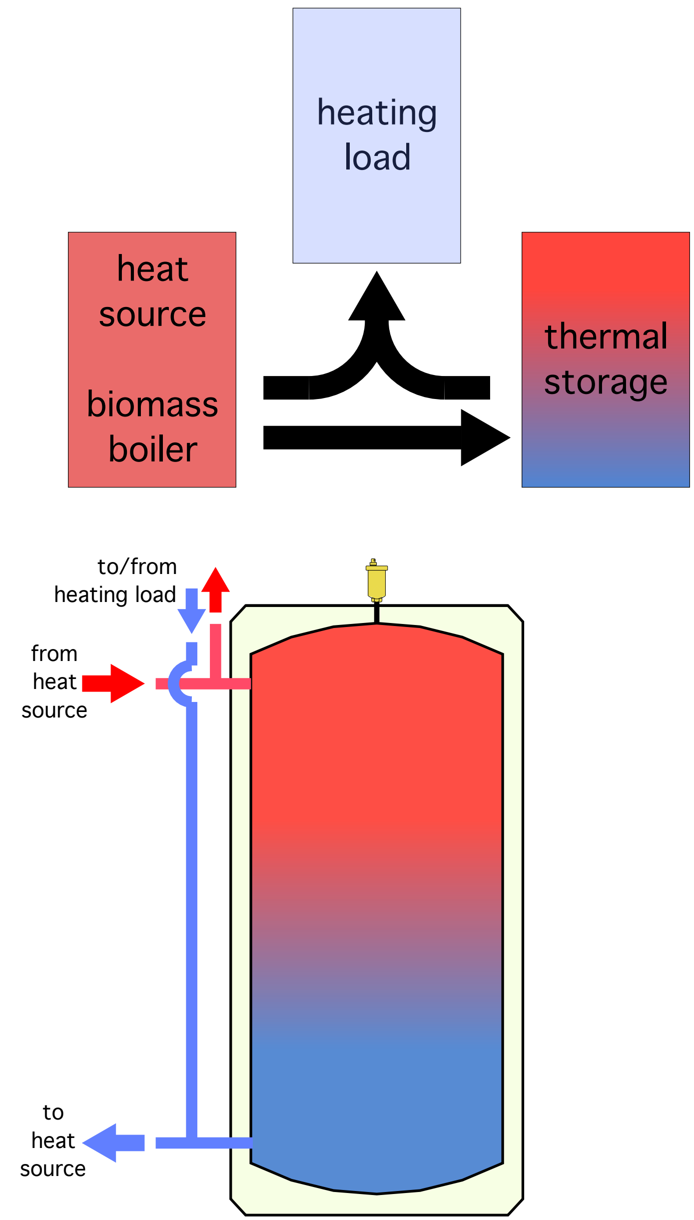




“2-pipe” versus “4-pipe buffer tank piping

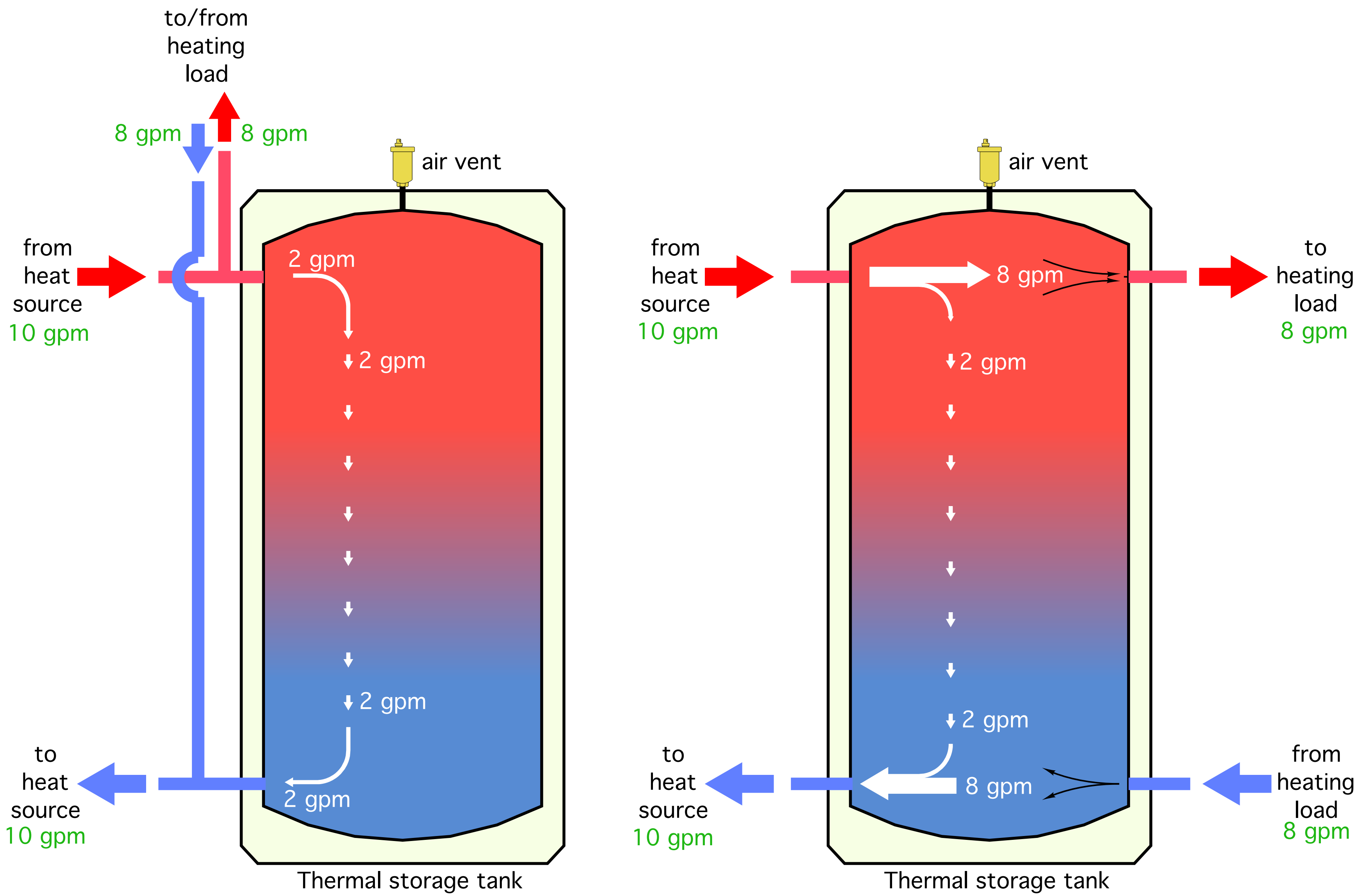


4-pipe configuration



2-pipe configuration

“2-pipe” versus “4-pipe buffer tank piping



2-pipe configuration

4-pipe configuration

Tanks designed for good stratification

- **All ingoing or exiting flow should be horizontal.**

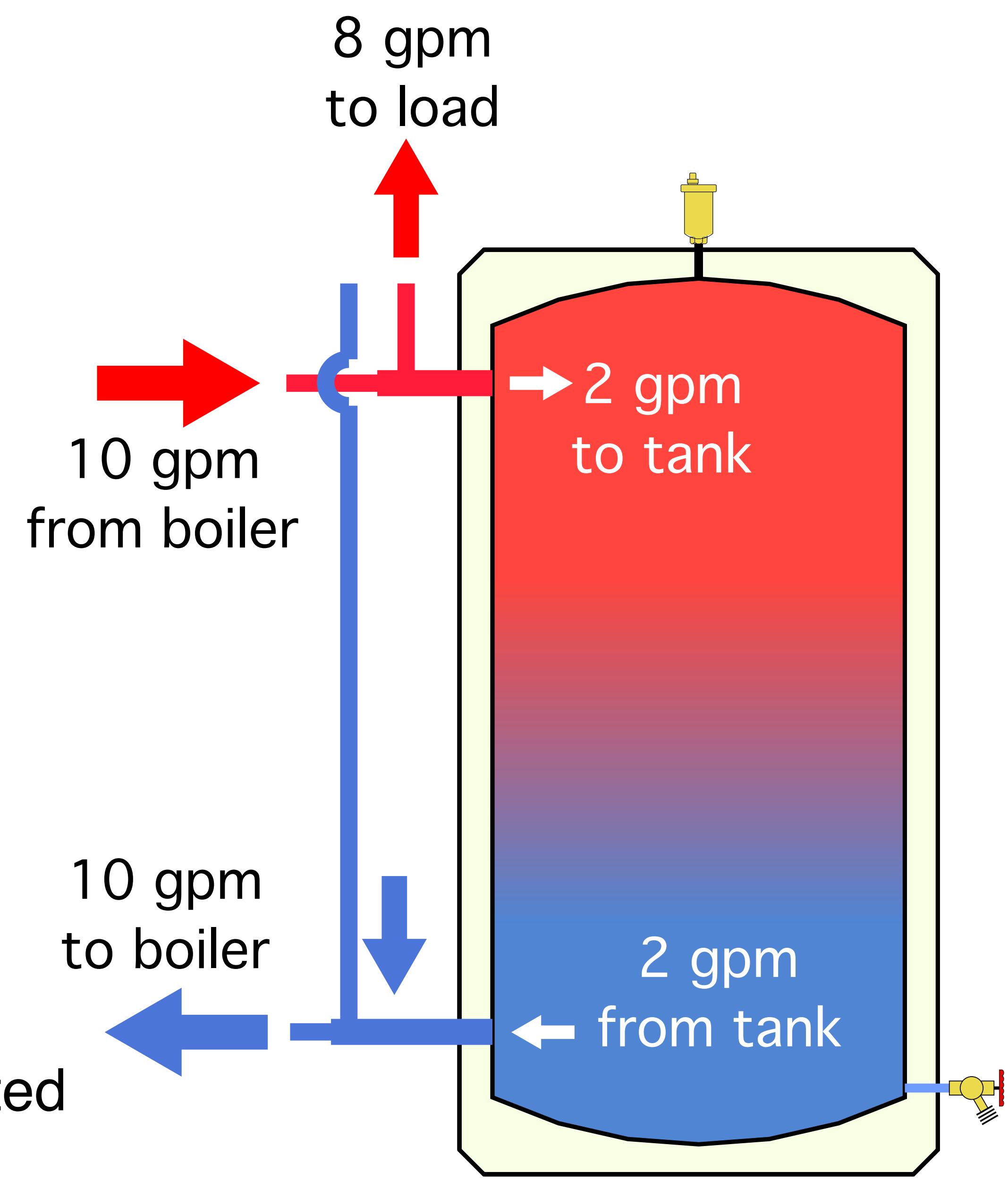
- Flow into tank = flow from boiler minus flow to load

- Lower flow velocities into & out of tank enhance temperature stratification.

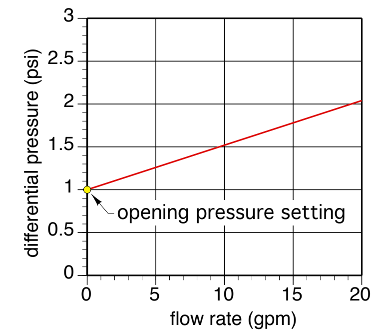
- Allows rapid heat delivery to load during recovery from setback or startup.

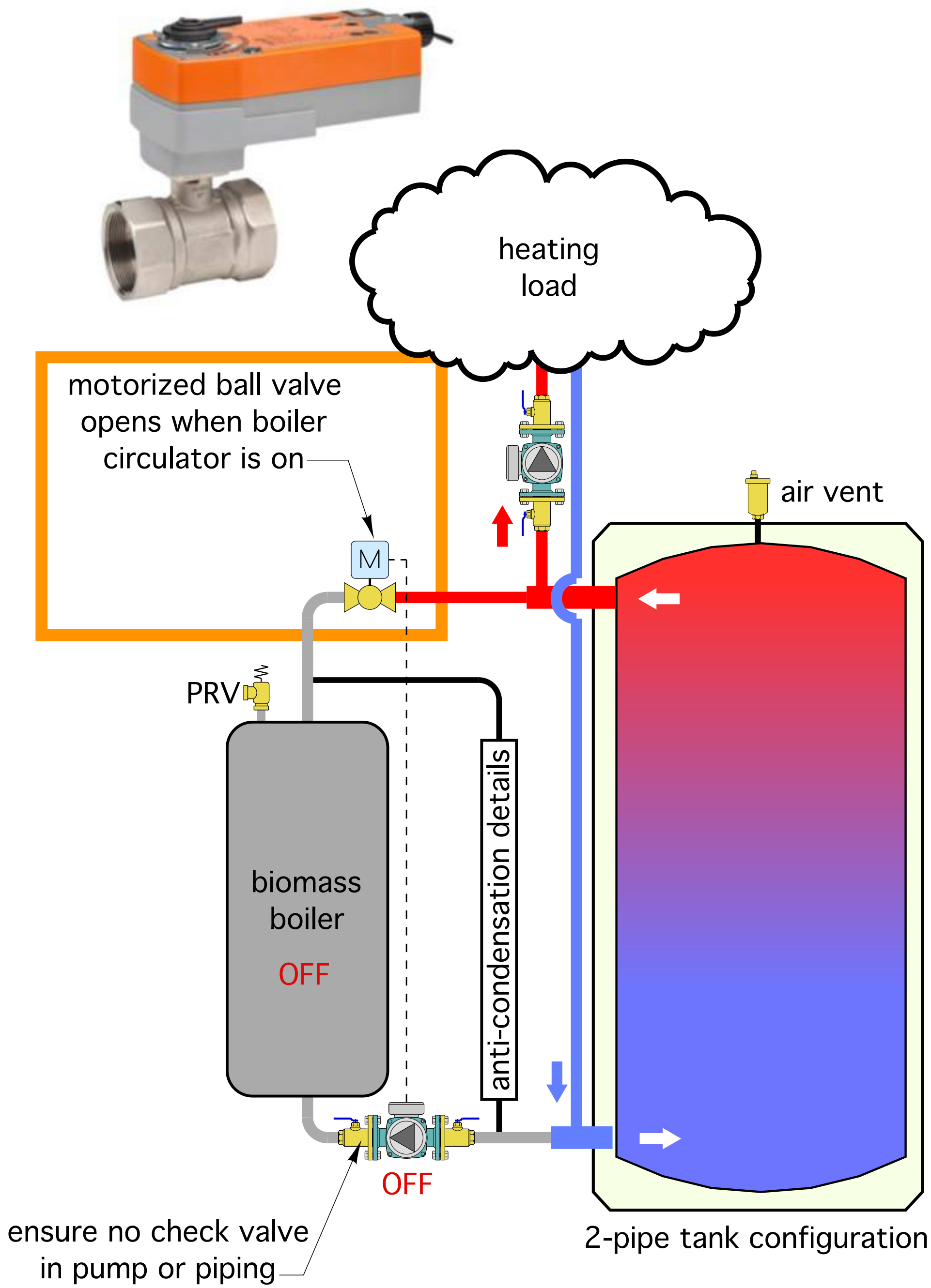
- Keep load connections close to tank, & use generous pipe sizing to tank connections, which provides hydraulic separation.

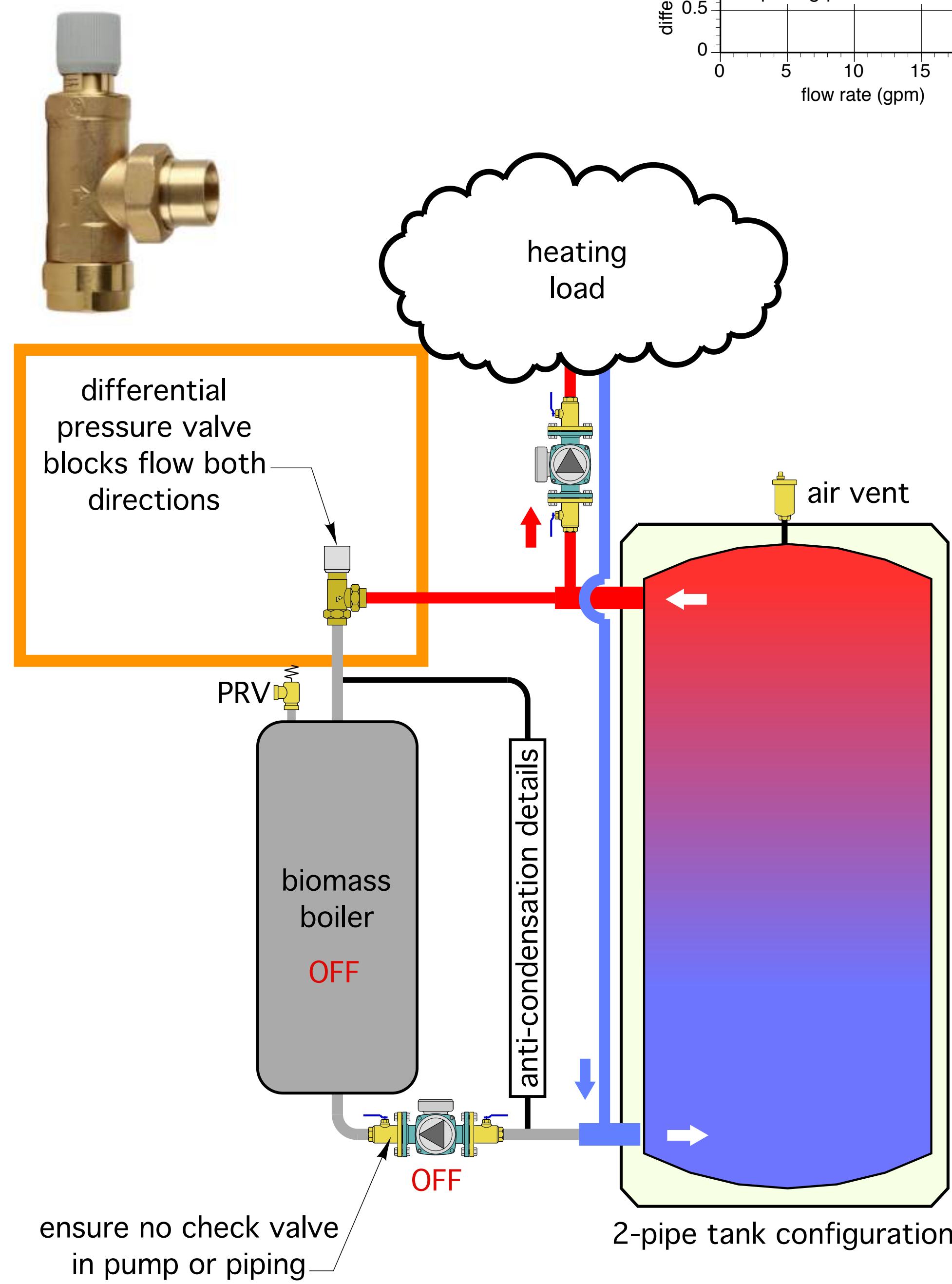
- Other side of tank can be connected for on-demand DHW subassembly.



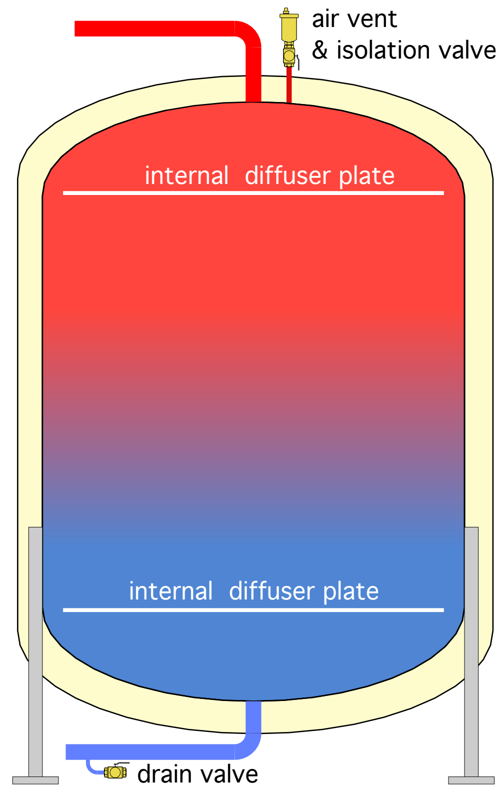
Preventing flow through unfired boiler

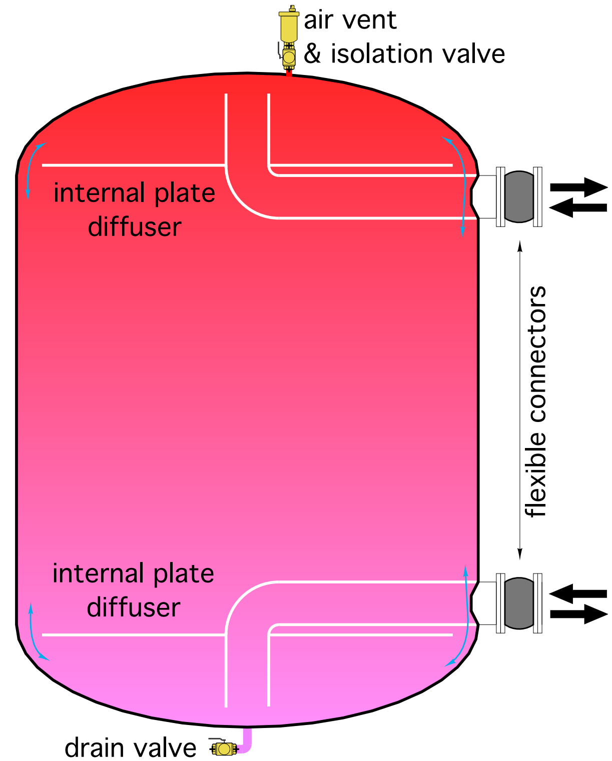






Design diffusers to access the full tank volume

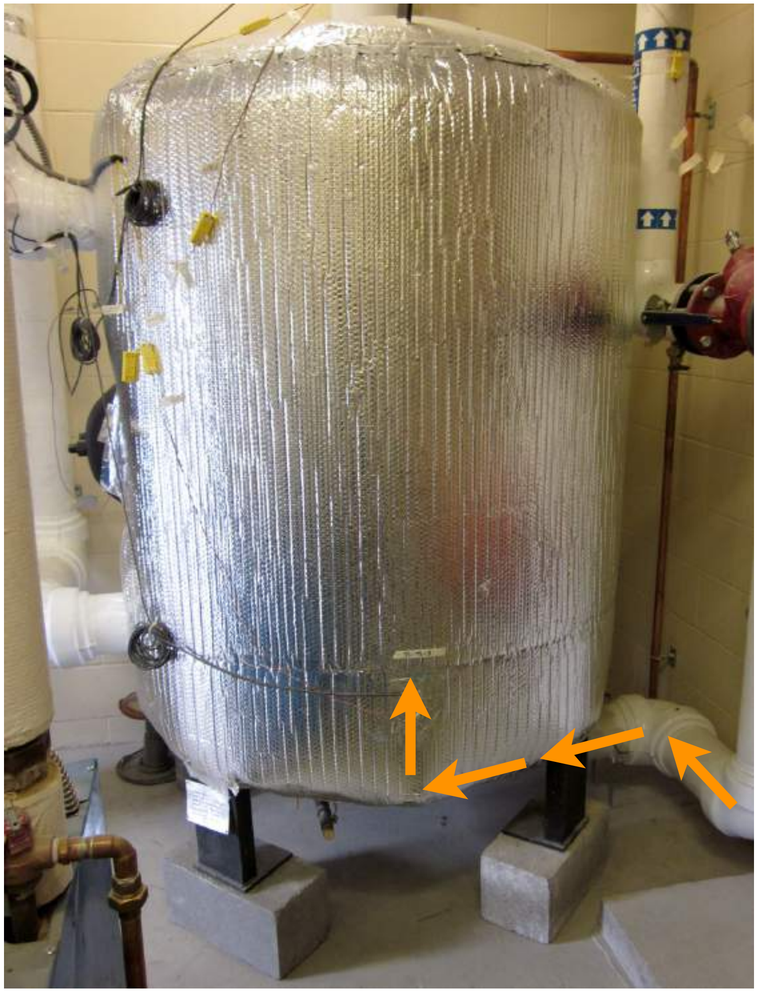


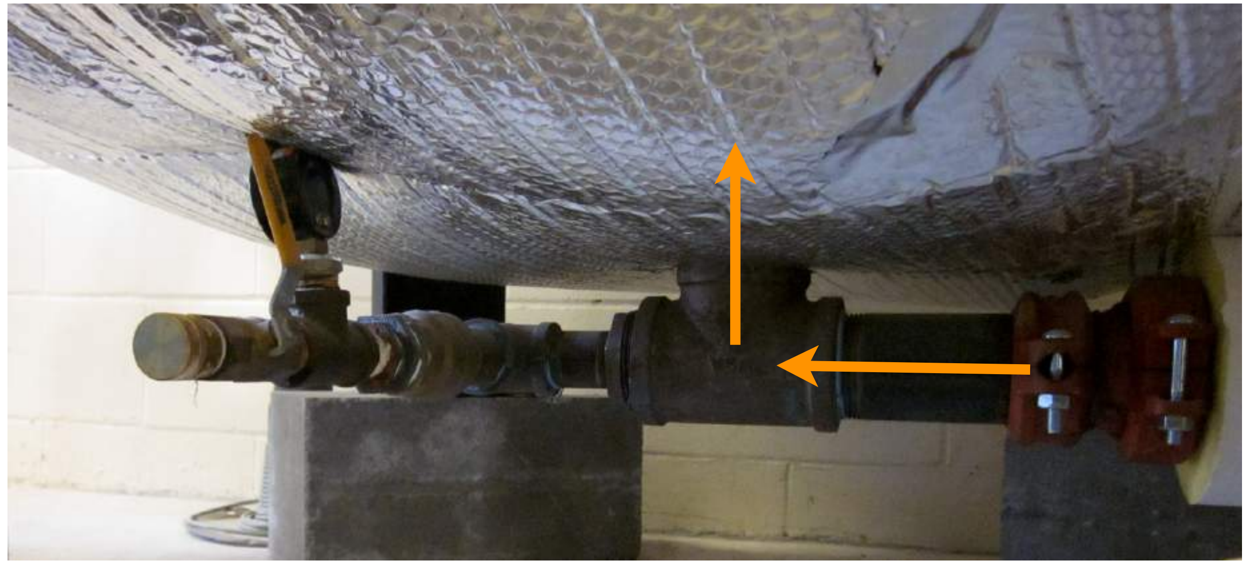


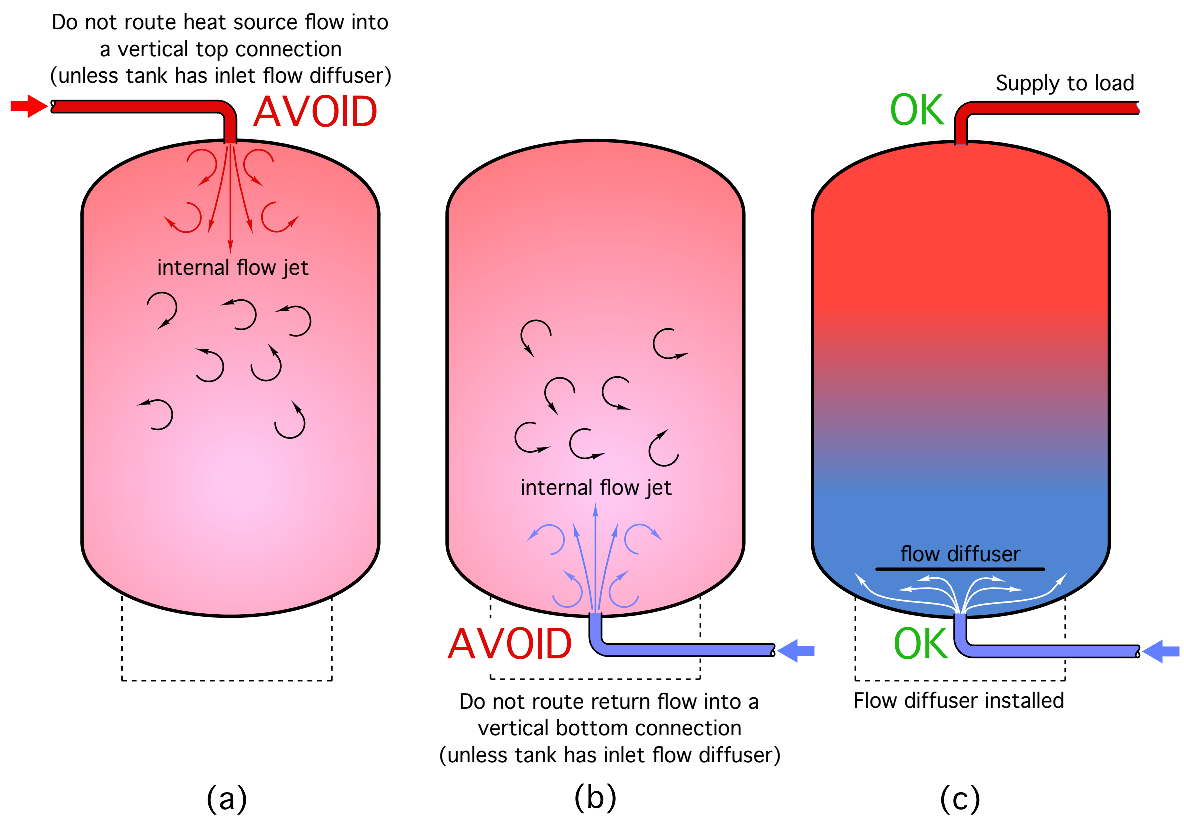
Baffle plate being welded into tank head & base shell at Troy Boiler Works

500 gallon ASME tank with poor stratification

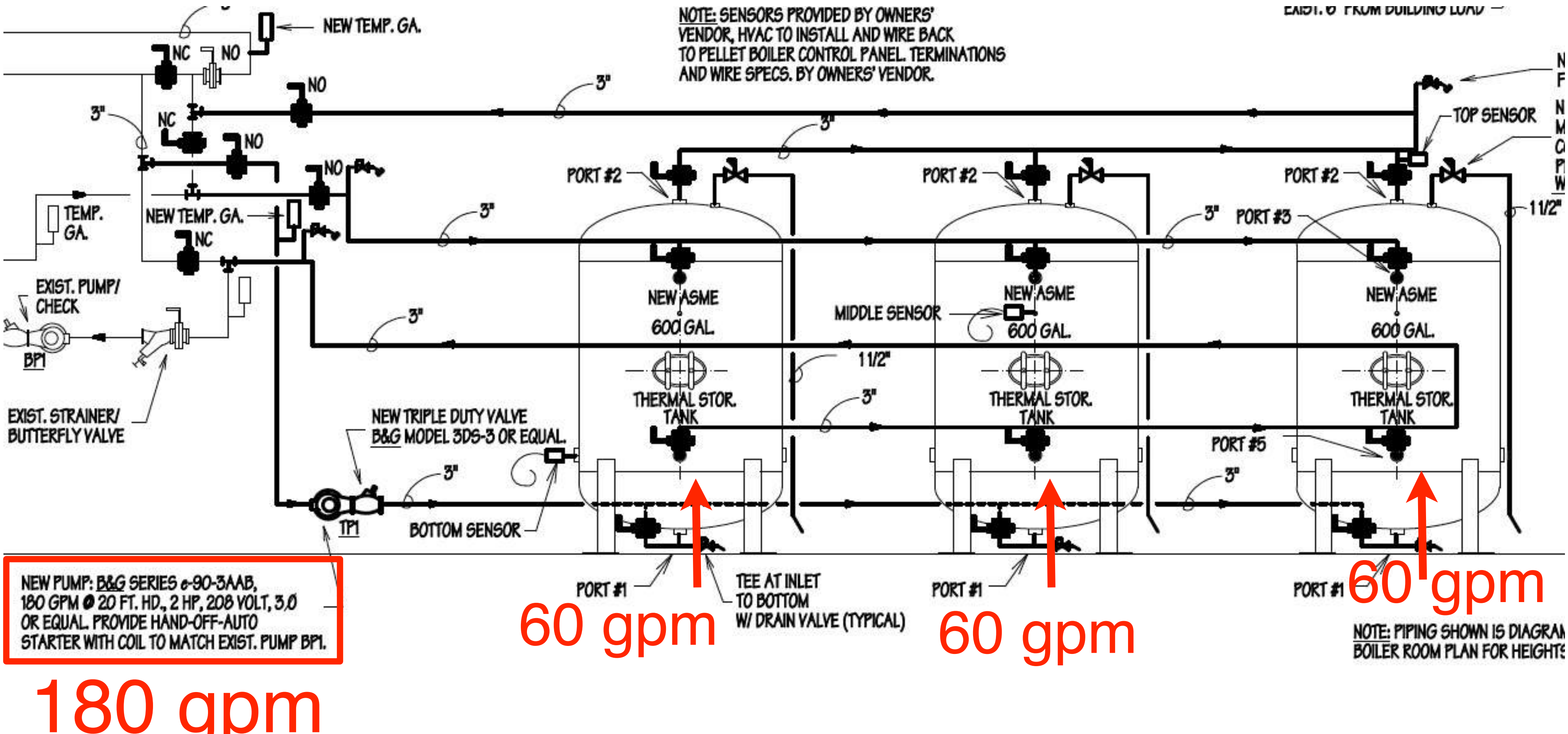
What's wrong?







Three, 600 gallon ASME tanks for storage in pellet boiler system.

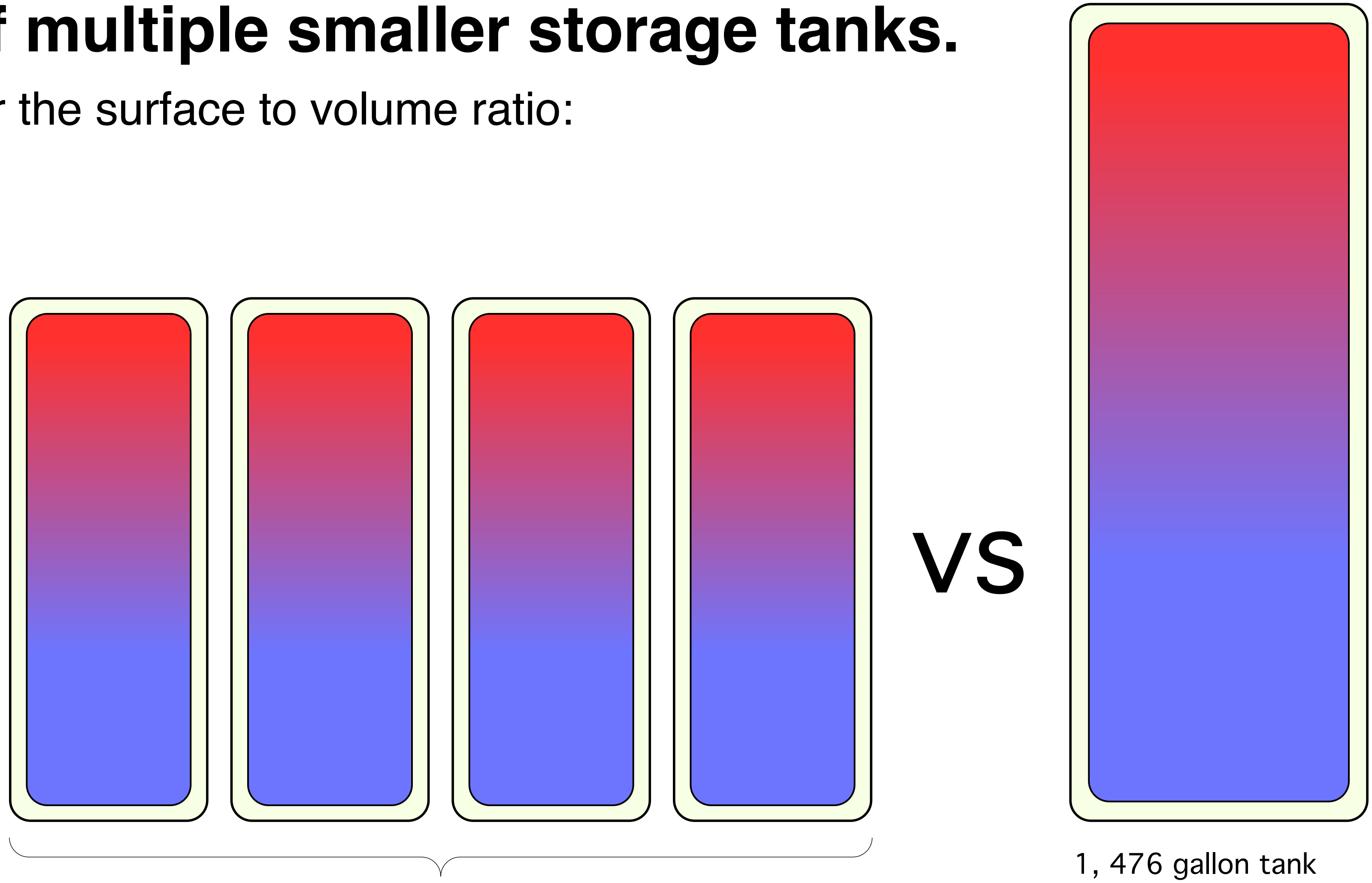


This piping will destroy stratification within the tank(s)

Multiple Storage Tank Arrays

Use of multiple smaller storage tanks.

Consider the surface to volume ratio:



4, 119 gallon tanks, total volume = 476 gallons
h/d ratio = 3
shell diameter = 22.7"
shell height = 68"
total surface area = 4 x 39.3 = 157.2 ft2

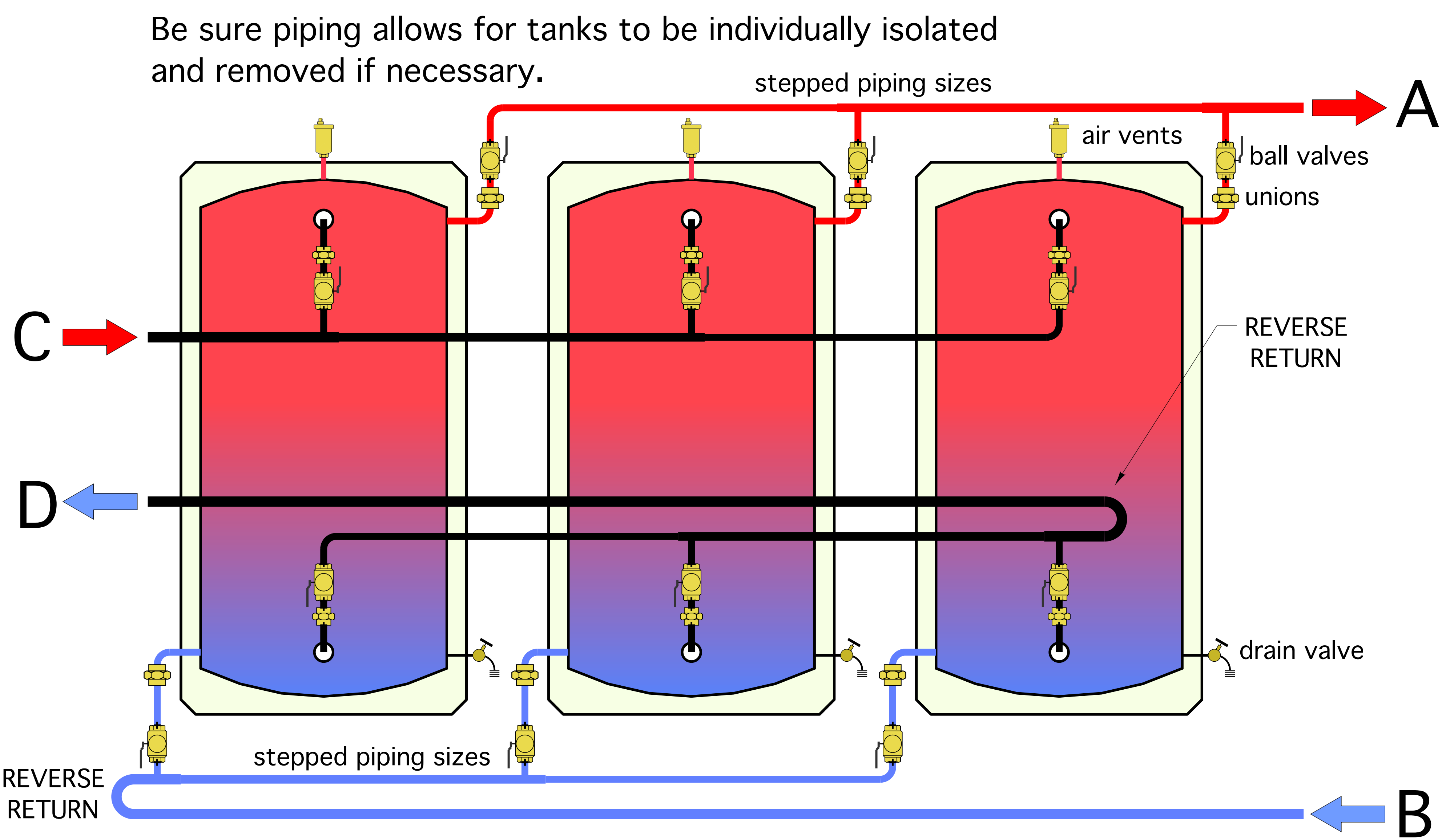
1, 476 gallon tank
h/d ratio = 3
shell diameter = 36"
shell height = 108
total surface area = 99 ft2

The 4 small tanks present 59% more surface area than the single large tank

The much higher surface-to-volume ration of the smaller tanks will significantly increase heat loss from the storage system.

Piping to ensure balanced flow in multiple tanks

Reverse return piping with stepped header sizes

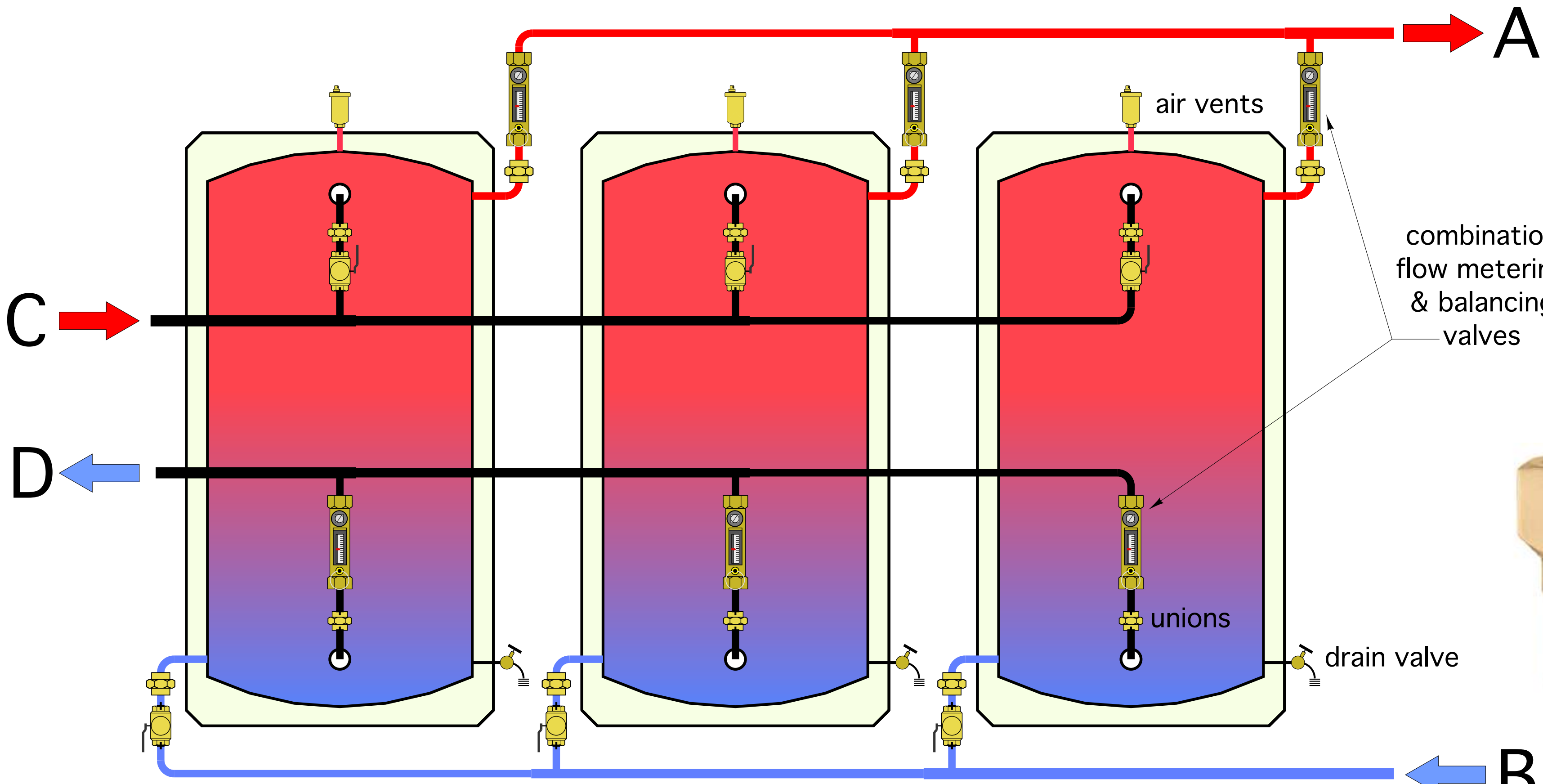


Could one of these tanks be removed - in tact- without disturbing the other tanks or piping?

Piping to ensure balanced flow in multiple tanks

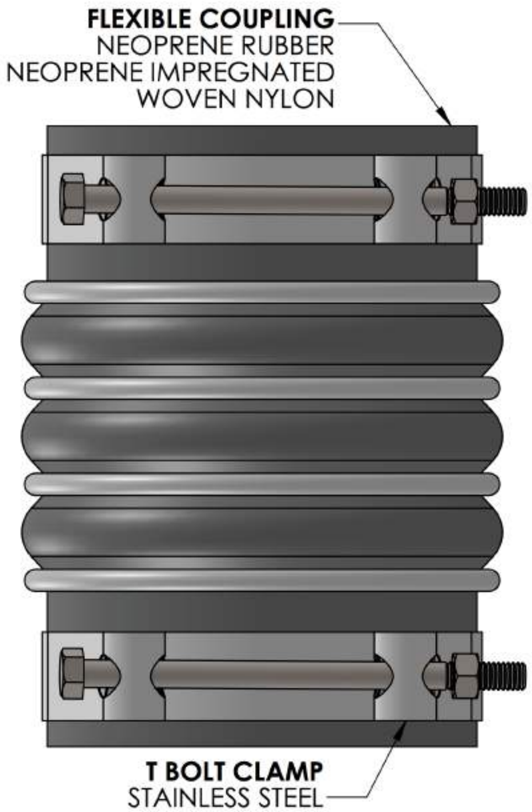
If direct return piping is used always install balancing valves

Be sure piping allows for tanks to be individually isolated and removed if necessary.



courtesy of Caleffi

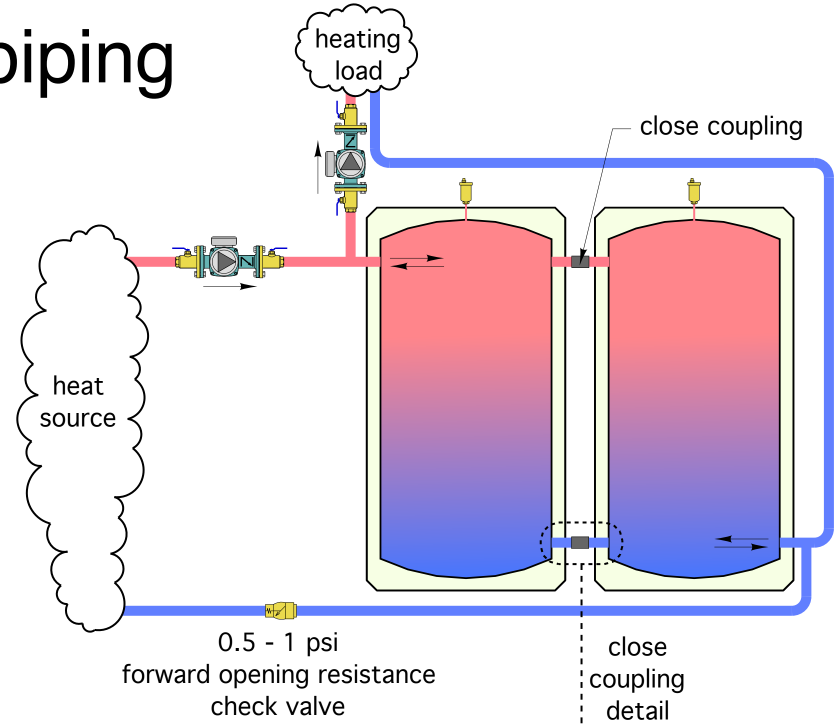
Hybrid parallel / series tank piping

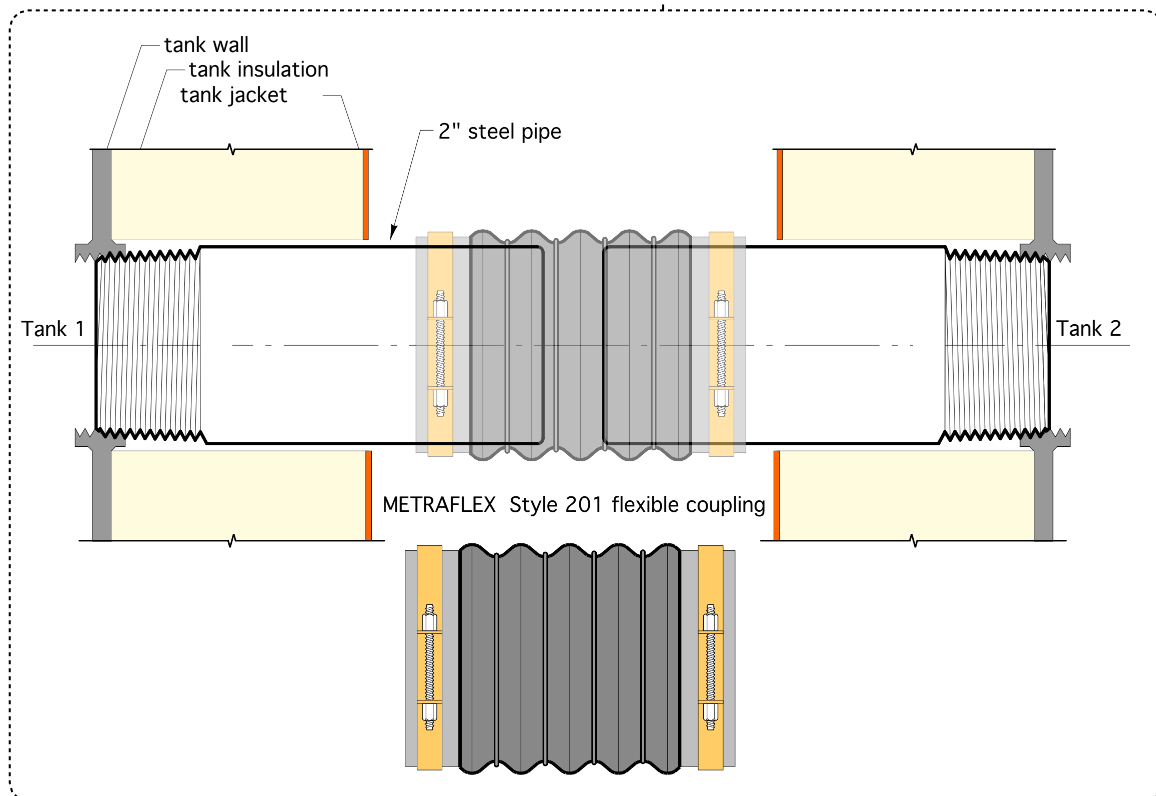


Metraflex Style 201 coupling

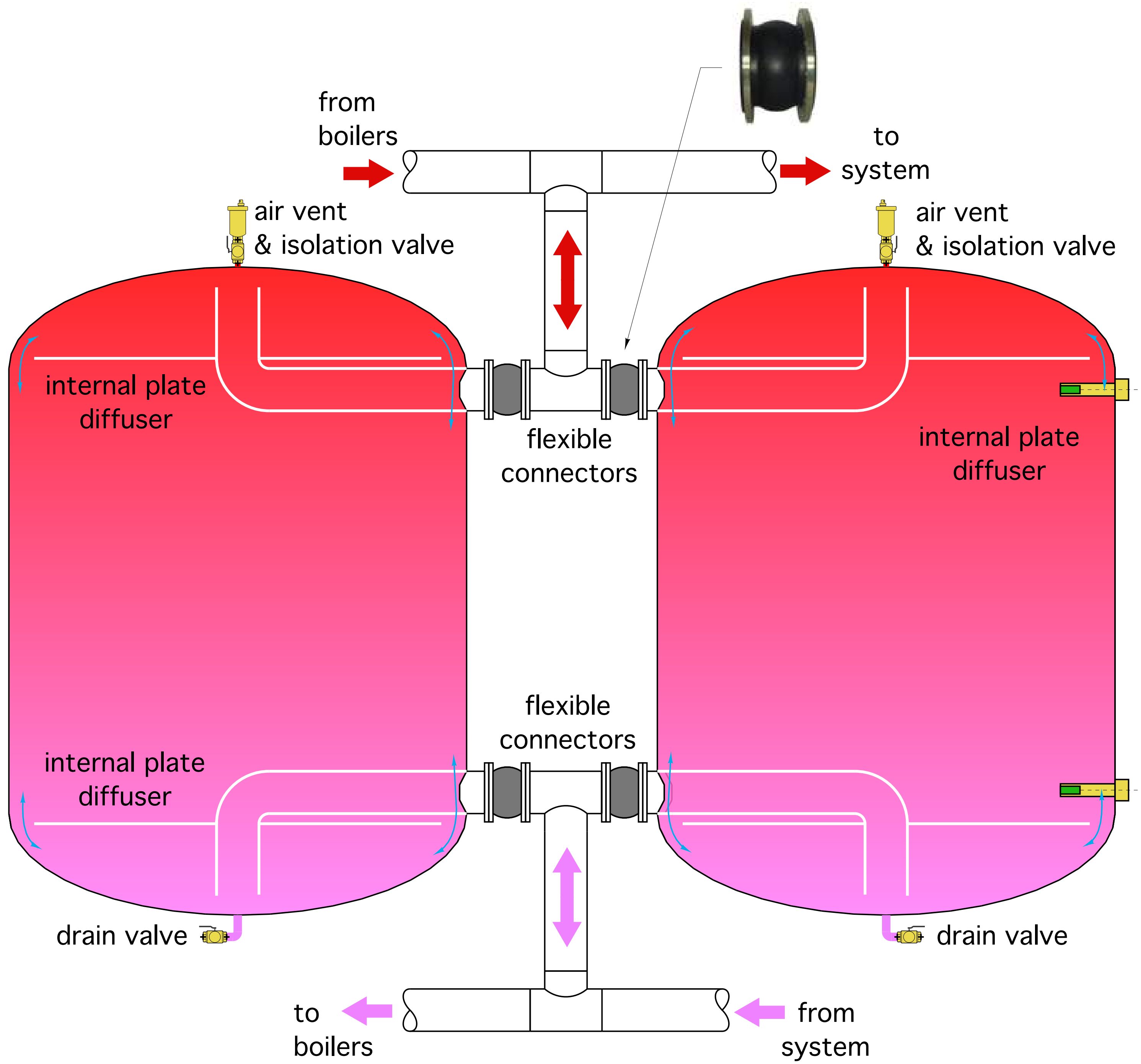
Rated to 225 °F / 75 psi

for pipe sizes 2" -12"





Hybrid parallel / series tank piping with flanged tanks



Flow rate from biomass boiler to strorage

One undesirable situation that has been observed on several biomass boiler systems is excessively high flow rate between the boiler and thermal storage. **High flow rates entering the tank create mixing currents that tend to break up temperature stratification, and reduce the temperature difference between the top and bottom of the thermal storage tank.**

$$f = \left[\frac{Q}{c \times \Delta T} \right]$$

Where:
f = boiler flow rate (gpm)
Q = rated boiler output (Btu/hr)
ΔT = temperature rise across boiler (ºF)
c = 500 (for water), 479 (for 30% glycol), 450 (for 50% glycol)

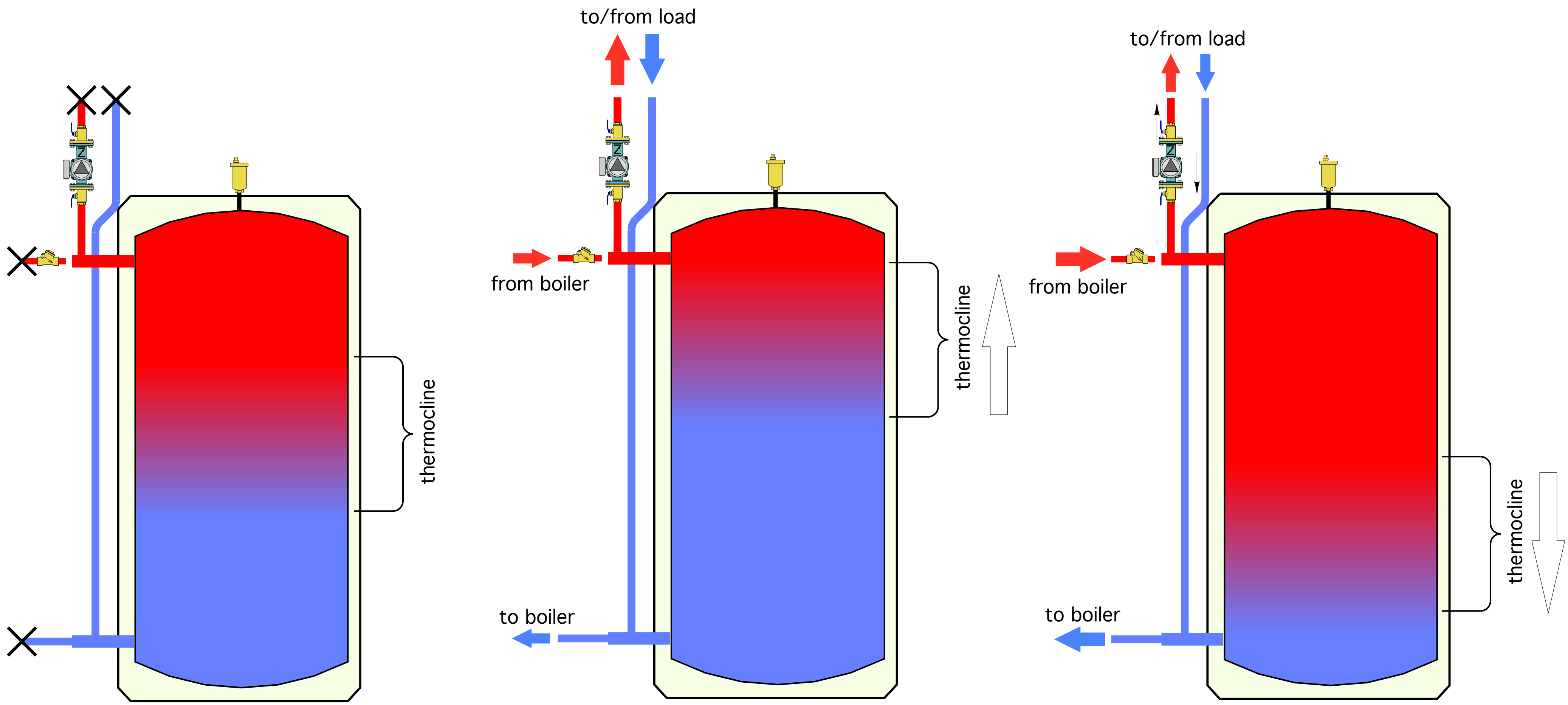
For example, a boiler rated at 150,000 Btu/hr, and operating with a 30 ºF temperature rise (e.g., difference between inlet and outlet temperature), in a water system, would require a flow rate of:

$$f = \left[\frac{Q}{c \times \Delta T} \right] = \left[\frac{150{,}000}{500 \times 30} \right] = 10\,gpm$$

Temperature Stacking in Thermal Storage Tanks

Thermocline movement in tank

Indicates relative energy flow between boiler and load.

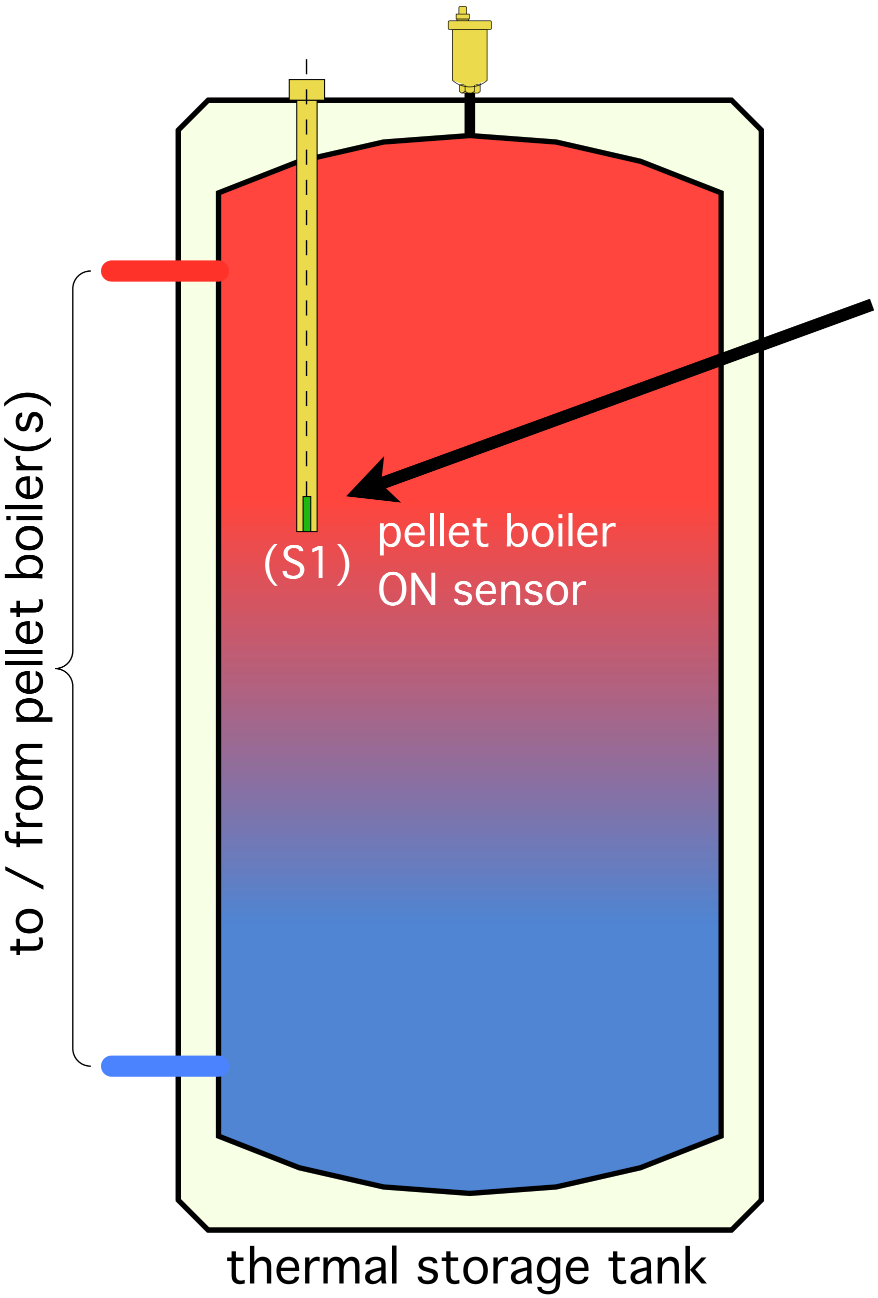


tank at rest. No flow from boiler or to load

load extracting heat at rate > rate of heat output from boiler.
Thermocline moves up

load extracting heat at rate < rate of heat output from boiler.
Thermocline moves down

The pellet fired boiler should be turned on ***before*** the hot water is depleted from top of tank.

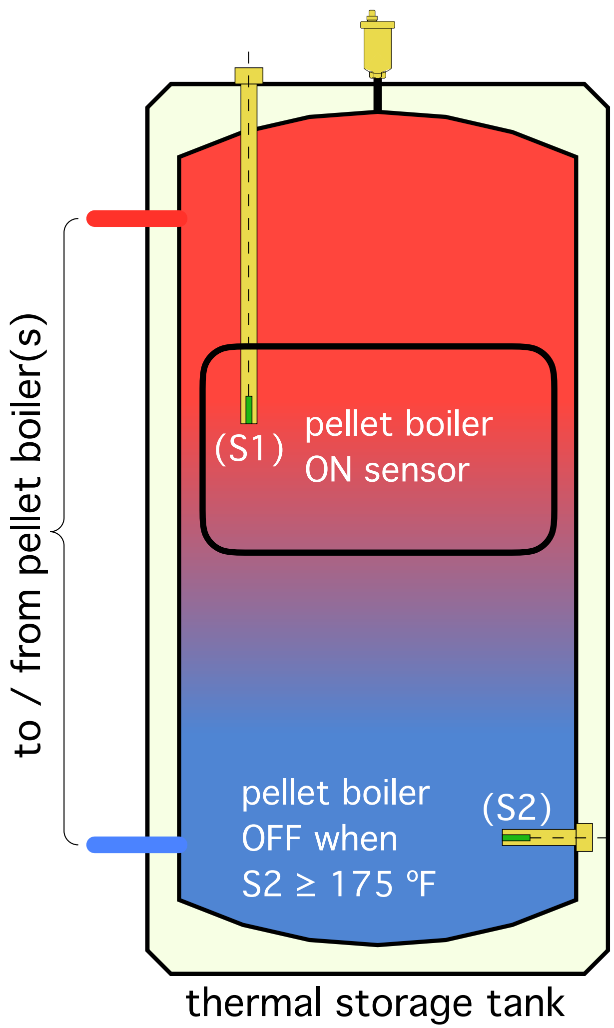


Sensor in vertical well detects "arrival" of rising cooler water. Turns on pellet fired boiler.

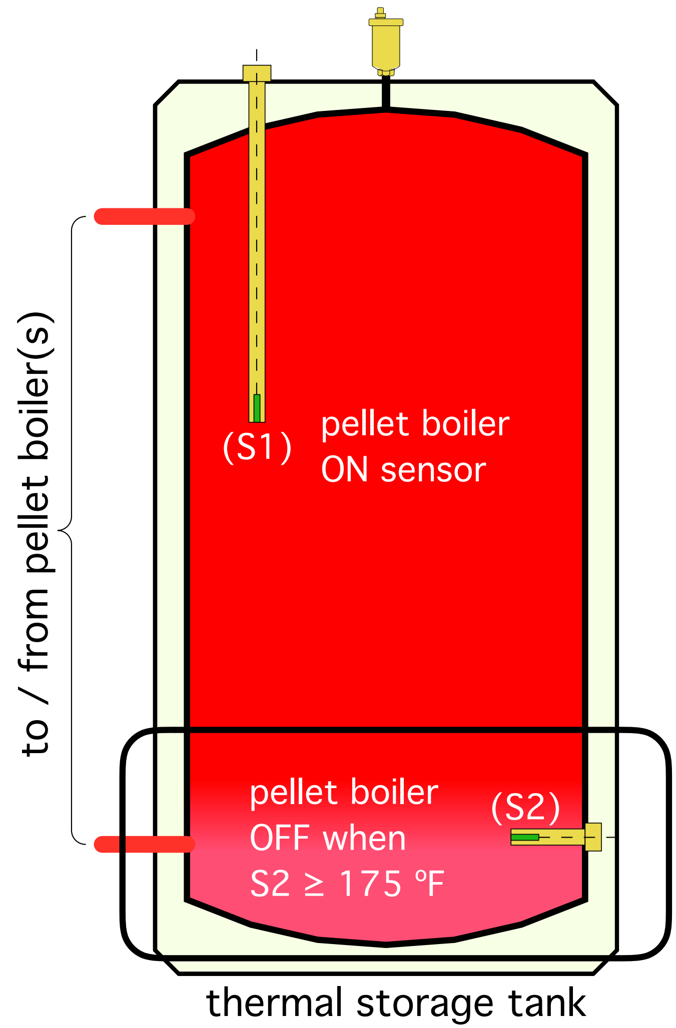
pellet boiler ON when upper sensor temperature ≤ minimum setpoint

Temperature stacking

To lengthen pellet boiler on-cycle, keep it operating until a sensor in lower portion of tank reaches some higher preset temperature.



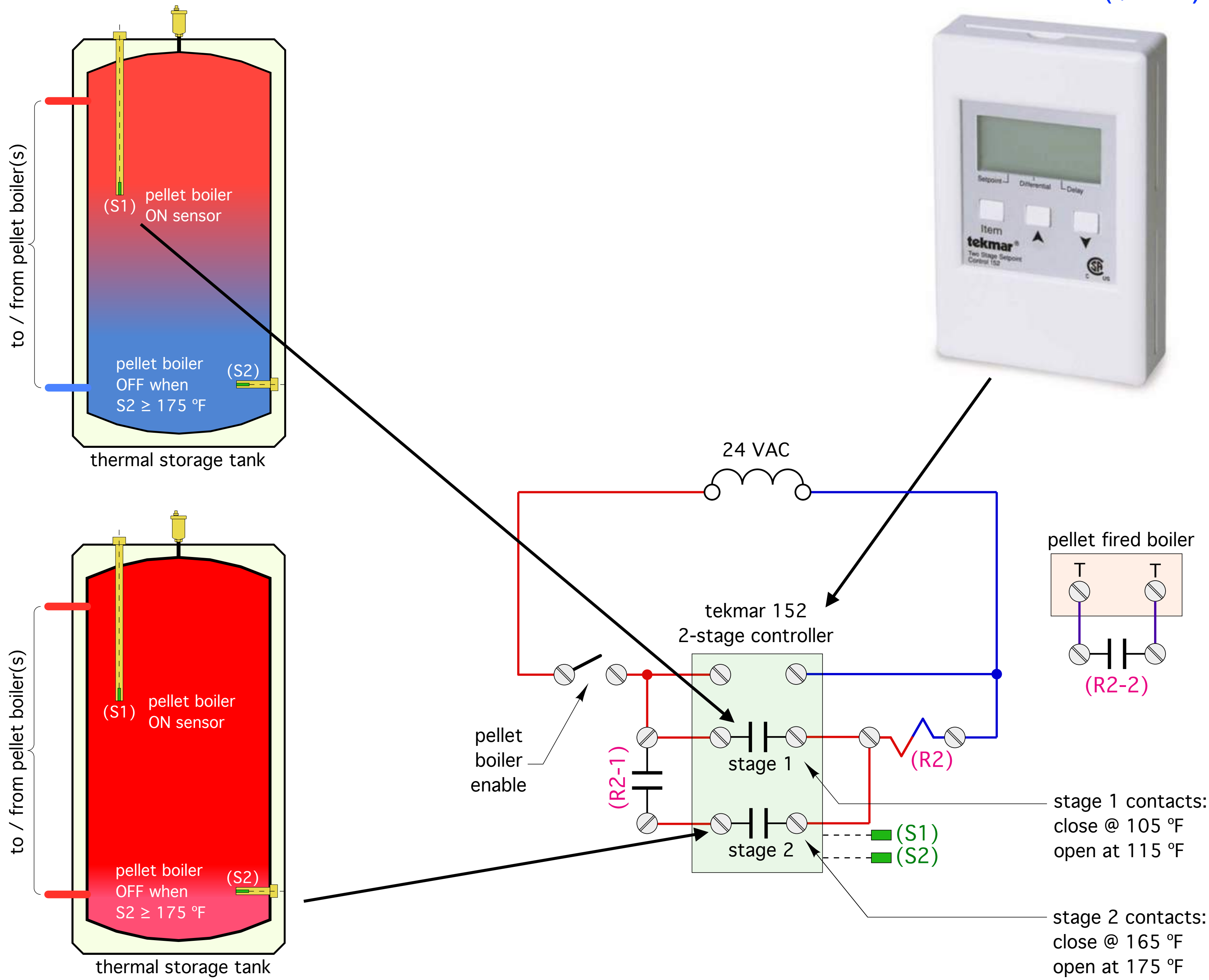
pellet boiler
“start”condition



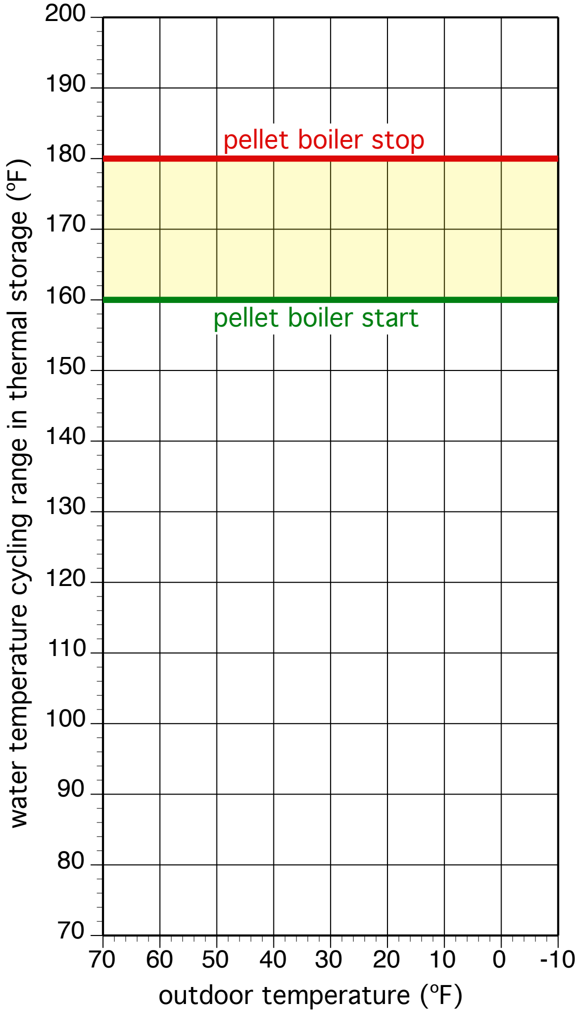
pellet boiler
“stop”condition

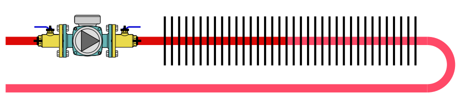
Temperature stacking *(using 2 setpoint temperatures)*

tekmar 152: ($217)



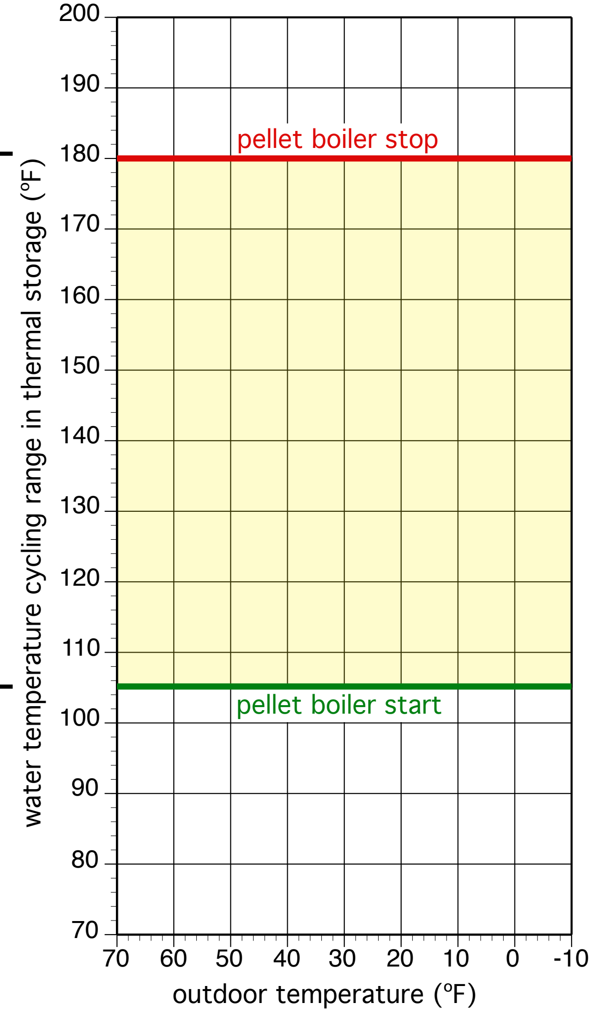
Temperature cycling range of storage is high dependent on the type of heat emitters used.

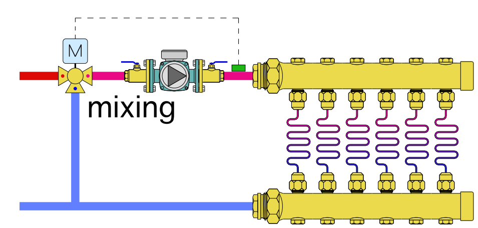




- HIGH temperature heat emitters
- No outdoor reset control of supply water temperature

Low temperature heat emitters allows for wider tank “draw down.”



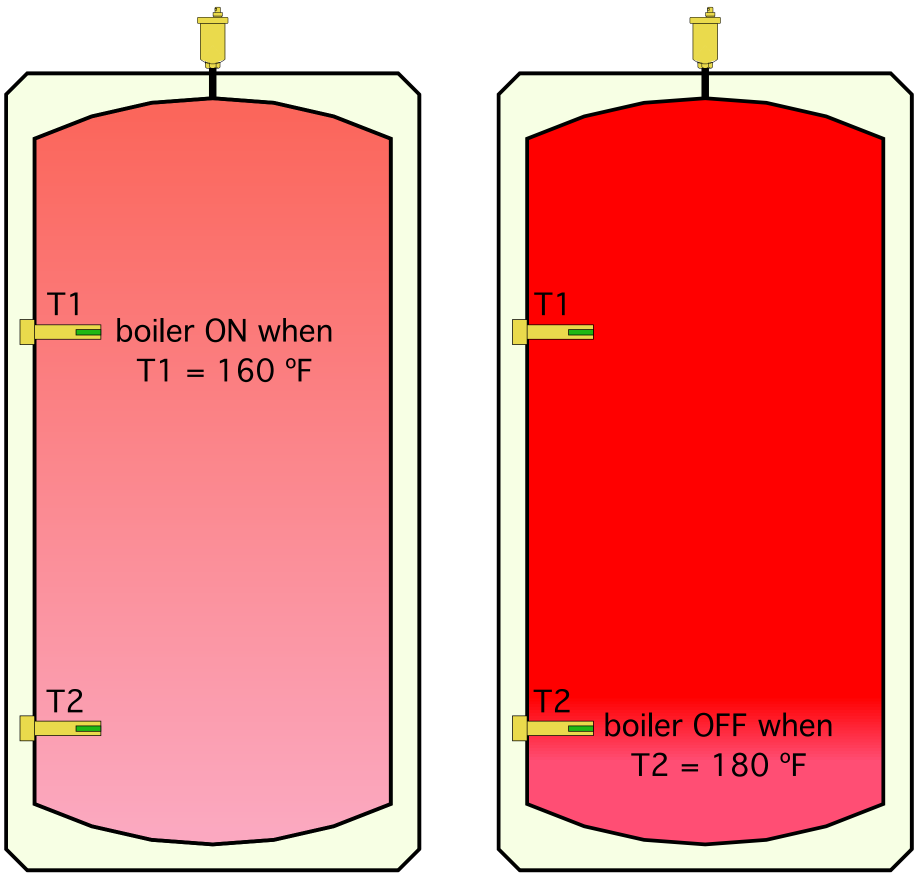


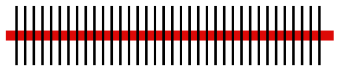
- LOW temperature heat emitters
- No outdoor reset control of supply water temperature

• **High temperature heat emitters**

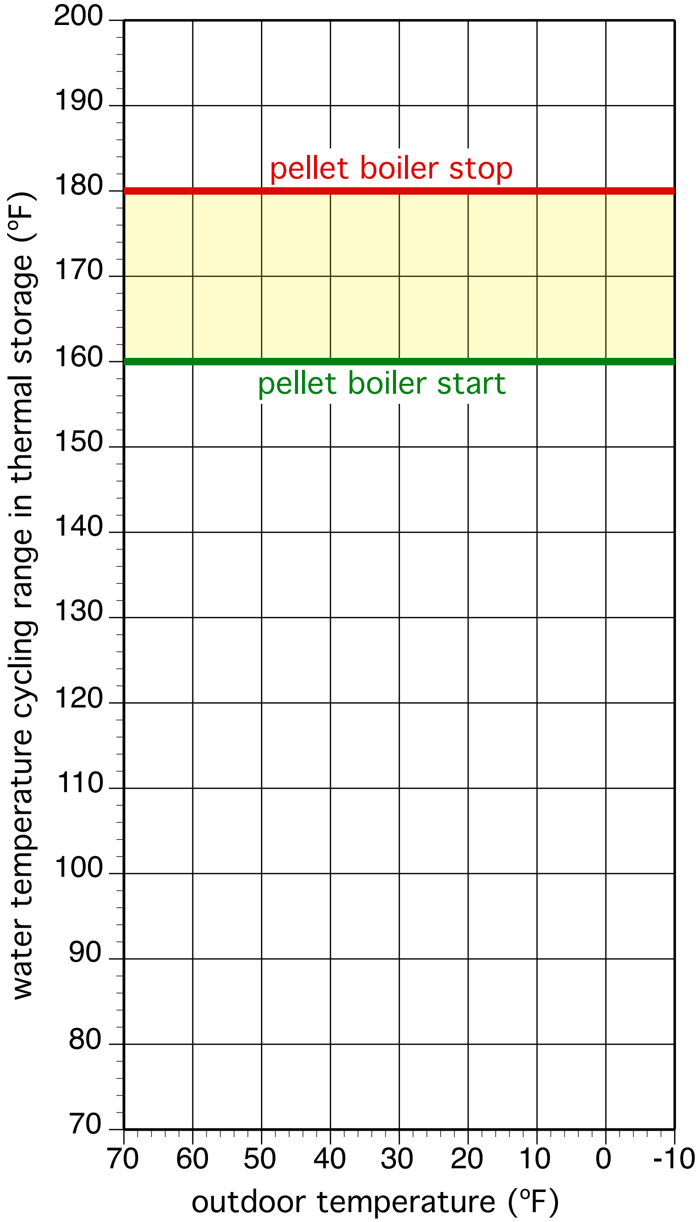
• Temperature stacking (w/ upper & lower tank temp. sensors)

[*setpoint* control of both upper and lower temperatures]





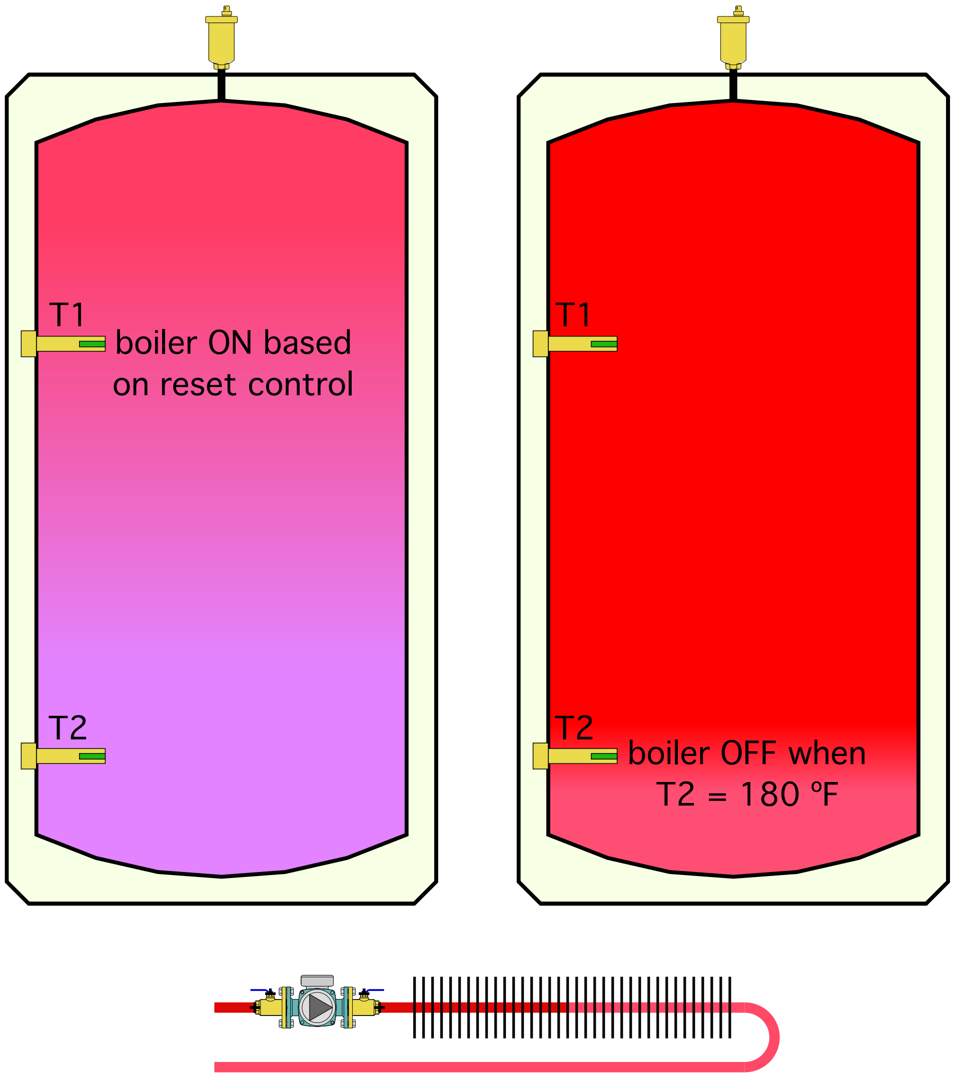
- High temperature heat emitters
- No outdoor reset control



• High temperature heat emitters

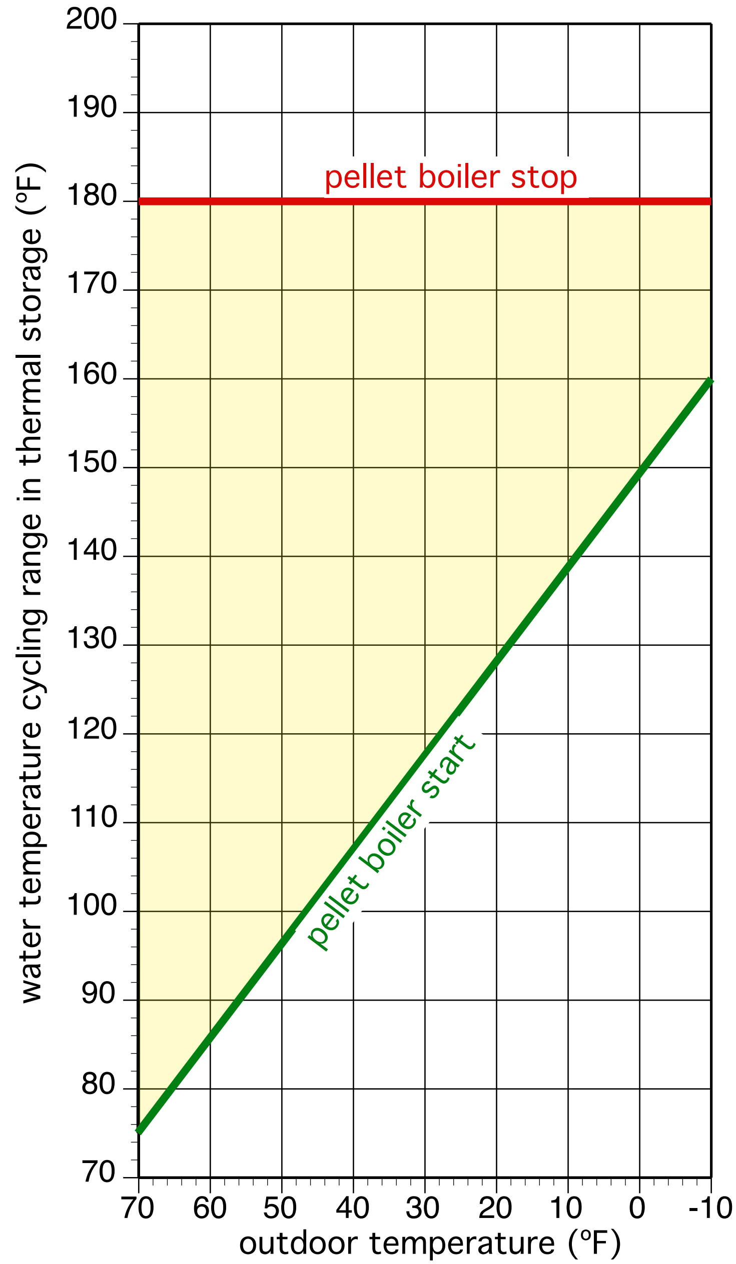
• Temperature stacking (w/ upper & lower tank temp. sensors

[*outdoor reset for boiler start, setpoint temperature for boiler off*]

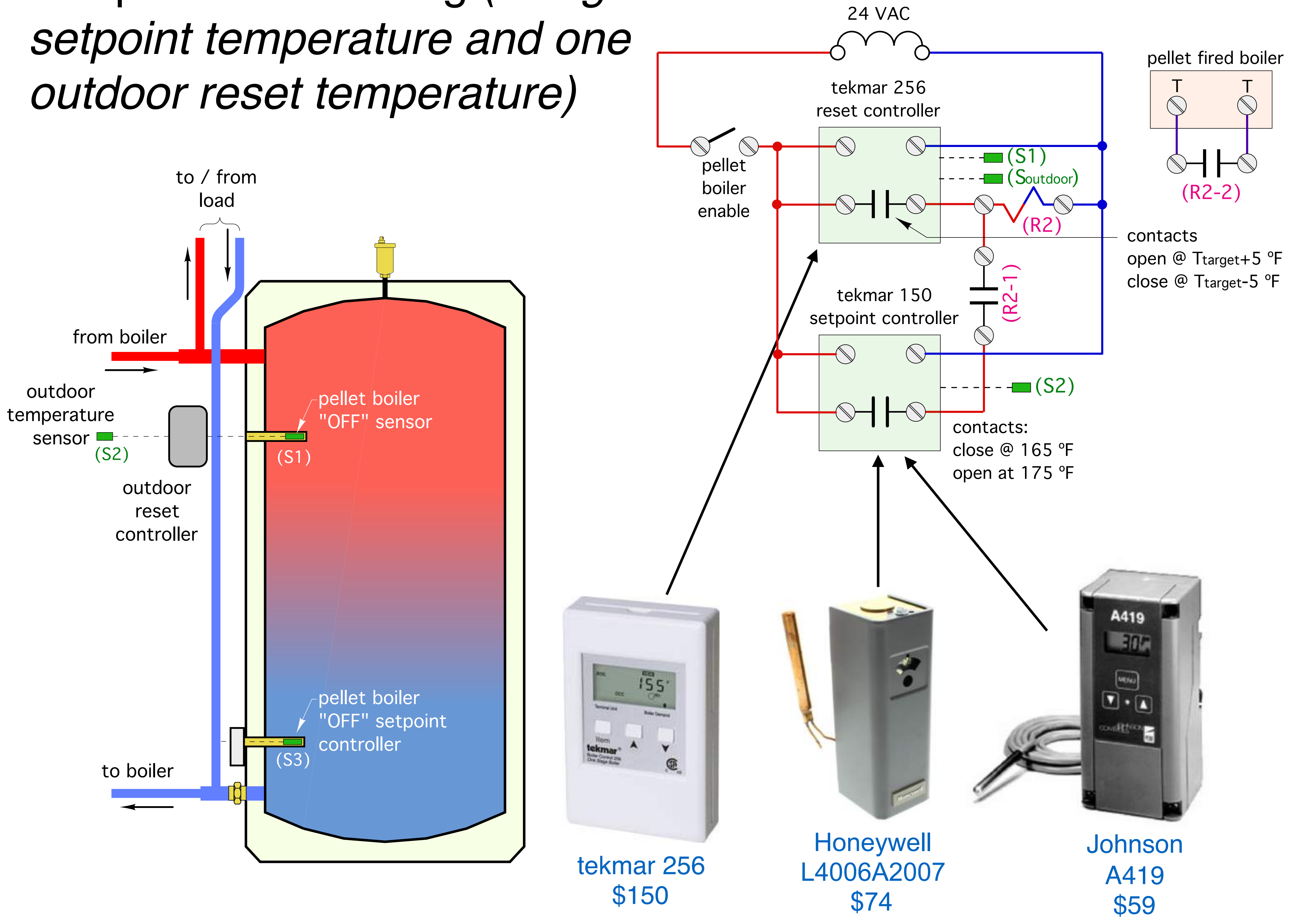


• HIGH temperature heat emitters

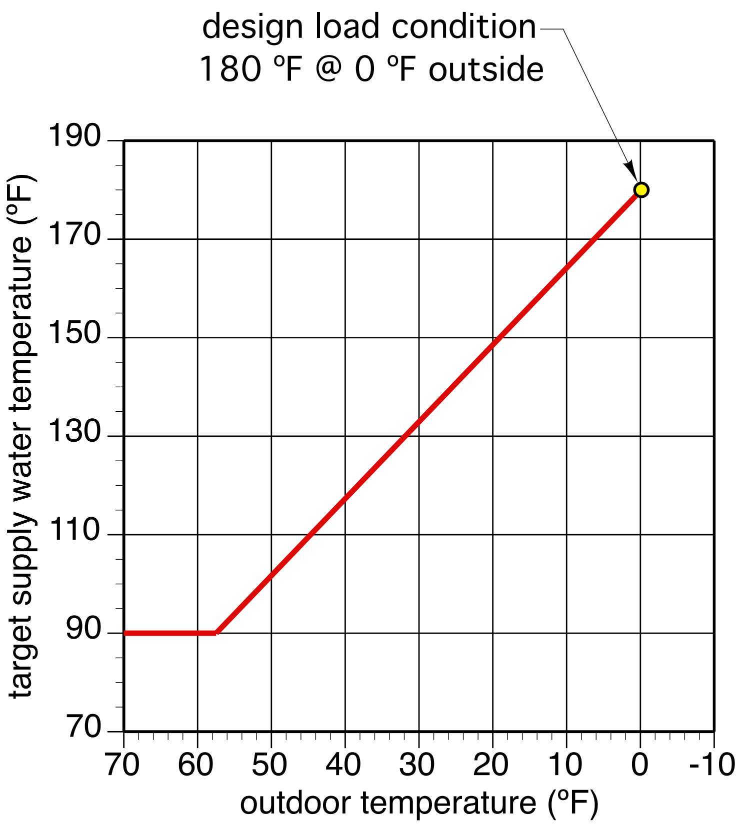
• Outdoor reset of pellet boiler start temperature

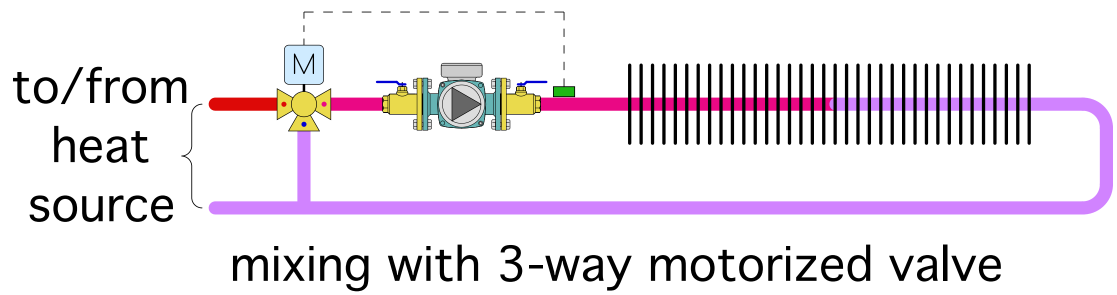


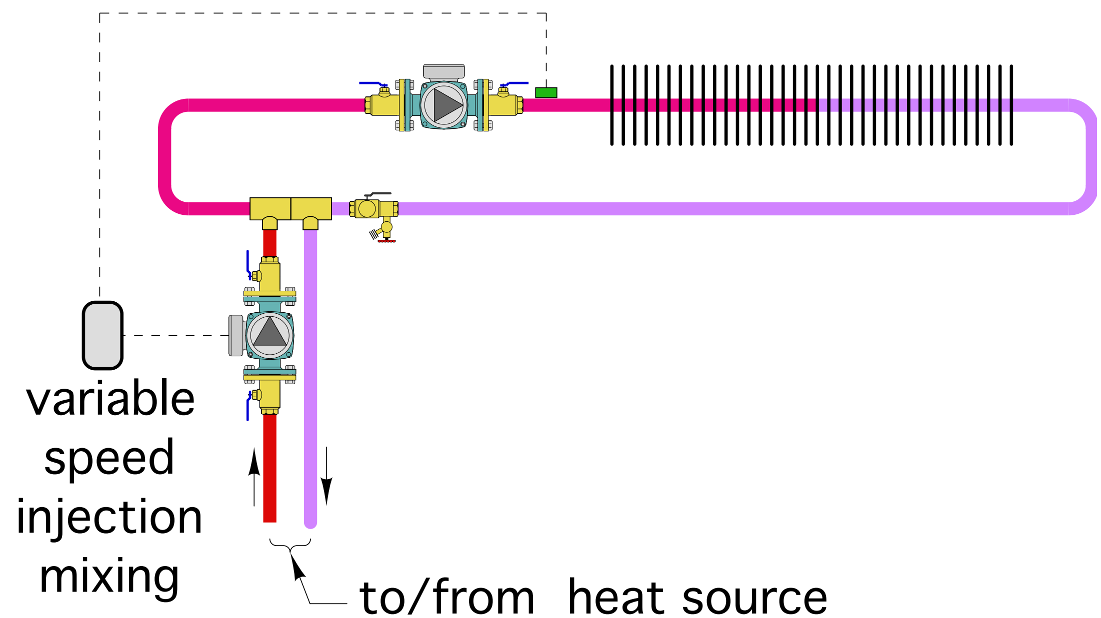
Temperature stacking *(using 1 setpoint temperature and one outdoor reset temperature)*



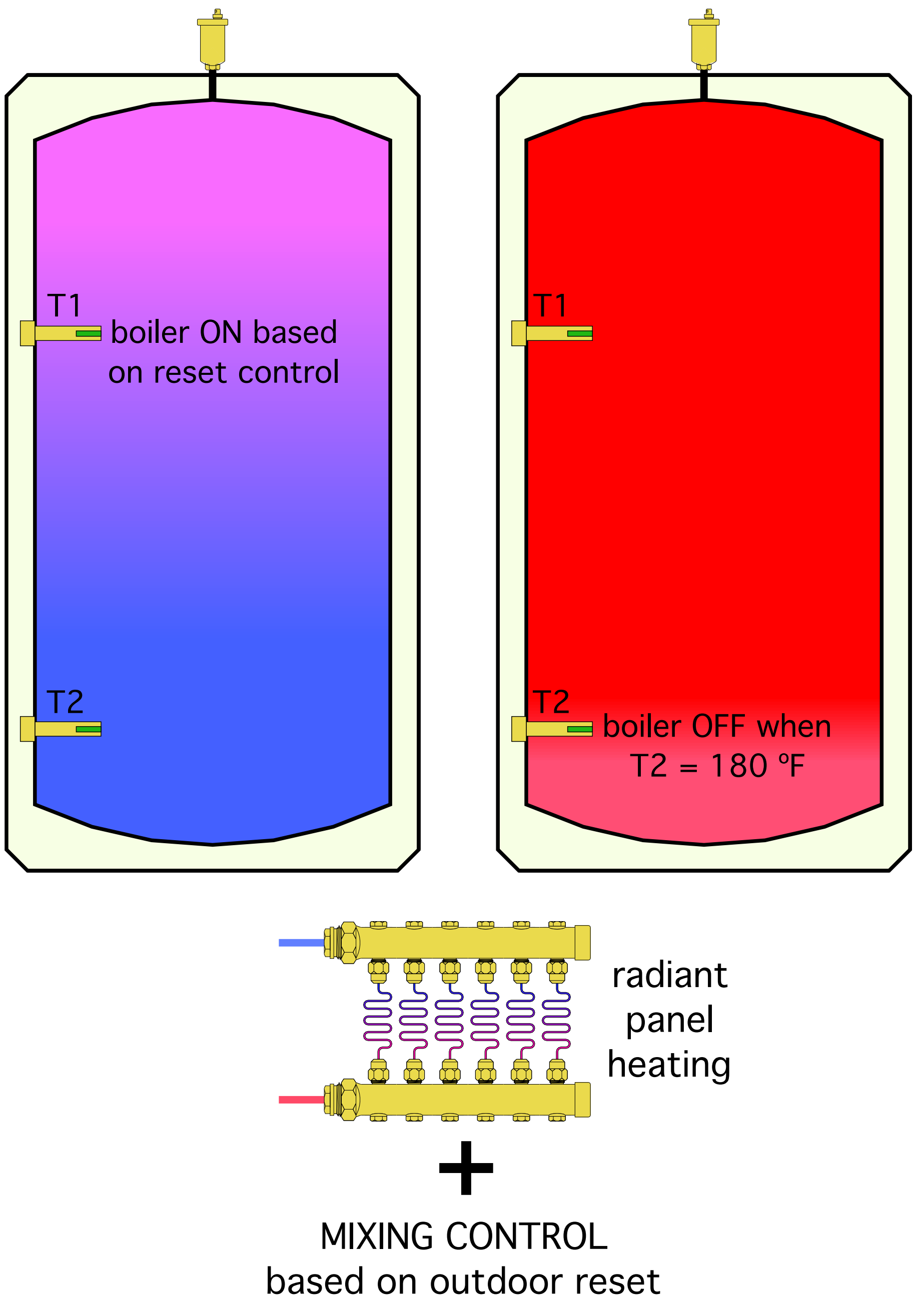
Adding ***mixing*** (based on outdoor reset) between the thermal storage tank and distribution system will smoothen heat delivery and significantly ***improve comfort***.

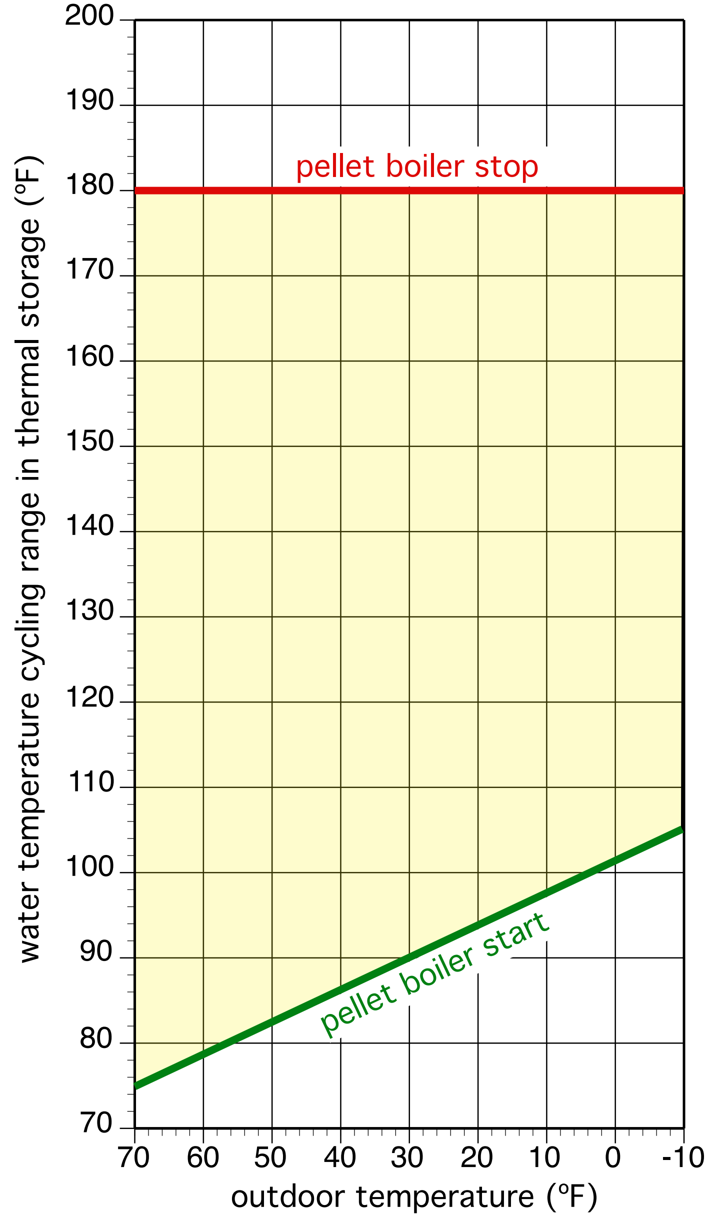




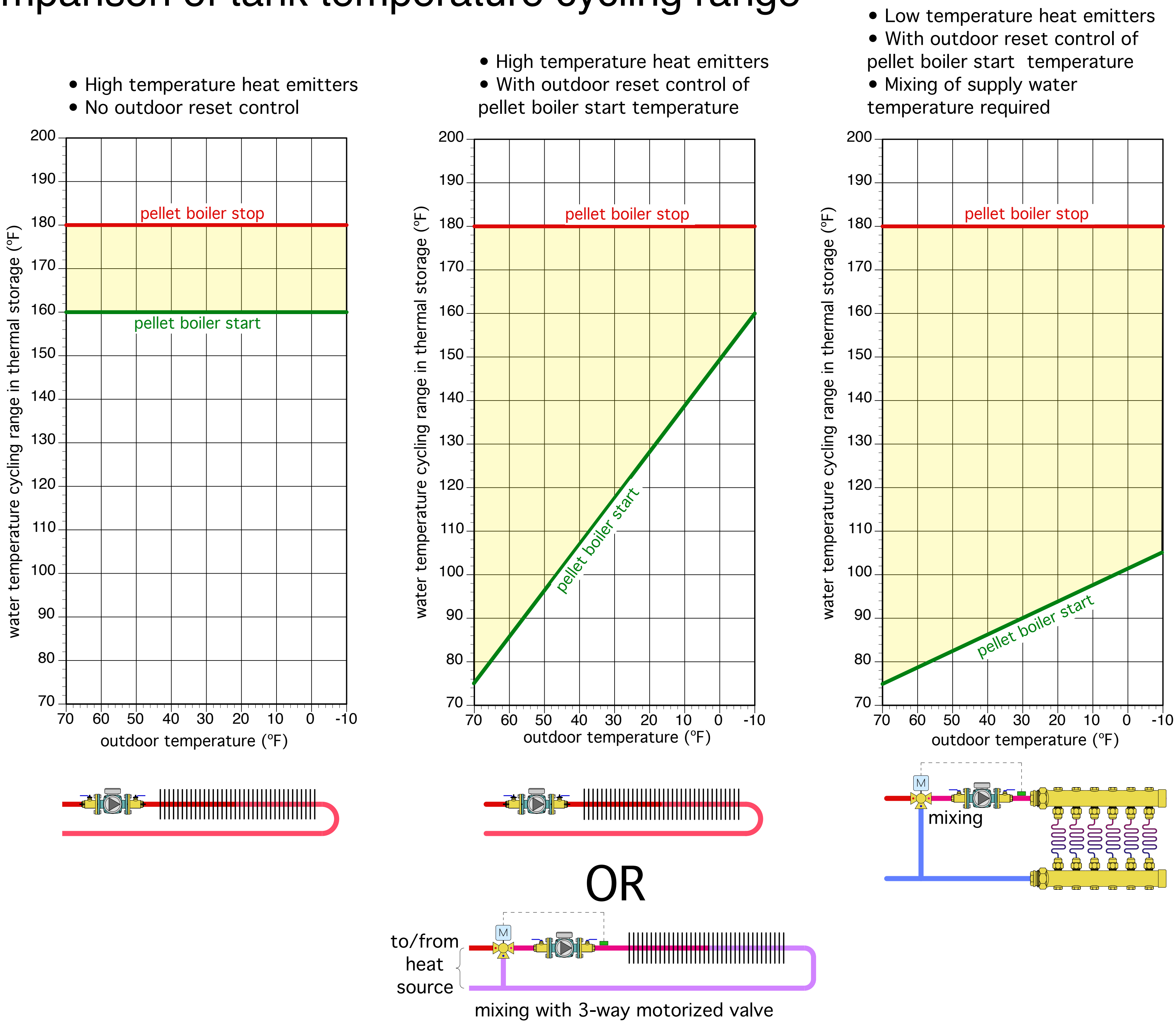


- **Low temperature heat emitters**
- Heat stacking (outdoor reset for boiler start, setpoint for boiler off)
- Mixing control of distribution water temperature





A comparison of tank temperature cycling range

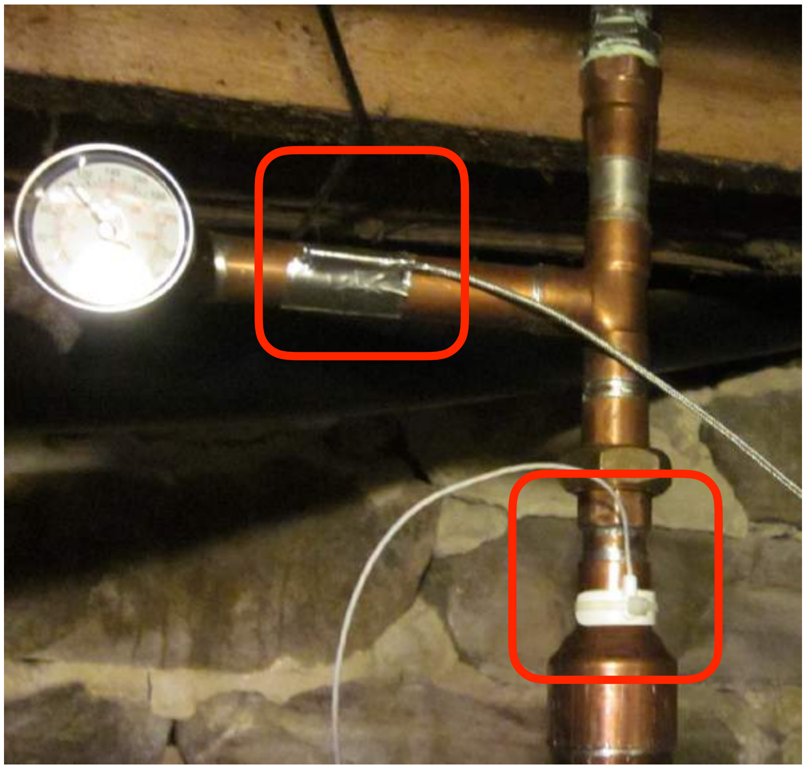


Poor temperature sensor placement

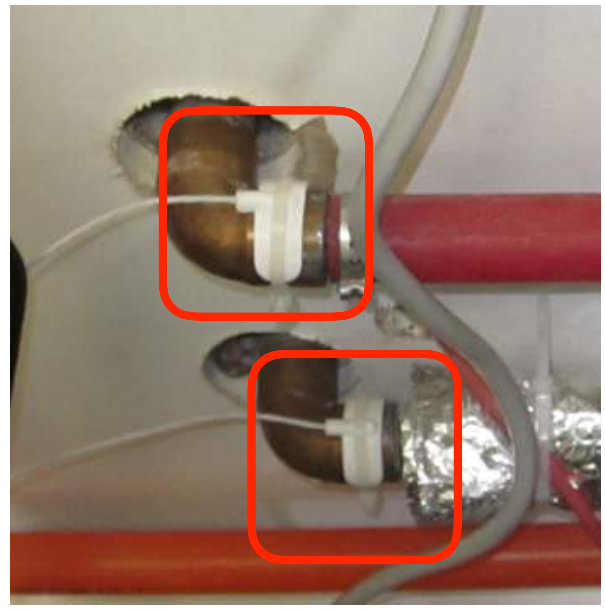
Poor sensor placement or lack of insulation

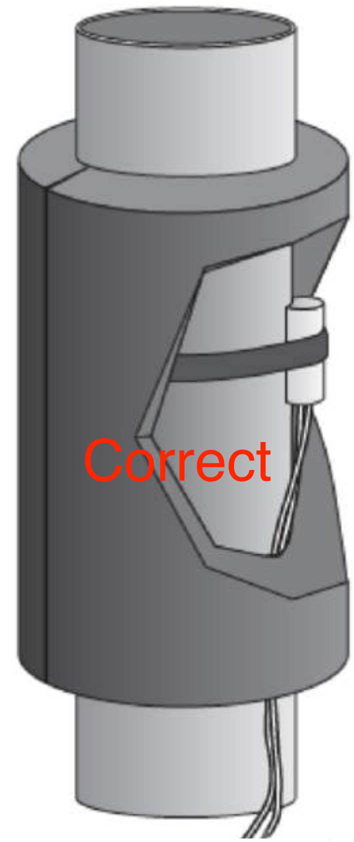
Controllers can only react to what temperatures their sensors "feel."

Solution: Surface mount sensors must be firmly attached, stay attached at elevated temperatures, and be insulated from surrounding air temperature.



non-insulated surfaced mounted temperature sensors





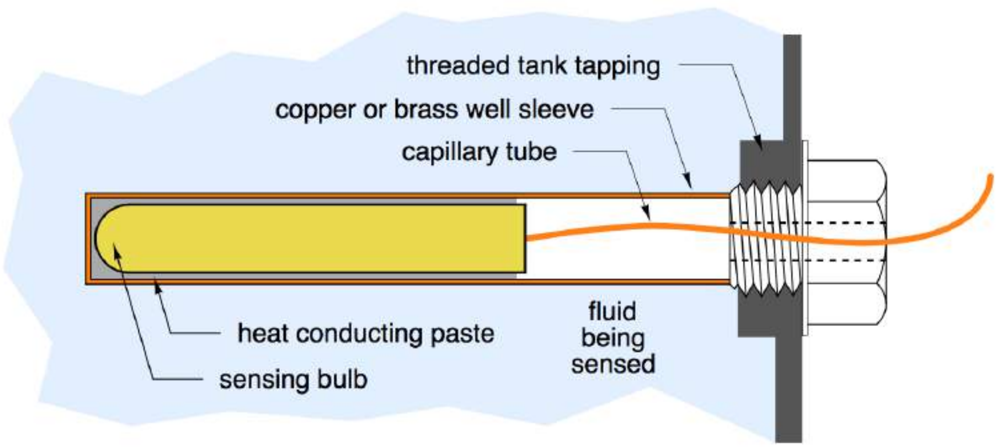
Some sensors have a concave shape to fit OD of pipe.

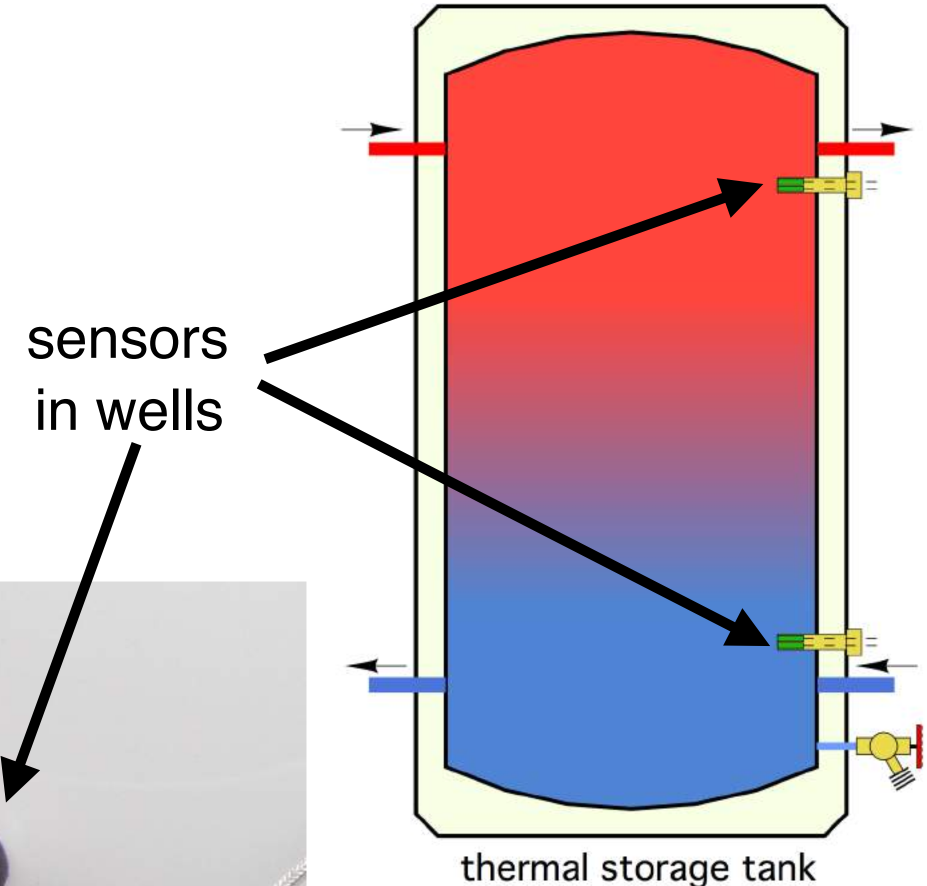
Poor sensor placement or lack of insulation

Pipe-mounted sensor with sealed insulation jacket

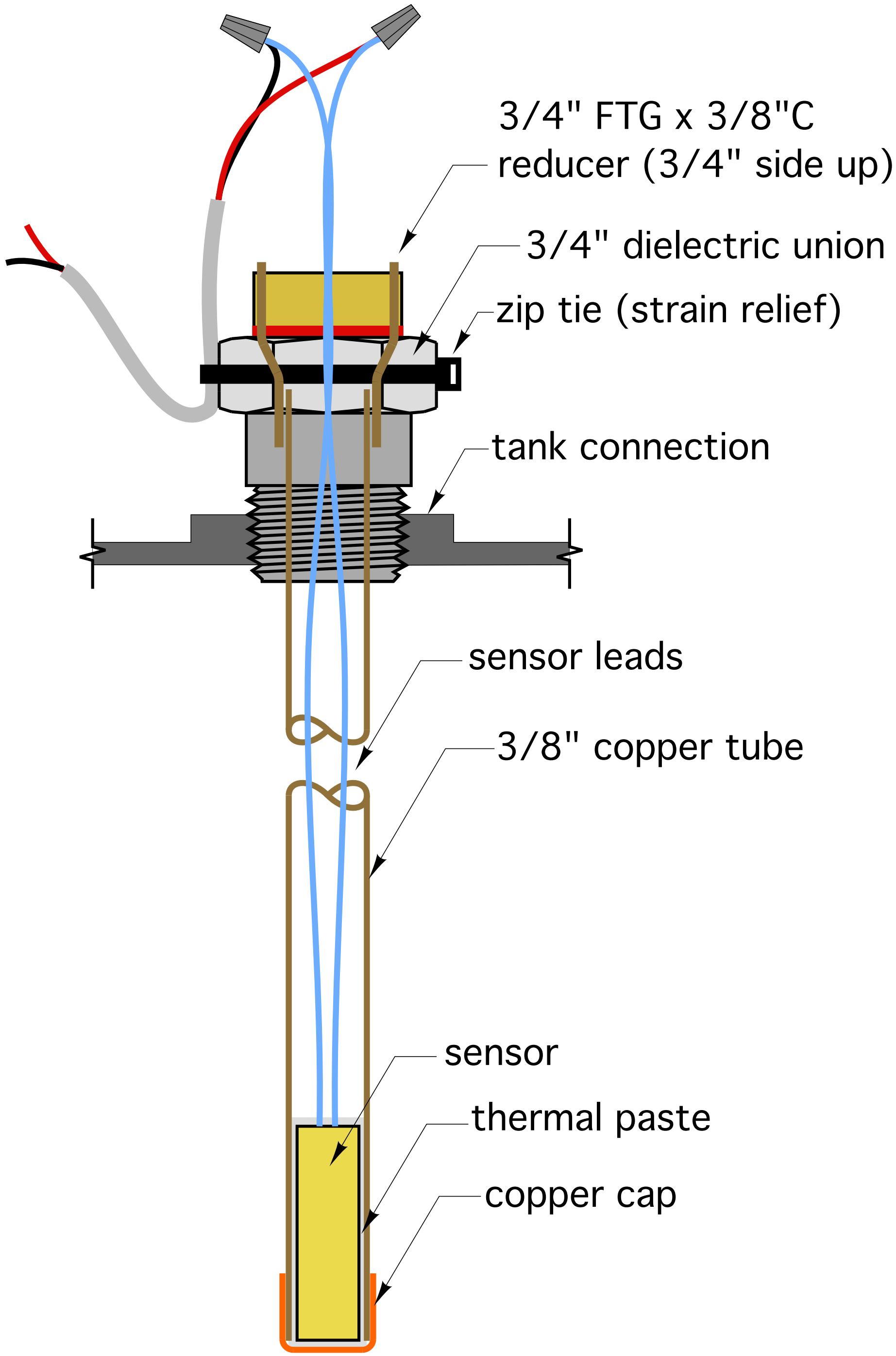
Poor sensor placement or lack of insulation

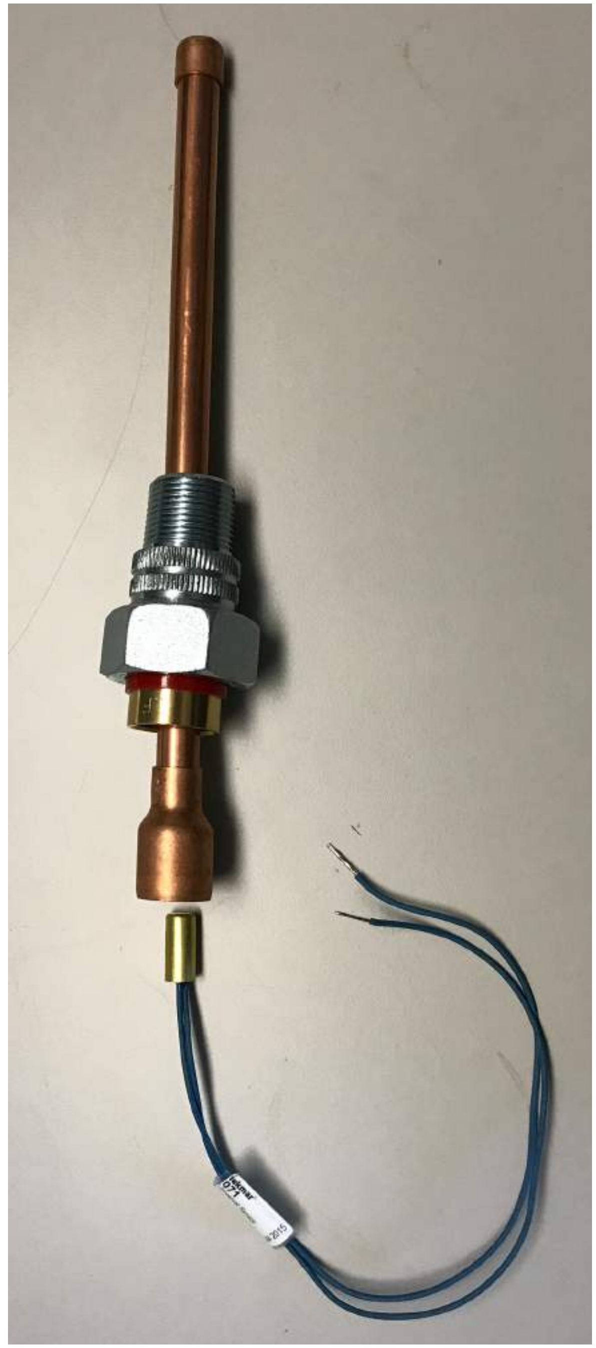
Solution: When measuring the temperature within heat sources, or thermal storage tanks, use a sensor well, and thermal grease.





Simple way to built a sensor well

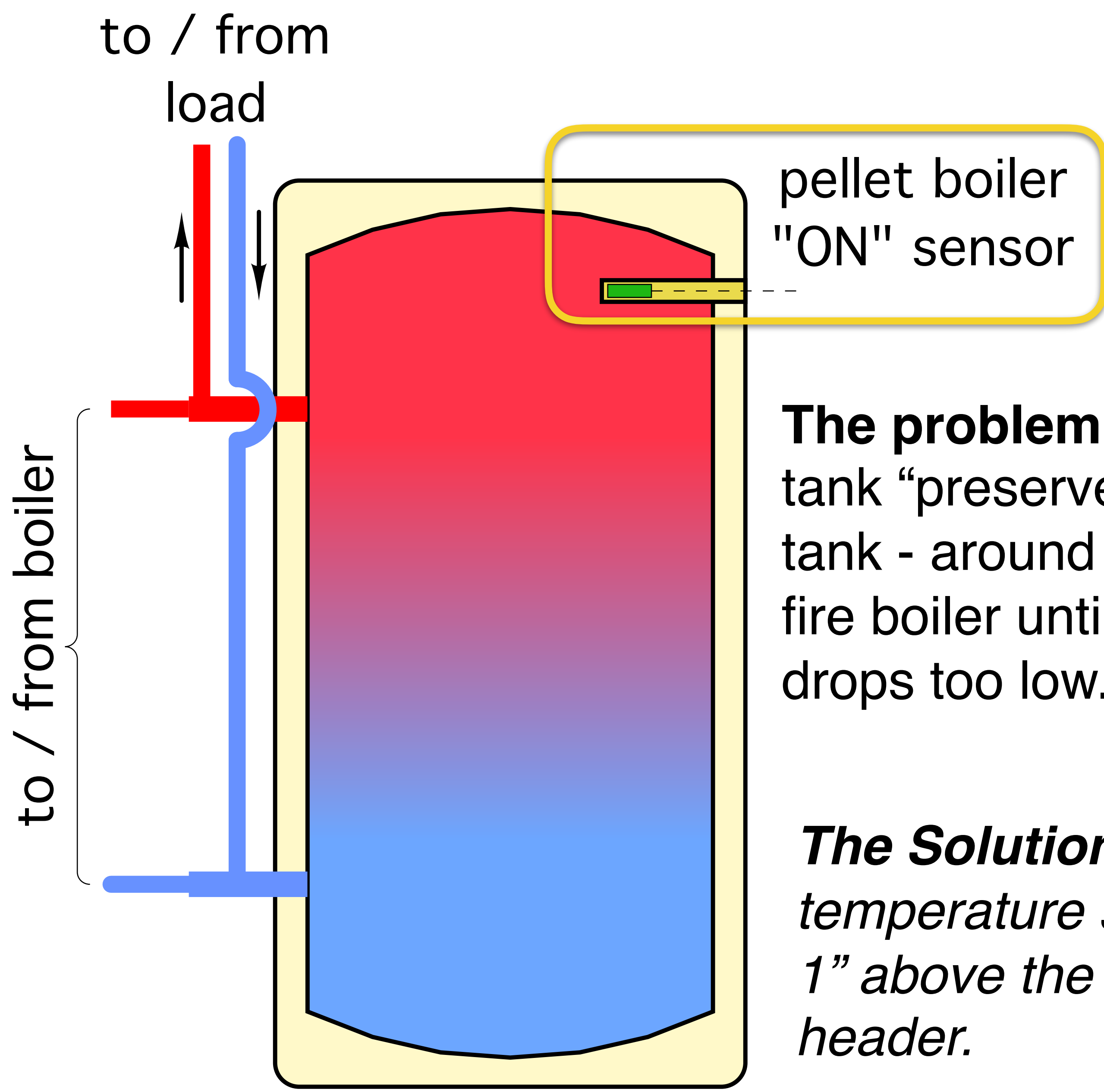




Thermal grease
in syringe:
$7, eBay

Honeywell
121371B
$15-25

Pellet boiler “ON” signal from high tank sensor with piping connections several inches below.



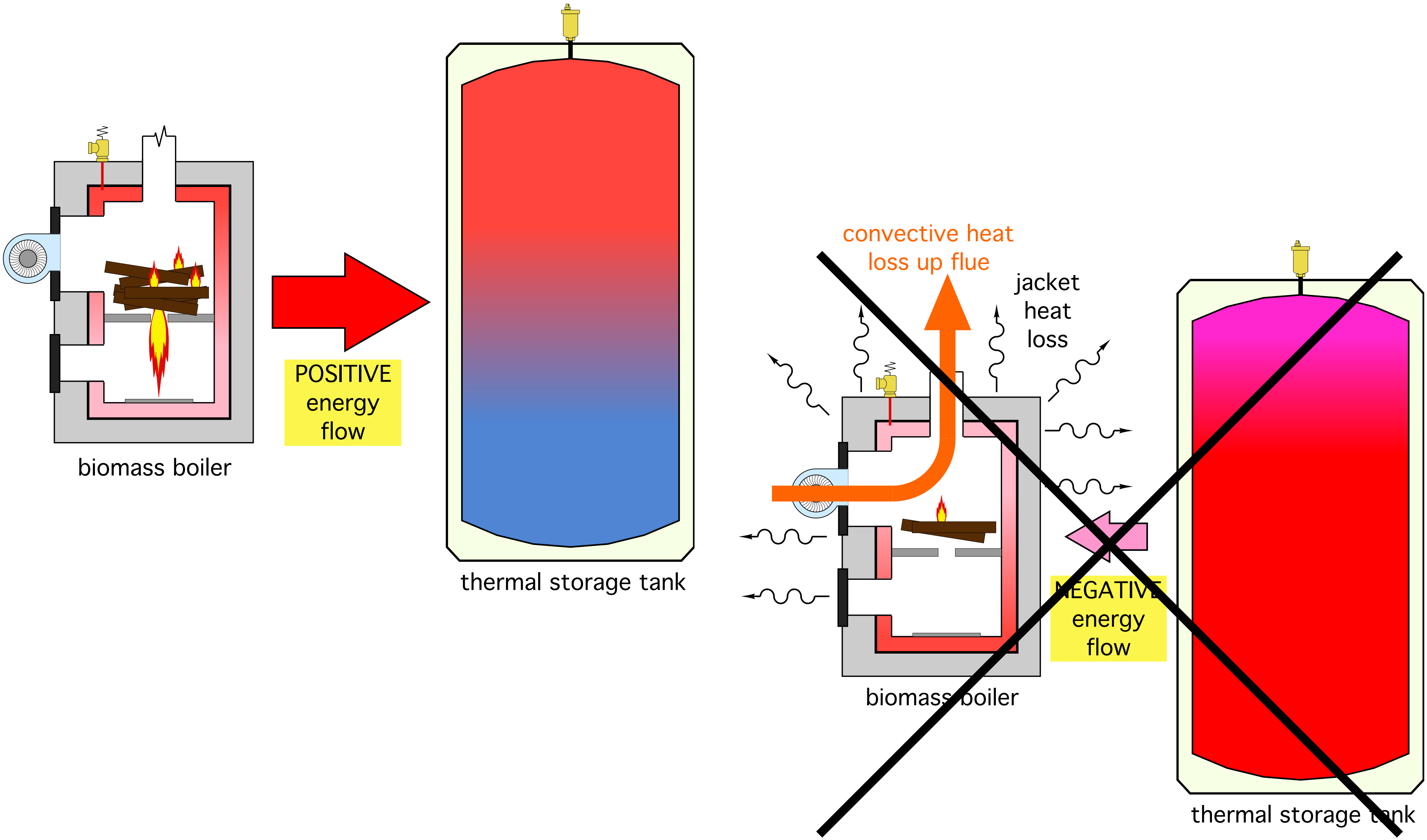
The problem: Stratification within tank “preserves” hot water at top of tank - around sensor - and fails to fire boiler until water temperature drops too low.

The Solution: *Keep the upper temperature sensor no more than 1” above the height of the upper header.*

Negative Energy Flow *(from storage to biomass boiler)* & how to prevent it

What is “Negative energy flow?”

Answer: Any condition that inadvertently transfers heat from thermal storage to the biomass boiler.

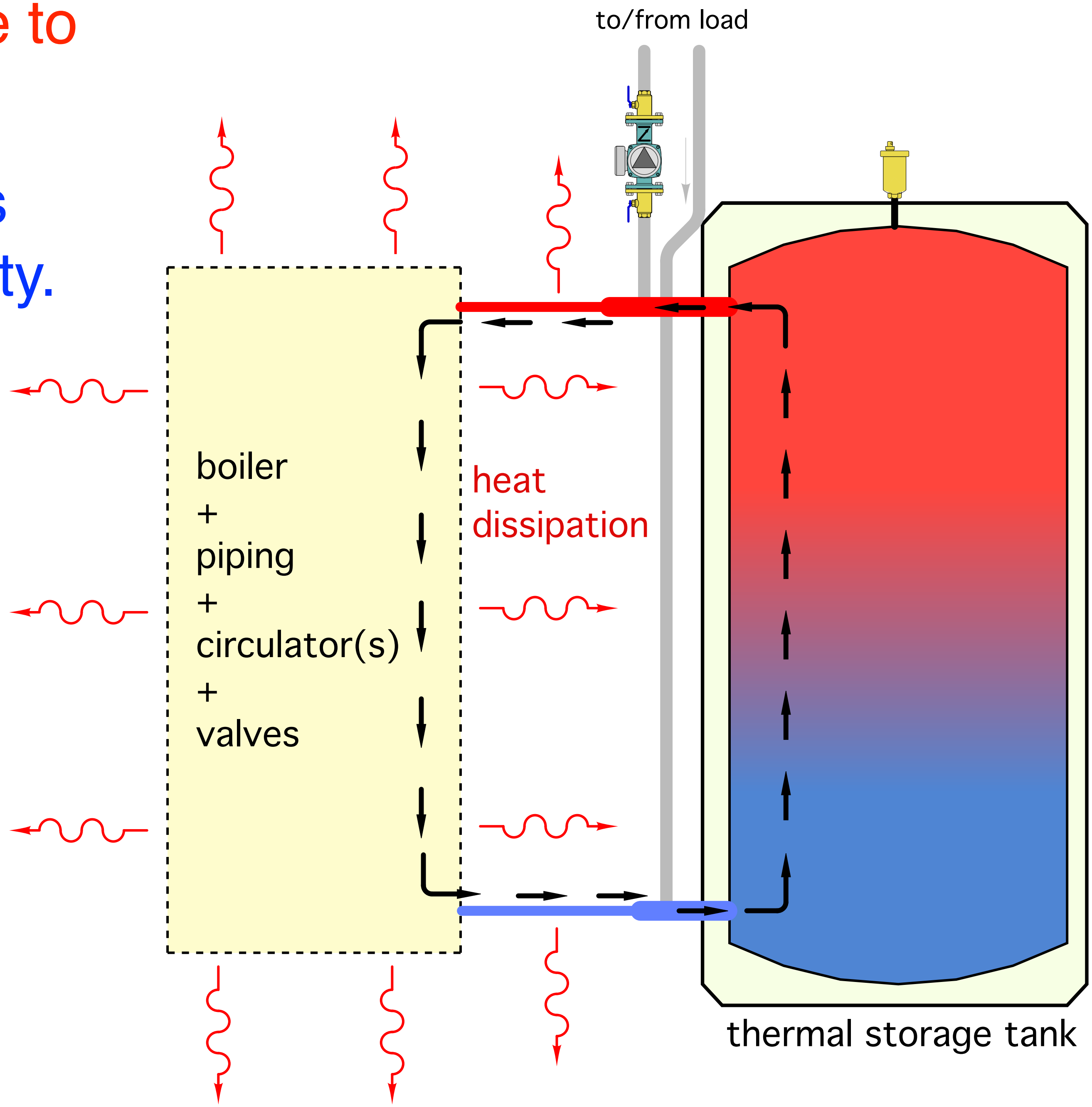


Reverse thermosiphoning is one form of negative energy flow.

Heated water rises due to reduced density.

Cooler water descends due to increased density.

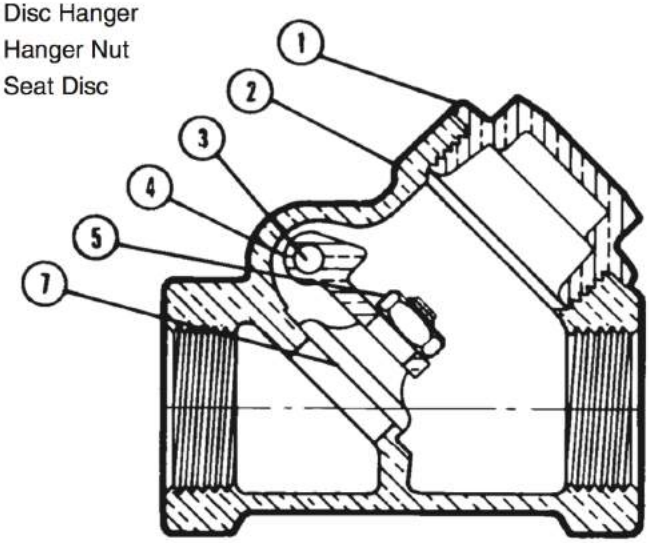
If unimpeded, warm water will flow out of tank, through any available path, dissipate heat in the process, and flow back into lower portion of tank.

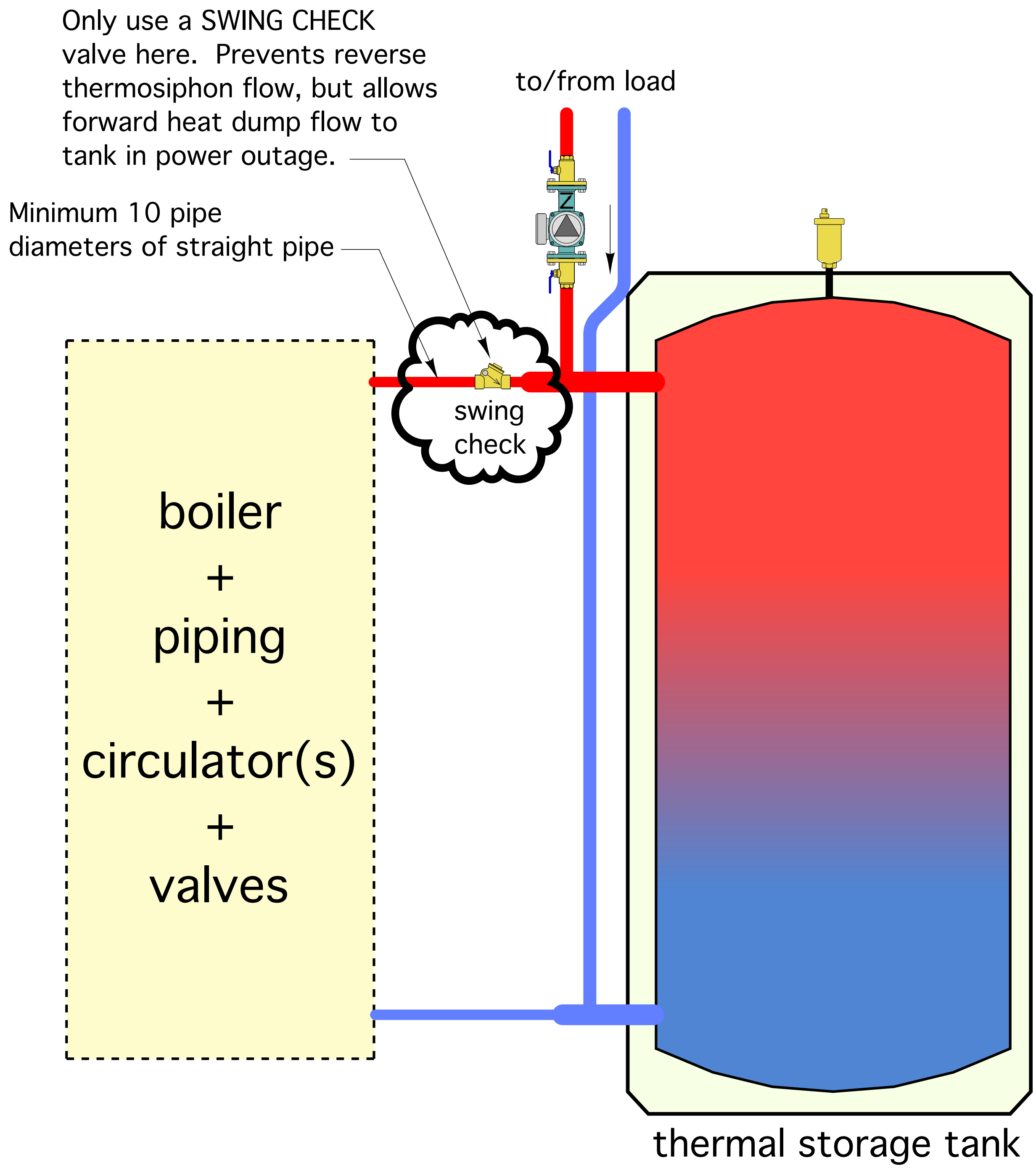


Use **swing check valve** to prevent reverse thermosiphoning.

swing check valves have virtually no resistance to forward thermosiphon flow

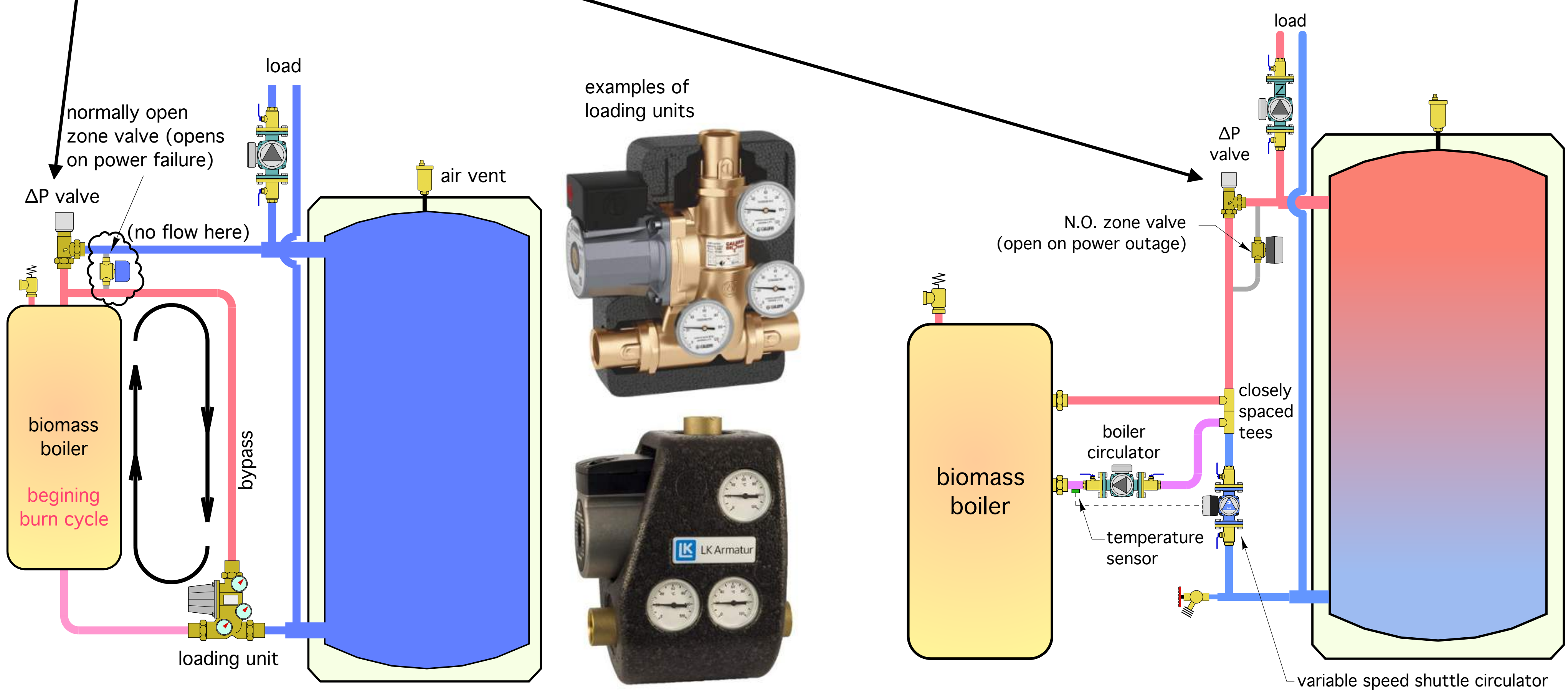
1. Bonnet
2. Body
3. Hinge Pin
4. Disc Hanger
5. Hanger Nut
7. Seat Disc





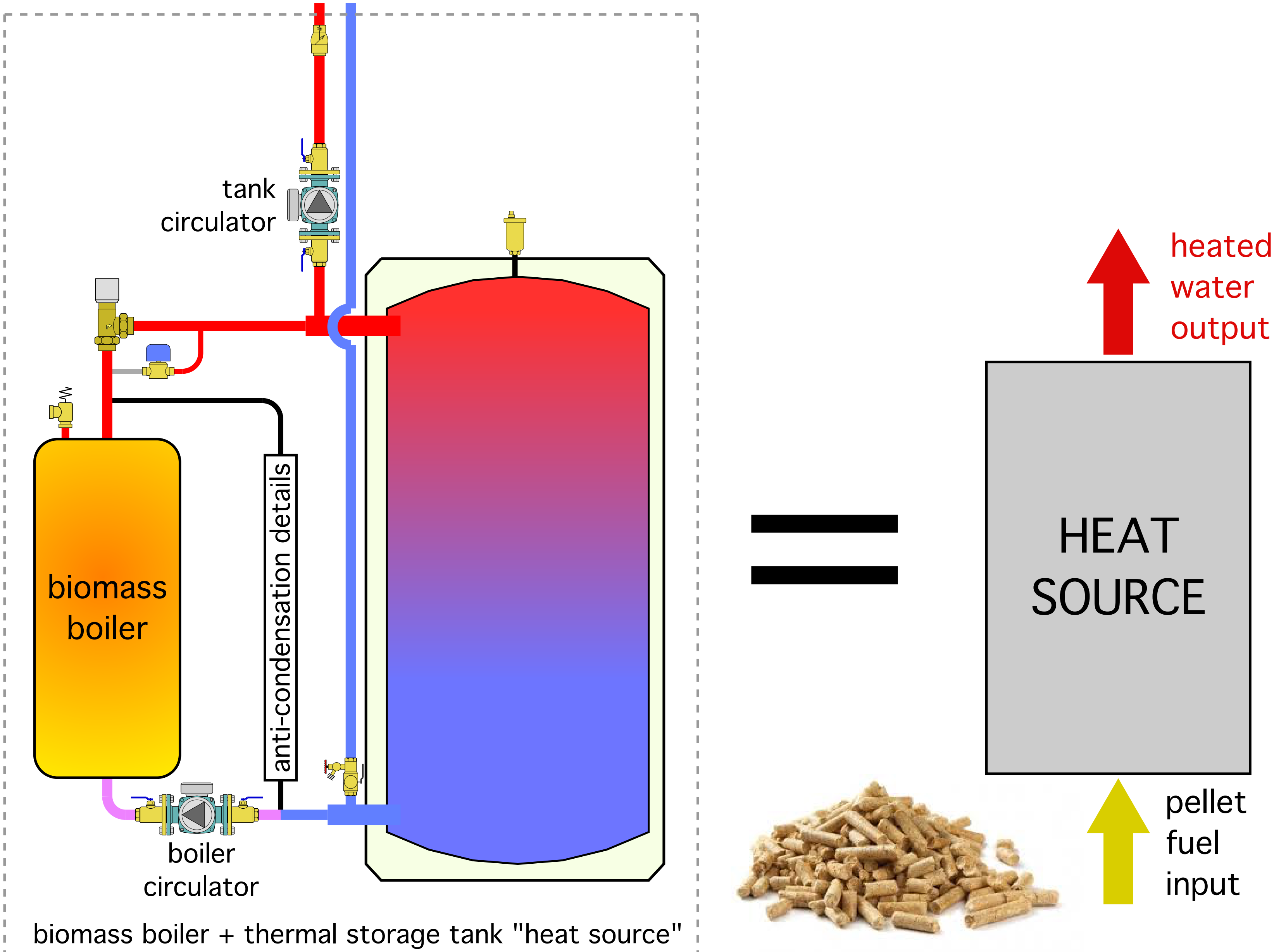
Using a **ΔP valve** to prevent reverse thermosiphoning.

- Set the valve for 1 to 1.5 psi forward opening pressure.
- Blocks forward and reverse thermosiphoning
- Can install normally open zone valve as bypass around ΔP valve to allow thermosiphoning in power outage



Preventing heat from auxiliary boiler from entering thermal storage tank

Think of the pellet boiler, combined with thermal storage as a "heat source" device



A typical "lead/lag" multiple boiler application

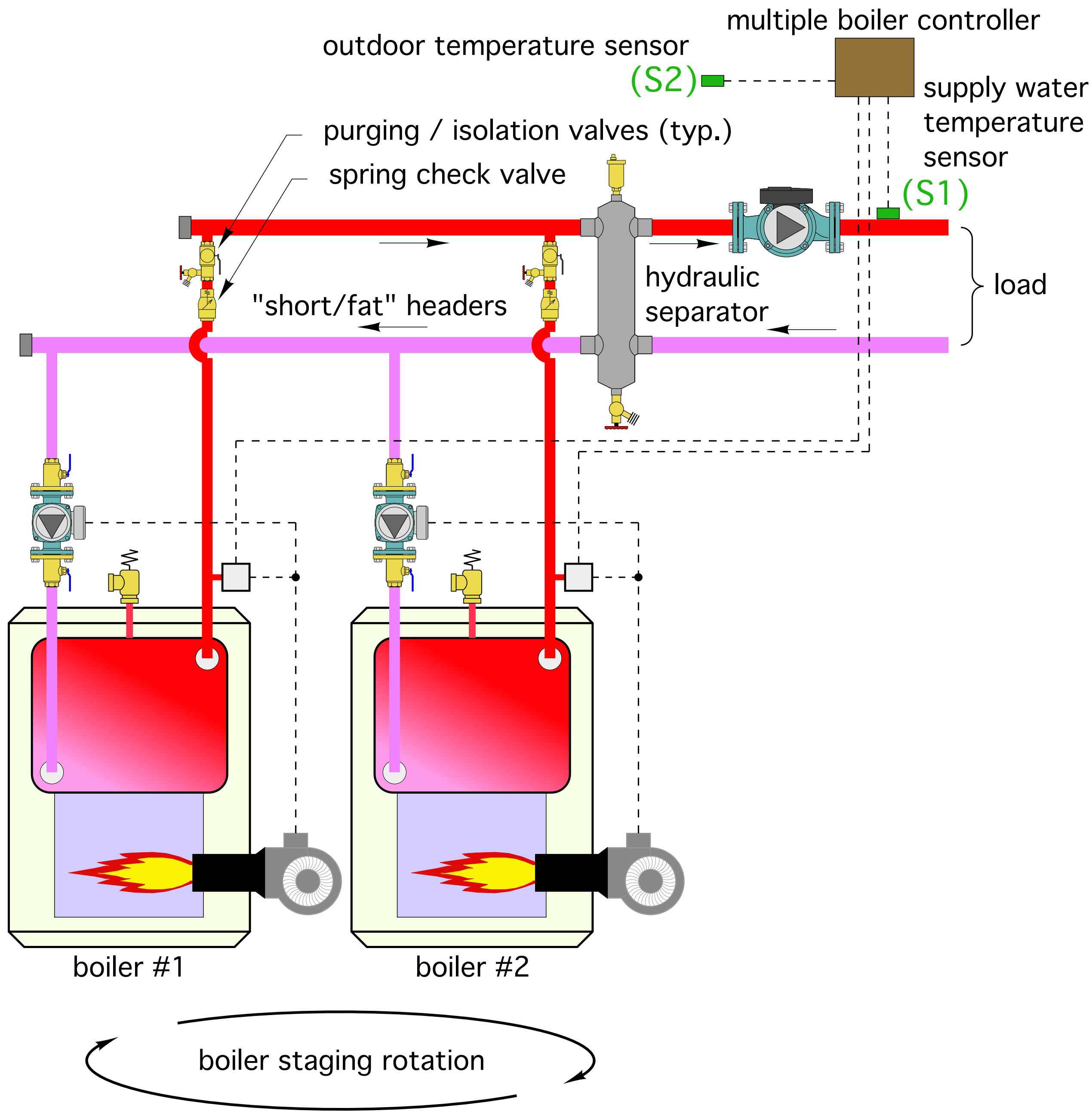
Boiler controller measures supply water temperature at sensor (S1), and compares it to the "target" supply water temperature.

If temperature at (S1) is lower than target temperature, one boiler is fired.

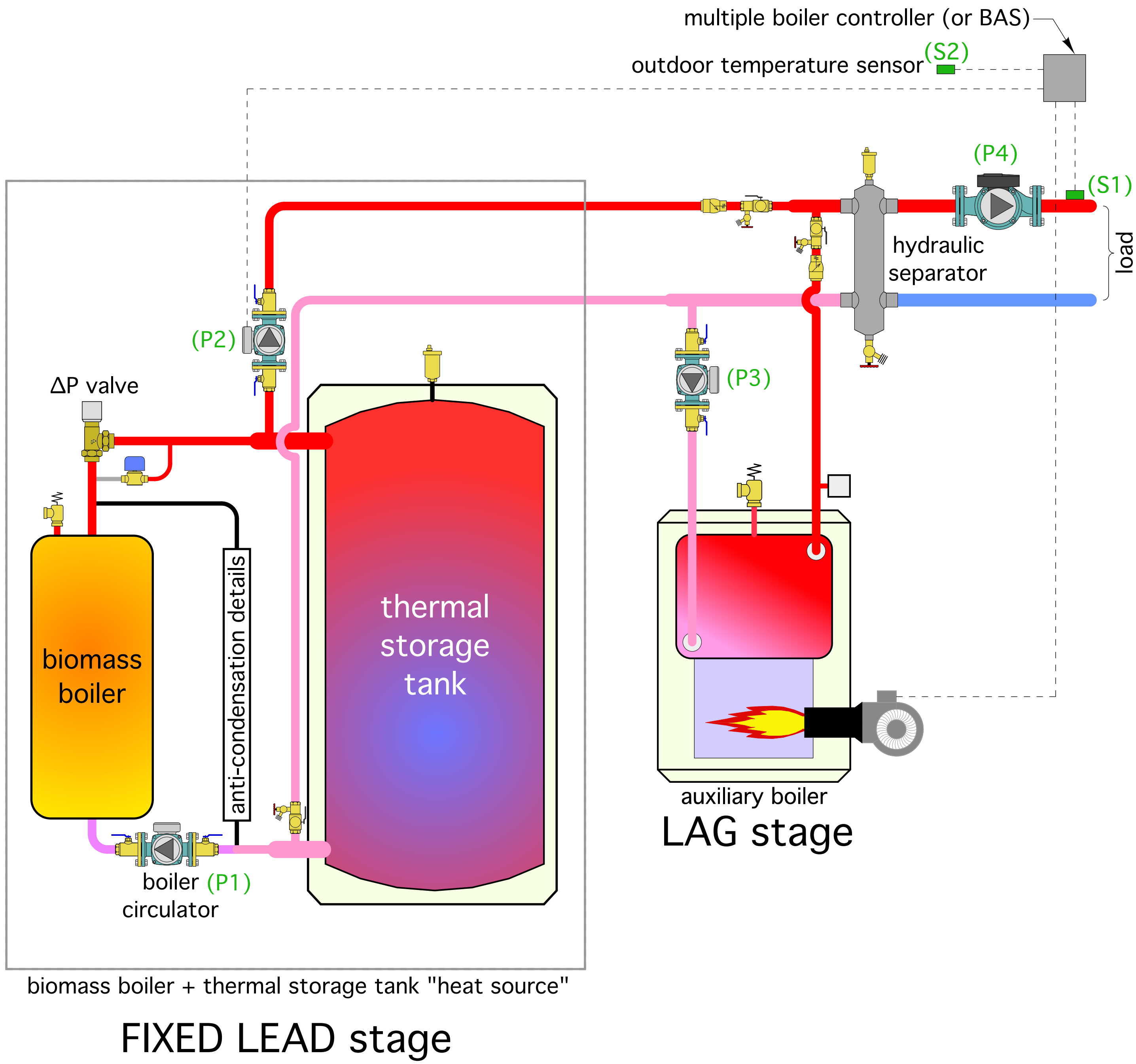
Boiler controller then uses PID logic to determine if more heat input is need. If it is, the other boiler is fired.

When all boilers are identical, the boiler controller typically "rotates" the firing order to create about the same run time for each boiler.

If boilers are different, one is designated as the "fixed lead" boiler, the other as the "lag" boiler.



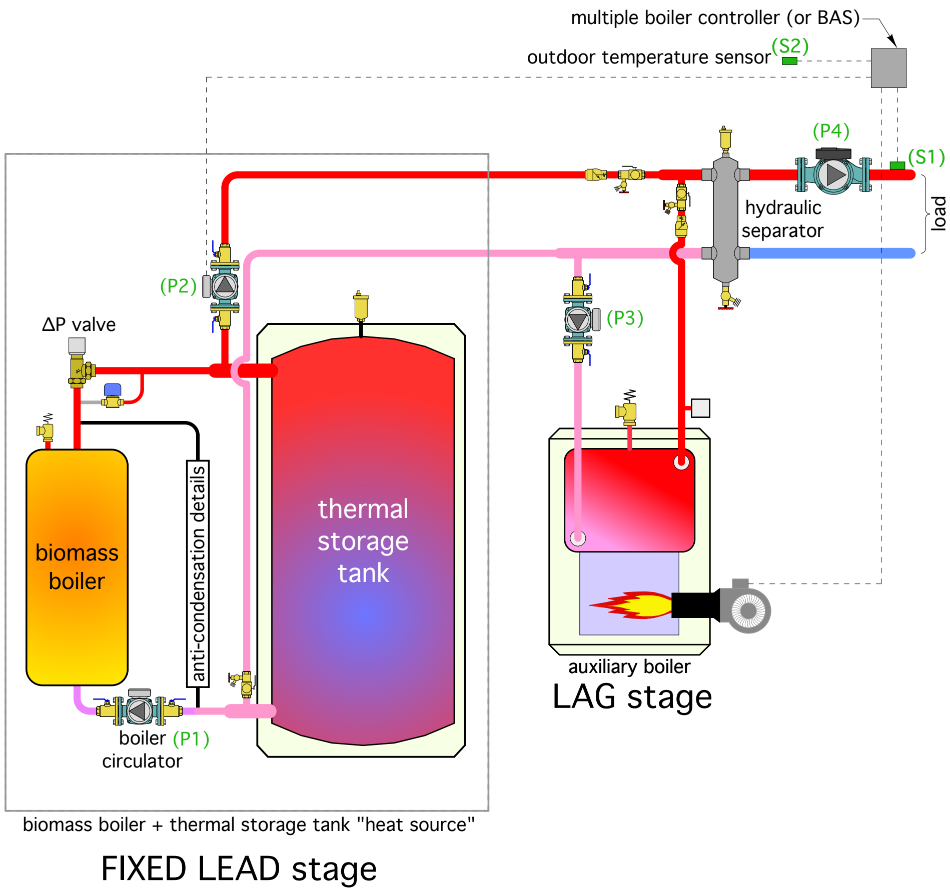
It’s “intuitive” for designers to create systems where the biomass boiler is treated as a “fixed lead” stage, and the auxiliary boiler is the “lag” stage.

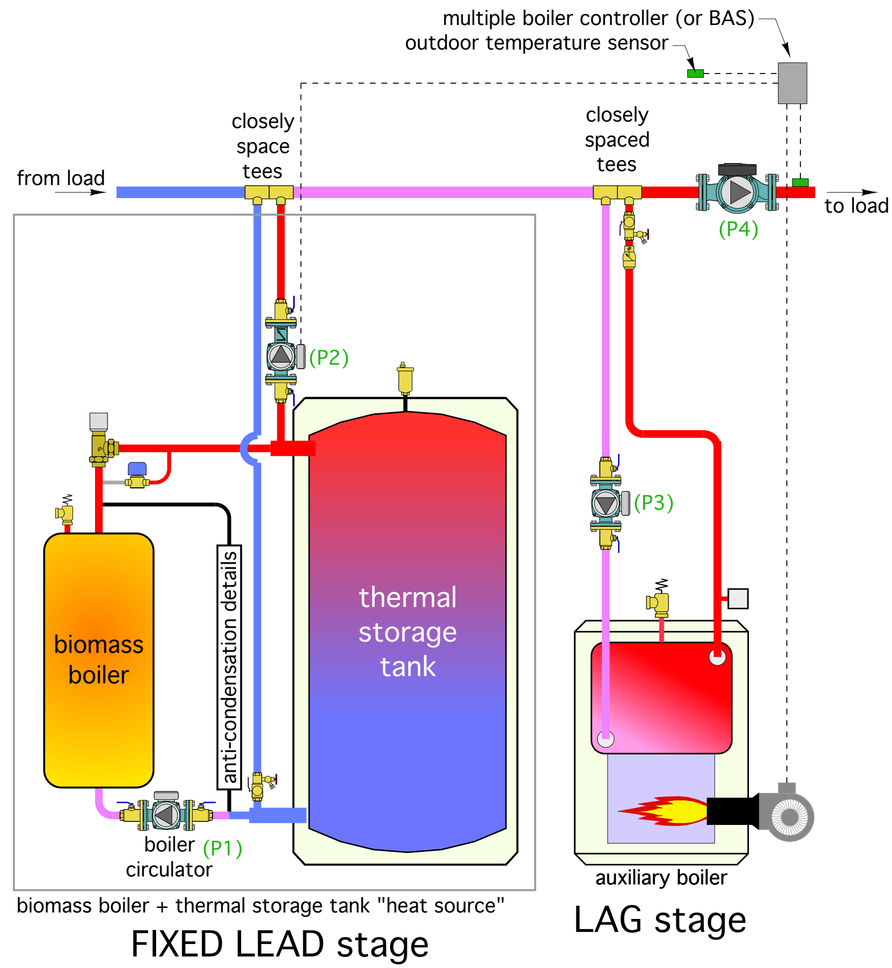


Both piping schemes provide hydraulic separation of all circulators

If combined flow rate of tank circulator (P2) and aux boiler circulator (P3) was greater than load flow rate there is some mixing inside the hydraulic separator. This would slightly increase return water temperature to the lower tank connection, which negatively impacts temperature stratification.

With this arrangement ***(and proper controls)*** energy added by aux boiler can be kept out of thermal storage. Assuming (P2) flow rate ≤ (P4) flow rate, the coolest water is returned to the lower tank connection.





The glitch…

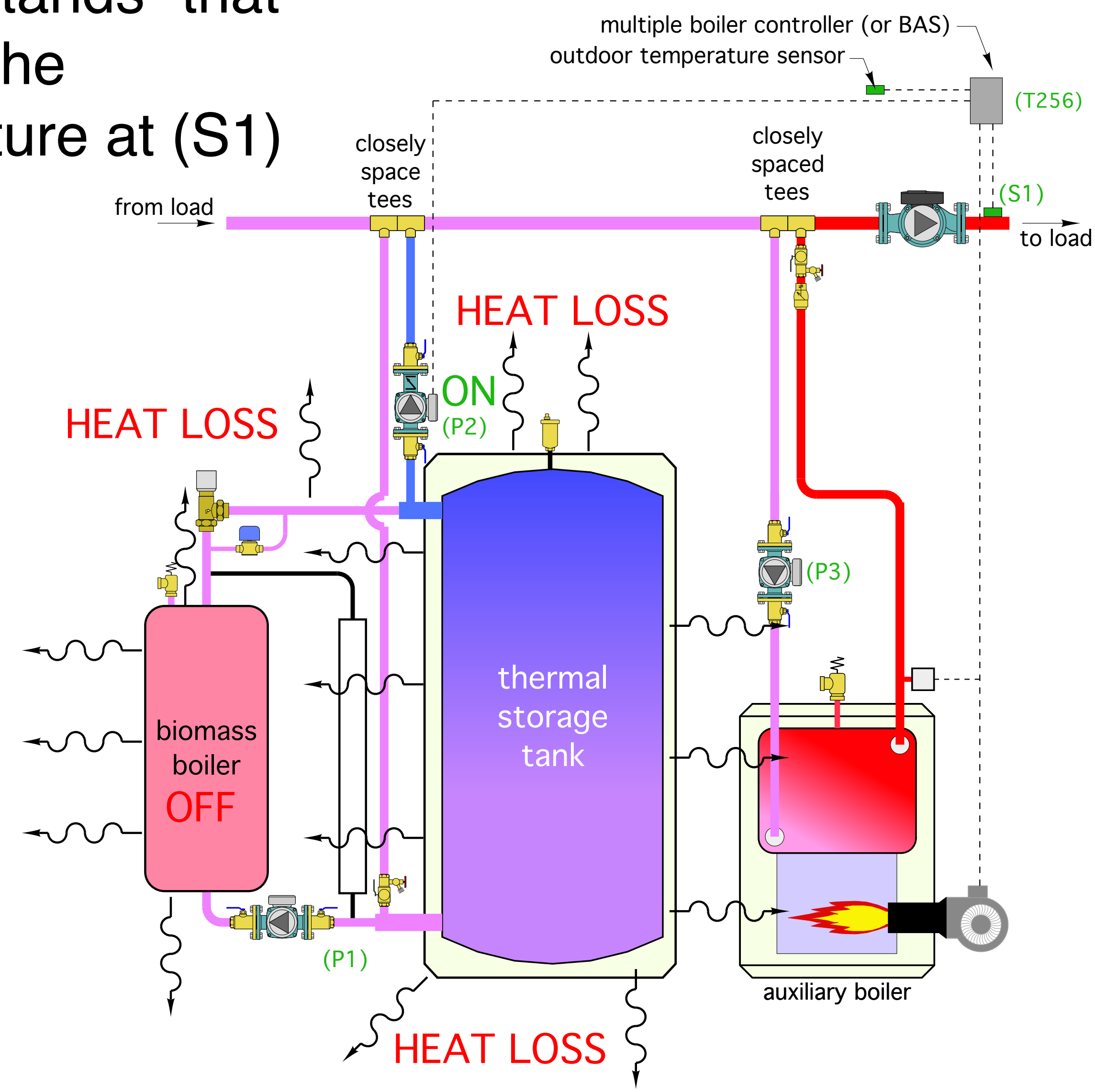
A standard multiple boiler controller "doesn't know" if the biomass boiler is *offline*, due to a fault, or if the tank is cooler than the minimum "useable" temperature of the distribution system.

The boiler controller only "understands" that the fix lead stage is not creating the necessary supply water temperature at (S1)

The boiler controller turns on stage 2, and keeps stage 1 on.

The result: The circulator creating flow between the tank and system remains on.

Heat produced by the auxiliary boiler is inadvertently carried into thermal storage, increasing heat loss to surrounding space.



In a conventional multiple boiler system the added heat loss created by flow of heated water through an unfired boiler - ***while not desirable*** - doesn't create substantial heat loss:

Most conventional boilers use either sealed combustion or have automatic flue dampers that close whenever the boiler is off. ***NOT the case with biomass boilers.***

Most conventional multiple boiler systems do not have larger thermal storage tanks. ***Lots of added surface area for heat loss.***

4000 gallon thermal storage tank (before insulation)

1200 gallon thermal storage tank

This really happens…

Ketchikan, AK new Public Library

This really happens…

When visited in March 2017:

- pellet boiler had been off for about 1 month awaiting service
- tank-to-load circulator was running
- boiler-to-tank circulator off at service switch, but on at BAS output
- tank temperature about 145 ºF, all heat coming from electric aux boiler
- If boiler-to-tank circulator had not been manually switched off, 145 ºF water would be circulating through boiler, creating jacket heat loss, and convective air currents up flue *(no flue dampers on pellet boilers).*

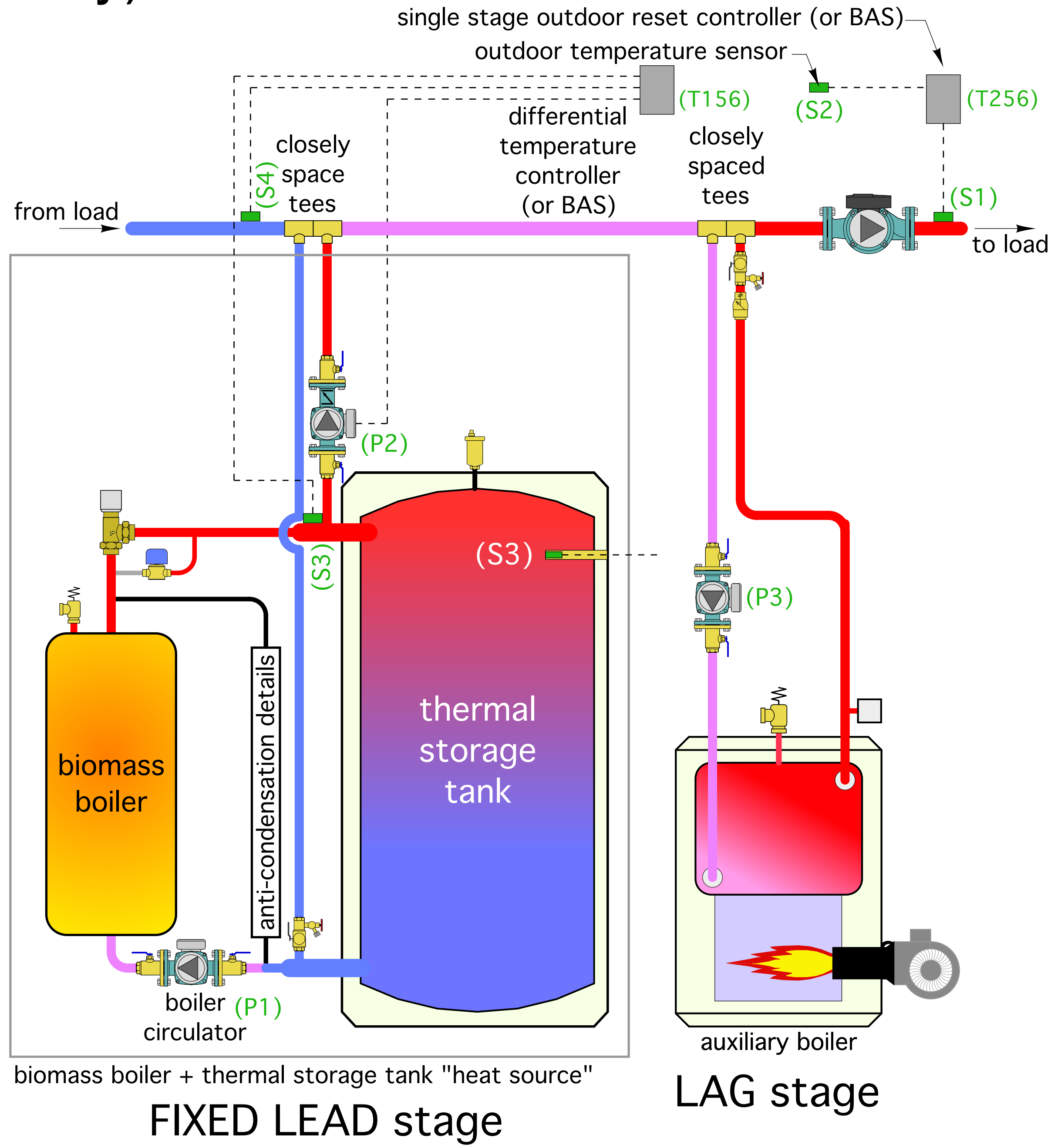
The solution is a simple *differential temperature controller* (or equivalent BAS functionality)

Compare the temperature at the upper tank header (S3) to the return temperature of the distribution system (S4).

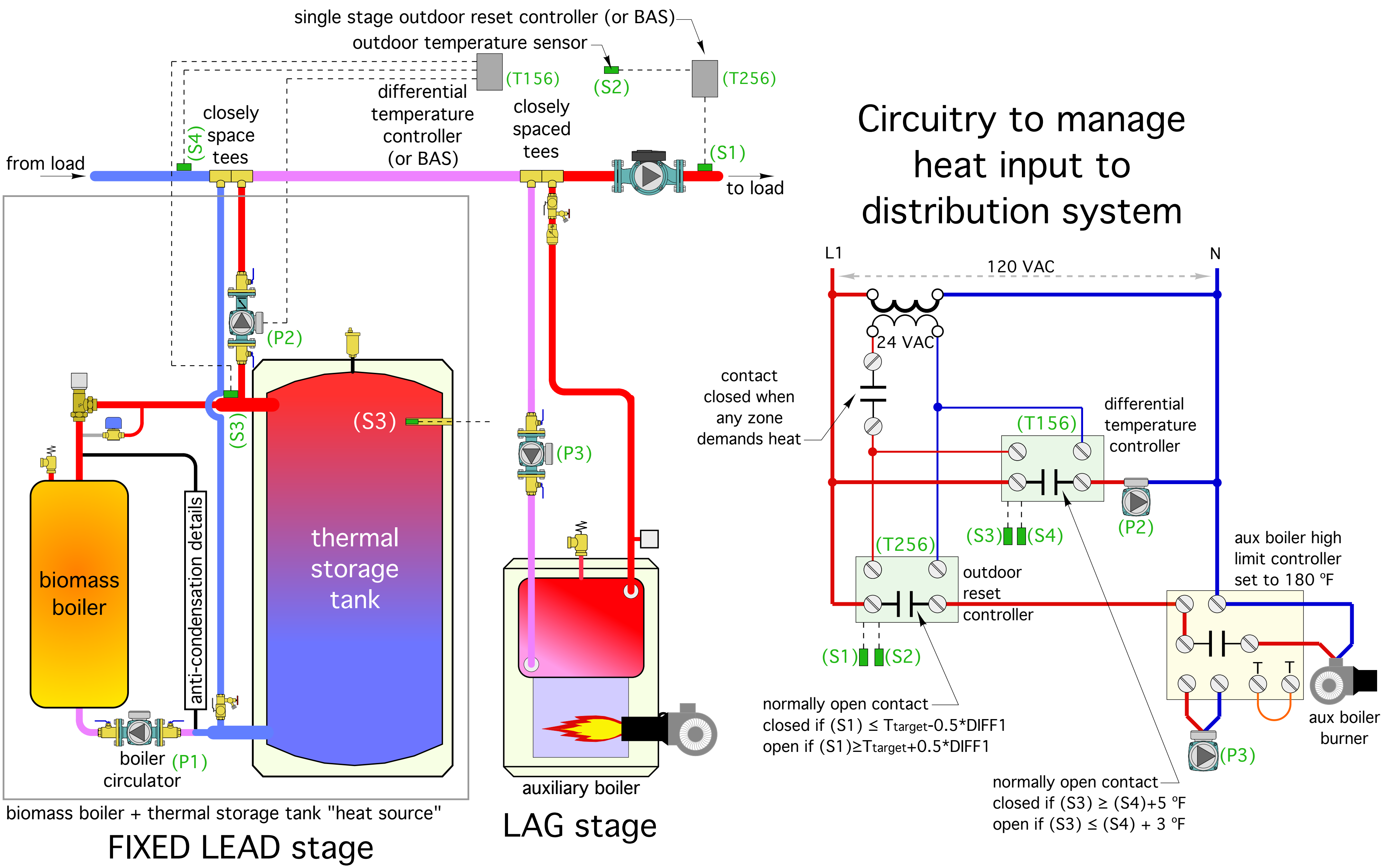
Circulator (P2) (tank to load) is only allowed to run when the tank can make a positive energy contribution to the system.

IF (S3) ≤ (S4) + 3 °F, THEN (P2) is OFF

IF (S3) ≥ (S4) + 5 °F THEN (P2) is ON



Using two simple, inexpensive controllers to manage heat flow to load



Sizing thermal storage

Thermal Storage Tank Sizing for wood-gasification boilers

The sizing procedure that follows is appropriate for wood-gasification boilers. ***It assumes that the thermal storage tank absorbs 95% of the heat released from burning a full charge of firewood, without any concurrent heating load.*** The volume of the required thermal storage tank can be determined using the following formula

$$v = \frac{701(w)(n)}{\Delta T}$$

Where:
v = required thermal storage tank volume (gallons)
w = weight of firewood that can be loaded in the combustion chamber (lb)
n = average efficiency of the combustion process (decimal percent)
ΔT = temperature rise of the tank based on absorbing all heat from the combustion (°F)
701 = a constant based on the heating fuel value associated with 20% moisture content firewood.

Thermal Storage Tank Sizing for wood-gasification boilers

Example: Assume that the firebox of a wood-gasification boiler, when fully loaded, can hold 65 pounds of seasoned firewood (20% m.c.). The boiler's average combustion efficiency ***for a complete burn cycle*** is 70%. Determine the thermal storage tank volume needed assuming the water in the tank will rise 60 °F as it absorbs 95% of the heat generated by burning the full charge of wood.

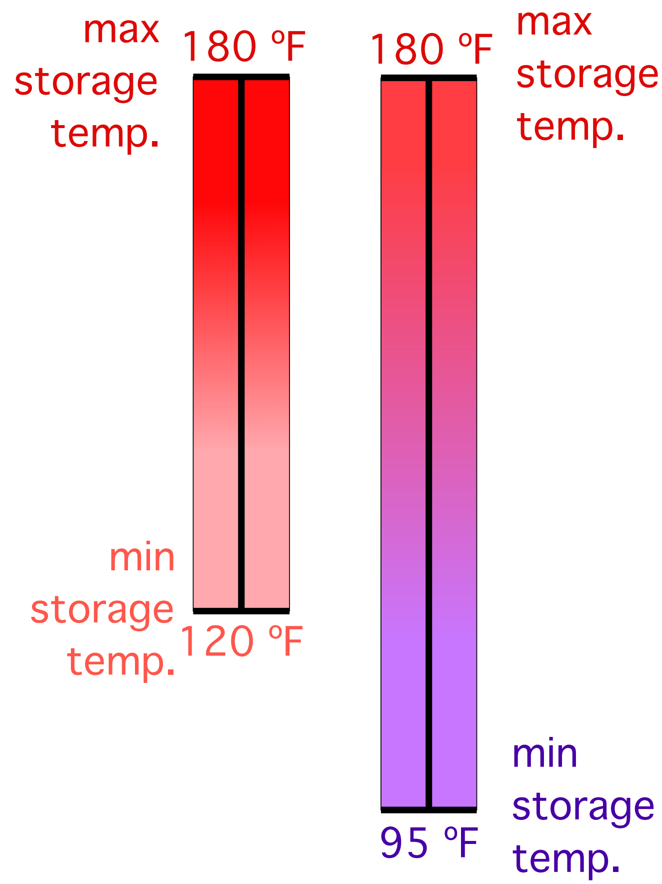
Solution: Putting the data into the formula yields:

$$v = \frac{701(w)(n)}{\Delta T} = \frac{701(65)(0.70)}{60} = 532\,gallons$$

This result shows that a substantial tank volume may be required in systems using wood-gasification boilers.

This volume can be achieved with a single tank, or by combining multiple tanks piped in parallel.

One way to reduce the required volume is to implement a control strategy that widens the temperature range over which the tank is used. With the upper temperature typically limited to 200 °F, ***the temperature range of the thermal storage tank can be widened by reducing the temperature at which the space-heating distribution system operates.***



ΔT 0f 85°F (180-95) yields 42% more Btu storage per gallon than ΔT of 60 °F (180-120)

Renewable Heat New York tank sizing criteria for wood-gasification boilers:

$$V_{tank} = [130 \times V_{cc}] - V_{wj}$$

where:

V_{tank} = volume of thermal storage (gallons)

V_{cc} = volume of primary combustion chamber (ft^3)

Vwj = volume of boiler water jacket (gallons)

Example: A wood gasification boiler has a combustion chamber measuring 16" x 20" x 24". Its water jacket holds 35 gallons of water. What is the required size of the thermal storage tank based on the above formula?

$$V_{cc} = (16in)(20in)(24in)\left(\frac{1ft^3}{1728in^3}\right) = 4.44\,ft^3$$

$$V_{tank} = [130 \times V_{cc}] - V_{wj} = [130 \times 4.44] - 35 = 542\,gallons$$

Boiler	Useable firebox volume (ft^3)	Multiplier (gallons/ft^3)	Water jacket volume (gallons)	=	Full thermal storage volume (gallons)	Acceptable sizing for commonly available vessels* (gallons)
A	5.0	130	32	=	618	600
B	6.3	130	42	=	777	700

* must be within 10%

http://www.nyserda.ny.gov/-/media/Files/FO/Current%20Funding%20Opportunities/PON%203010/3010alldocs.pdf

Sizing the storage tank for a modulating pellet fuel boiler

European recommendations: 1-2 gallons of buffer tank storage per 1,000 Btu/hr of boiler capacity.

Renewable Heat NY will require 2 gallons of buffer tank storage per 1,000 Btu/hr of boiler capacity.

The requirement for water-side thermal storage is also partially determined by the thermal mass and zoning of the heating distribution system.

High thermal mass + minimal zoning = minimal need for water-side thermal storage

Low thermal mass + extensive zoning = maximum need for water-side thermal storage

This topic is being researched, and the results should lead to more specific guidance on thermal storage in the near future.

Sizing considerations for wood-fired boilers

Impact of Wood Boiler Oversizing

Increased footprint requirements within limited boiler room space. (May require separate building to house boiler).

Significant capital cost premium for boiler.

Increased capital cost premium for fuel moving components.

Increased capital cost premium for flue gas treatment if necessary.

Excess hours under idle or low part-load operating conditions.

Efficiency penalty due to increased thermal mass re: start-up for morning heat during Fall/Spring shoulder seasons.

Increased emissions due to lower average flame temperature during part-load conditions.

Source: Technical and Economic Sizing Considerations for Commercial and Industrial Wood-fired Boiler Systems "Small can be beautiful",
Ray Albrecht, P.E. 2012, http://nebiomassheat.com/pdfs/2012/keyPrinciples/albrecht_boiler.pdf

Sizing a wood gasification boiler

Don’t size a wood gasification boiler based on its BTU/hr rating!

These boilers operate on “batches” of combustion rather than quasi-steady operation.

The sizing of a wood-gasification boiler is based on the number of firing cycles the owner is comfortable with during a design day.

Two complete firing cycles during a design day is common.

$$W = \frac{[T_{inside} - (T_d + 5)](UA_b)24 + E_{daily}}{eCN}$$

Where:

W = weight of firewood required to fill firebox of wood gasification boiler (lb)
T_{in} = indoor air temperature for design load conditions (ºF)
T_d = outdoor design air temperature (ºF)
UA_b = heat loss coefficient of building (Btu/hr/ºF)
24 = hour in day
E_{daily} = daily heat required for domestic hot water (Btu)
e = average efficiency of wood gasification boiler while operating (decimal %)
C = lower heating value of firewood being used (Btu/lb)
N = number of complete firing cycles per day under design load conditions
5 = the 24 hour average outdoor temperature is assumed to be 5 ºF above the outdoor design temperature

The sizing of a wood-gasification boiler is based on the number of firing cycles the owner is comfortable with during a design day.

Example: Estimate the firebox size, based on weight of wood it can contain, for a wood gasification boiler that supplies a building with a design heating load of 50,000 Btu/hr in a climate where the outdoor design temperature is -5 ºF, and the desired indoor temperature is 70 ºF. The building also requires 60 gallons per day of domestic hot water heated from 50 to 120 ºF. ***The owner wishes to have no more than two complete firing cycles during a design day.*** Assume the wood gasification boiler will be burning sugar maple at an average moisture content of 20%, and has an average combustion efficiency of 80%.

Solution: The value of UA_b is found by dividing the design heat load by the design temperature difference:

$$UA_b = \frac{50{,}000\,\frac{Btu}{hf}}{70^\circ F - (-5^\circ F)} = 667\,\frac{Btu}{hr\cdot^\circ F}$$

The daily energy required for domestic water heating is estimated

$$E_{daily} = (G)(8.33)(T_{hot} - T_{cold}) = (60)(8.33)(120-50) = 34{,}986\,Btu$$

The lower heating value of the specified wood is estimated:

$$LHV = 7950 - 90.34(w) = 7950 - 90.34(20) = 6143\,\frac{Btu}{lb}$$

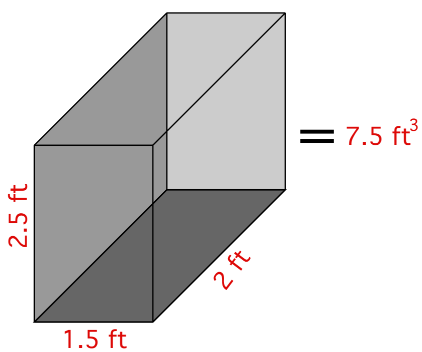
The wood capacity of the firebox is now estimated:

$$W = \frac{[T_{inside} - (T_d + 5)](UA_b)24 + E_{daily}}{eCN} = \frac{[70 - (-5+5)](667)24 + 34986}{(0.8)(6143)2} = 118lb$$

Measurements have shown that typical placement of split hardwood in an operating firebox yields an *effective packing density* of about 15 lb/ft³, thus the total firebox volume required is found as follows:

$$V_{firebox} = \frac{118lb}{15\frac{lb}{ft^3}} = 7.9\,ft^3$$

This would be the *minimum* firebox volume required, and based on the total internal dimensions of the firebox.



If 3 firings per design day were used, firebox volume = 5.3 ft³:

courtesy of Brookhaven Labs

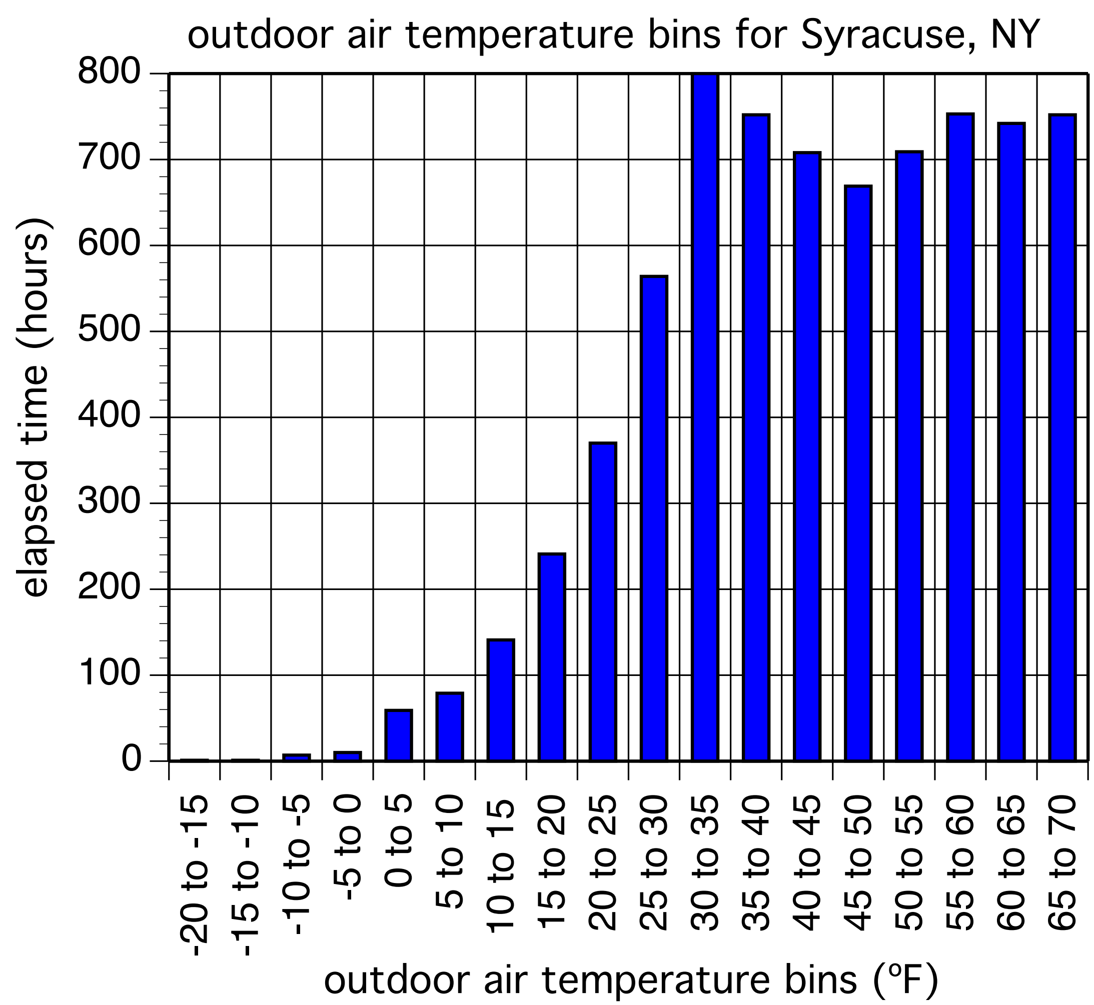
Sizing a pellet-fired boiler

(in combination with an auxiliary boiler)

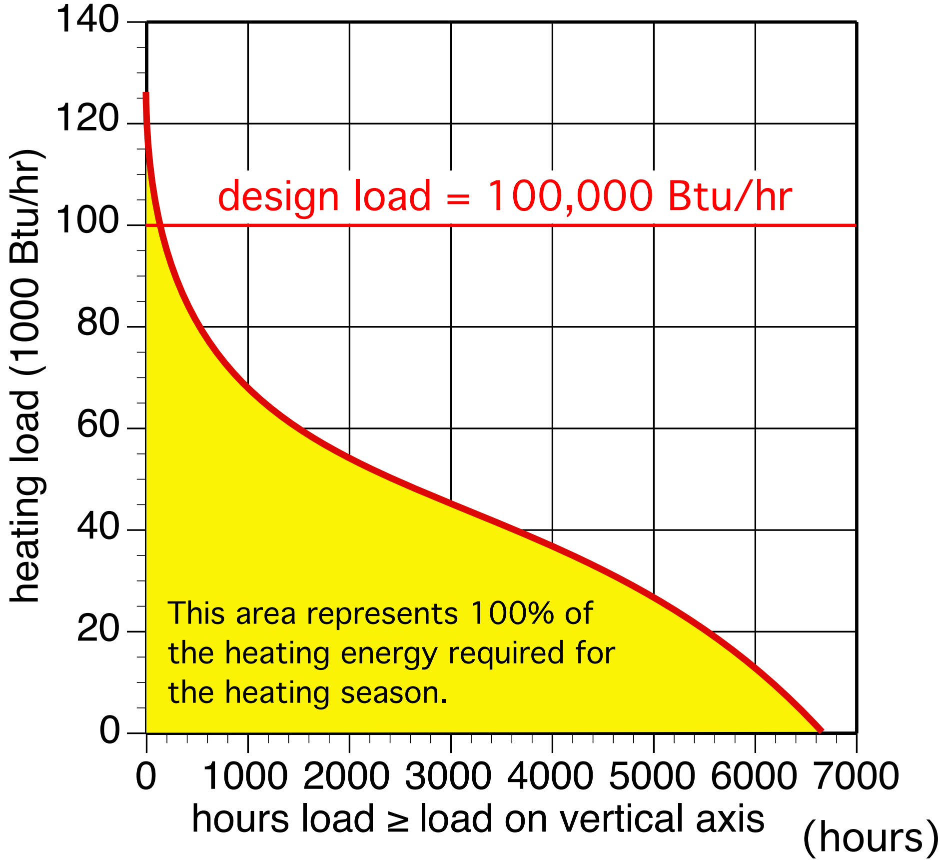
For good thermal and emissions performance, a pellet-fired boiler should operate over long cycles relative to their warm up time.

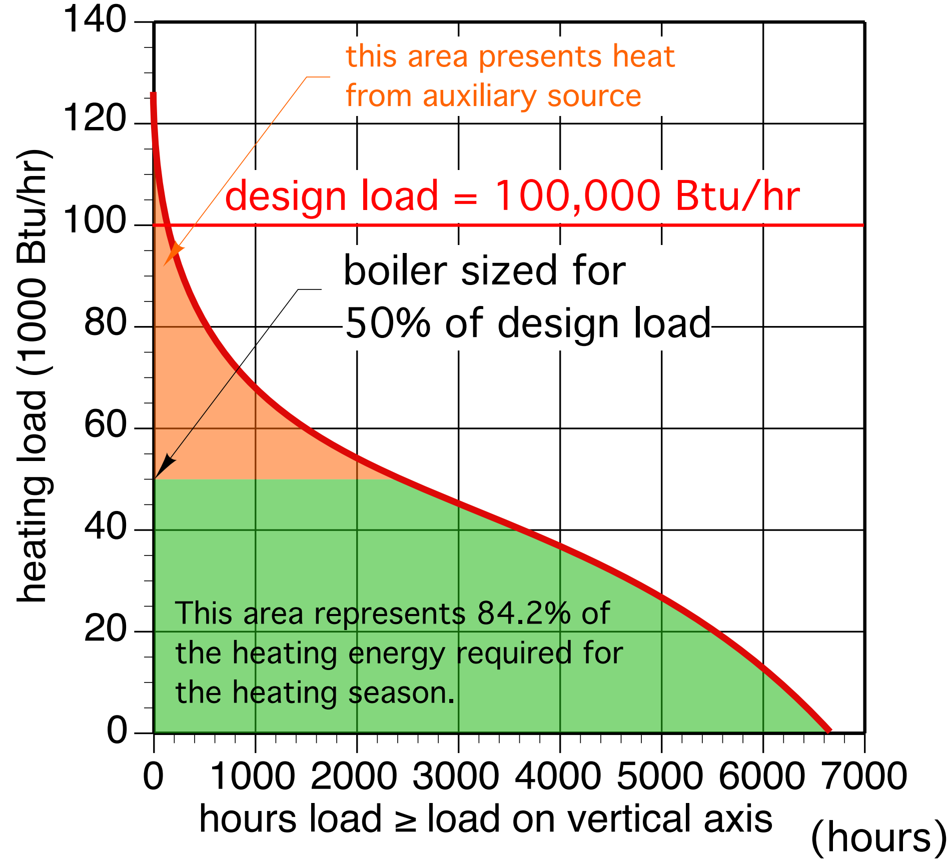
In situations where an existing boiler is present, or a new "auxiliary boiler" will be used, do not size the pellet-fired boiler to full design load.

Consider partial load analysis:



Partial load analysis:



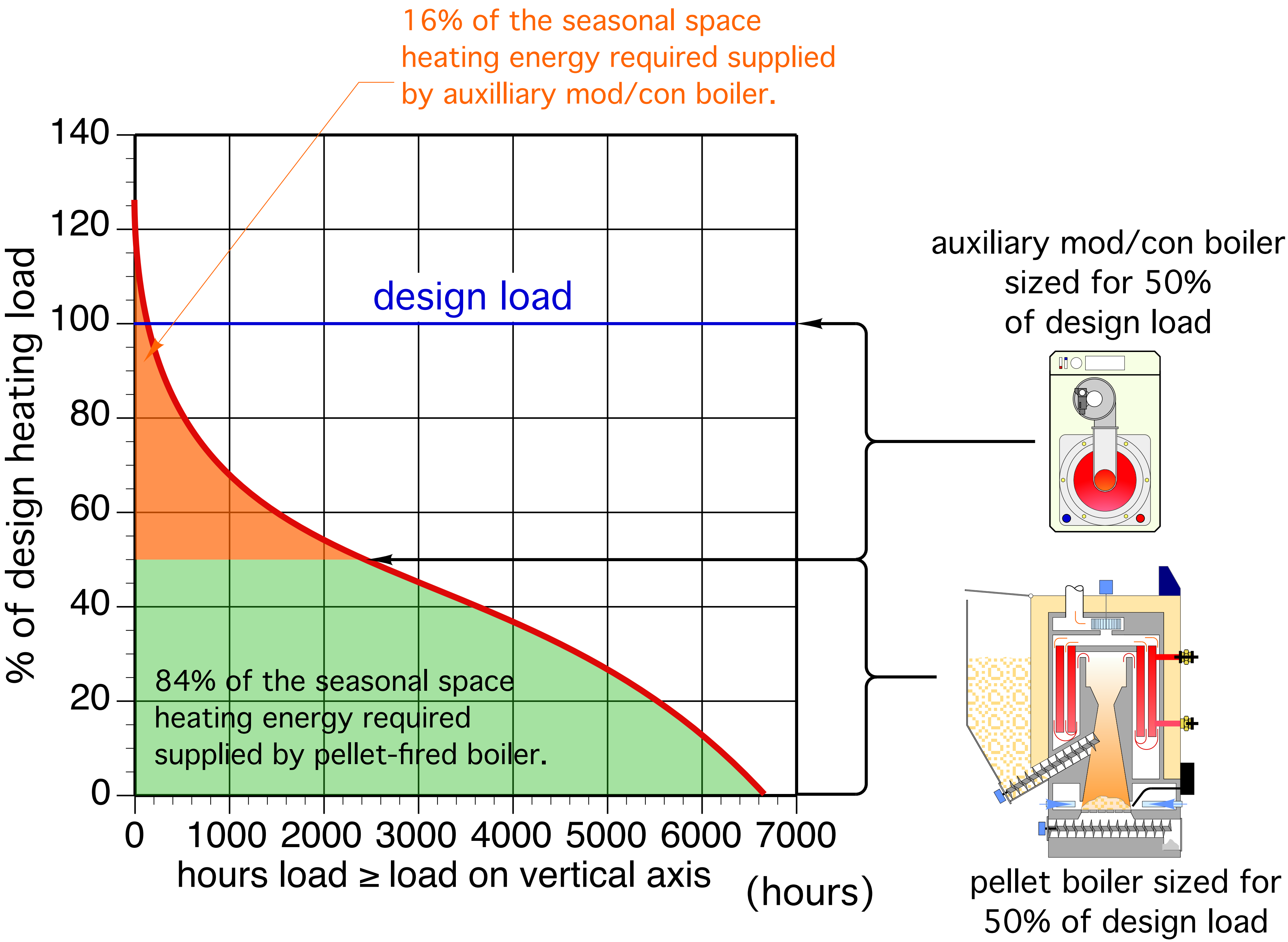


Boiler sized @ 50% of design load provides about 84% of seasonal space heating energy.

Boiler sized @ 60% of design load provides about 90% of seasonal space heating energy.

Boiler sized @ 75% of design load provides about 96% of seasonal space heating energy.

Partial load analysis:



Guidelines for sizing a pellet-fired boiler:

1. ***In systems where the pellet-fired boiler is the only heat source, the boiler is typically sized to the design load of the building.***

2. ***In systems where auxiliary heat is used, DON'T size the pellet boiler for design load.*** **Instead, size the pellet-fired boiler for 60 to at most 75% of design load.**

The higher end being for pellet boiler with wide modulation capabilities such as a 5:1 (or higher) turndown ratio.

This allows the pellet boiler to supply "base load" heating, while leaving only 5 to 10% of the total seasonal heating energy to be supplied by an auxiliary heat source.

3. ***For systems where the pellet boiler is ≥ 300,000 Btu/hr, RHNY requires that the pellet boiler capacity not exceed 60% of design load. Auxiliary heating is needed.***

4. ***For systems where the design heating load is ≥ 300,000 Btu/hr, the use of multiple pellet-fired boilers is encouraged. Higher financial incentives are available through (RHNY) for these "tandem" boiler systems.***

Using Existing Underground Piping

Using existing underground piping

With few exceptions, the insulated underground piping installed for outdoor furnaces is 1” PEX

This existing piping should be evaluated if it is being considered for carrying heat from a new biomass boiler.

For a nominal working temperature drop of 20ºF, the piping and circulator(s) should provide 1 gallon per minute (gpm) of water flow per 10,000 Btu/hr of rated biomass boiler capacity.

Head loss for 1” PEX carrying 150ºF water

$$H_L = \left(\frac{L_{total}}{100}\right)(0.2034) f^{1.75}$$

H_L = head loss (feet)
L_{total} = round trip circuit length (feet)
f = flow rate (gpm)

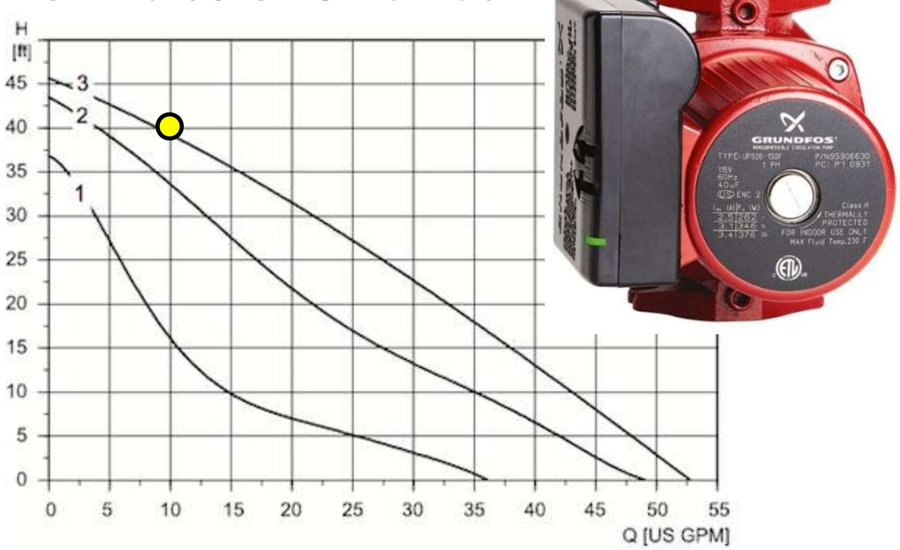
Using existing underground piping

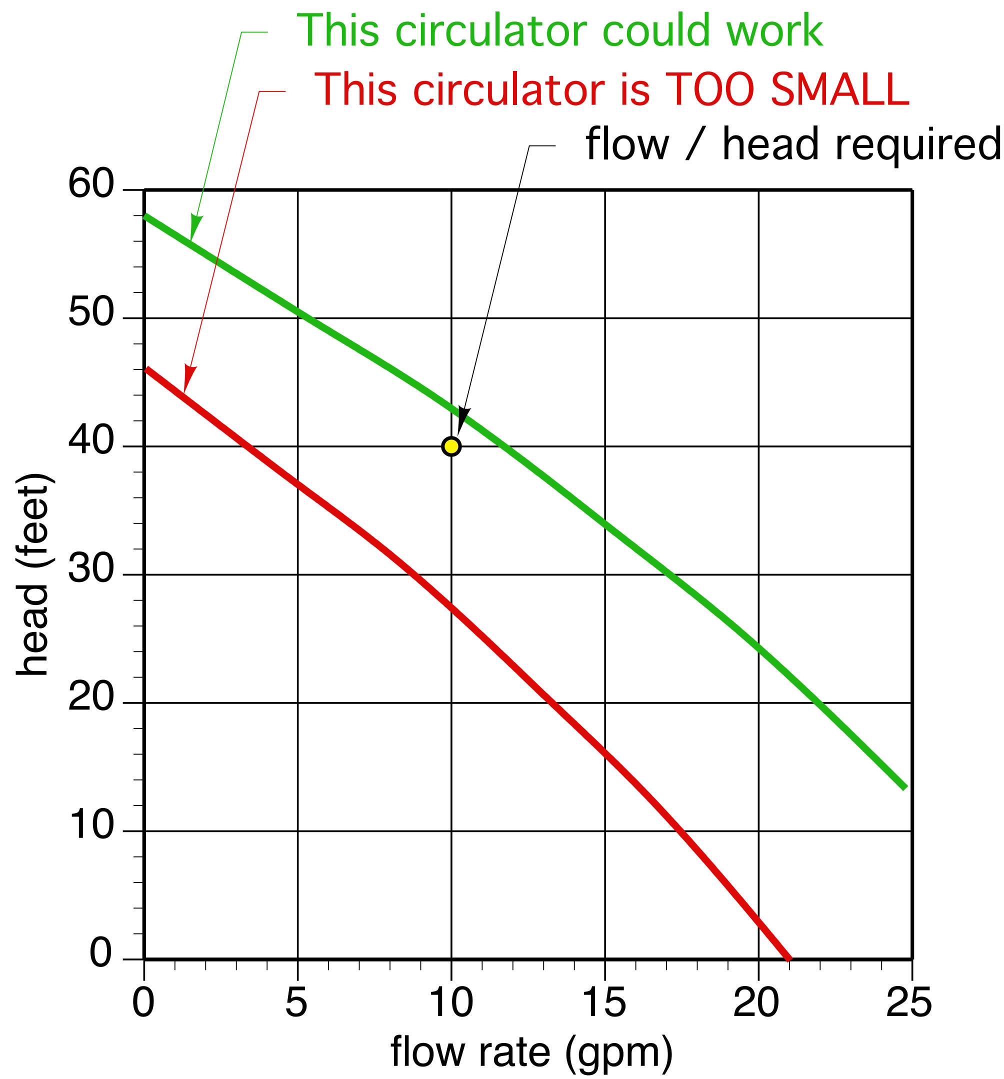
Example: Find the head loss of a 1” PEX circuit with a total length of 350 feet, and carrying water at 10 gpm.

$$H_L = \left(\frac{L_{total}}{100}\right)(0.2034)\,f^{1.75} = \left(\frac{350}{100}\right)(0.2034)[10]^{1.75} = 40\,feet$$

Now - select a circulator that can produce at about 10 gpm at 40 feet of head.

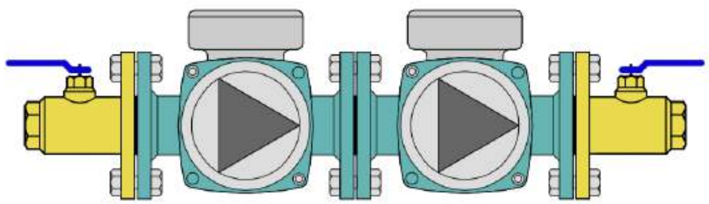
published pump curves for Grundfos UPS 26-150





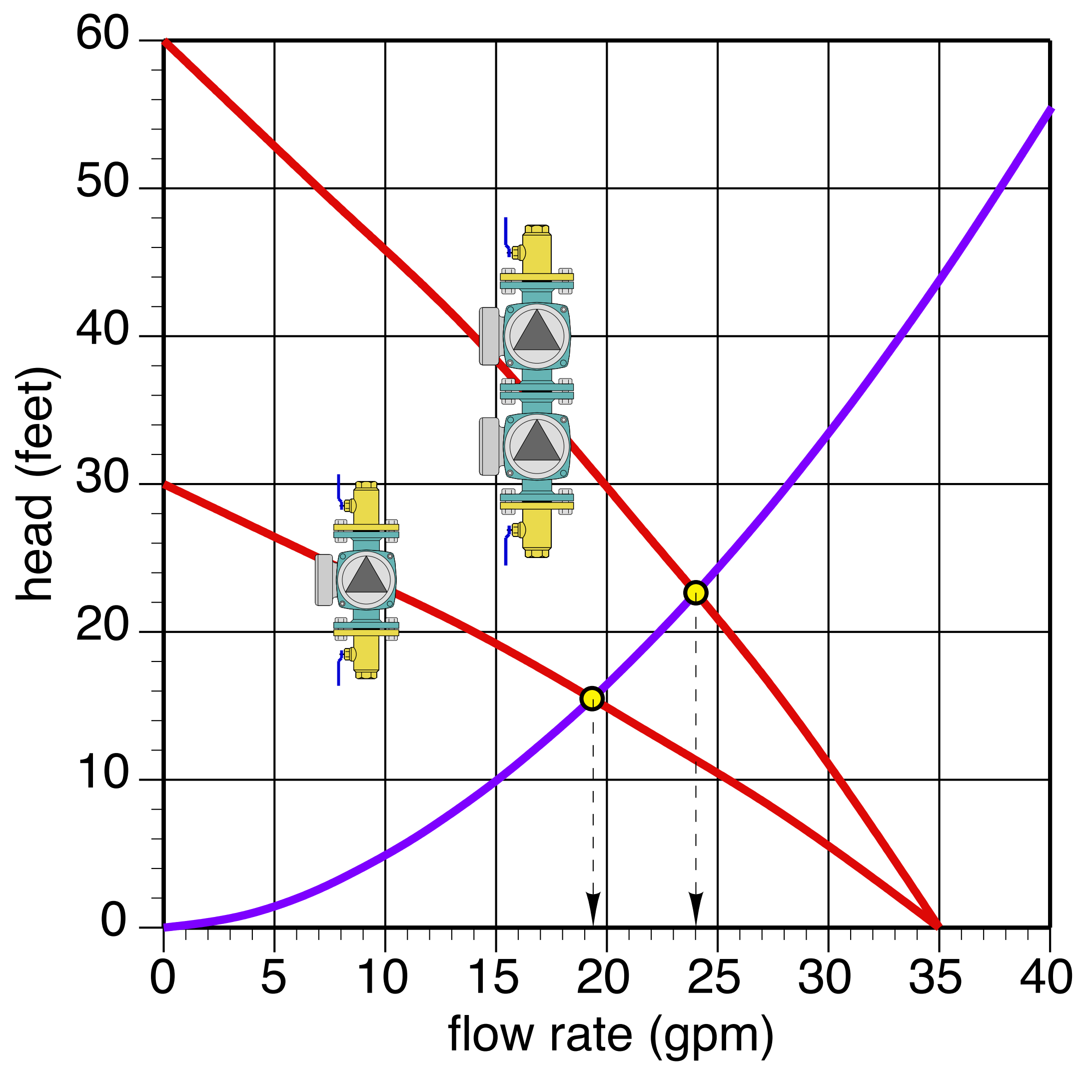
Using existing underground piping

When the head requirement is high, it's often best to use two circulators in "close coupled" series arrangement.



The pump curve for 2 circulators in series is found by doubling the head at each flow rate.

NOTE: 2 circulators in series will NOT double the flow rate in the circuit.

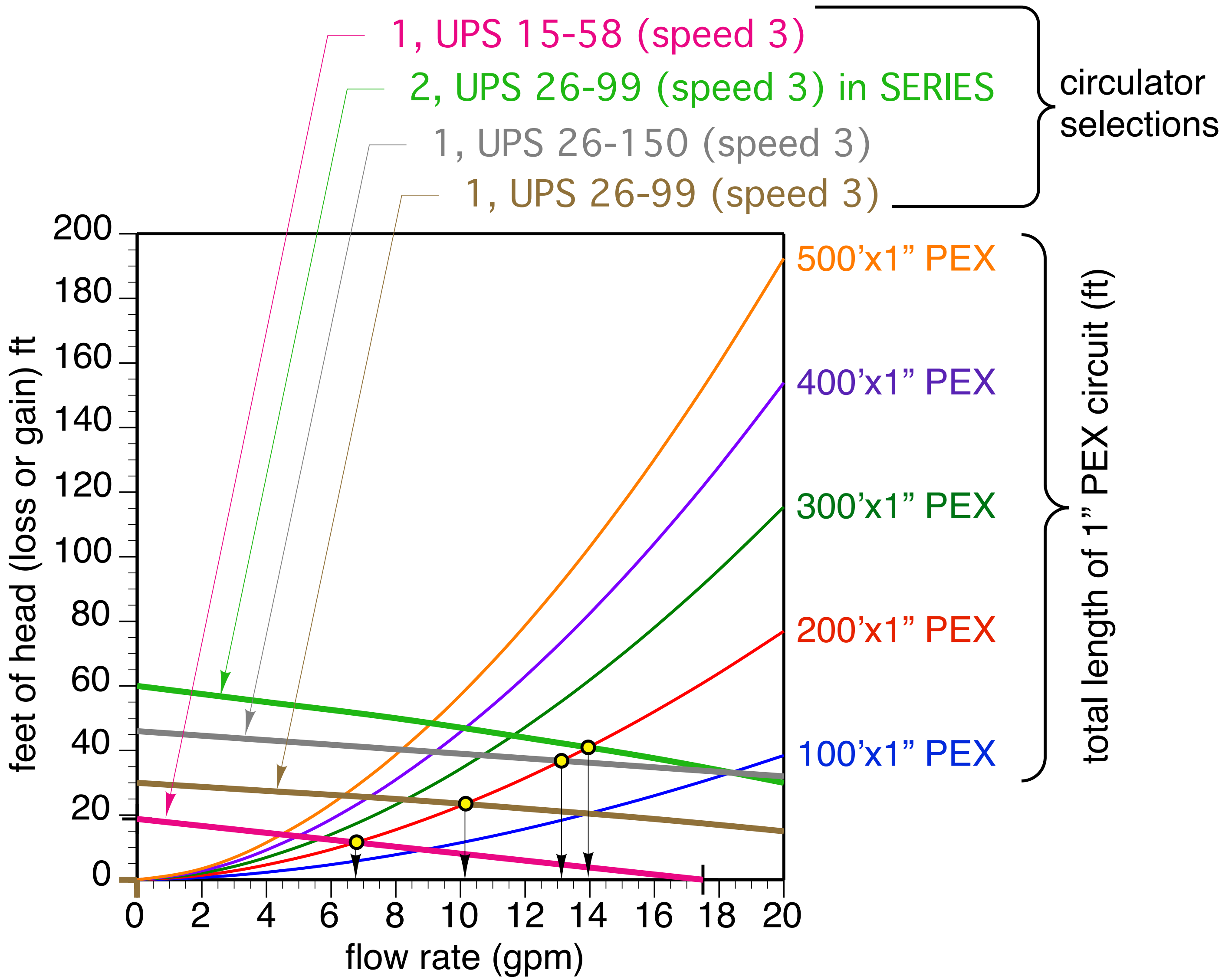


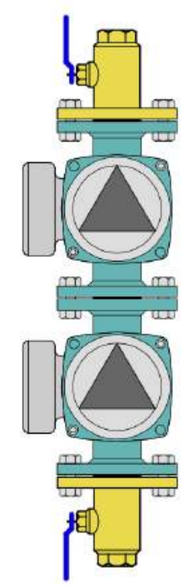
Using existing underground piping

The flow in any given circuit is found at the intersection of the pump curve and circuit head loss curve…

Grundfos UPS 26-99

Grundfos UPS 26-150





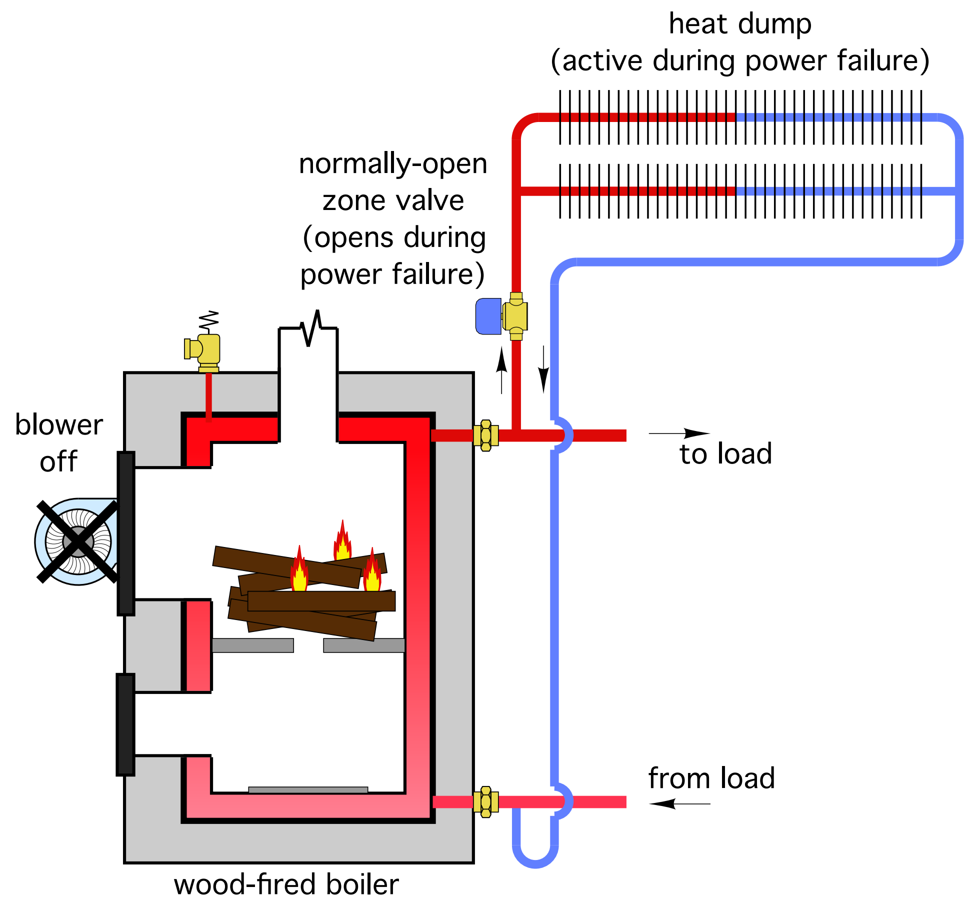
2 circulators in "close-coupled" series. ***Double the head at each flow rate.***

Boiler Protection Considerations

Boiler protection:

- Against low entering water temperature
- Against overheating during power failure

creosote



It's necessary to protect wood-fired boilers from low entering water temperatures.

This can be done several ways:

1. Thermostatic bypass valve
2. Loading units (circulator + valve)
3. Variable speed shuttle pump
4. On/off "toggled" circulators

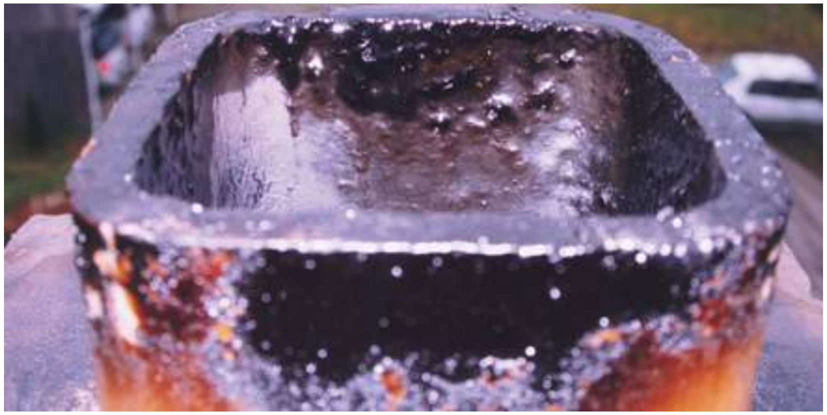
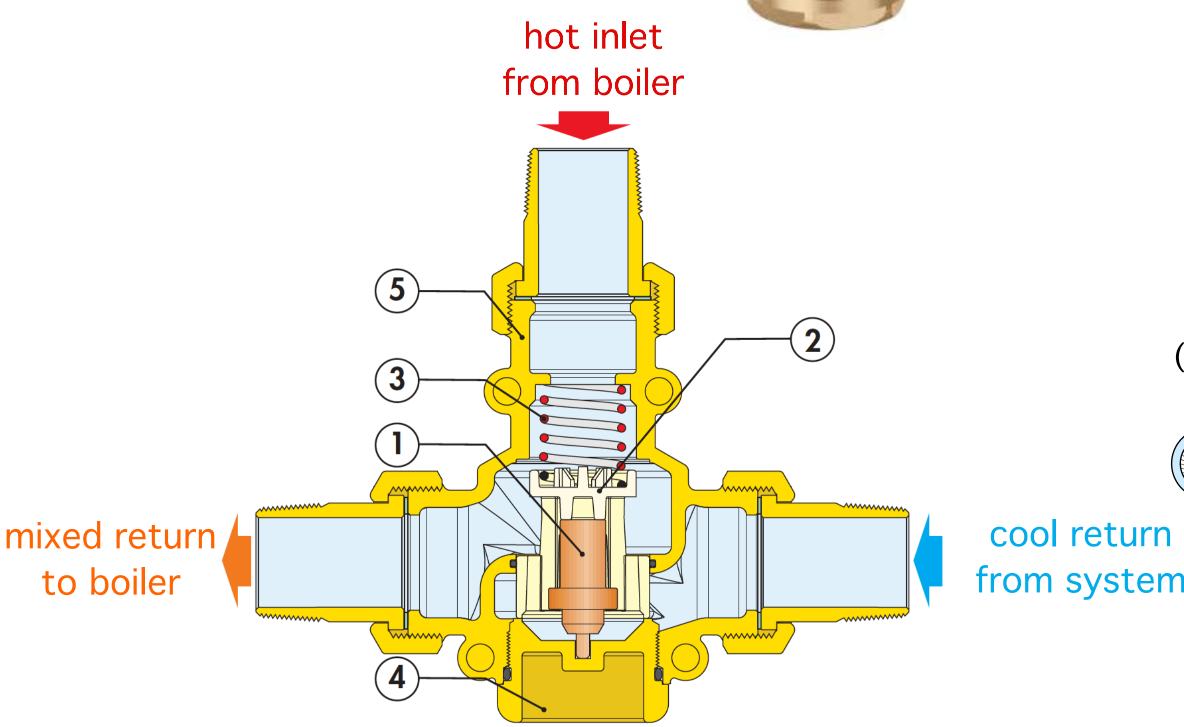
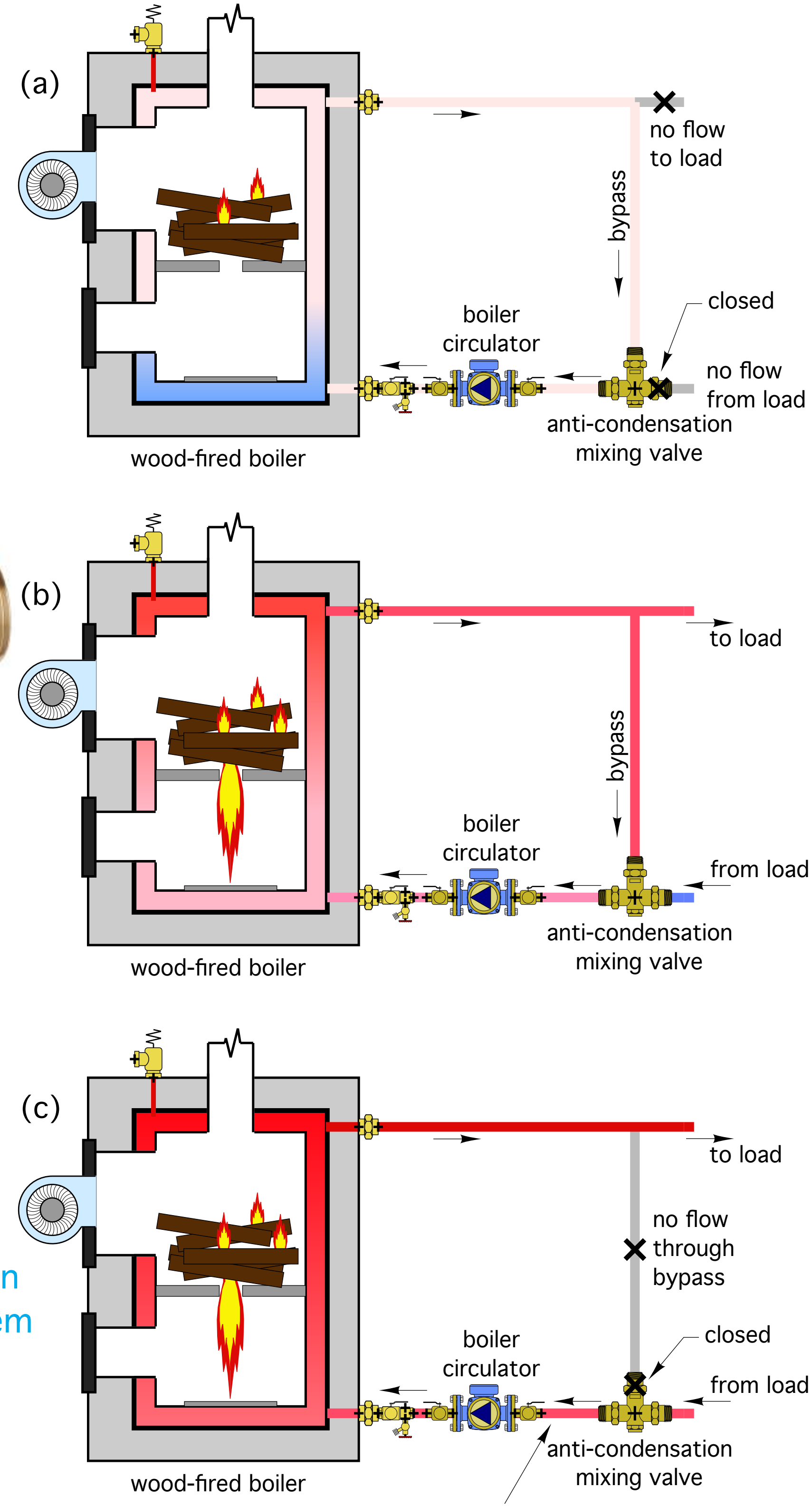


image courtesy of Mark Odell

Thermostatic bypass valves

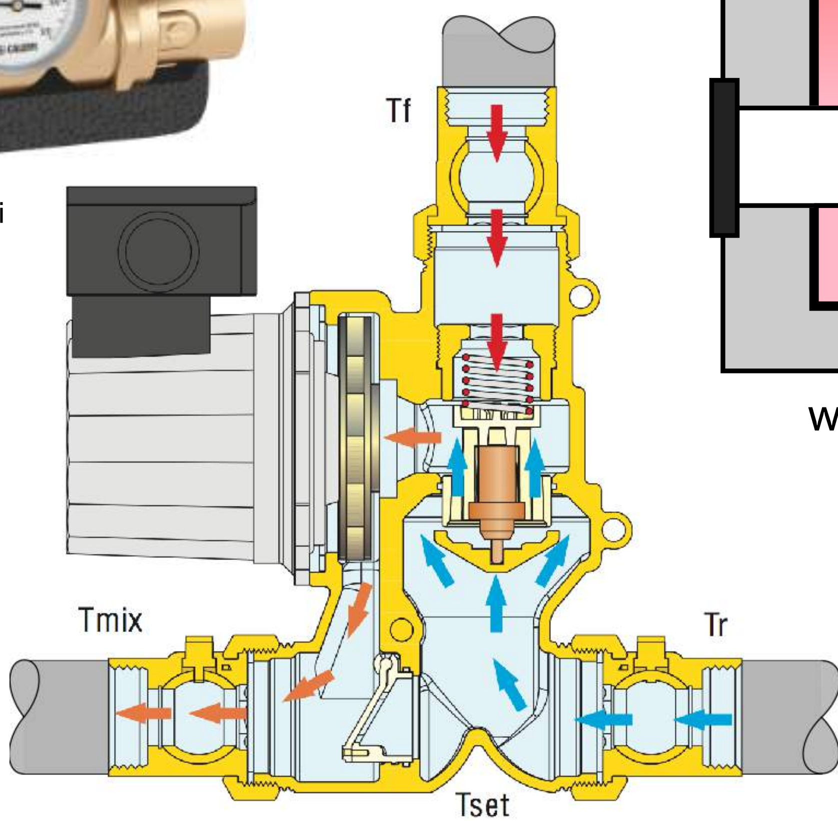


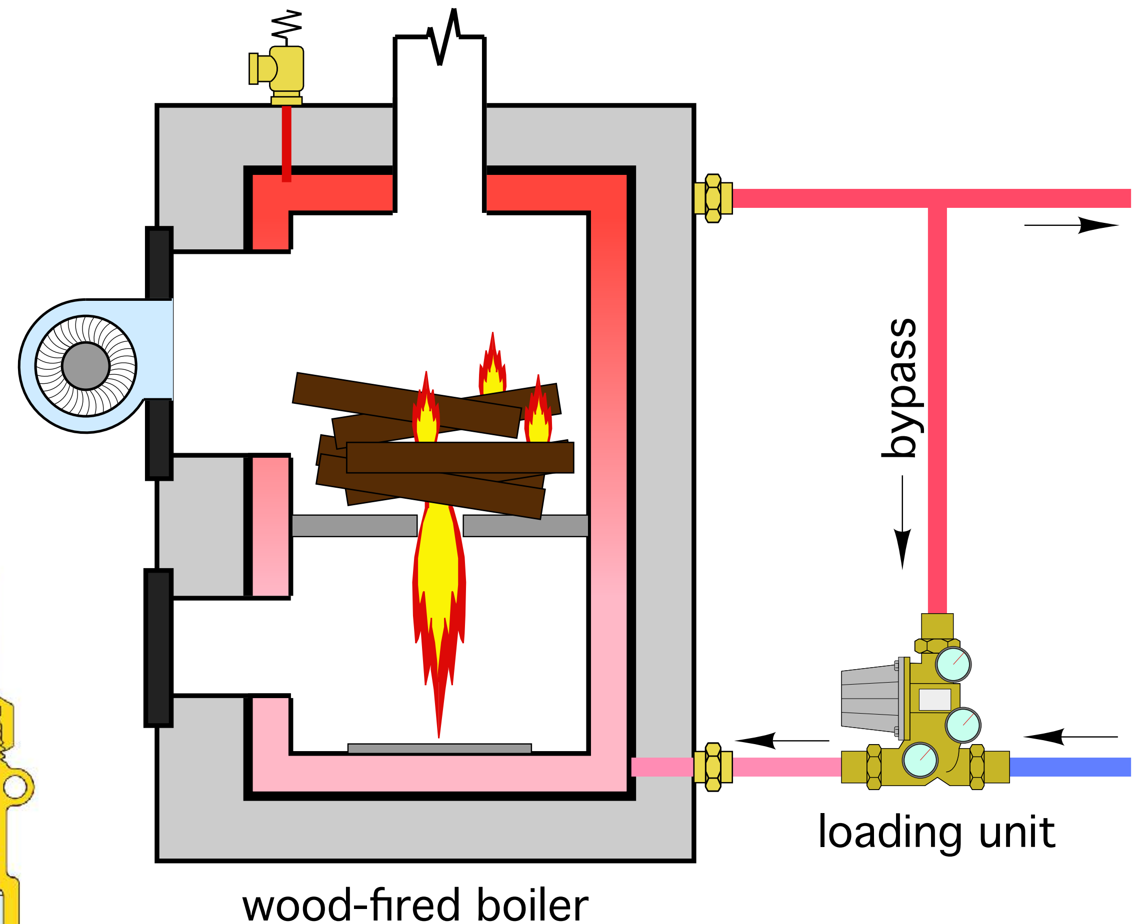


Loading units

(thermostatic mixing valve + circulator + flapper valve)

Images courtesy of Caleffi

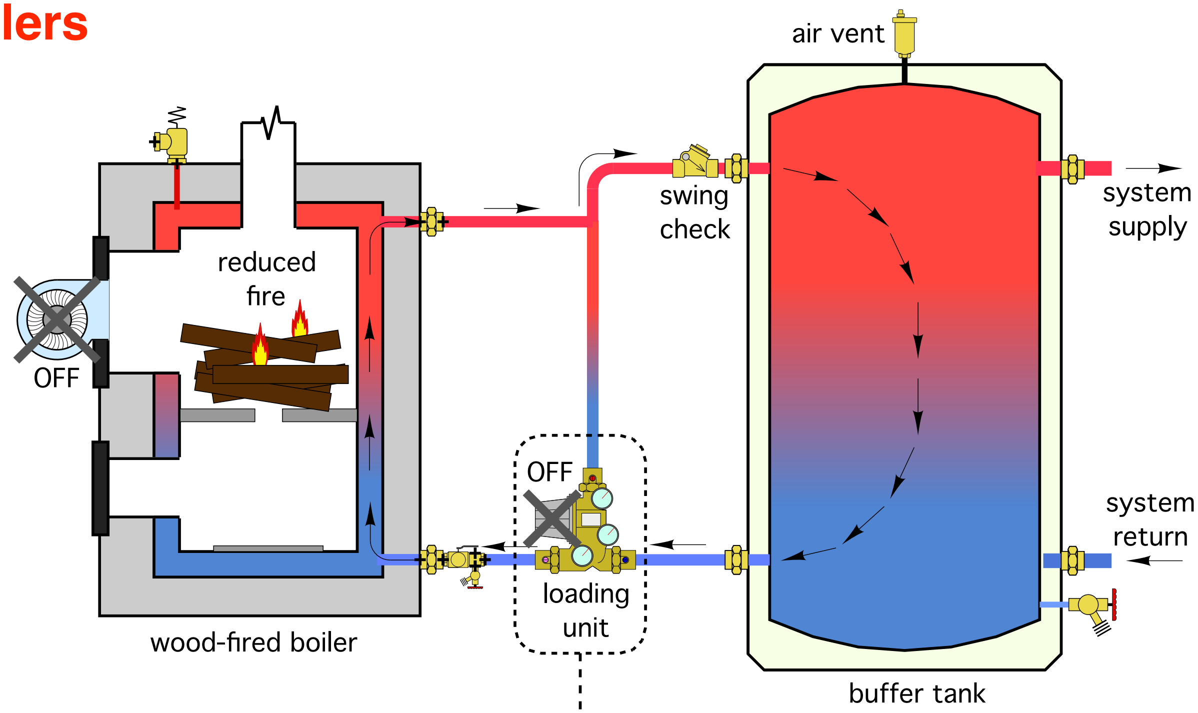


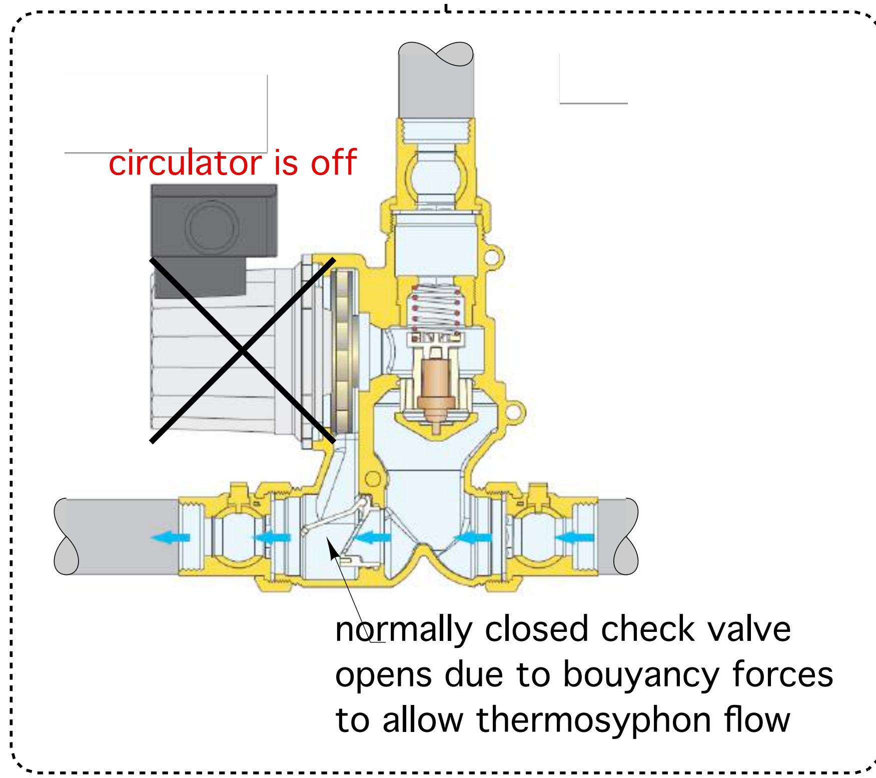


Loading units
(thermostatic mixing valve + circulator + flapper valve)

Video courtesy of LK Armatur

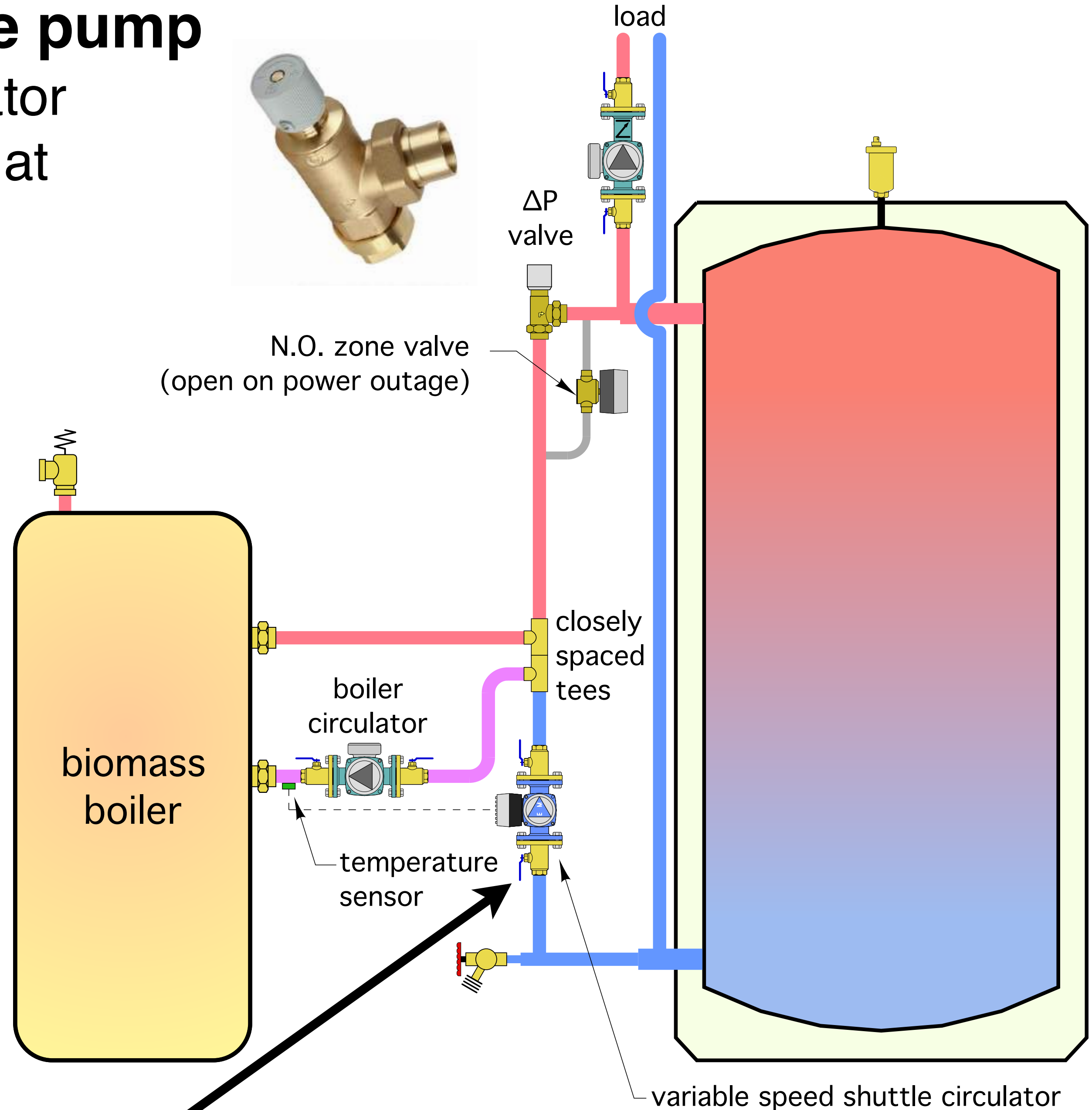
Loading units





Variable speed shuttle pump

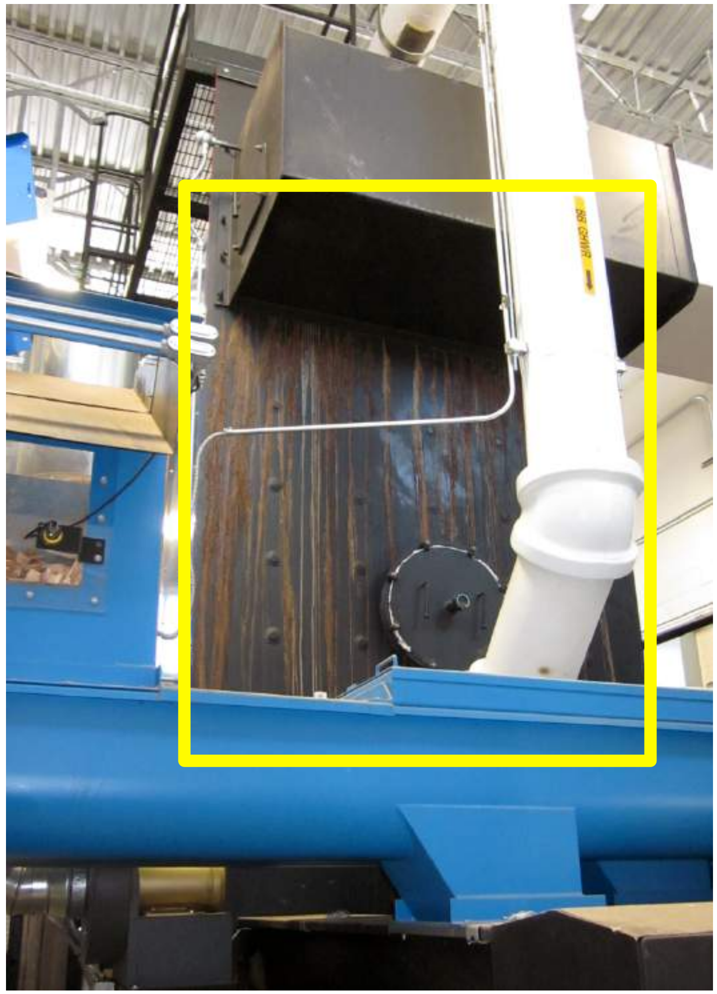
The variable speed circulator slows down if the setpoint at boiler inlet drops below a setpoint (typically 130°F).



Taco VT2218 temperature controlled circulator

3-way motorized mixing valve supplied with & controlled by EVO WORLD boiler

A 12.8 MMBtu/hr wood chip boiler ($2,300,000 installation), without a mixing device to regulate inlet water temperature.

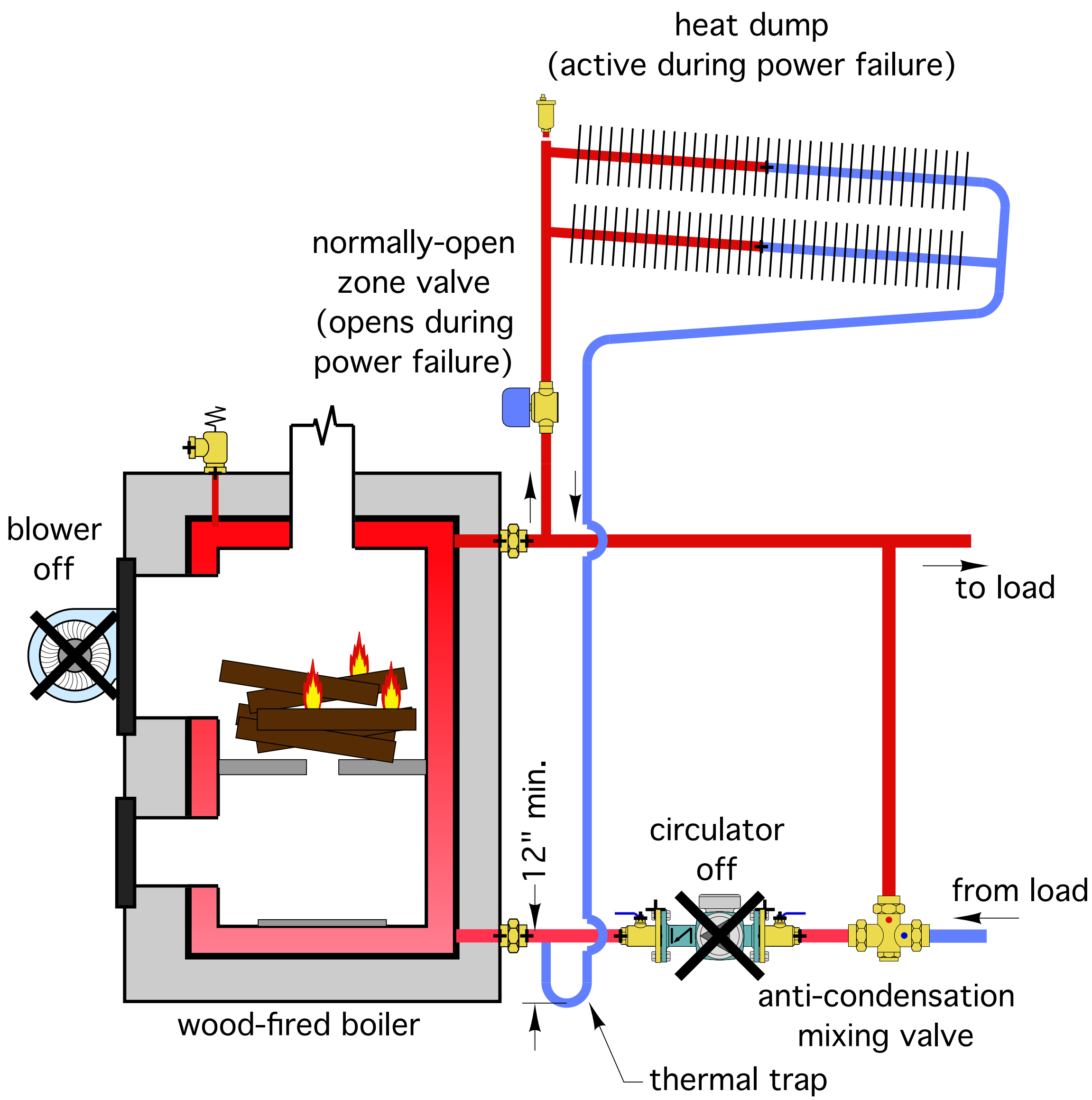


Notice the signs of flue gas condensation on rear boiler plate.

Boiler over-temperature protection

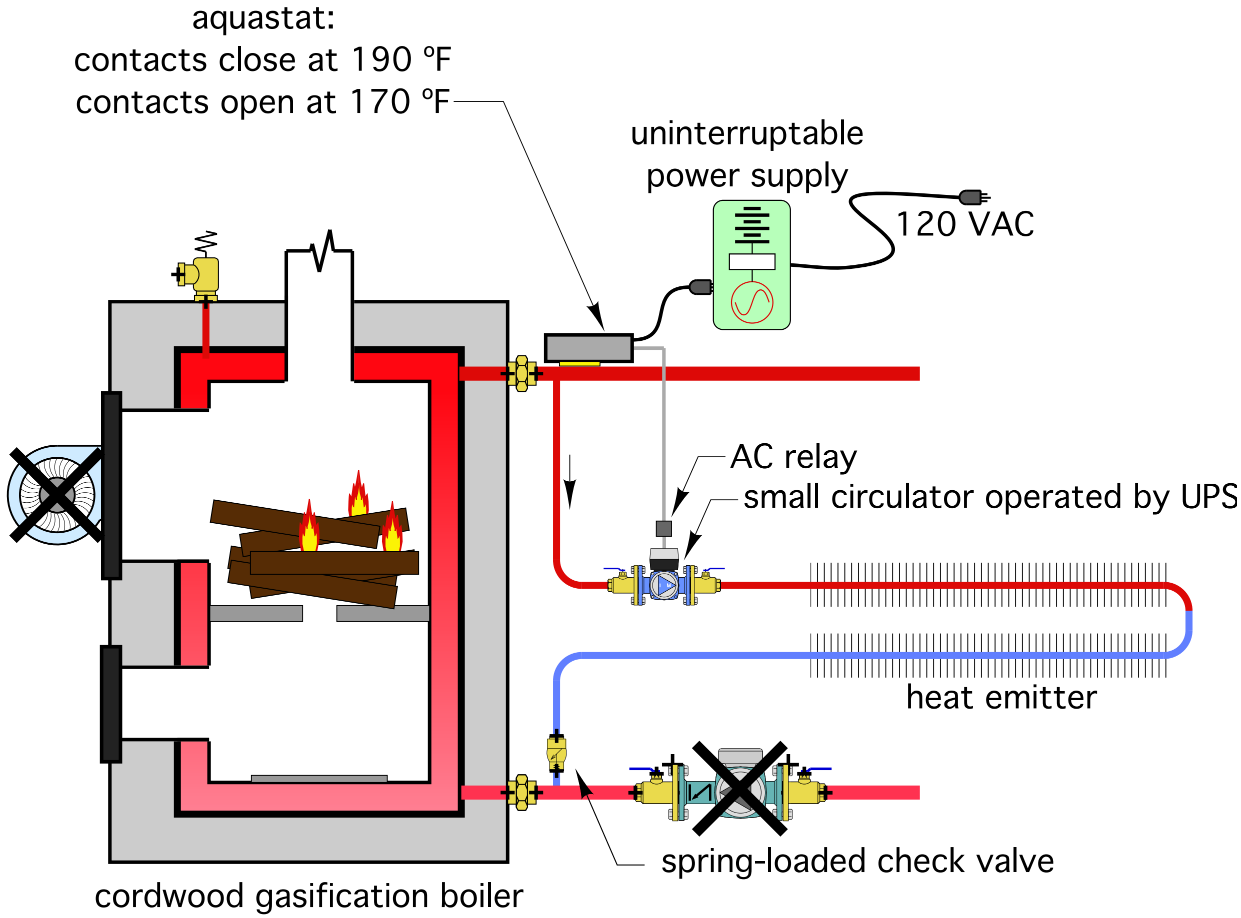
Heat dump activates upon power failure

The normally open zone valve opens at power failure to allow thermosiphon flow through sloped fin tube assembly.

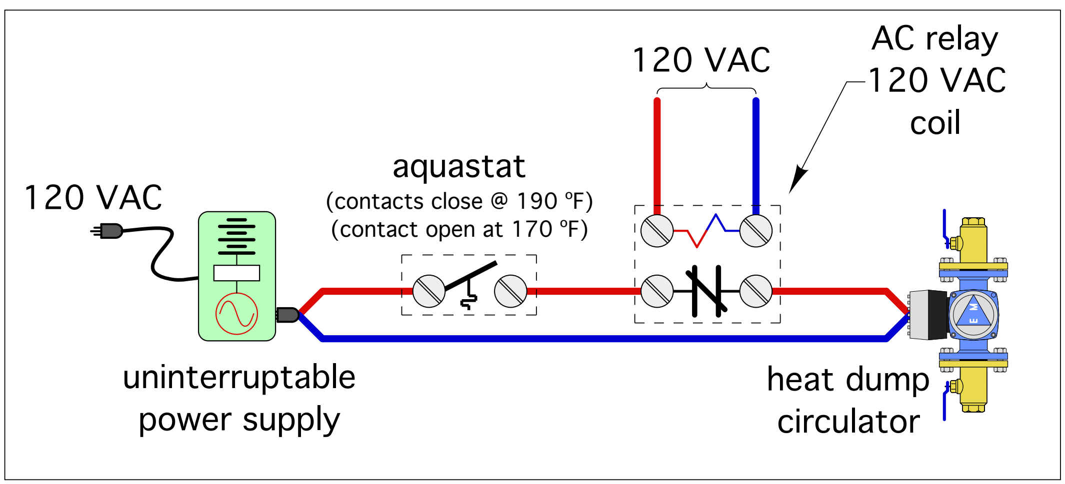


Courtesy of Mark Odell

Small circulator driven by UPS protects against overheating during power outages.



B&G Ecocirc (VARIO)
adjustable from
6-50 watts

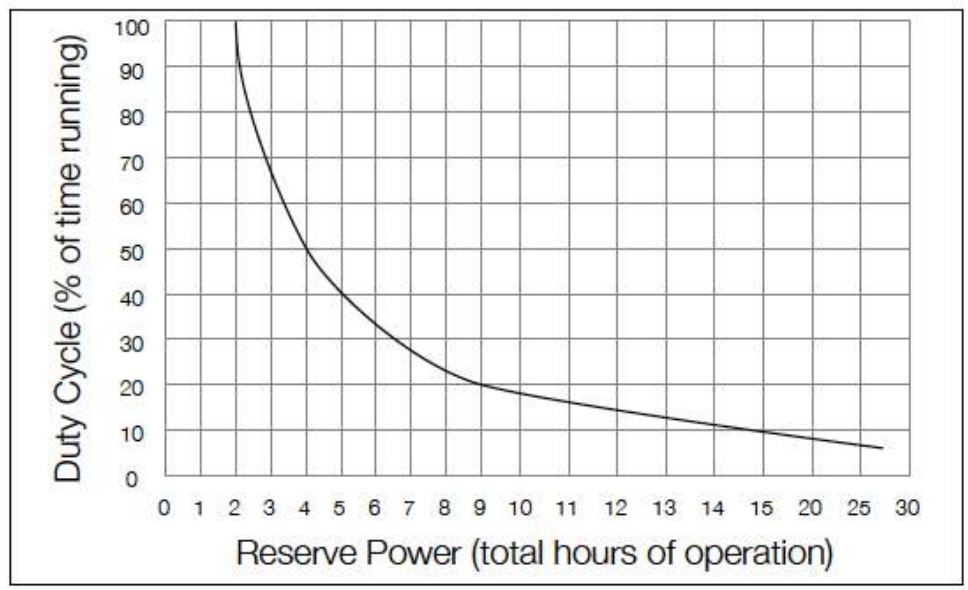


The circulator allows possibility of heat dump being underneath the boiler.

High capacity uninterruptable power supplies (UPS) are available

- 24 VDC deep cycle battery bank
- rated for up to 1800 watt output
- can be recharged by solar PV

The SUMPRO® is designed to operate a load up to 12 Amps. If operating more than one pump, the combined FLA cannot exceed 12 Amps.



Performance curve results using a 3/4 HP pump with a 7.5 FLA and (2) Metropolitan Power Plus model 31P-36 batteries.

Low temperature / hydronic heat emitters

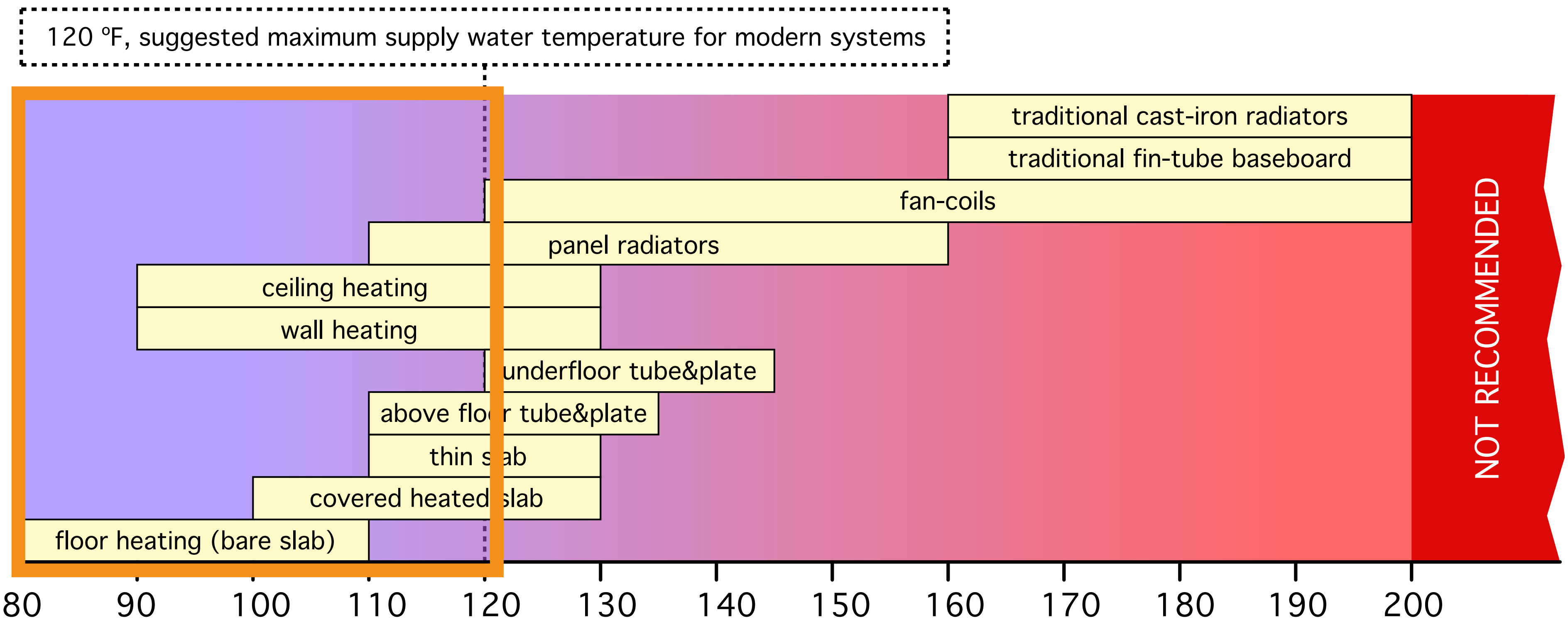
Water temperature ranges for various hydronic heat emitters

• The heat output of ***any*** heat emitter always drops with decreasing water temperature.

• There is always ***some*** output provided the supply water temperature is above the room air temperature.

• There is always a trade off between the *total surface area of the heat emitters* in the system, and the *supply water temperature* required to meet the heating load.

• ***More heat emitter area always lowers the required supply water temperature.***



• Don't feel constrained to select heat emitters based on traditional supply water temperatures…

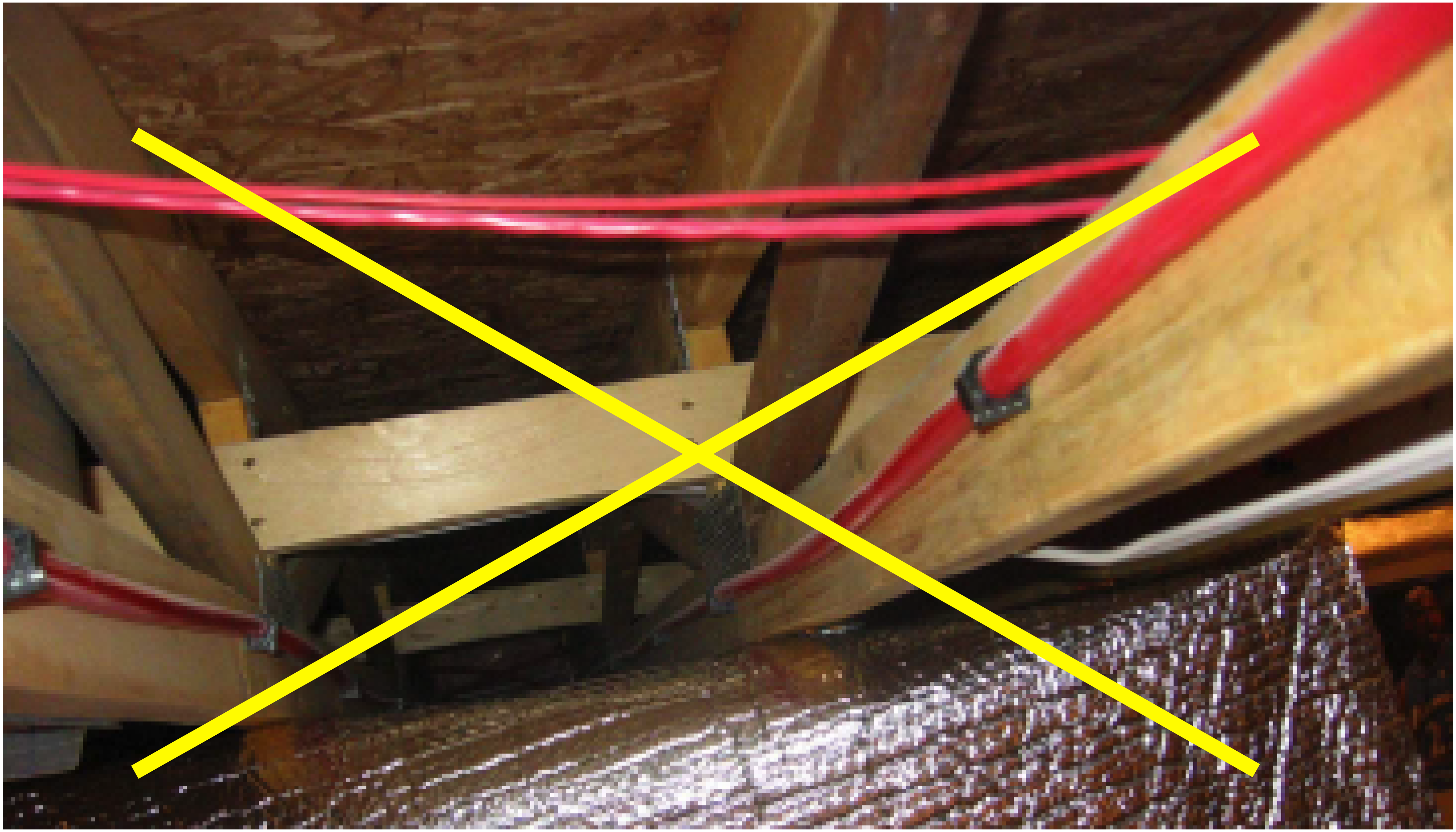
What kind of heat emitters should be used in combination with wood gasification or pellet boilers?

• They should operate at **<u>low supply water temperatures</u>** to allow maximum “draw down” on thermal storage.

Max suggested supply water temperature @ design load = 120 °F

Low temperature hydronic distribution systems also help “future proof” the system for use with heat sources are likely to thrive on low water temperatures.

<u>Don't do this with ANY hydronic heat source!</u>

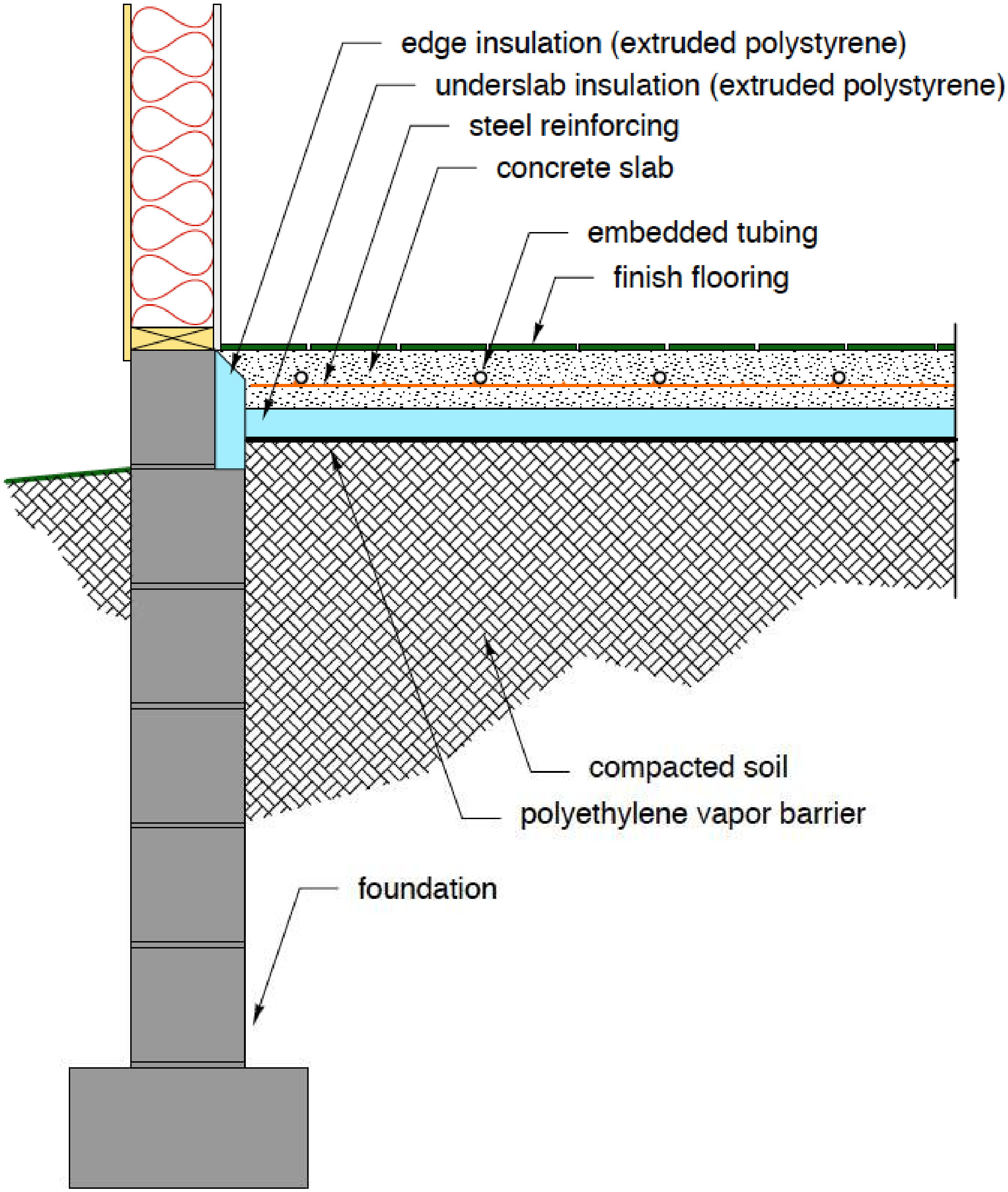


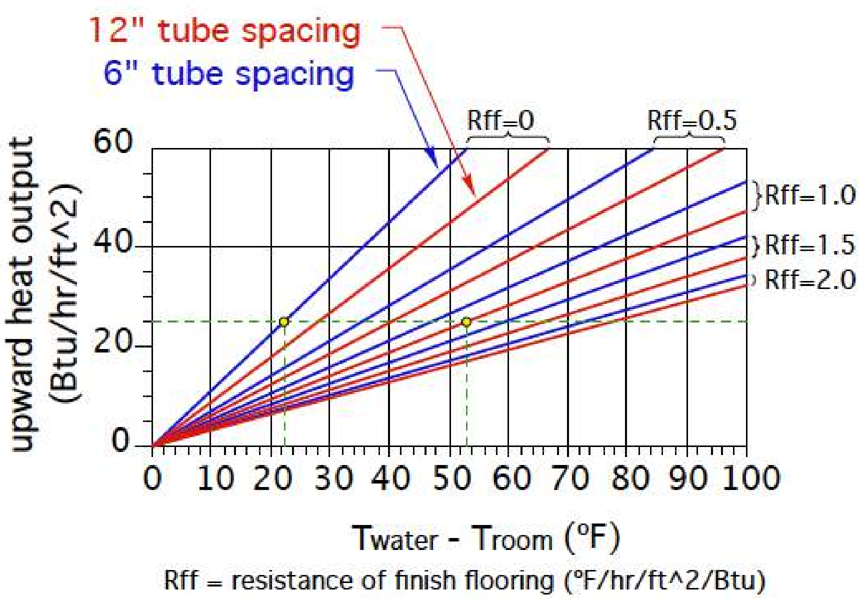
Heat transfer between the water and the upper floor surface is severely restricted!

Don't do this with ANY hydronic heat source!

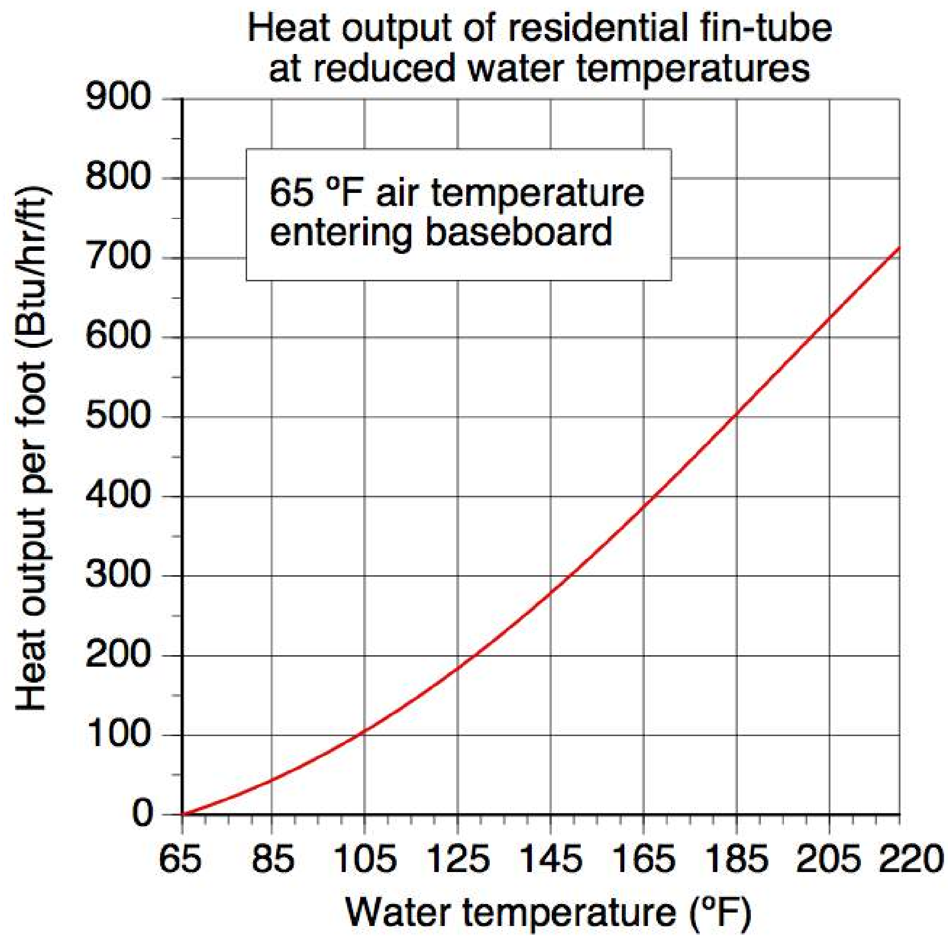
Heat transfer between the water and the upper floor surface is severely restricted!

Slab-on-grade floor heating





Most CONVENTIONAL fin-tube baseboard has been sized around boiler temperatures of 160 to 200 ºF. Much too high for good thermal performance of low temperature hydronic heat sources.

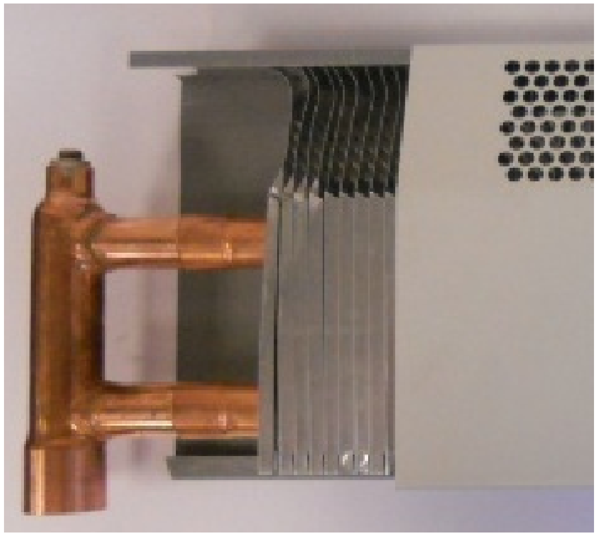


Could add fin-tube length based on lower water temperatures. BUT...

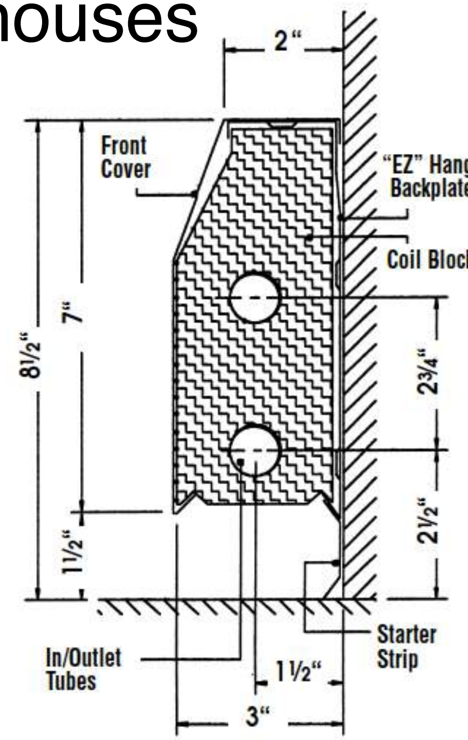
Fin-tube output at 120 ºF is only about 30% of its output at 200ºF

Hydronic heat emitters options for low energy use houses

Some low- temperature baseboard is now available



Images courtesy Emerson Swan



Heating Edge™
Hot Water Performance Ratings

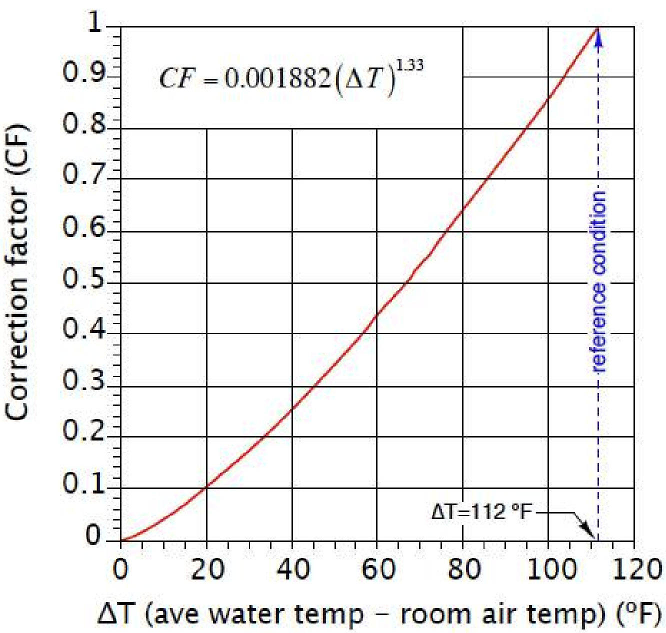
	Flow Rate GPM	PD in ft of H_20	90°F	100°F	110°F	120°F	130°F	140°F	150°F	160°F	170°F	180°F	190°F	200°F	210°F
			Average Water Temperature (BTU/hr/ft @AWT in °F)												
TWO SUPPLIES PARALLEL	1	0.0044	130	205	290	385	460	546	637	718	813	911	1009	1113	1215
	4	0.0481	155	248	345	448	550	651	755	850	950	1040	1143	1249	1352
TOP SUPPLY BOTTOM RETURN	1	0.0088	105	169	235	305	370	423	498	570	655	745	836	924	1016
	4	0.0962	147	206	295	386	470	552	640	736	810	883	957	1034	1110
BOTTOM SUPPLY TOP RETURN	1	0.0088	103	166	230	299	363	415	488	559	642	730	819	906	996
	4	0.0962	140	212	283	350	435	524	623	722	792	865	937	1013	1093
BOTTOM SUPPLY NO RETURN	1	0.0044	75	127	169	208	260	311	362	408	470	524	576	629	685
	4	0.0481	85	140	203	265	334	410	472	536	599	662	723	788	850

Performance Notes: • All ratings include a 15% heating effect factor • Materials of construction include all aluminum "patented" fins at 47.3 per LF, mechanically bonded to two 3/4' (075) type L copper tubes ("Coil Block") covered by a 20 gauge perforated, painted cover all mounted to a backplate. Please see dimensional drawing for fin shape and dimensions • EAT=65°F • Pressure drop in feet of H_2O per LF.

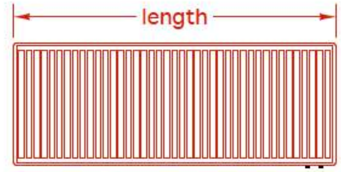
Heating Edge (HE2) has been performance tested in a BSRIA standards laboratory. The test chamber was set up according to IBR testing protocol. The above chart is shown in Average Water Temperatures (AWT) per market request.

Panel Radiators

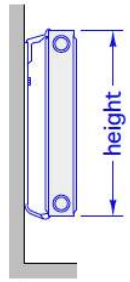
Adjust heat output for operation at lower water temperatures.



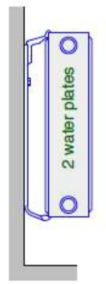
Reference condition:
Ave water temp. in panel = 180°F
Room air temperature = 68°F



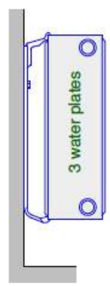
Heat output ratings (Btu/hr)
at reference conditions:
Average water temperature in panel = 180°F
Room temperature = 68°F
temperature drop across panel = 20°F



1 water plate panel thickness	16" long	24" long	36" long	48" long	64" long	72" long
24" high	1870	2817	4222	5630	7509	8447
20" high	1607	2421	3632	4842	6455	7260
16" high	1352	2032	3046	4060	5415	6091



2 water plate panel thickness	16" long	24" long	36" long	48" long	64" long	72" long
24" high	3153	4750	7127	9500	12668	14254
20" high	2733	4123	6186	8245	10994	12368
16" high	2301	3455	5180	6907	9212	10363
10" high	1491	2247	3373	4498	5995	6745

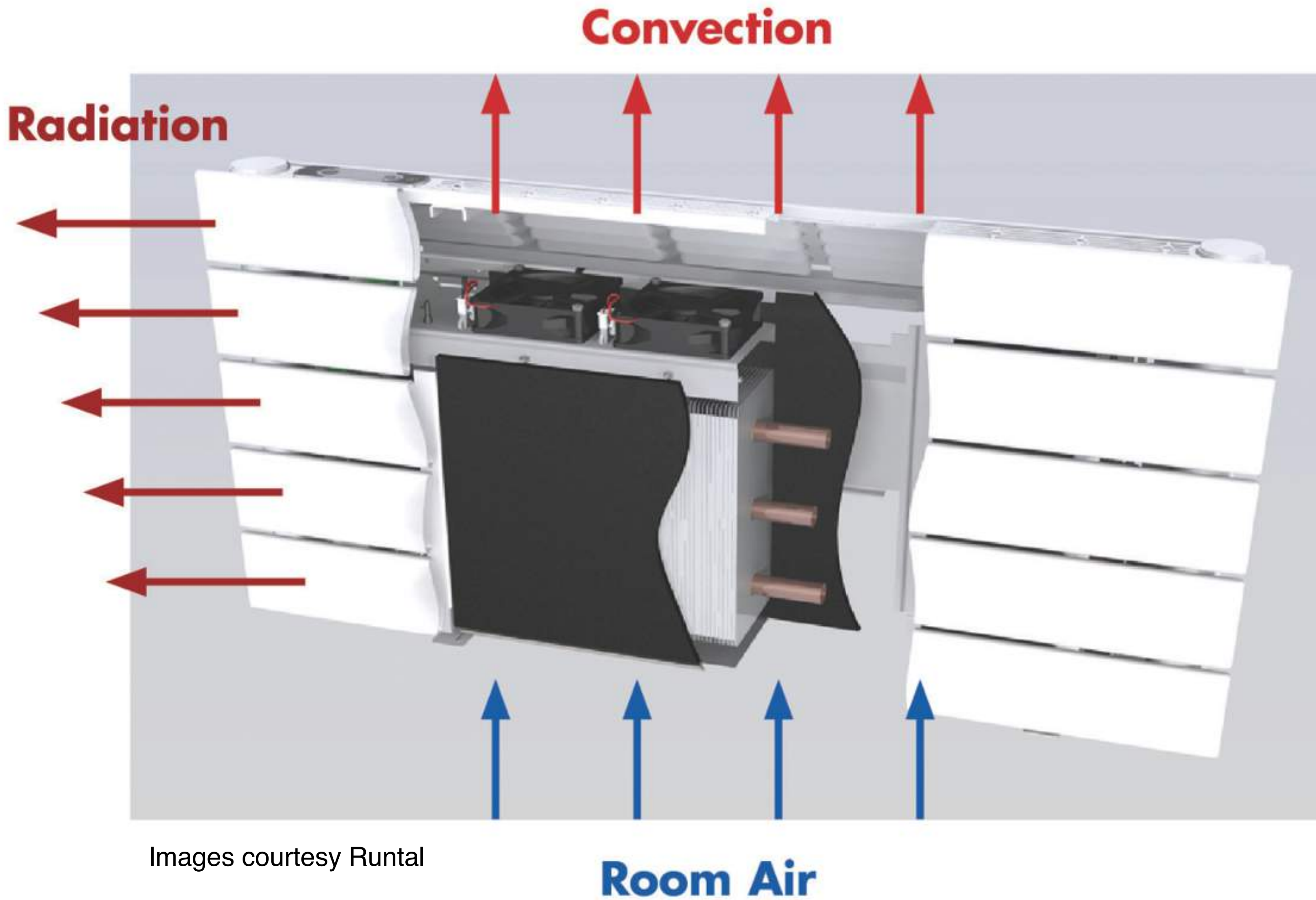


3 water plate panel thickness	16" long	24" long	36" long	48" long	64" long	72" long
24" high	4531	6830	10247	13664	18216	20494
20" high	3934	5937	9586	11870	15829	17807
16" high	3320	4978	7469	9957	13277	14938
10" high	2191	3304	4958	6609	8811	9913

As an approximation, a panel radiator operating with an average water temperature of 110 °F in a room room maintained at 68 °F, provides approximately 27 percent of the heat output it yields at an average water temperature of 180 °F.

Fan-assisted Panel Radiators

The "NEO", from Runtal North America

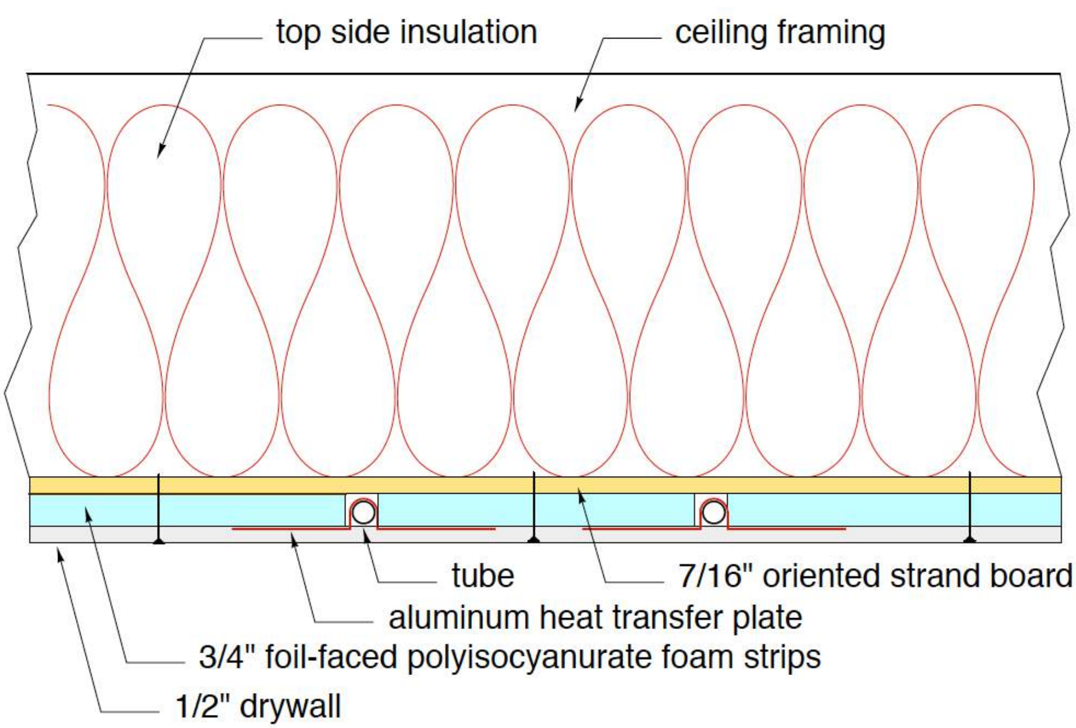


Images courtesy Runtal

8 tube high x 31.5" wide produces 2095 Btu/hr at average water temperature of 104 ºF in 68ºF room

8 tube high x 59" wide produces 5732 Btu/hr at average water temperature of 104 ºF in 68ºF room

Site built radiant CEILINGS...



Thermal image of radiant ceiling in operation

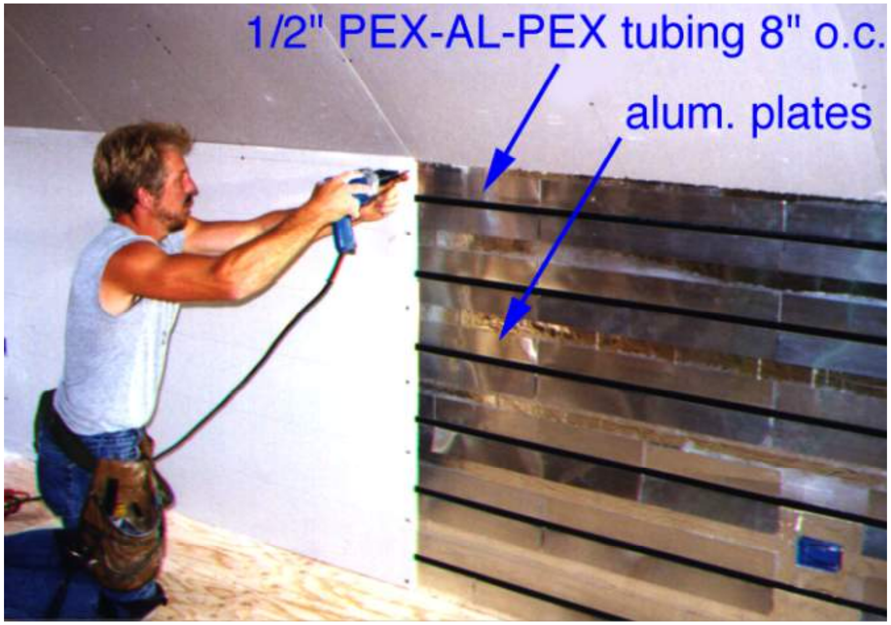
Heat output formula:

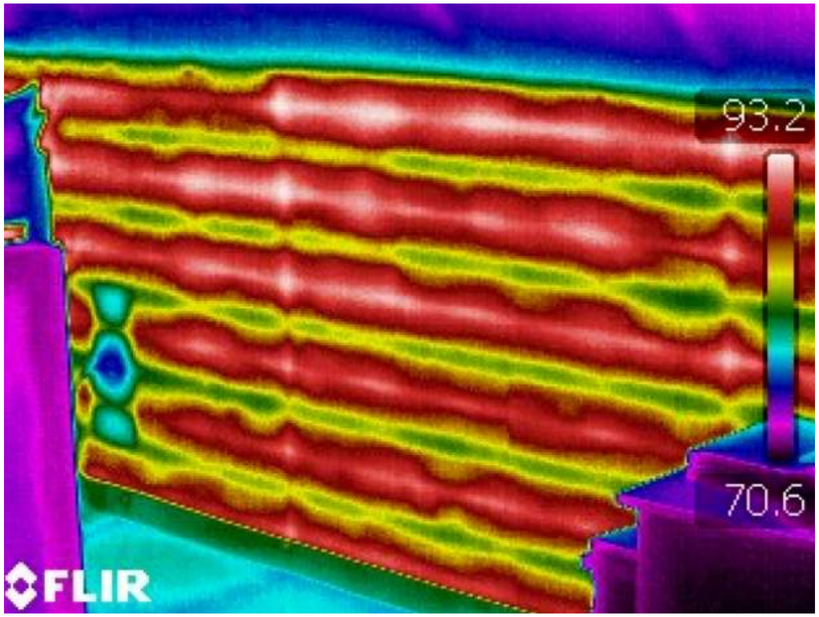
$$q = 0.71 \times (T_{water} - T_{room})$$

Where:

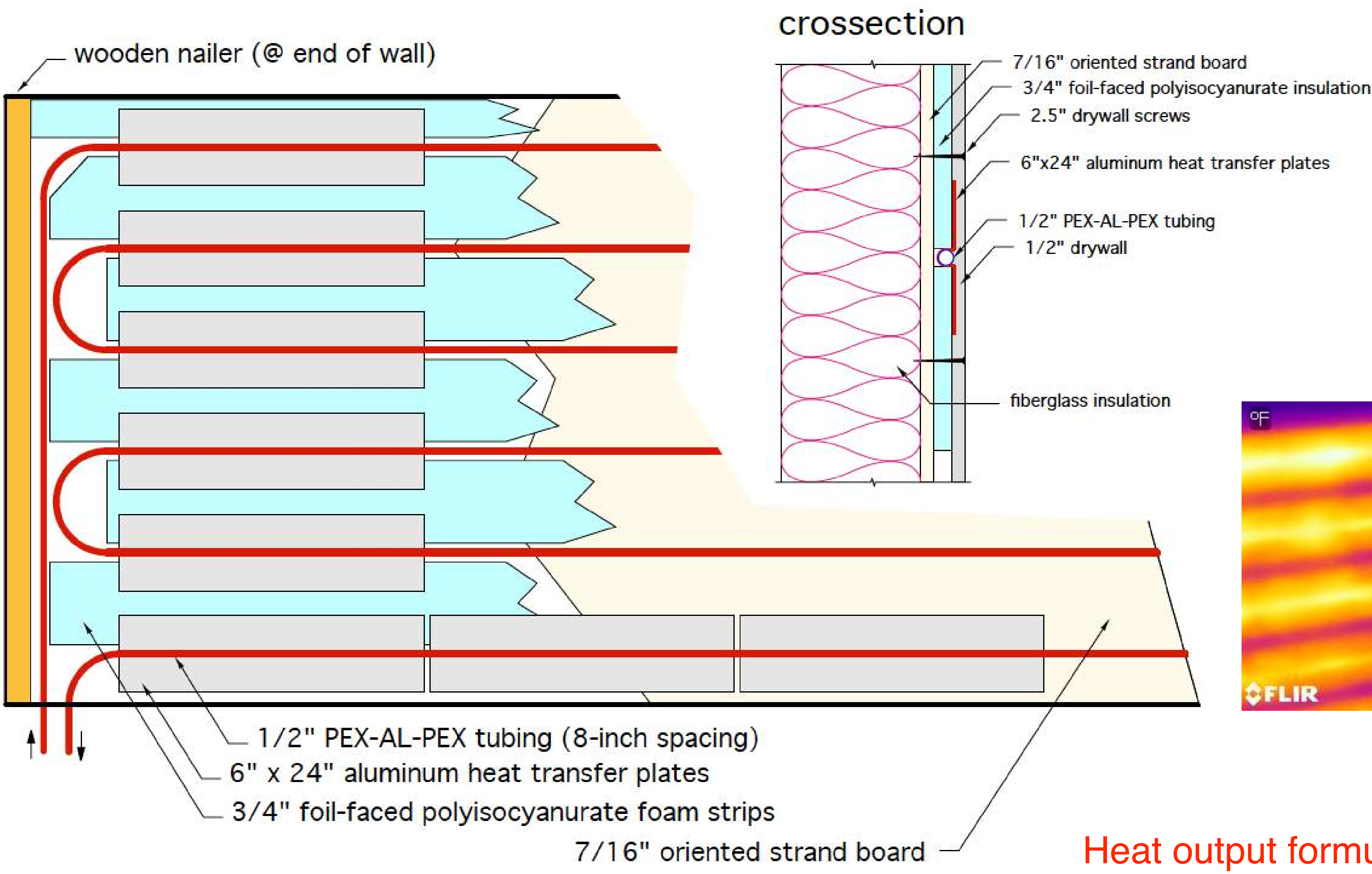
Q = heat output of ceiling (Btu/hr/ft^2)
T_{water} = average water temperature in panel (°F)
T_{room} = room air temperature (°F)

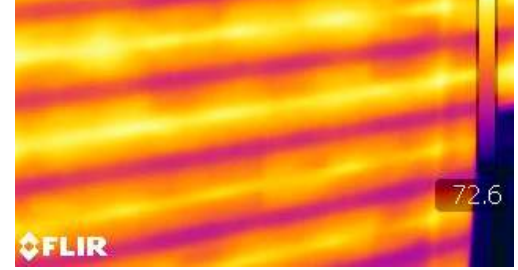
Site built radiant WALLS...





Site built radiant WALLS...





- completely out of sight
- low mass -fast response
- reasonable output at low water temperatures
- stronger than conventional drywall over studs
- don't block with furniture

Heat output formula:

$$q = 0.8 \times (T_{water} - T_{room})$$

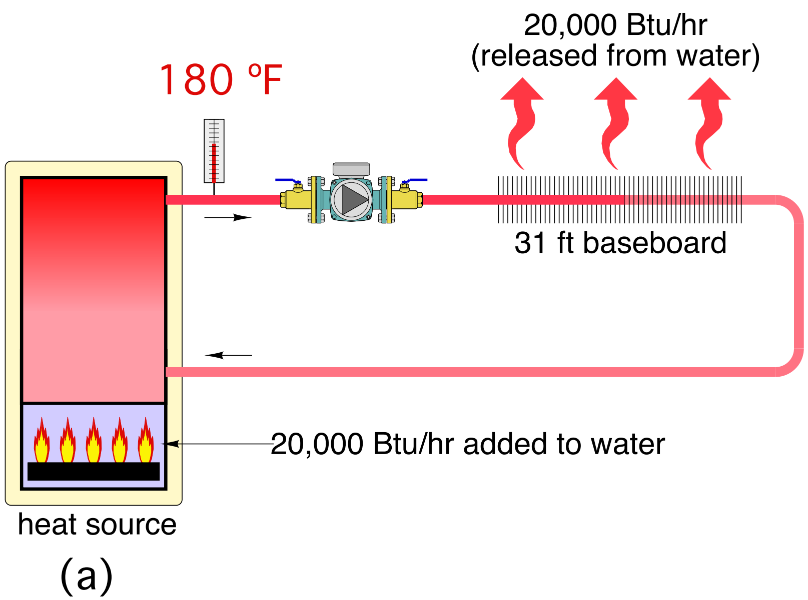
Where:

Q = heat output of wall (Btu/hr/ft^2)
T_{water} = average water temperature in panel (°F)
T_{room} = room air temperature (°F)

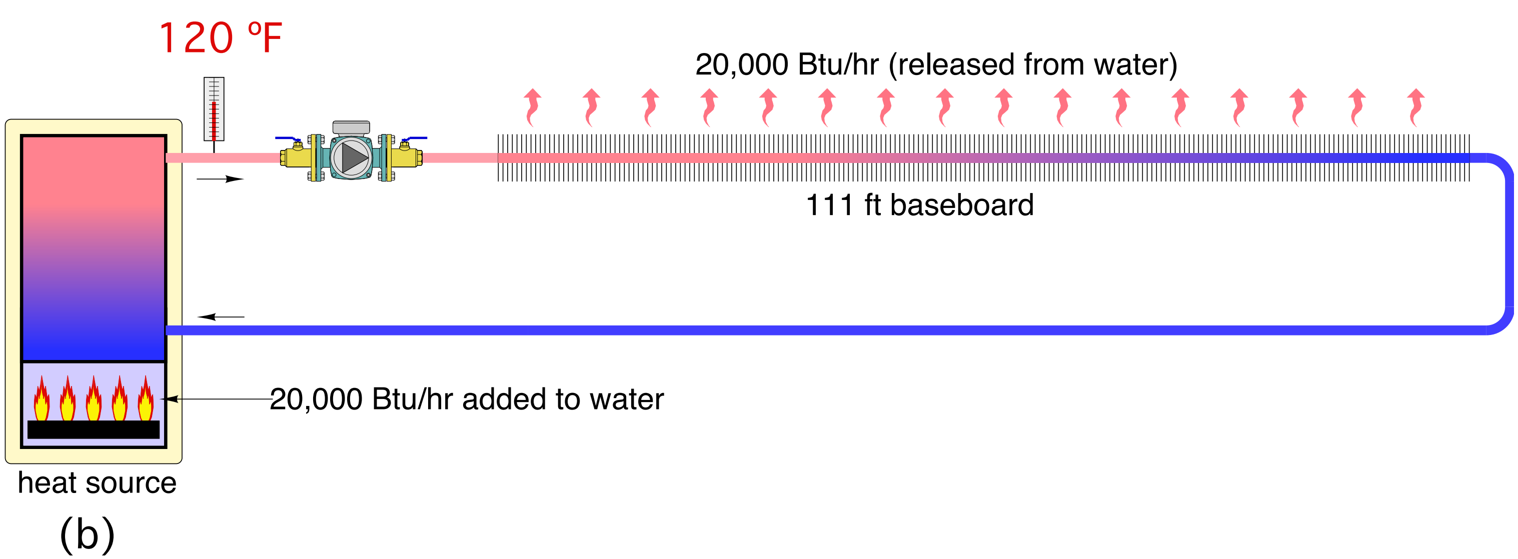
Retrofitting existing high water temperature distribution systems for lower water temperature operation

Retrofitting existing high temperature distribution systems

Increasing the total surface area of the heat emitters lowers the water temperature at which a given rate of heat deliver can occur.

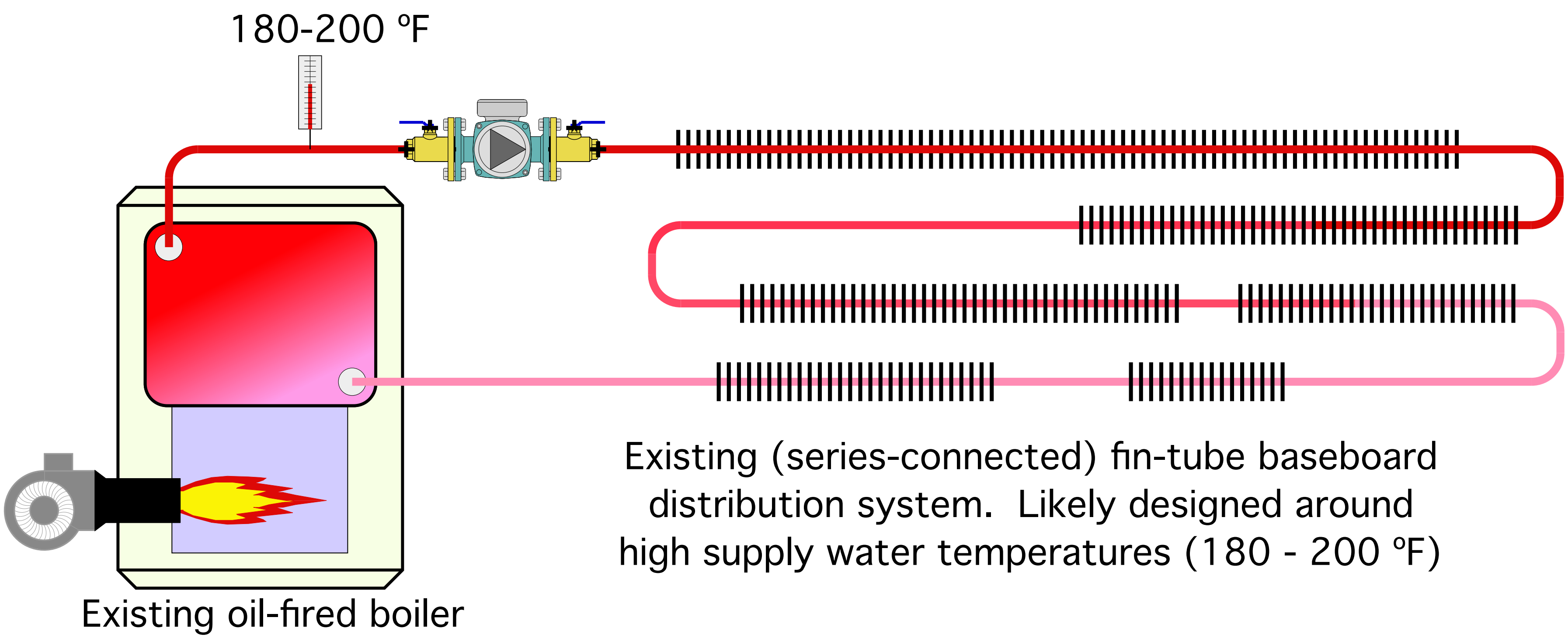


The greater the linear footage of baseboard, the lower the supply water temperature requirement.



Retrofitting existing high temperature distribution systems

In retrofit applications the existing heat emitters and distribution system are likely to be sized based on relatively high supply water temperatures (180-200 ºF) at design load conditions.



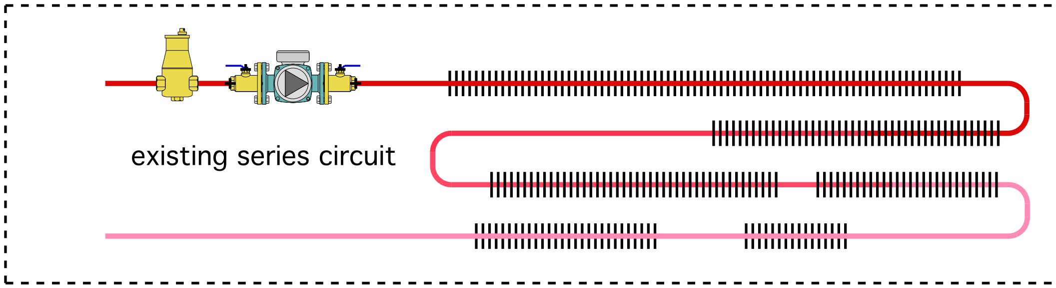
It's also likely that fin-tube baseboard will be connected in one or more series circuits as shown.

Although a biomass boiler can produce these temperatures, the thermal storage tank becomes ineffective if it cannot cycle over a reasonable range of temperature.

Retrofitting existing high temperature distribution systems

1. Lowering the supply water temperature at which the distribution system can deliver design load allows more heat to be “drained” from storage. This results in longer boiler operating cycles.

EXISTING DISTRIBUTION SYSTEM

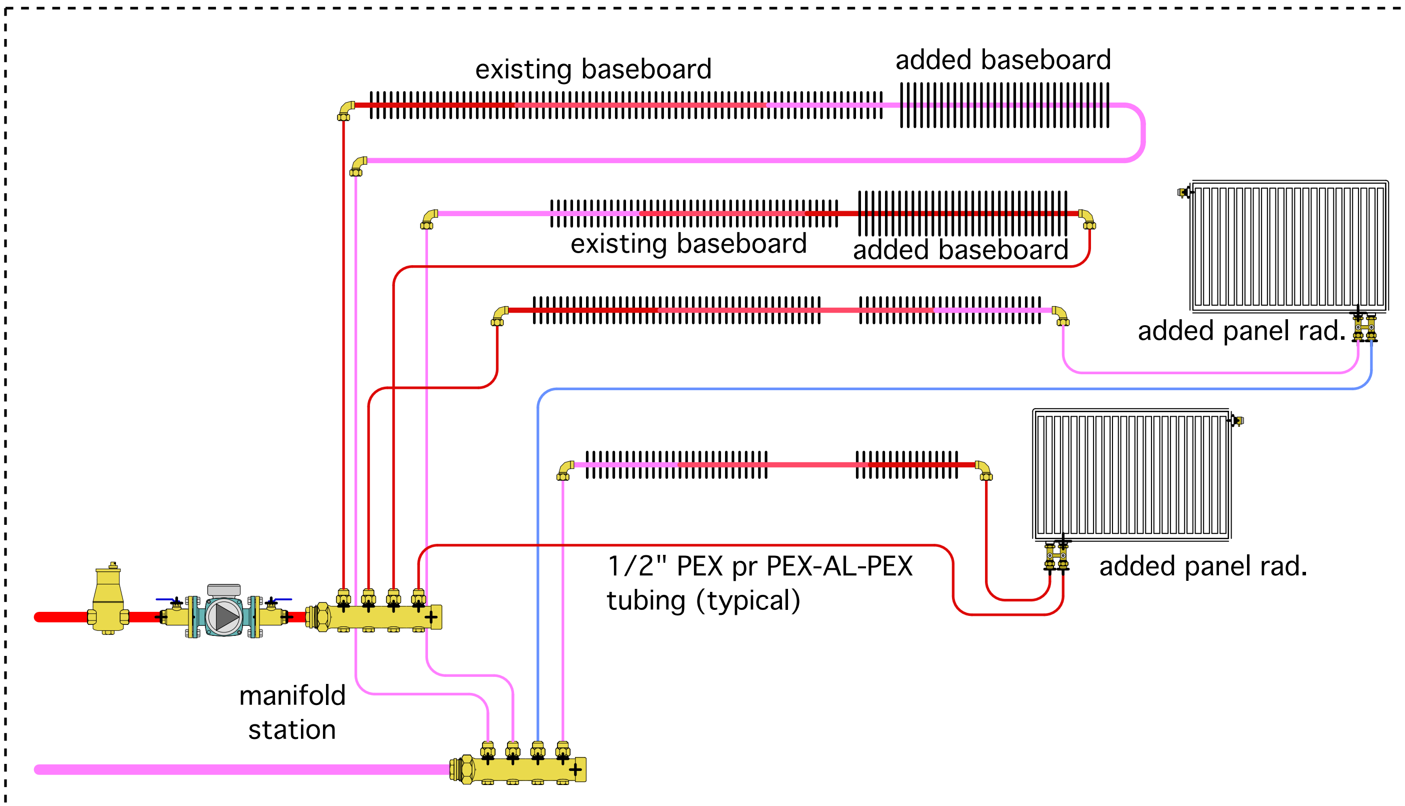


2. Parallel piping of heat emitters is preferred over series piping because is eliminates sequential temperature drop from one heat emitter to another.

3. Parallel piping also allows for easier zoning and flow balancing.

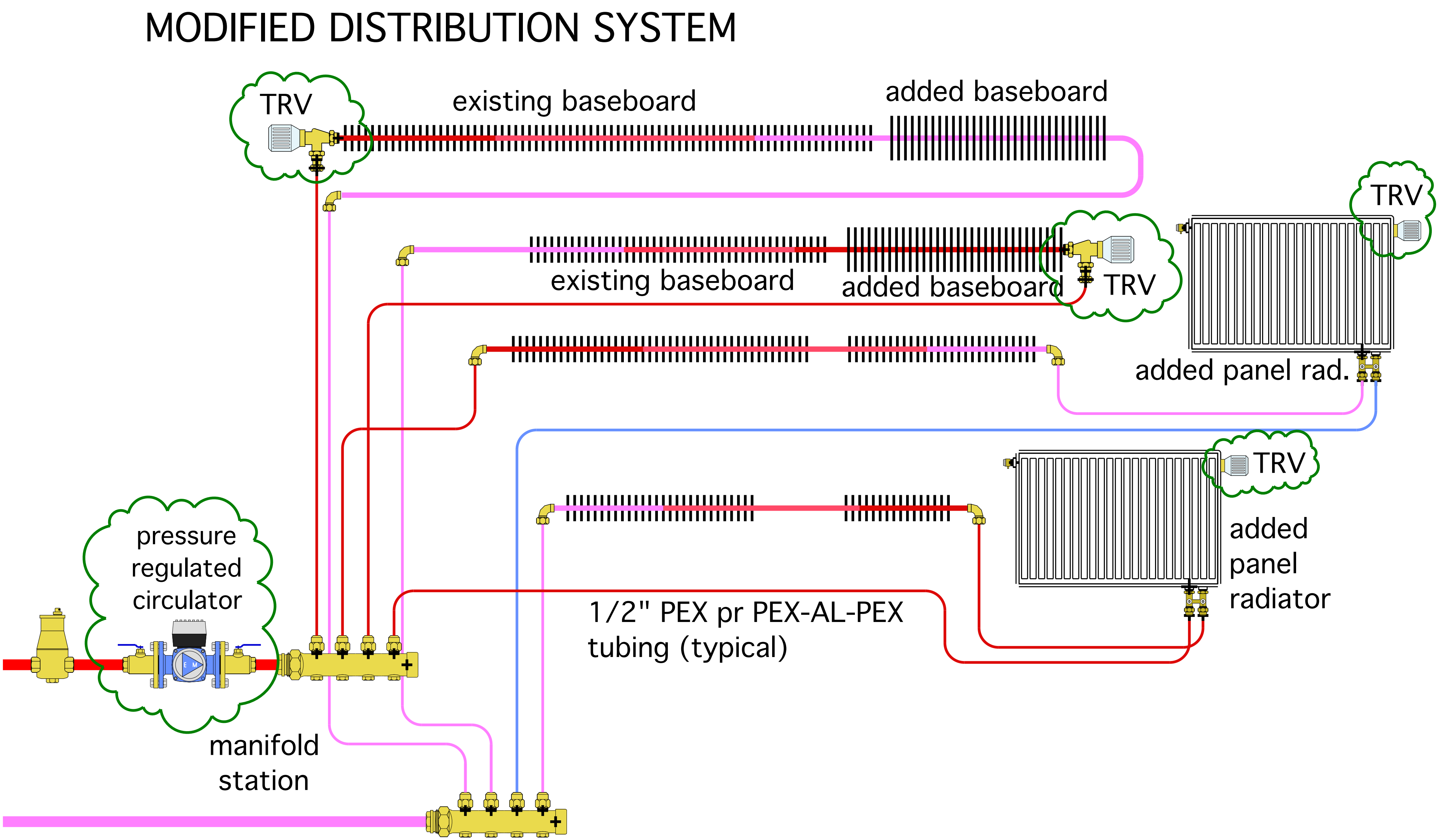
4. Likely easier to “morph” distribution system from series to parallel using homerun circuits of 1/2” PEX or PEX-AL-PEX.

MODIFIED DISTRIBUTION SYSTEM



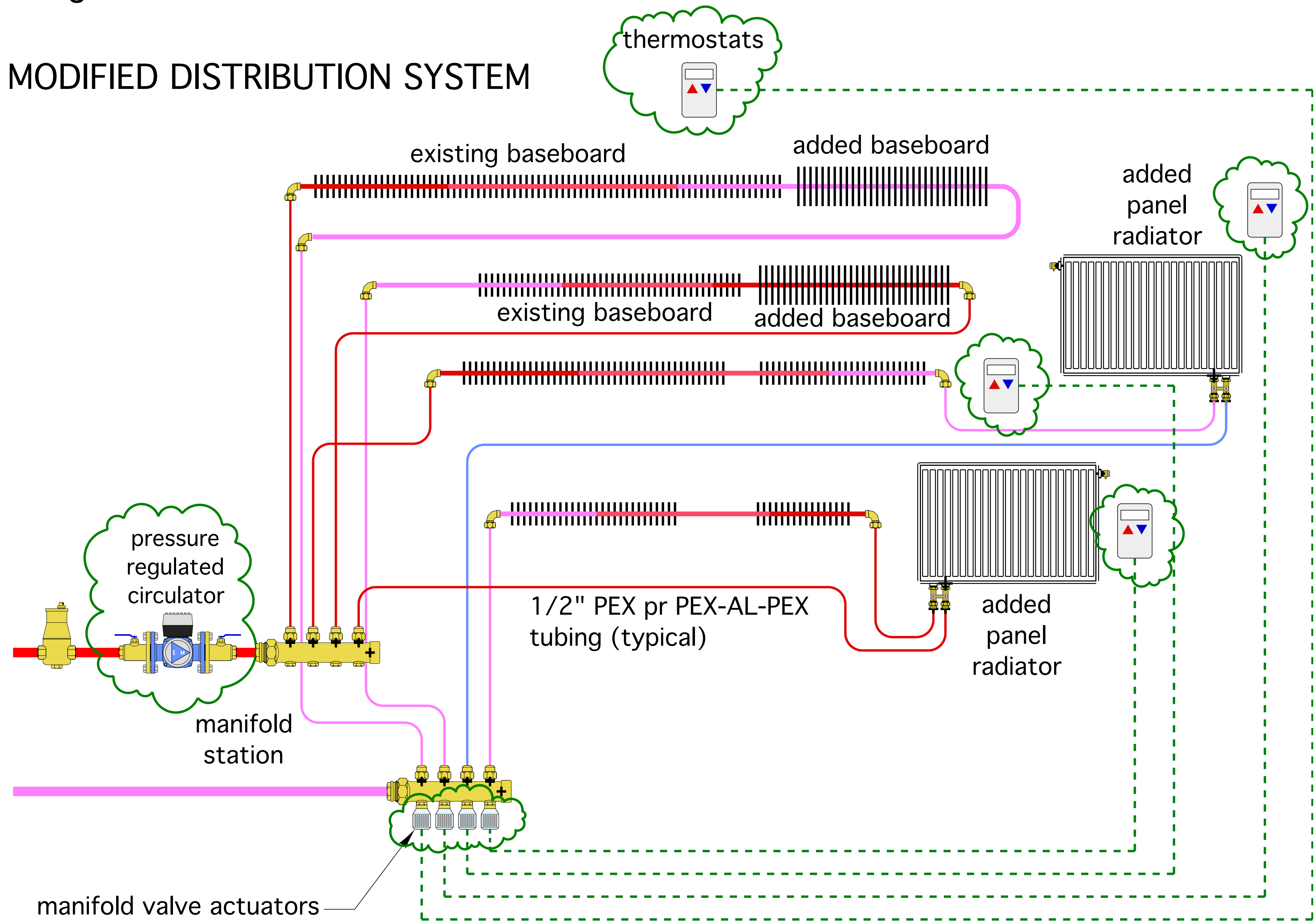
Retrofitting existing high temperature distribution systems

1. Using non-electric thermostatic radiator valves.



Retrofitting existing high temperature distribution systems

1. Using 24 VAC manifold valve actuators.



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.

thermostatic radiator valves are easy to use...

manual setback

dog reset control

dogs are "thermally discriminating."

Lessons Learned

Domestic Water Heating + space heating from pellet boiler system

Should DHW be provide by the pellet boiler that supplies space heating?

Arguments FOR doing this:

1. heat created from pellets is significantly lower cost in $/MMBtu compared to conventional fuel options.

2. DHW load is significant % of total heating energy use in building.

3. There is no other DHW energy source (or electricity is very expensive)

Arguments AGAINST doing this:

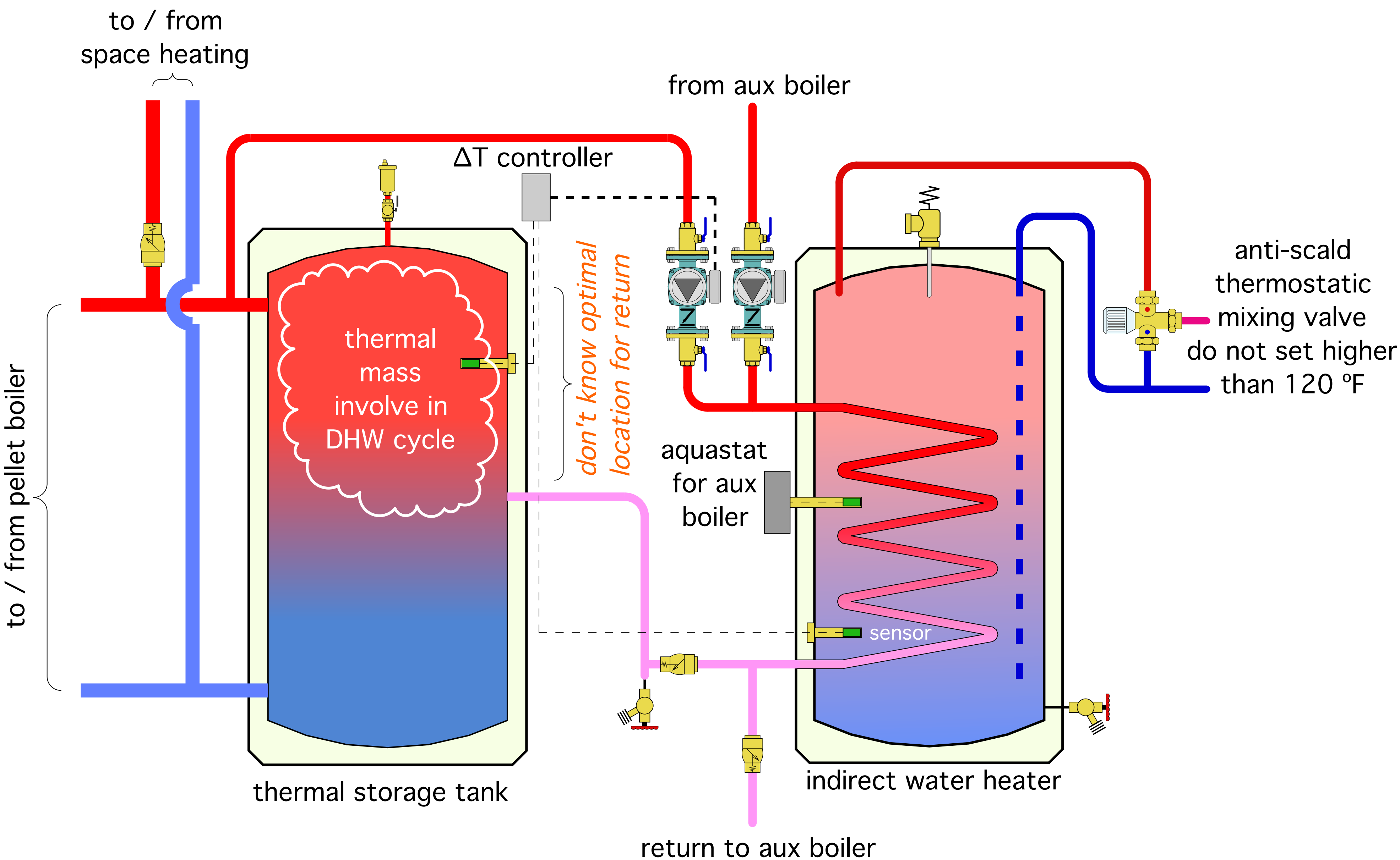
1. Don’t want to keep pellet boiler and thermal storage active during non-heating season.

2. Fuel cost difference between pellets and other fuel options is low.

3. DHW load is relatively small, and could cause pellet boiler to short cycle

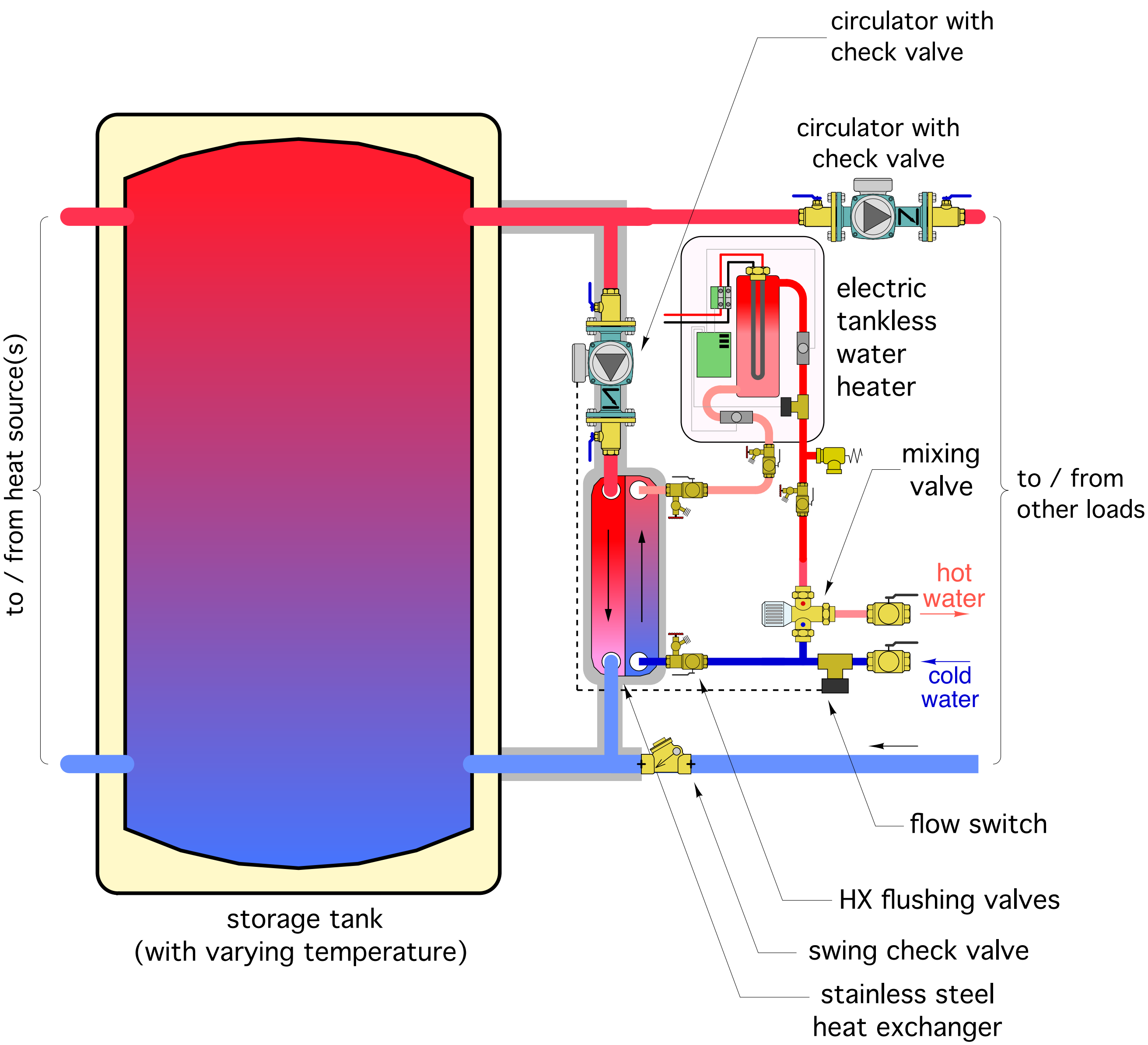
4. Don’t know how to do it.

Convert the “2-pipe” thermal storage tank to a “3-pipe” configuration forcing water returning from indirect tank coil to pass through thermal storage tank under all conditions (e.g., pellet boiler ON or OFF)



Instantaneous DHW subassembly

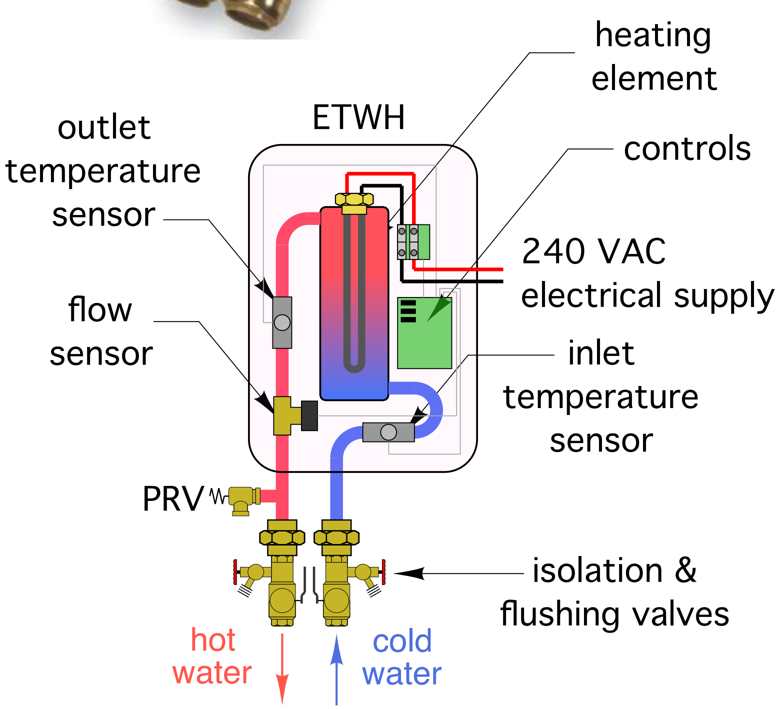
Instantaneous DHW subassembly

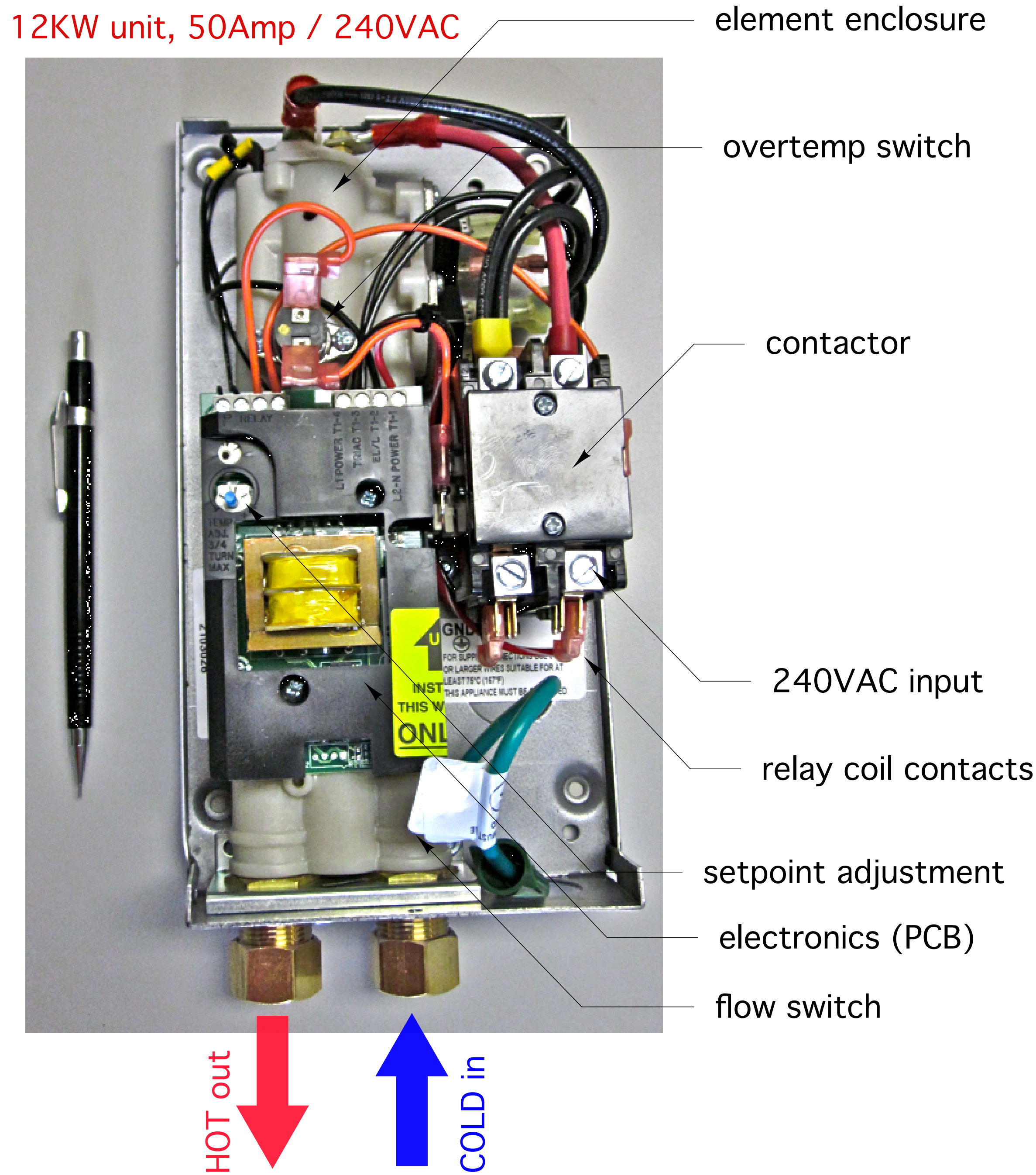


- Leverages the thermal mass for stabilizing DHW delivery.
- Brazed plate heat exchanger provides very fast response (1-2 seconds)
- Fully serviceable heat exchanger (unlike an internal coil heat exchanger) Can be cleaned or replaced if necessary.
- Predictable heat exchanger performance
- Very little heated domestic water is stored (reducing potential for Legionella growth).
- Very low wattage circulator needed on primary side of heat exchanger

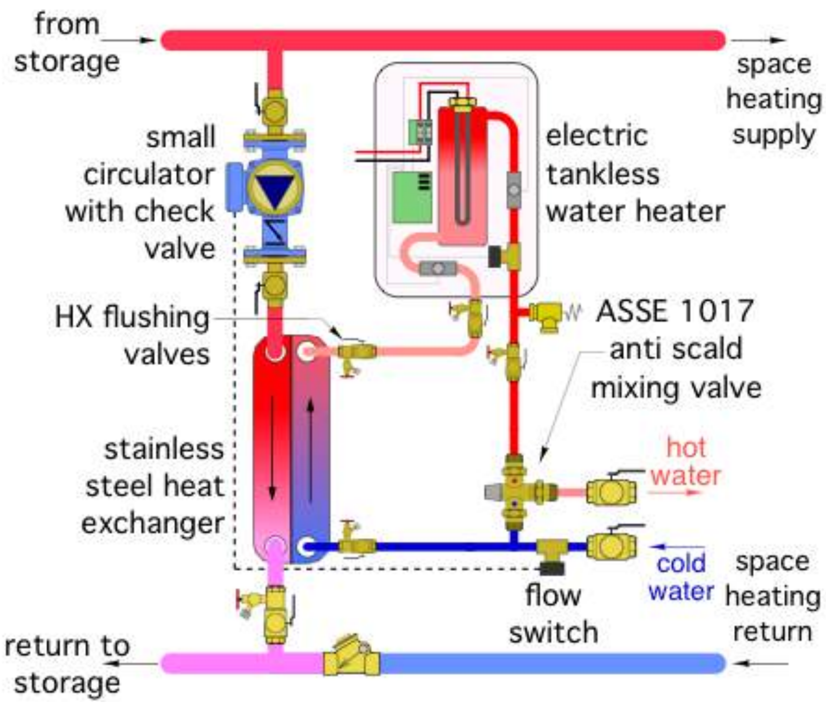
Thermostatically controlled electric tankless water heaters

Image courtesy Eemax





Instantaneous DHW subassembly




3”x5”

5”x12”

5”x20”

Brazed plate stainless steel heat exchangers are widely available.

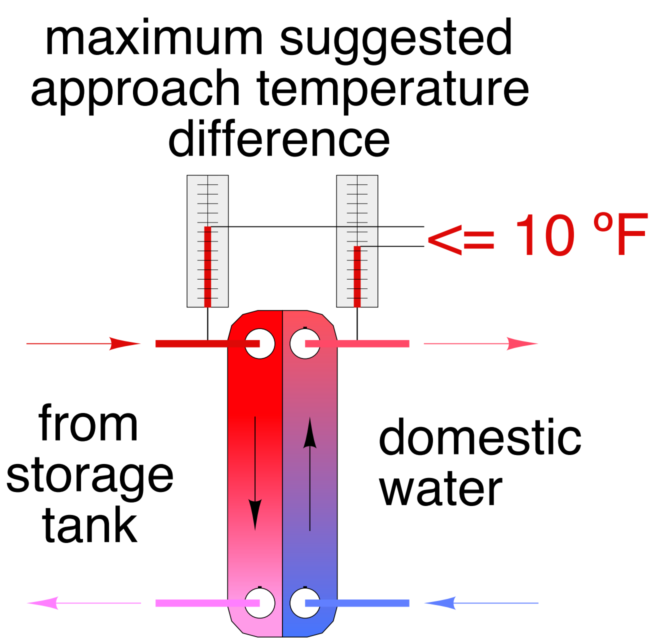
They have very high ratio of surface area to volume.

Response time to quasi steady state = 1 to 2 seconds

Response time of this subassembly is likely under 5 seconds.
(assuming short, insulated piping b/w HX and storage tank)

Sizing the brazed plate heat exchanger

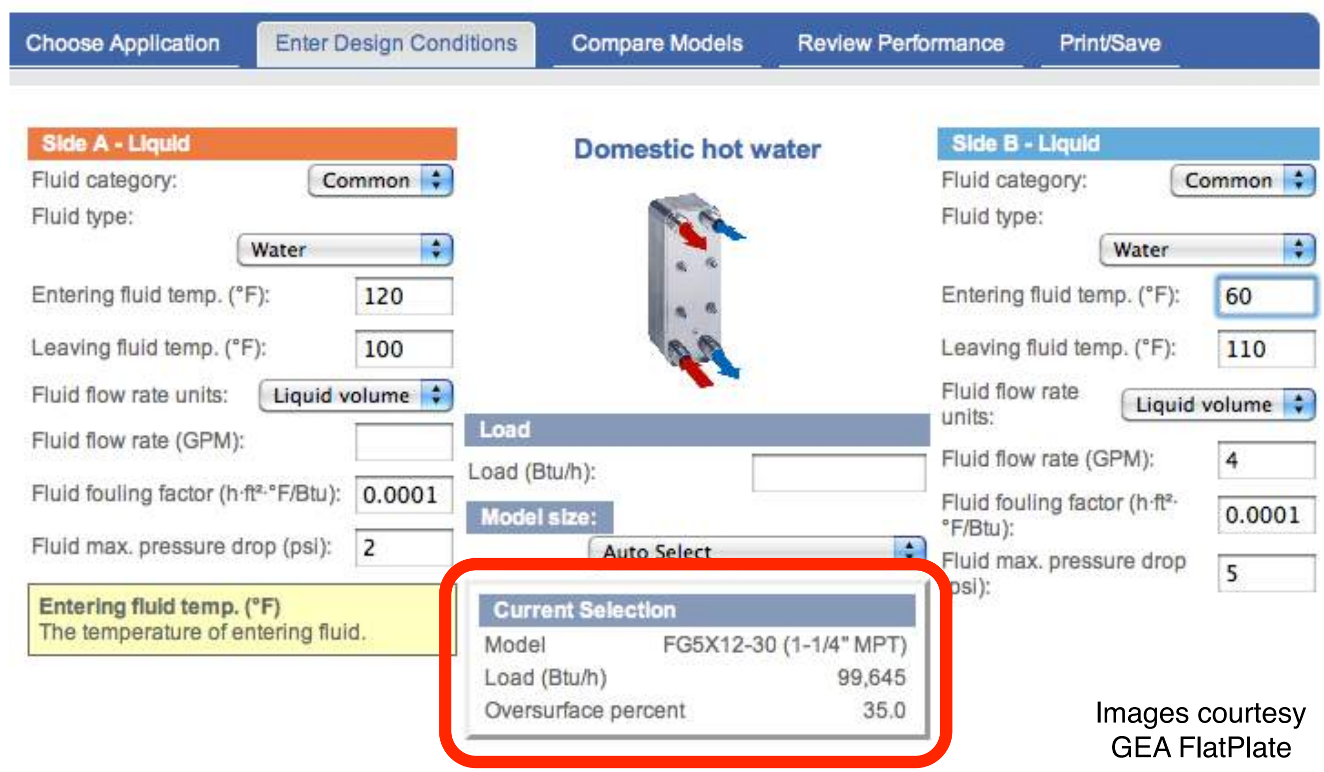
Suggest a maximum approach temperature difference of 10 °F under max. anticipated water demand, and minimum preheat inlet temperature.



FG5x12-30
5” wide x12” long -30 plates

http://flatplateselect.com

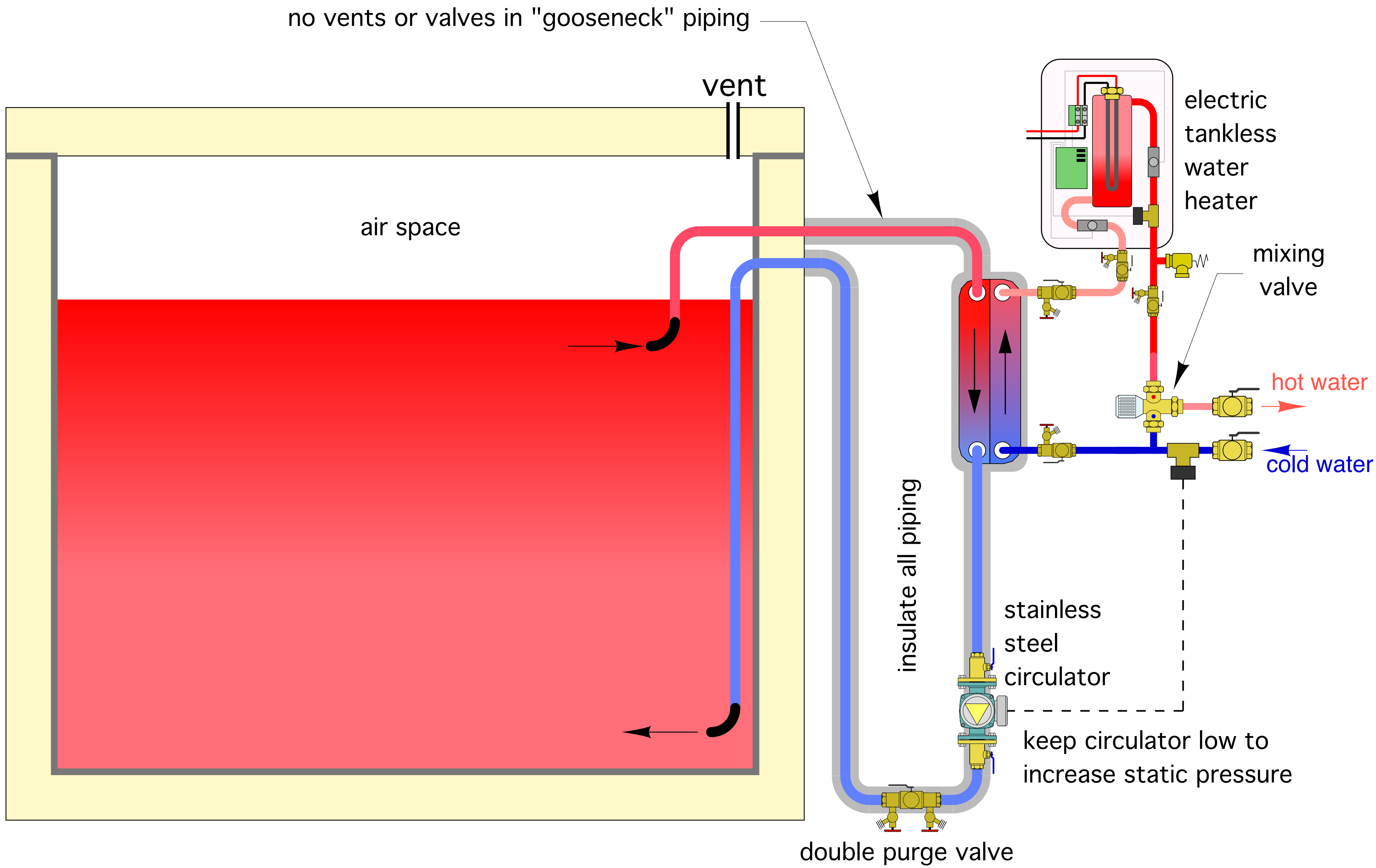
GEA FlatPlateSELECT™ – ONLINE



Images courtesy GEA FlatPlate

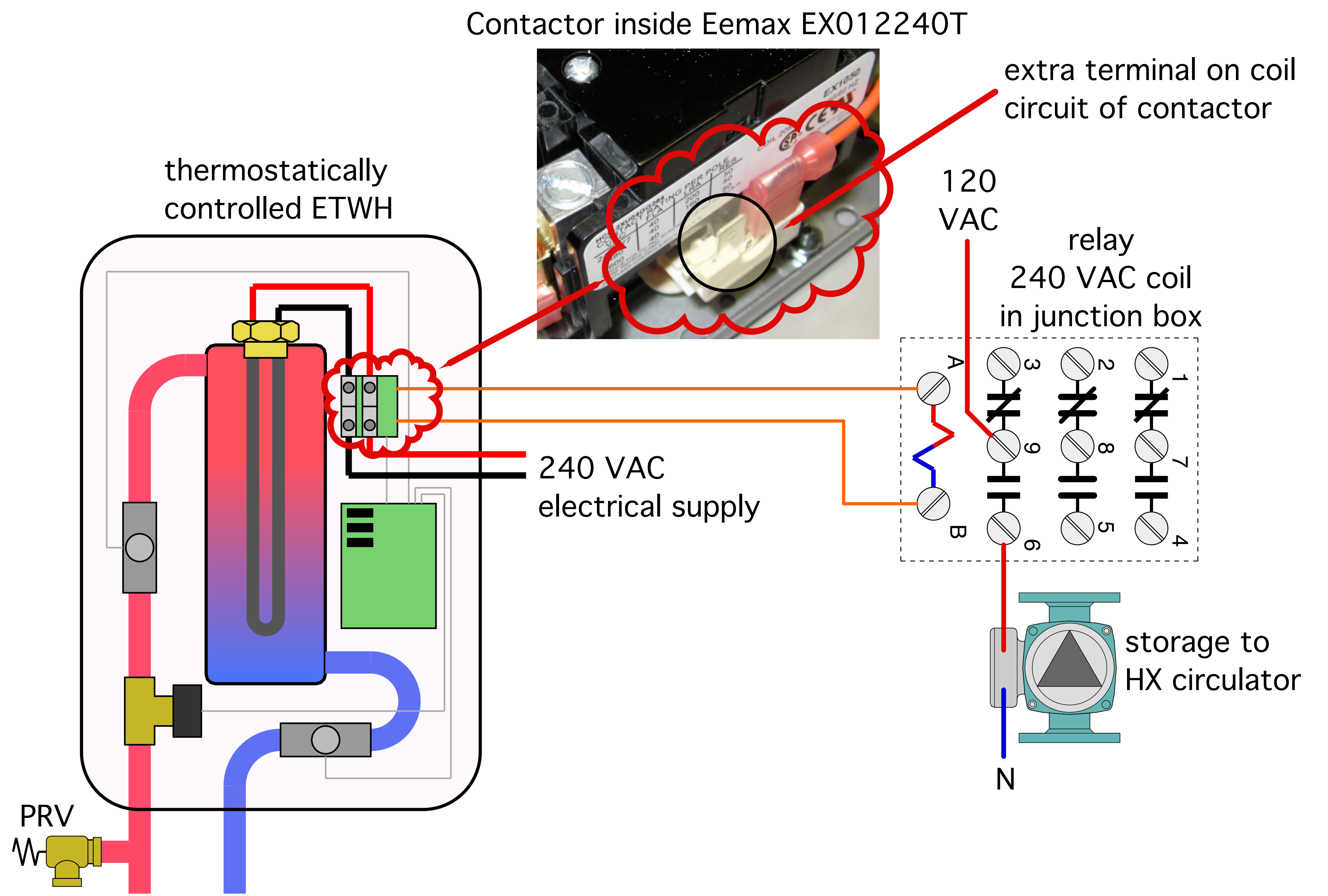
Instantaneous DHW subassembly piping

Using it with unpressurized thermal storage



Using extra terminal on ETWH contactor to operate circulator

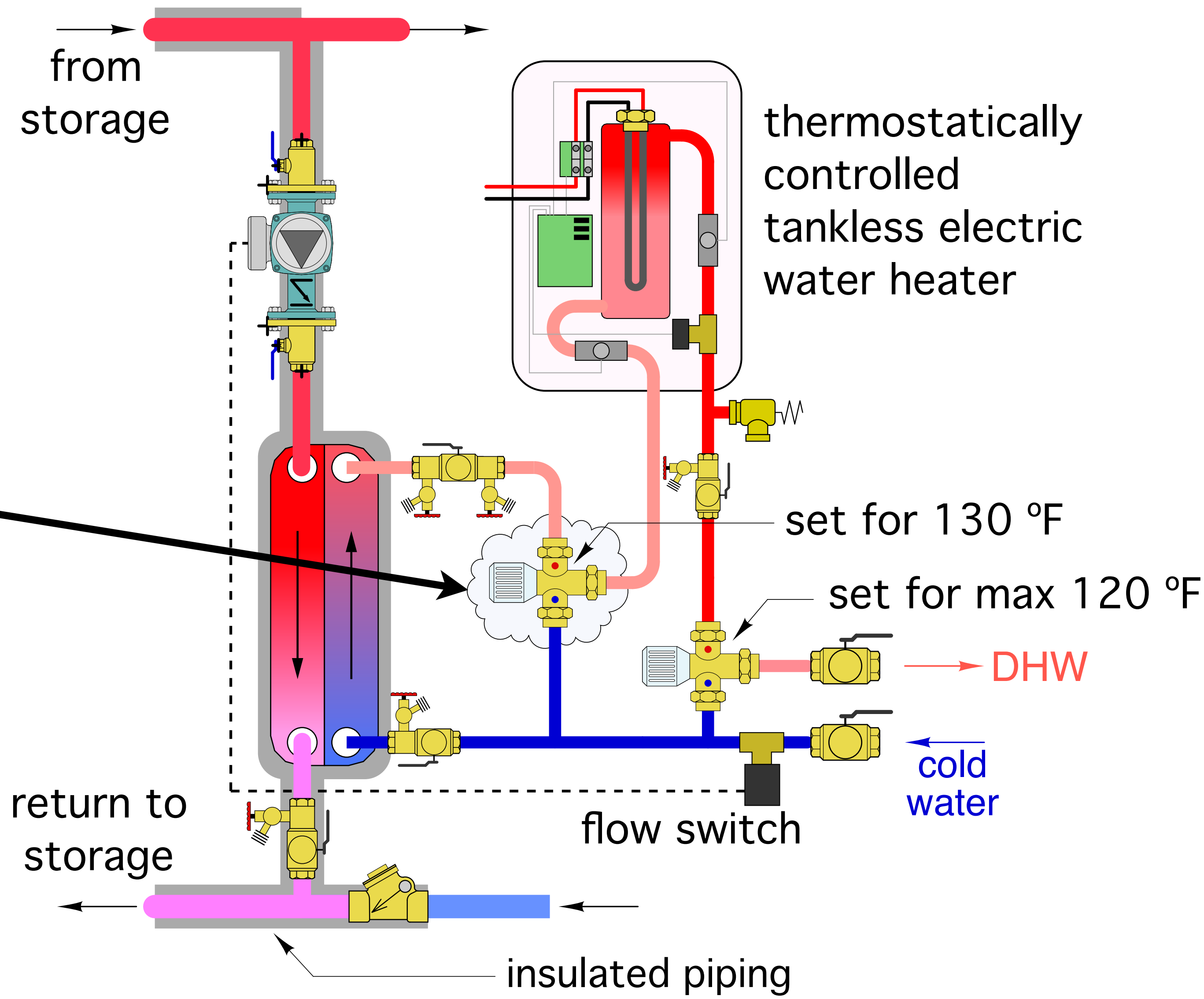
This eliminates the need for the flow switch.



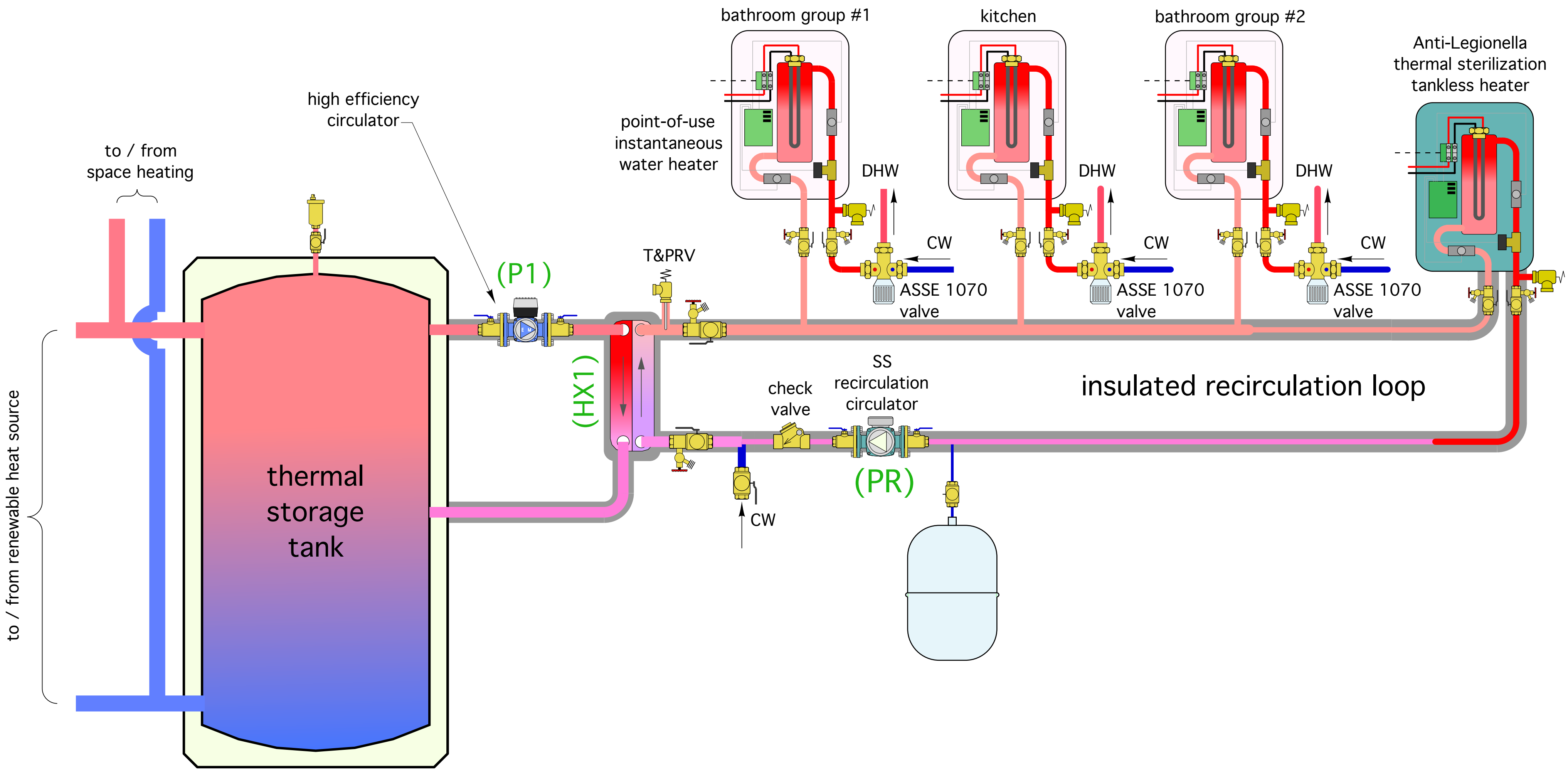
Some ETWH have a safety switch that cannot be set higher than 140 ºF.

This could cause automatic shut down of the ETWH

Solution:Add 2nd thermostatic valve if the high limit switch can't be set higher than 140 ºF.

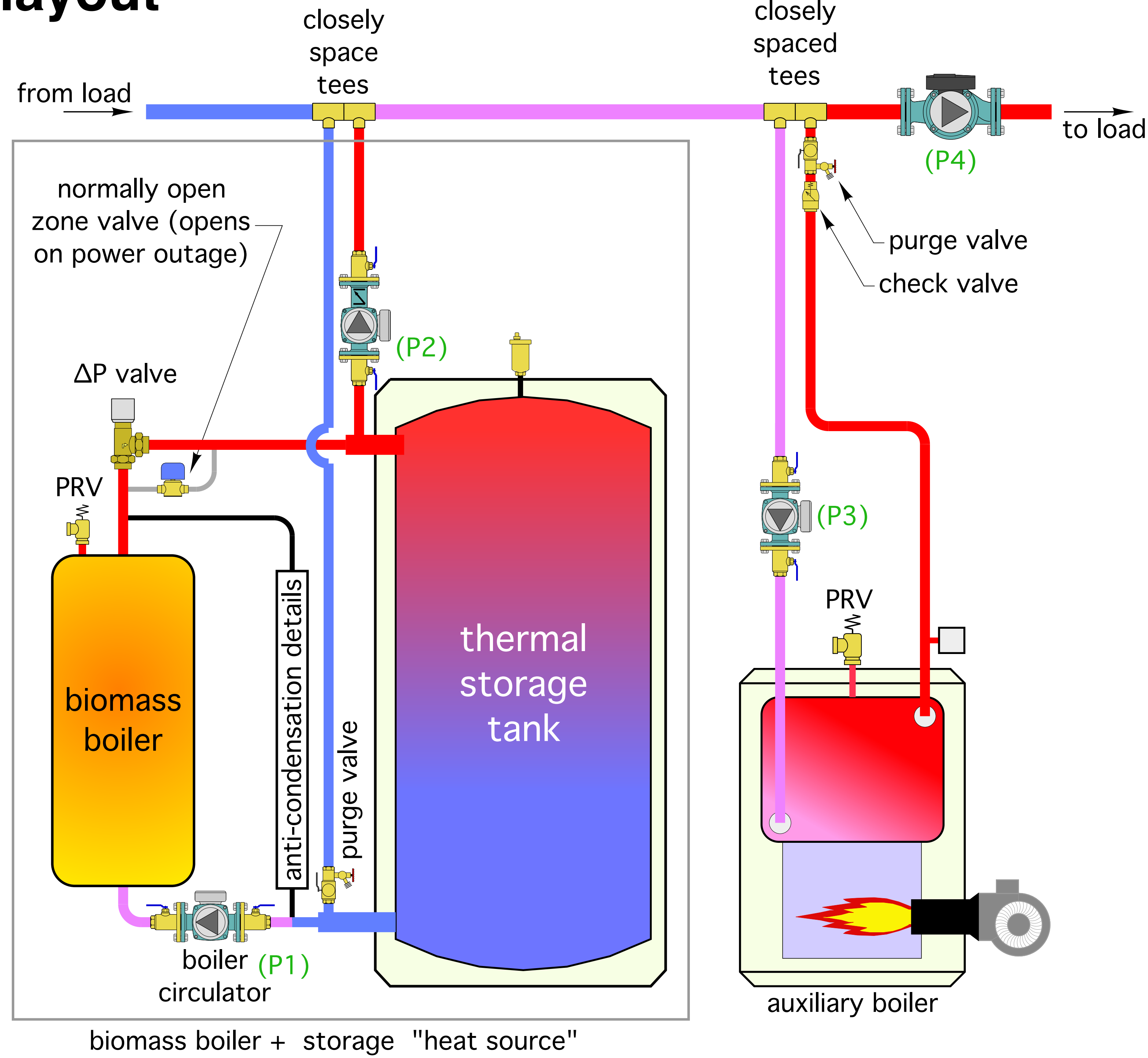


Adding recirculation and anti-Legionella details…

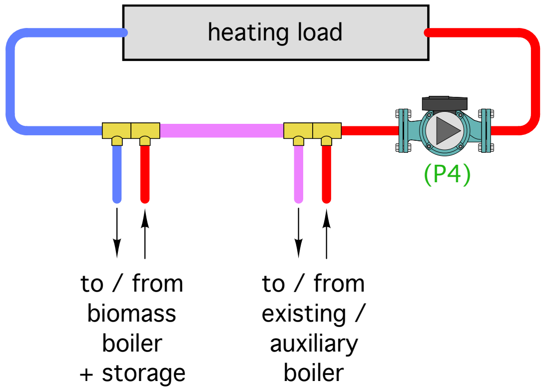


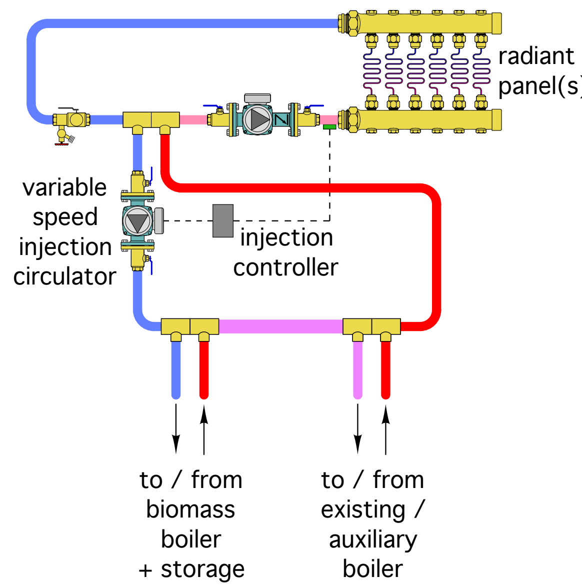
System Examples (putting the pieces together)

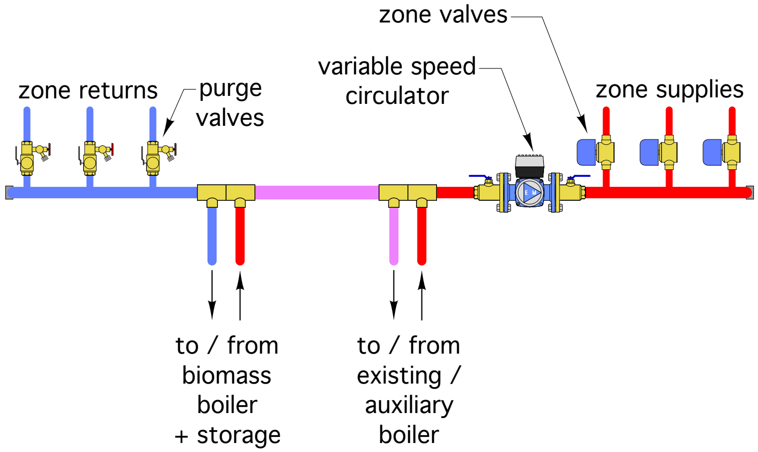
System layout

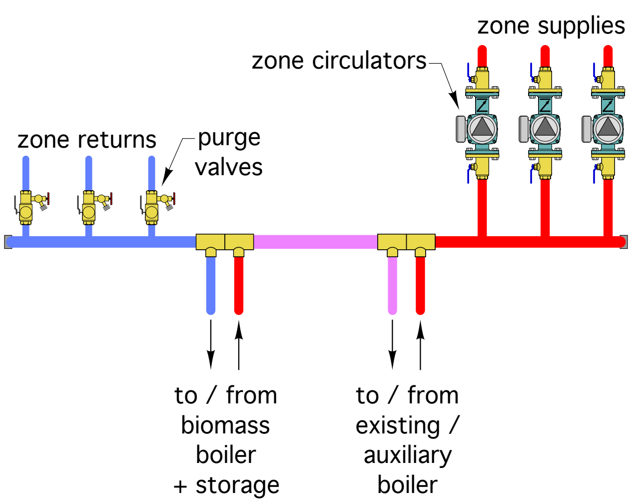


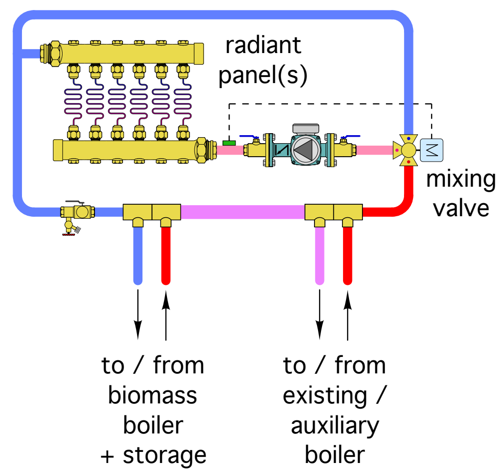
The distribution system can take many forms



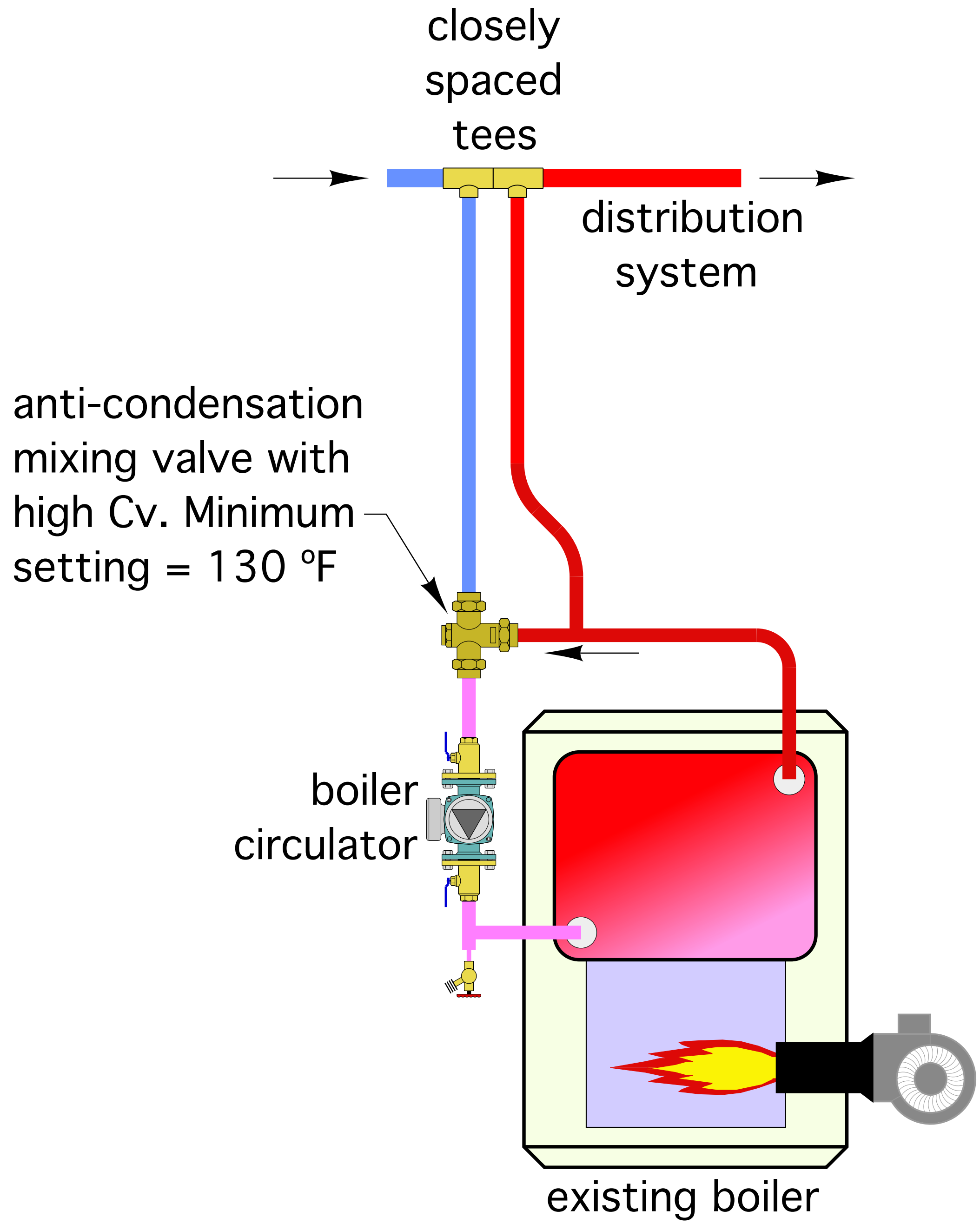








If distribution system can operate at low temperature remember to protect "conventional" boiler from sustained flue gas condensation



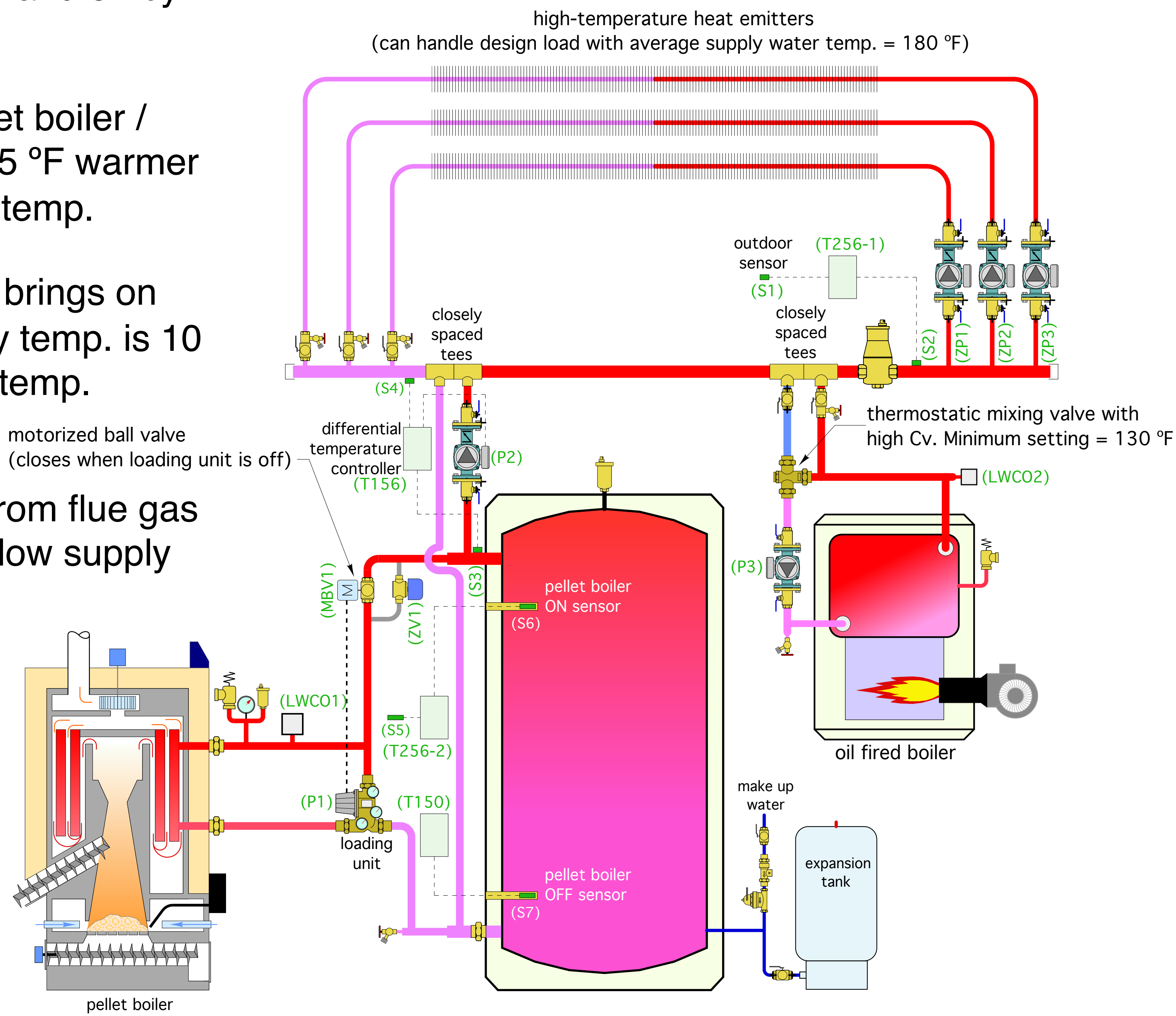
System #1 (space heating w/ pellet boiler + Aux boiler

- Pellet boiler turned on and off by two tank sensors.

- ΔT control allows pellet boiler / tank to add heat when 5 °F warmer than distribution return temp.

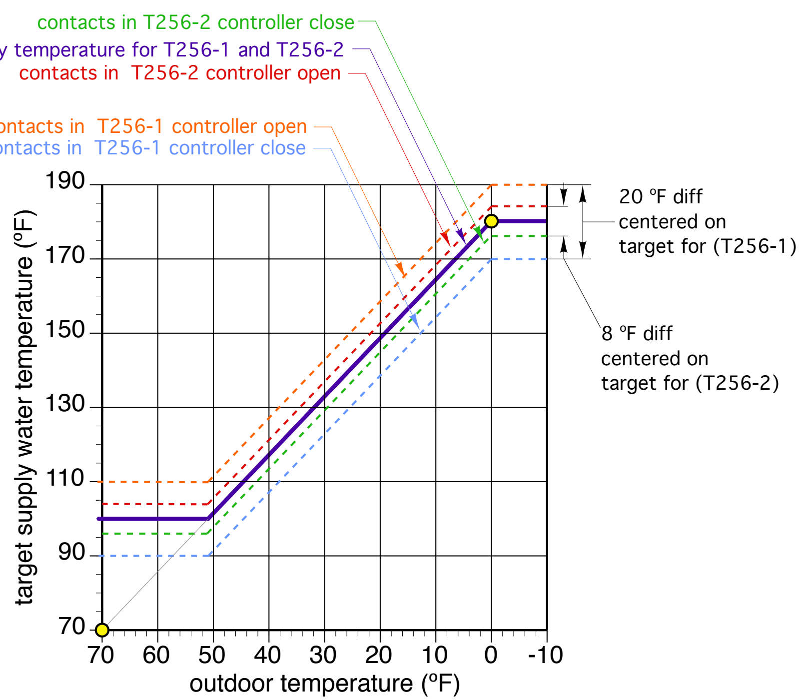
- Outdoor reset control brings on aux. boiler when supply temp. is 10 °F below target supply temp.

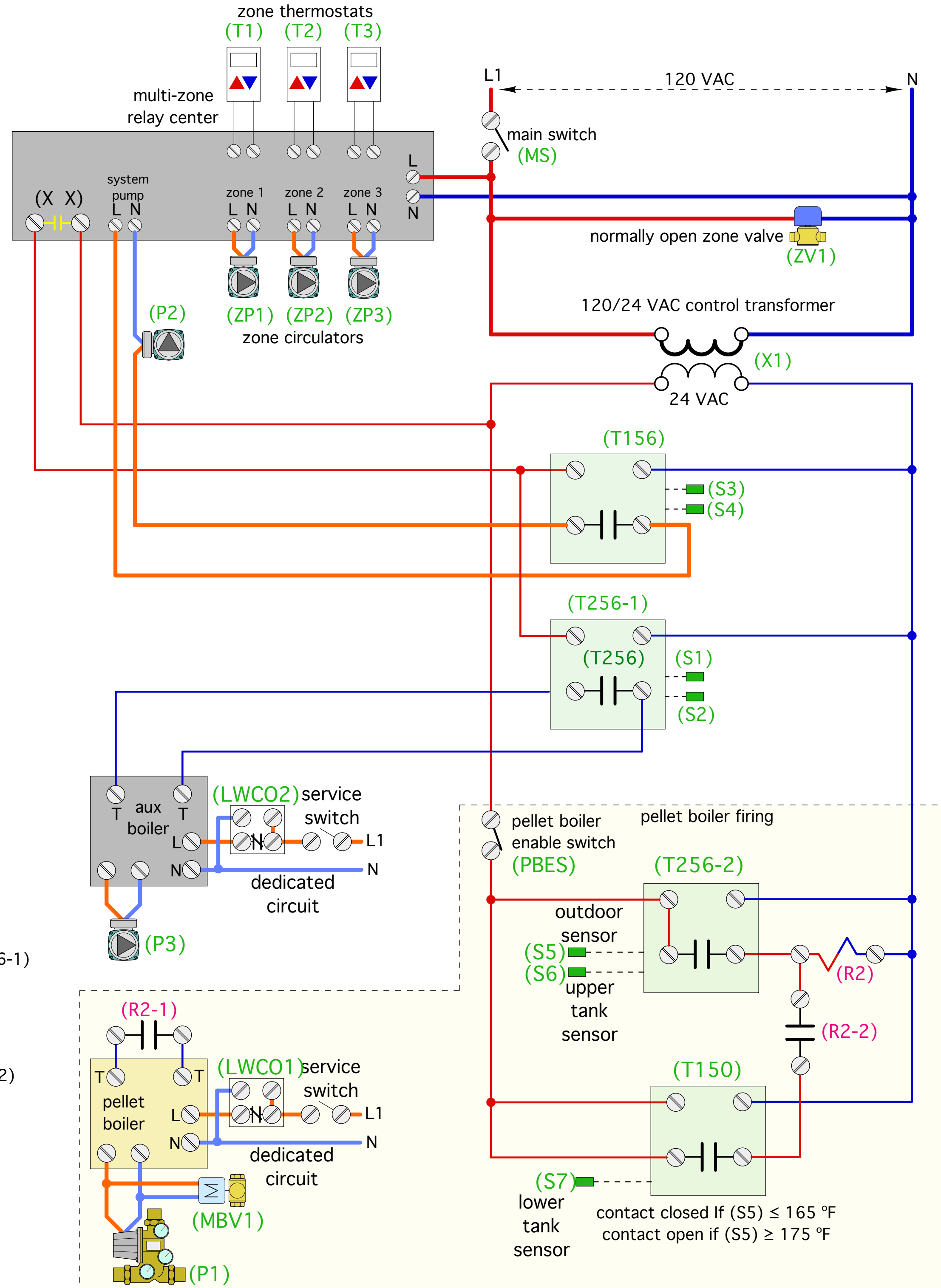
- Aux boiler protected from flue gas condensation allowing low supply water temps.



System #1

- 180 °F supply water at 0 °F outdoor temperature (design condition).
- Simple, inexpensive controllers.
- Takes advantage of lowest possible storage tank temperatures during partial load conditions.
- Aux boiler activates whenever supply water temperature is 10 °F below target temperature. (adjustable).





System #1

Please read through this later....

Description of operation:

Power Supply: *120 VAC power for the pellet boiler is supplied from a dedicated circuit. The service switch for the pellet boiler must be closed, and the low water cutoff (LWCO1) must detect water for the pellet boiler to operate.*

120 VAC power for the auxiliary boiler is supplied from a dedicated circuit. The service switch for the auxiliary boiler must be closed, and the low water cutoff (LWCO2) must detect water for the auxiliary boiler to operate.

Power for the zone circulators (ZP1, ZP2, ZP3), 24 VAC transformer, normally open zone valve (ZV1), and controllers (T156), (T256-1), (T256-2), and (T150) is supplied through another 120 VAC dedicated circuit. The main switch (MS) for this circuit must be closed for these devices to operate.

Pellet Boiler Operation: *The pellet boiler enable switch must be closed for the pellet boiler to operate. This switch would typically be closed at the start of the heating season and opened at the end of the heating season. The pellet boiler is turned on by an outdoor reset controller (T256-2). The (T256-2) controller measures the outdoor temperature at sensor (S5), and uses this temperature along with its settings to determine the "target" temperature at the upper tank sensor (S6) at which the pellet boiler will be turned on. The target temperature for this controller is shown on the graph in figure 8-1c. When the temperature at the upper tank sensor (S6) drops to 4 ºF below the target temperature, the normally open contacts in the (T256-2) controller close. This passes 24 VAC to the coil of relay (R2). Relay contact (R2-1) closes across the external demand terminal of the pellet boiler. The pellet boiler turns on loading unit circulator (P1) and initiates its start up sequence. Motorized ball valve (MBV1) opens to allow flow between the pellet boiler and thermal storage tank. Relay contact (R2-2) also closes. 24 VAC passes through the closed contacts of setpoint controller (T150) and through the closed contacts (R2-2) to provide another path for 24 VAC to relay coil (R2). When the temperature at the upper tank sensor (S6) reaches 4 ºF above the target temperature the contacts in the outdoor reset controller (T256-2) open. However, 24 VAC continues to pass through the closed contacts in controller (T150) and closed contacts (R2-2) until the lower tank sensor (S7) reaches 175 ºF. At that point the contacts in setpoint controller (T150) open, breaking 24VAC to relay coil (R2), which removes the external demand from the pellet boiler, allowing it to shut down.*

The pellet boiler is equipped with a loading unit (P1) which contains a thermostatic mixing valve that recirculates water through the pellet boiler when necessary to allow the temperature of the pellet boiler to quickly climb above the dewpoint of the exhaust gases.

During a power outage, the normally open zone valve (ZV1) opens to allow an unblocked thermosiphon piping path between the pellet boiler and thermal storage tank. A thermosiphon flow will occur that dissipate residual heat from the pellet boiler into thermal storage.

If the pellet boiler switch (PBES) is opened, such as at the end of the space heating season, the pellet boiler, its associated controllers, and its circulator (P1) will not operate.

Distribution system: *Upon a call for heating from any zone thermostat (T1, T2, T3), the associated zone circulator (ZP1, ZP2, ZP3) is turned on. 120 VAC is also present at the "system pump" terminals in the multi-zone relay center. The isolated relay contact (X X) in the multizone relay center closes passing 24VAC power from transformer (X1) to outdoor reset controller (T256-1) and differential temperature controller (T156). The (T156) compares the temperature of the upper tank header sensor (S3) to the temperature of water returning from the distribution system at sensor (S4). If the upper tank header temperature is at least 5 ºF above the return water temperature the contacts in the (T156) controller close. This allows 120VAC to reach circulator (P2) to inject heat from the upper tank header into the distribution system.*

The (T256-1) controller measures outdoor temperature at sensor (S1) and calculates a target supply water temperature for the distribution system. This is the same target temperature calculated by controller (T256-2). If the temperature of the water passing sensor (S2) on the supply side of the distribution system is 10 ºF or more below the target supply water temperature the contacts in the (T256-1) controller close across the (T T) terminals of the auxiliary boiler enabling it, and circulator (P3) to operate. Heat from the oil-fired boiler is now injected into the distribution system. Circulator (P2) continues to run unless the temperature on the return side of the distribution system at sensor (S3), climbs to within 3 ºF of the temperature of the upper tank header at sensor (S4). If this occurs, the contacts in the (T156) controller open turning off circulator (P2). Heat from the oil-fired boiler continues to flow into the distribution system until the supply water temperature reaches 10 ºF above the target temperature. At that point the oil fired boiler and circulator (P3) turn off. Assuming the heating demand from one or more zones continues, the water temperature at sensor (S1) will eventually drop to 10 ºF below the target temperature, at which time the oil-fired boiler and circulator (P3) will turn on.

System #1

Please read through this later....

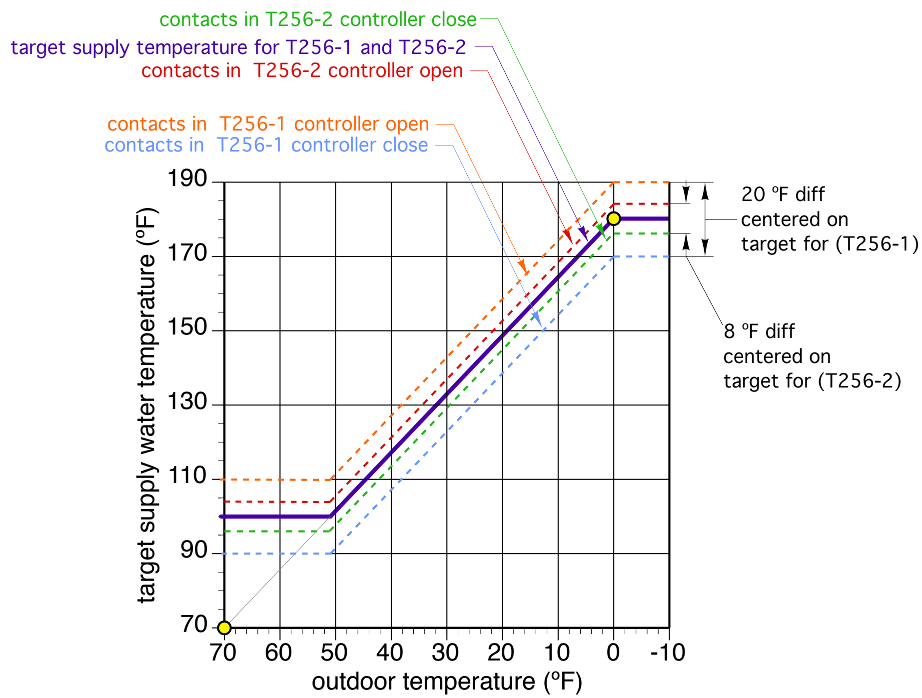
Suggested initial controller settings:

- *T256-2 outdoor reset controller (monitors upper tank sensor (S6))*
  - *Outdoor design temperature = 0 °F*
  - *Supply water temperature at outdoor design temperature = 180 °F*
  - *Maximum supply water temperature = 180 °F*
  - *Minimum supply water temperature = 100 °F*
  - *Outdoor temperature at no load condition = 70 °F*
  - *Supply water temperature at no load condition = 70 °F*
  - *Differential = 8 °F (centered on target temperature)*

- *T256-1 outdoor reset controller (monitors supply temp. sensor for distribution system (S2))*
  - *Outdoor design temperature = 0 °F*
  - *Supply water temperature at outdoor design temperature = 180 °F*
  - *Maximum supply water temperature = 180 °F*
  - *Minimum supply water temperature = 100 °F*
  - *Outdoor temperature at no load condition = 70 °F*
  - *Supply water temperature at no load condition = 70 °F*
  - *Differential = 20 °F (centered on target temperature)*

- *T150 setpoint controller (monitors lower tank temperature sensor (S7)*
  - *setpoint = 170 °F*
  - *Differential = 10 °F (centered on target temperature)*

- *T156 differential temperature controller*
  - *contacts close if high temperature sensor ≥ 5 °F above low temperature sensor*
  - *contacts open if high temperature sensor ≤ 3 °F above low temperature sensor*
- *Pellet Boiler high limit temperature = 200 °F*
- *Oil-fired boiler high limit temperature = 200 °F*
- *Oil fired boiler differential = 5 °F (below target temperature)*



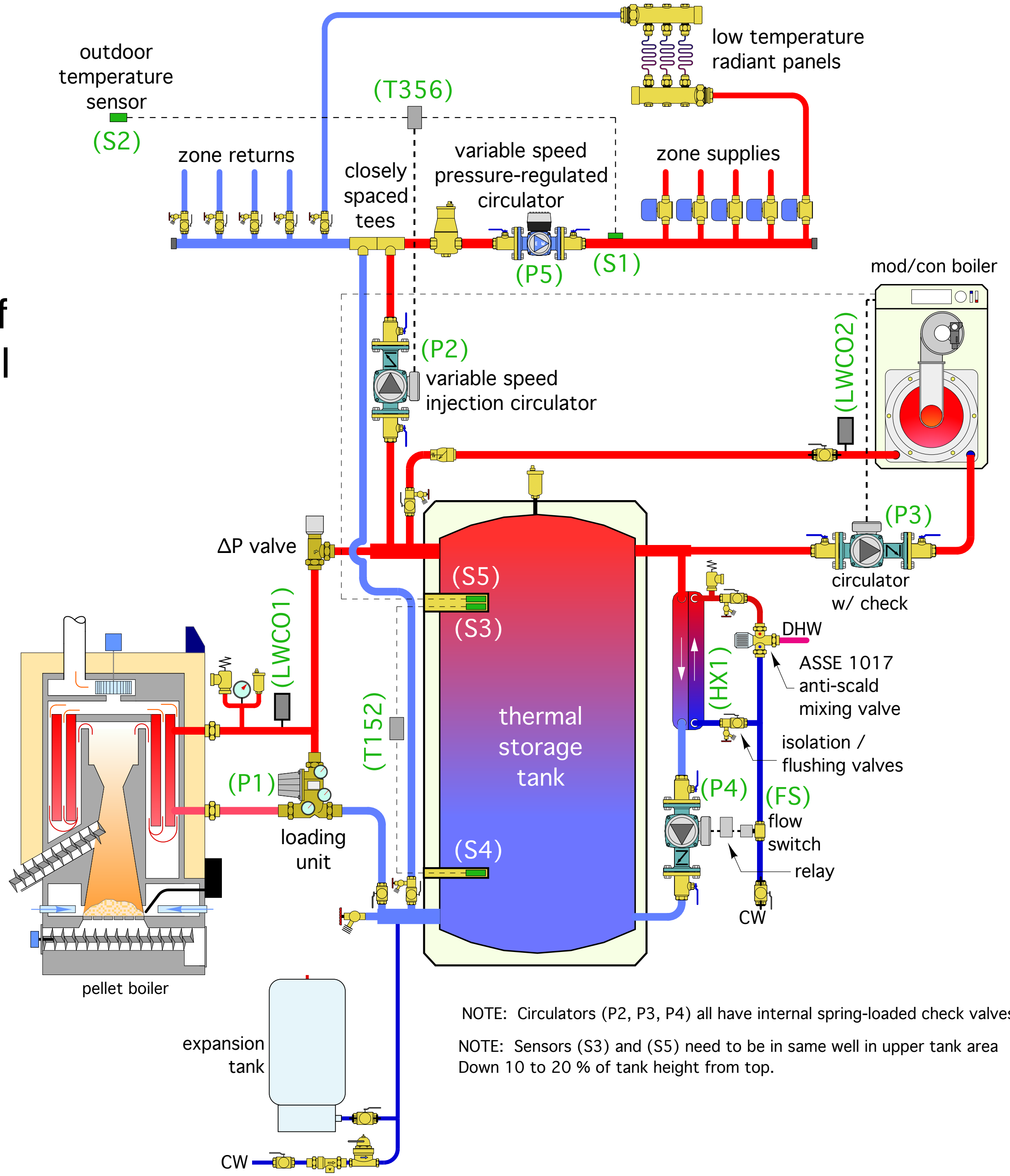
System #3: space heat + DHW w/ pellet boiler + Aux boiler

- Single tank buffers both space heating and DHW loads.

- Circulator (P2) operates as a variable speed injection pump to provide full outdoor reset control of supply temperature to radiant panel circuits.

- Mod/con boiler buffered by upper portion of tank. Maintains upper tank at sufficient temperature for DHW production.

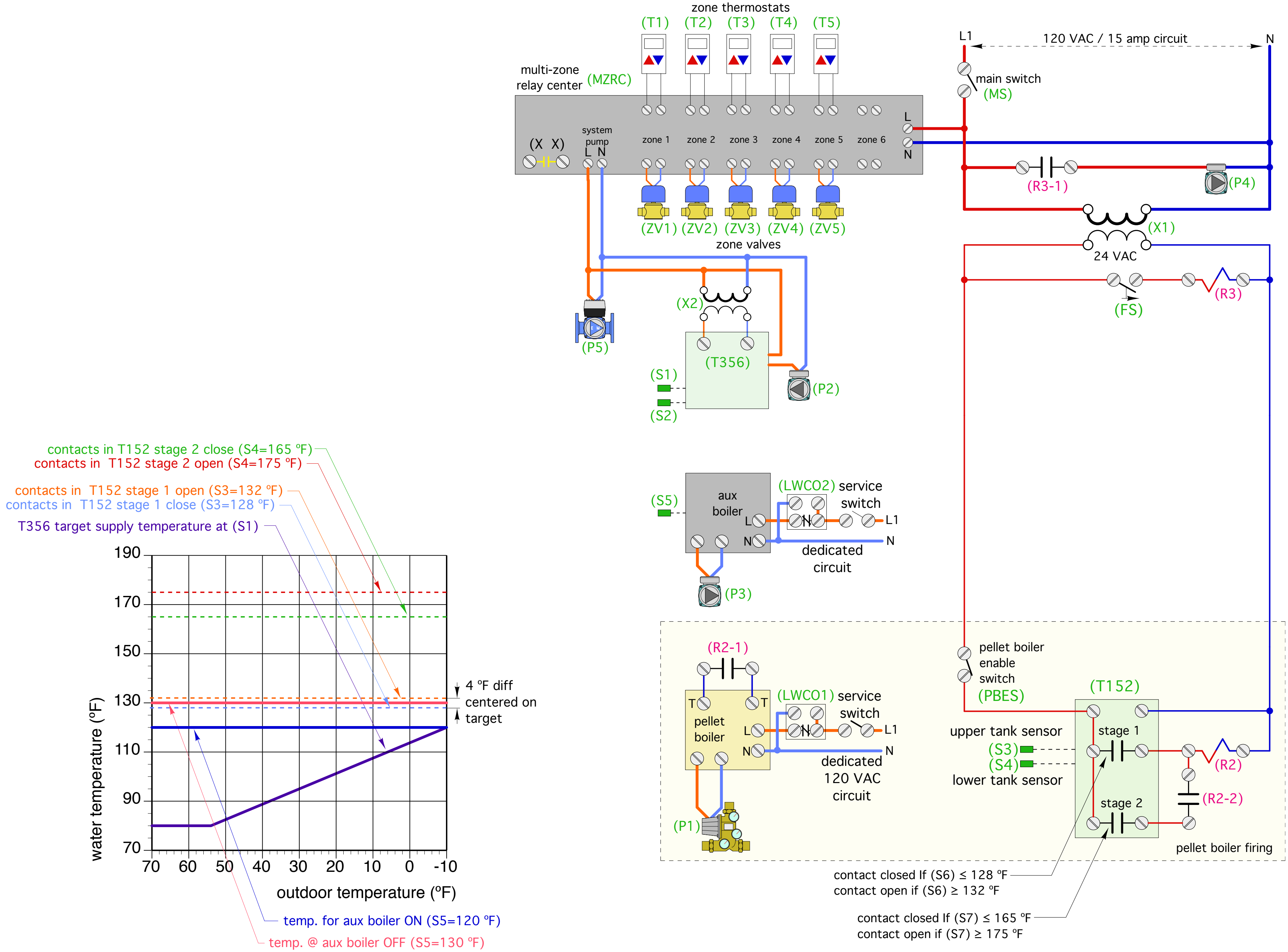
- In summer the pellet boiler can be tuned off. Mod/con maintains tank for DHW production.



NOTE: Circulators (P2, P3, P4) all have internal spring-loaded check valves

NOTE: Sensors (S3) and (S5) need to be in same well in upper tank area Down 10 to 20 % of tank height from top.

System #3: space heat + DHW w/ pellet boiler + Aux boiler



System #3: space heat + DHW w/ pellet boiler + Aux boiler

Please read through this later....

Description of operation:

Power Supply: *120 VAC power for the pellet boiler is supplied from a dedicated circuit. The service switch for the pellet boiler must be closed, and the low water cutoff (LWCO1) must detect water for the pellet boiler to operate.*

120 VAC power for the auxiliary boiler is supplied from a dedicated circuit. The service switch for the auxiliary boiler must be closed, and the low water cutoff (LWCO2) must detect water for the auxiliary boiler to operate.

Power for the circulators (P2) (P4) and (P5), the 24 VAC transformer (X1), the multi-zone relay center (MZRC), temperature controller (T152), and relay coil (R2) is supplied through another 120 VAC dedicated circuit. The main switch (MS) must be closed for these devices to operate.

Pellet boiler operation: *The pellet boiler enable switch (PBES) must be closed for the pellet boiler to operate. Whenever sensor (S3) in the upper portion of the thermal storage tanks is below 128 ºF the stage 1 contacts in the (T152) controller close. This passes 24VAC from transformer (X1) to relay coil (R2). Relay contact (R2-1) closes across the external demand terminal of the pellet boiler. The pellet boiler turns on circulator (P1) and initiates its startup routine. Relay contact (R2-2) also closes. 24 VAC passes through the closed stage 2 contacts of controller (T152) and through the closed contacts (R2-2) to provide another path for 24 VAC to relay coil (R2). When the temperature at the upper tank sensor (S3) reaches 132 ºF the stage 1 contacts in the outdoor reset controller (T152) open. However, 24 VAC continues to pass through the closed stage 2 contacts in controller (T152) and closed contacts (R2-2) until the lower tank sensor (S4) reaches 175 ºF. At that point the stage 2 contact in controller (T152) opens, breaking 24VAC to relay coil (R2), which removes the external demand from the pellet boiler, allowing it to follow its normal shut down procedure.*

Auxiliary boiler operation: *The internal controller within the auxiliary boiler monitors the temperature at sensor (S5) in the upper portion of the thermal storage tank. If that temperature drops to or below 120 ºF, the auxiliary boiler turns on, along with its associated circulator (P3). Heated water is directed from the auxiliary boiler to the upper left header of the thermal storage tank. From there is can either flow to the load through circulator (P2) if a heating zone is active, or through the upper portion of the thermal storage tank. When the temperature at sensor (S5) reaches 130 ºF, the auxiliary boiler and circulator (P3) are turned off.*

Space heating distribution system operation: *Upon a call for heating from any zone thermostat (T1, T2, T3, T4, T5), the associated zone valve (ZV1, ZV2, ZV3, ZV4, ZV5) is turned on the by the multi-zone relay center (MZRC). Circulator (P5) is turned on, and operates in a preset constant differential pressure mode. 120 VAC is also passed to transformer (X2) which provides 24 VAC to the (T356) variable speed injection controller. The (T356) controller boots up and measures the current outdoor temperature. It uses that temperature along with its settings to calculate a target supply water temperature for the distribution system. The (T356) then controls the speed of circulator (P2) to inject hot water from the upper left header of the thermal storage tank into the distribution system at the closely spaced tees. The rate of hot water injection varies in an attempt to hold the supply water temperature measured at sensor (S1) as close to the target temperature as possible. This operation continues as long as one or more zones remain active. When all zone thermostats are satisfied, the (MZRC) turns of circulator (P5), transformer (X2), and the injection mixing controller (T356).*

Domestic water heating: *The temperature of the upper portion of the thermal storage tank is continuously maintained at or above 120 ºF by either the pellet boiler or auxiliary boiler. Whenever there is a demand for domestic hot water of 0.6 gallons per minute or higher, flow switch (FS) closes, passing 24VAC to the coil of relay (R3). Relay contact (R3-1) closes to turn on circulator (P4) which immediately routes hot water from the top of the thermal storage tank through the primary side of stainless steel heat exchanger (HX1). Cold domestic water passes in counterflow through the other side of heat exchanger (HX1) and is fully heat to or above the desired domestic hot water delivery temperature of 115 ºF. The hot water leaving (HX1) passes through an ASSE 1017 listed anti-scaled mixing valve to ensure that the maximum hot water delivery temperature to the plumbing system is 115 ºF. When the domestic hot water flow rate drops to 0.4 gpm or less the flow switch (FS) opens, turning off relay coil (R3) and circulator (P4).*

System #3: space heat + DHW w/ pellet boiler + Aux boiler

Please read through this later....

Suggested initial controller settings:

Stage 1 contacts in (T152) controller: (monitors upper tank temperature)
contacts close at 128 ºF, open at 132 ºF

Stage 2 contacts in (T152) controller: (monitors lower tank temperature)
contact close at 165 ºF, open at 175 ºF

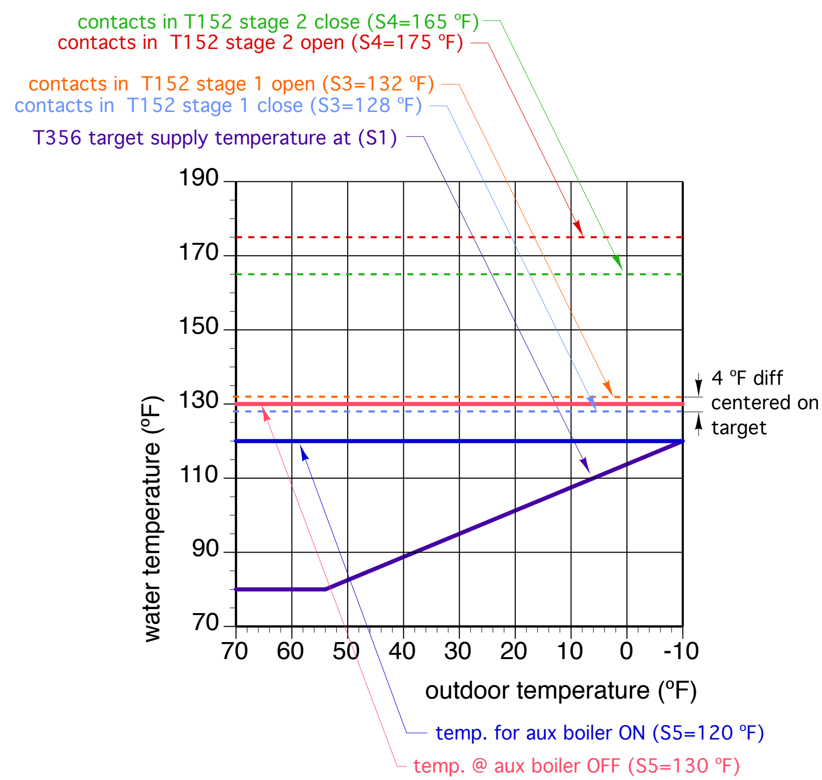
Injection mixing controller (T356) settings:
No load condition: 70 ºF supply water temperature when outdoor temperature is 70 ºF
Design load condition: 110 ºF supply water temperature when outdoor temperature is 0 ºF or lower
Minimum supply water temperature = 80 ºF
Maximum supply water temperature = 110 ºF

Circulator (P5) setting:
Differential pressure constant at the required ΔP with all zone valves open

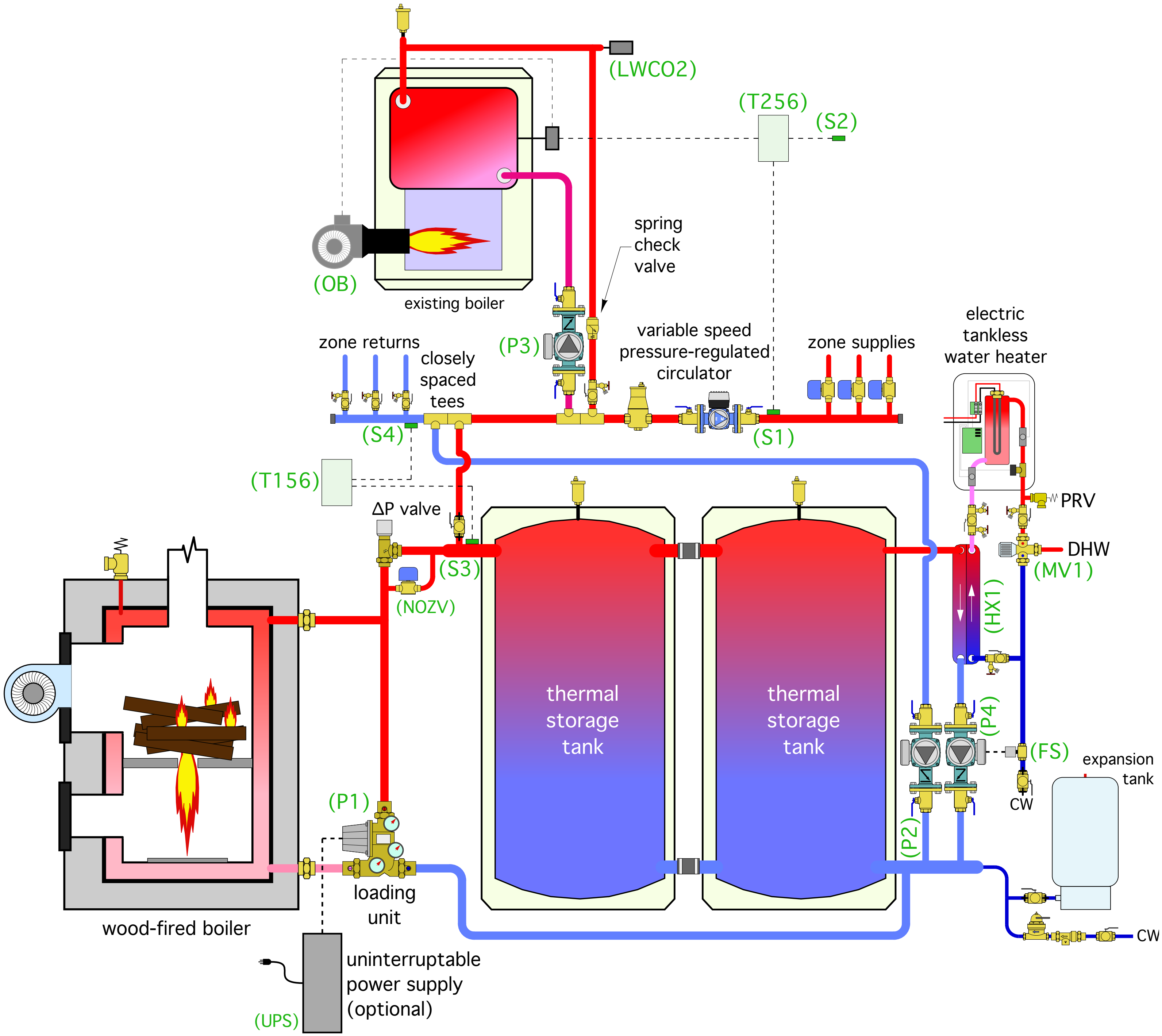
Auxiliary boiler setting:
Boiler on when temperature at sensor (S5) is 120 ºF or lower
Boiler off when temperature at sensor (S5) is 130 ºF or higher

Pellet boiler settings:
High limit temperature = 200 ºF
Other setting as per boiler manufacturer's recommendations

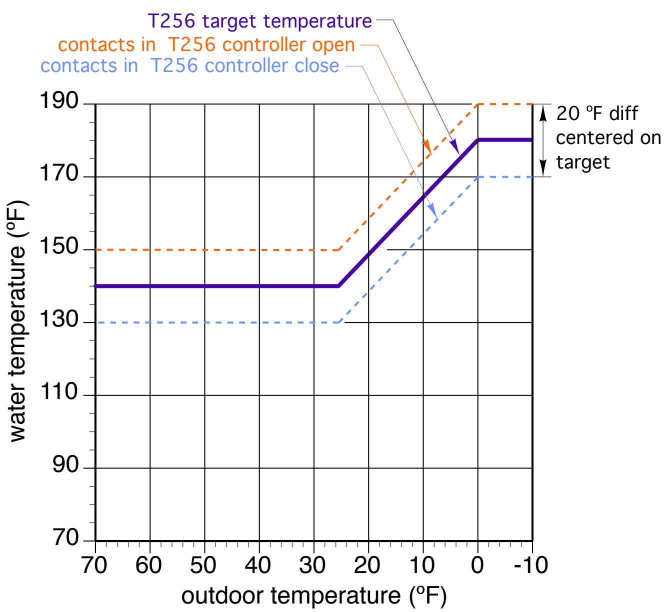
Anti-scald mixing valve setting:
115 ºF domestic hot water leaving temperature

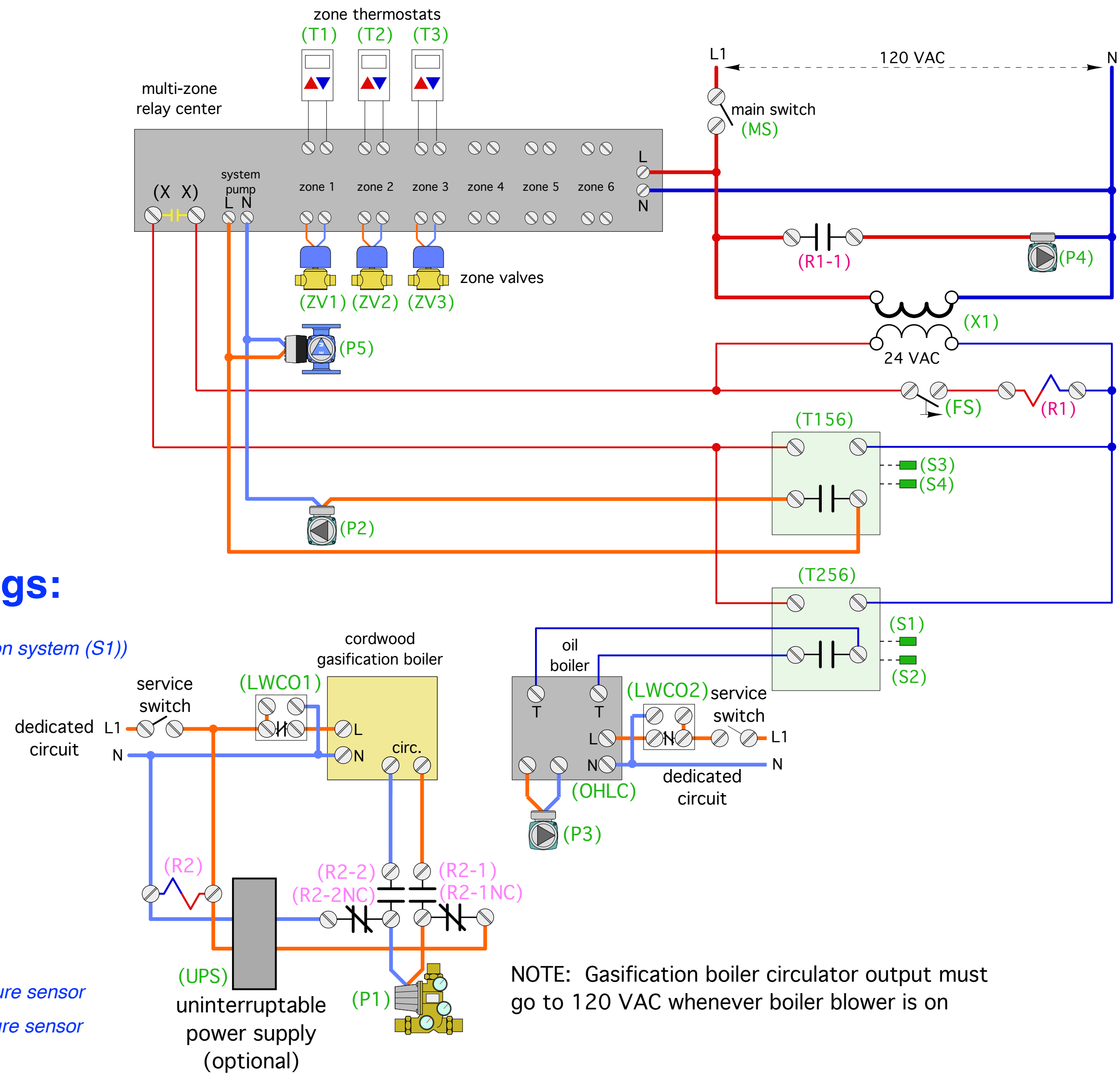


System #4: heat + DHW w/ cordwood boiler + Aux boiler



System #4: heat + DHW w/ cordwood boiler + Aux boiler





Suggested initial controller settings:

- *T256 outdoor reset controller (monitors supply temp. sensor for distribution system (S1))*
  - *Outdoor design temperature = 0 °F*
  - *Supply water temperature at outdoor design = 180 °F*
  - *Maximum supply water temperature = 180 °F*
  - *Minimum supply water temperature = 140 °F*
  - *Outdoor temperature at no load condition = 70 °F*
  - *Supply water temperature at no load condition = 70 °F*
  - ***Differential = 20 °F (centered on target temperature)***
- *T156 differential temperature controller*
  - *contacts close if high temperature sensor ≥ 5 °F above low temperature sensor*
  - *contacts open if high temperature sensor ≤ 3 °F above low temperature sensor*
- *Cordwood gasification boiler high limit temperature = 200 °F*
- *Oil-fired boiler high limit temperature = 195 °F*
- *Oil fired boiler differential = 20 °F (below target temperature)*

System #4: heat + DHW w/ cordwood boiler + Aux boiler

Please read through this later....

Description of operation:

Power Supply: *120 VAC power for the cordwood gasification boiler is supplied from a dedicated circuit. The service switch for the pellet boiler must be closed, and the low water cutoff (LWCO1) must detect water for the pellet boiler to operate.*

120 VAC power for the oil-fired boiler is supplied from a dedicated circuit. The service switch for the auxiliary boiler must be closed, and the low water cutoff (LWCO2) must detect water for the oil-fired boiler to operate.

Power for circulators (P2) (P4) and (P5), the 24 VAC transformer (X1), the multi-zone relay center (MZRC), controllers (T156) (T256), and relay coil (R2) is supplied through another 120 VAC dedicated circuit. The main switch (MS) must be closed for these devices to operate.

Cordwood gasification boiler operation: *After a fire is kindled in the boiler, and the chamber is loaded with wood, the operator turns on the boiler's blower switch. The circulator output of the boiler must be wired to go to 120 VAC whenever the boiler is being fired. This passes 120 VAC to the loading unit (P1). The cold port of loading unit is fully closed, and the bypass port is fully open while the boiler is warming above the dewpoint of its exhaust gases. This prevents heat from the boiler from reaching the load or thermal storage. As the water temperature leaving the loading unit rises above 130 ºF, the cold port of the loading unit begins to open, allowing some hot water to flow to the load or thermal storage. When the water temperature leaving the loading unit reaches 148 ºF or higher the cold port is fully closed and there is no flow into the bypass port. At that point all flow through the boiler is passing through the ΔP valve and is available to either the load or thermal storage tanks.*

During a power outage the normally open zone valve (NOZV) between the boiler and upper tank header opens to provide a thermosiphon path around the ΔP valve. Thermosiphon flow will develop between the boiler and tanks. If the optional uninterruptible power supply is used, an additional relay (R2) is installed. Upon a utility power loss relay coil (R2) is deenergized. This opens relay contacts (R2-1) and (R2-2) which disconnects both the line and neutral leads from the boiler to (P1), and connects the line and neutral leads of (P1) to the output of the UPS via contact (R2-1 NC) and (R2-2 NC). The UPS operates circulator (P1) until utility power is restored, or the battery in the UPS can no longer supply backup power to (P1). The battery in the UPS should be periodically tested to ensure it can provide the necessary backup power for at least 60 minutes. If not it should be replaced. The (NOZV) should also be periodically tested by removing power and ensuring that the valve immediately opens.

Oil-fired boiler operation: *Power is supplied to the high limit controller on the oil-fired boiler (OHLC) through the low water cutoff (LWCO-2). When there is a closed circuit across the (T T) terminals in the high limit controller, circulator (P3) is turned on, and the burner is enabled to fire. Assuming the circuit across the TT terminals remains closed the burner fires until the boiler's water temperature reaches 195 ºF, at which point the burner turns off but circulator (P3) remains on. The burner will fire again when the water temperature in the boiler drops to 175 ºF. NOTE: The 195 and 175 ºF temperatures associated with the boiler high limit controller are in effect "safety" settings. The operating controller for the boiler is the (T256). It will only allow the burner to operate up to a supply water temperature, at sensor (S1), and under design load conditions, of 190 ºF.*

Space heating distribution system operation: *Upon a call for heating from any zone thermostat (T1, T2, T3), the associated zone valve (ZV1, ZV2, ZV2) is turned on the by the multi-zone relay center (MZRC). Variable speed circulator (P5) is also turned on when any zone called for heating.*

The (X X) contacts of the (MZRC) close passing 24VAC power from transformer (X1) to differential temperature controller (T156). This controller compares the temperature at the return side of the distribution system, at sensor (S4) to the temperature of the upper tank header, at sensor (S3). If the temperature at (S3) is at least 5 ºF higher than the temperature at (S4), the normally open contacts in the (T156) controller close. This passes 120 VAC to circulator (P2) to create flow between the upper tank header and the upstream pair of closely spaced tees in the distribution system. Circulator (P2) continues to operate unless the temperature at (S3) drops to 3 ºF or less above the temperature at (S4), at which point the contacts in the (T156) controller open turning off circulator (P2). This control action prevents heat created by the oil-fired boiler from inadvertently entering the thermal storage tank.

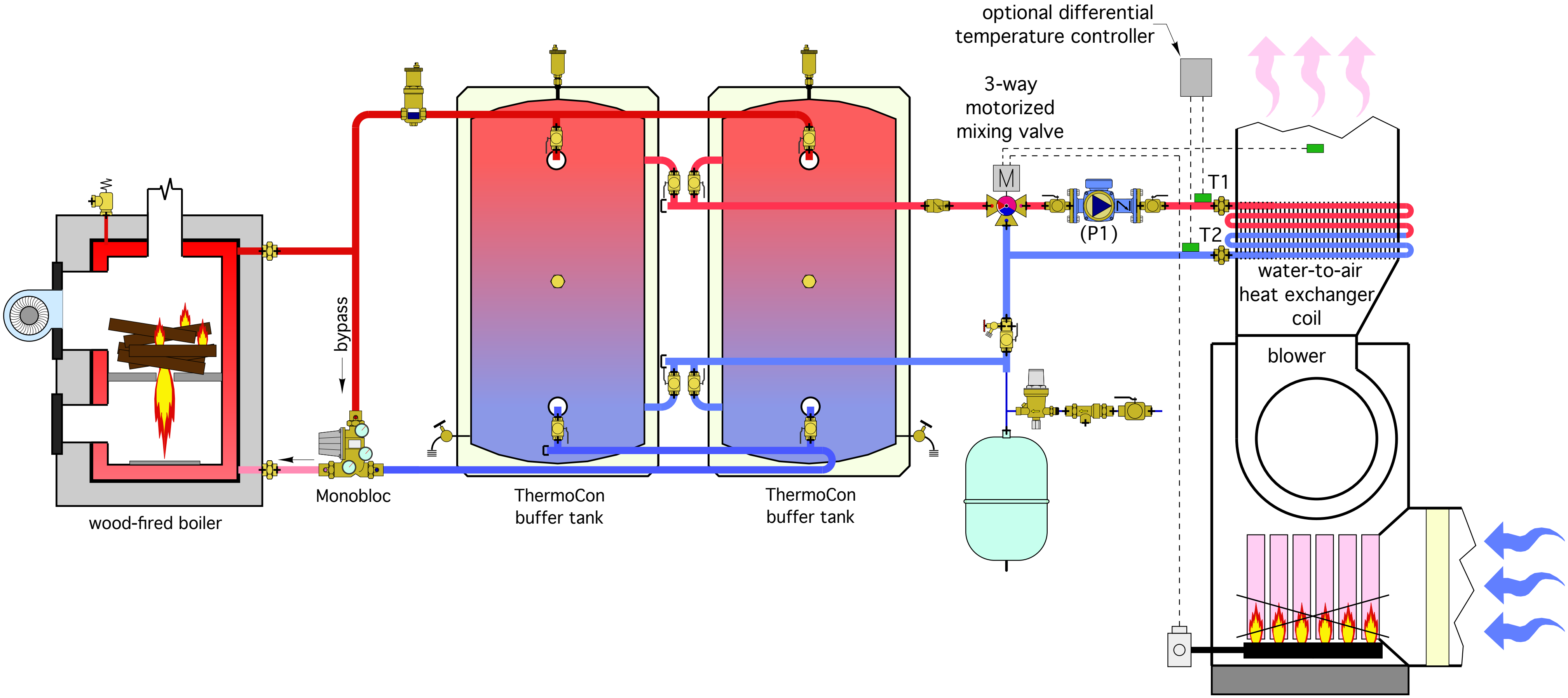
The (X X) contacts of the (MZRC) also pass 24VAC power to outdoor reset controller (T256). The (T256) measures outdoor temperature at sensor (S2) and calculates a target supply water temperature for the distribution system. If the temperature of the water passing sensor (S1) on the supply side of the distribution system is 10 ºF or more below the calculated target supply water temperature the contacts in the (T256) controller close across the (T T) terminals of the oil-fired boiler high limit controller (OHLC) enabling it to fire and circulator (P3) to operate. Heat from the oil-fired boiler is injected into the distribution system at the downstream pair of closely spaced tees.

Domestic water heating: *Whenever there is a demand of domestic hot water of 0.6 gallons per minute or higher flow switch (FS) closes, passing 24VAC to the coil of relay (R1). Relay contact (R1-1) closes to turn on circulator (P4) which immediately routes hot water from the top of the thermal storage tanks through the primary side of stainless steel heat exchanger (HX1). Cold domestic water passes in counterflow through the other side of heat exchanger (HX1) and is heated to within 5 ºF of the temperature at the top of the thermal storage tanks.*

The heated water leaving heat exchanger (HX1) passes through an electric tankless water heater, which is thermostatically controlled to limit heat input so that the water leaving the heater is not more than 115 ºF (assuming it enters the heater at a lower temperature). If the water entering the heater is above 115 ºF, the elements will not turn on. Hot water leaving the heater passes through a thermostatic mixing valve (MV1), which limits hot water delivery temperature to 115 ºF.

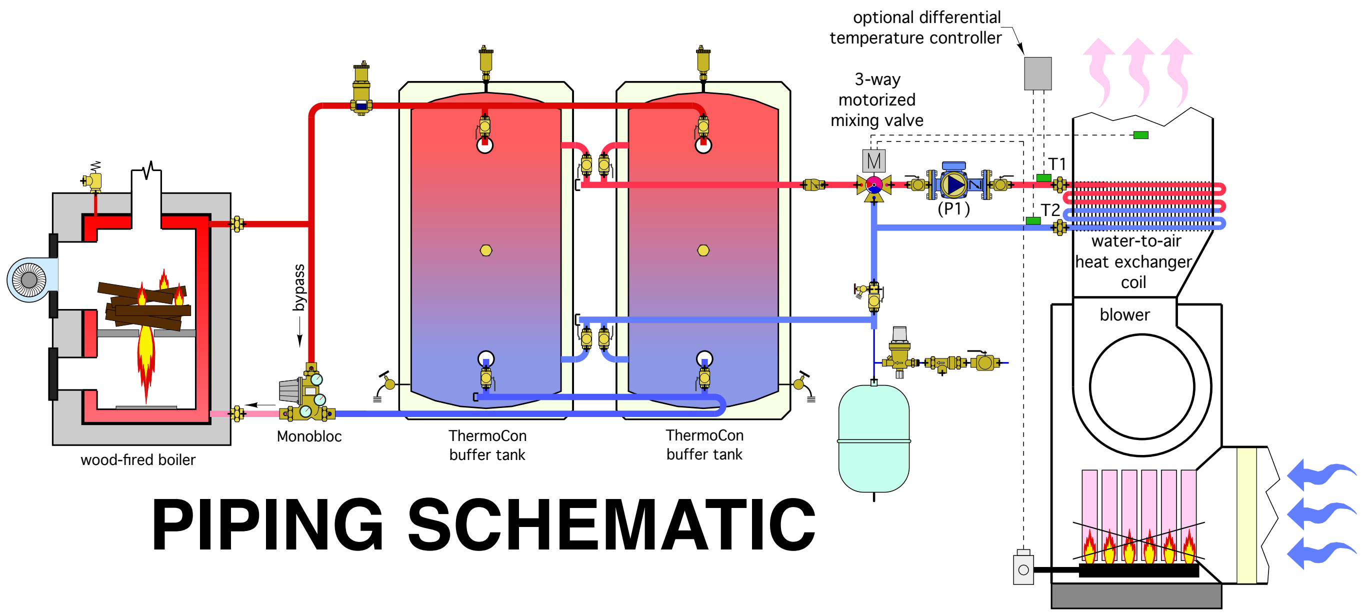
System using forced air furnace

- space heating only
- ΔT logic to operate storage to lowest temperature
- dual parallel-piped thermal storage tanks
- Could add instantaneous DHW assembly

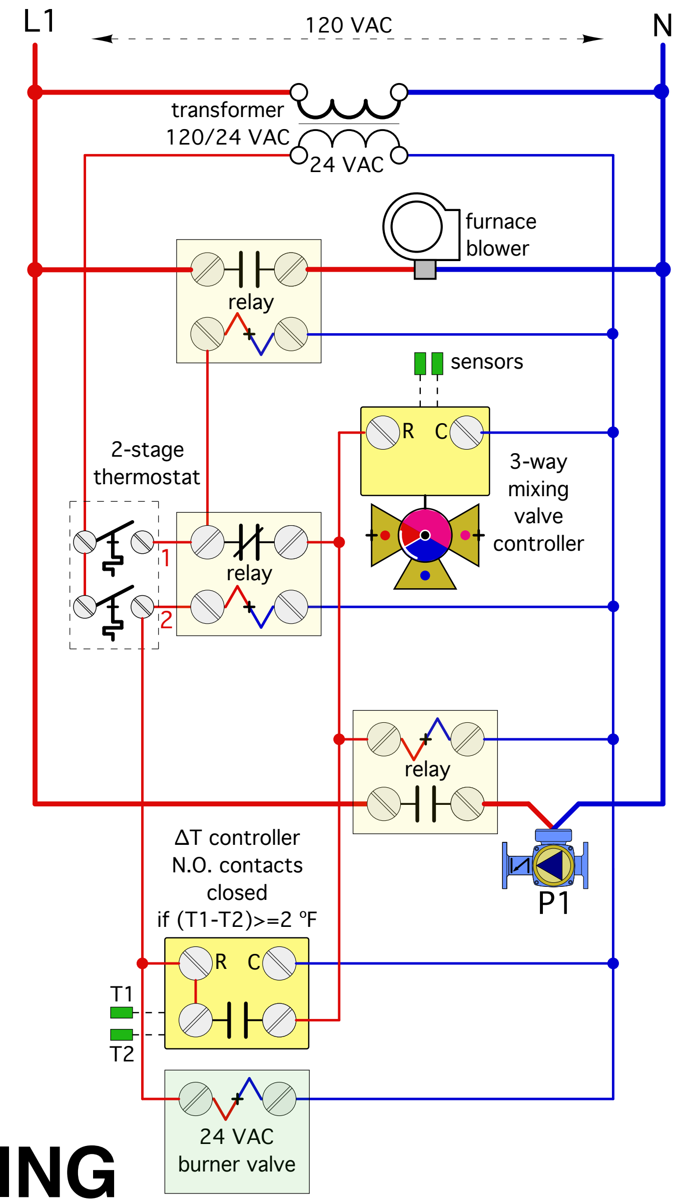


System using forced air furnace

- space heating only
- ΔT logic to operate storage to lowest temperature
- dual parallel-piped thermal storage tanks
- Could add instantaneous DHW assembly
- 2-stage thermostat



PIPING SCHEMATIC



WIRING SCHEMATIC

Please, refer back to the PDF file for this session, and "walk" your way through this control schematic

Design questions that should be addressed for biomass boiler systems

1. How is the biomass boiler protected against low entering water temperatures that would cause sustained flue gas condensation?

2. If the system uses an auxiliary boiler, how and when do the system's controls call for the auxiliary boiler to operate?

3. If the system allows for ***simultaneous*** heat flow from the thermal storage tank supplied by the biomass boiler, and the auxiliary boiler, how is heat generated by the auxiliary boiler prevented from being ***unintentionally*** routed into the thermal storage tank?

4. What is the exact operating logic of the biomass boiler? Is its operation invoked by a heat demand, or does the boiler operate independently of heat demands?

5. How flue gas leakage prevented during a cold boiler start into a cold chimney?

6. What is the mixing system used between the thermal storage tank and a low temperature distribution system?

7. If the system is zoned and has an auxiliary boiler, How is the auxiliary boiler protected against short cycling when *only the smallest zone* on the system is calling for heat?

8. How is the biomass boiler protected from overheating if a power failure occurs when the boiler is operating at full heat output?

Design questions that should be addressed for biomass boiler systems

9. If the system uses an auxiliary boiler, how is it taken “off-line” (e.g., without heated water passing through it) when all heat is being supplied from the biomass boiler.

10. How do the piping connections and inlet flows to the thermal storage tank allow for good thermal stratification? How is mixing within the thermal storage tank prevented?

11. How is heat loss from thermal storage due to thermosiphoning through external piping prevented?

12. What is the temperature cycling range of the thermal storage system under design load conditions. What are the highest and lowest water temperature in the upper portion of the thermal storage tank under design load conditions.

13. What is the minimum supply water temperature at which the heat emitters in the building can provide design load heat output to the building?

14. Are all required safety controls specified for both the biomass boiler and the auxiliary boiler (if present)?

15. Is the required air for combustion and mechanical room ventilation provided?

Additional Resources:

1. ***Planning and Installing Bioenergy Systems***, 2007, The German Solar Energy Society. ISBN 978-1-88407-132-6.

2. ***Heating with Renewable Energy****, 1st Edition, Siegenthaler, 2016, ISBN -13: 978-1-285-07560-0* Cengage Learning

3. ***Modern Hydronic Heating,*** 3rd Edition, Siegenthaler, 2012. ISBN-13: 978-1-4283-3515-8, Cengage Learning

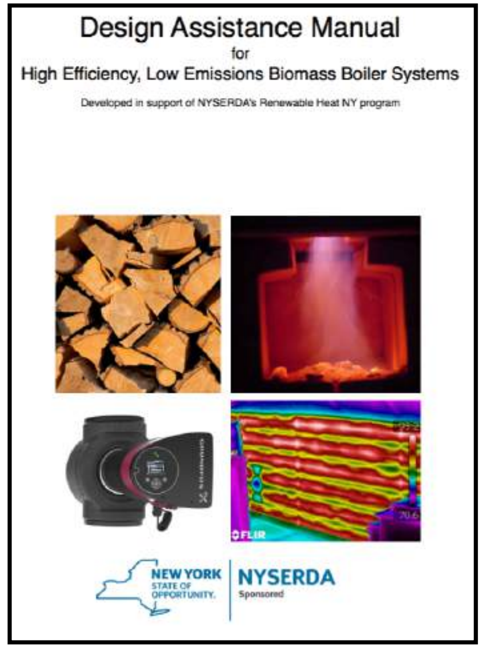
Web resources:

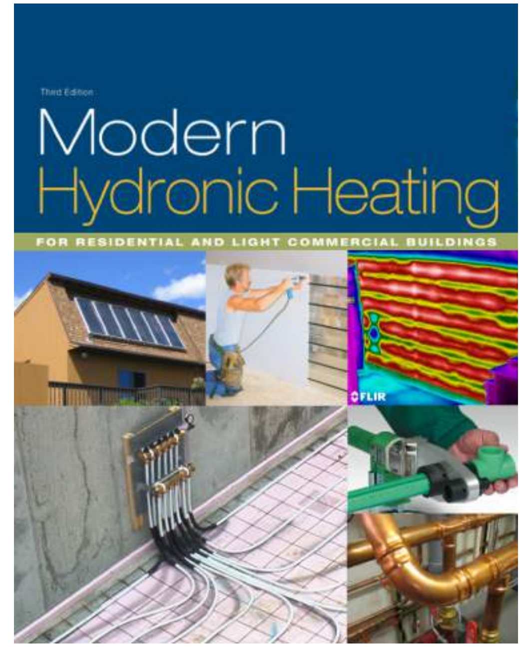
http://www.nyserda.ny.gov/All-Programs/Programs/Renewable-Heat-NY

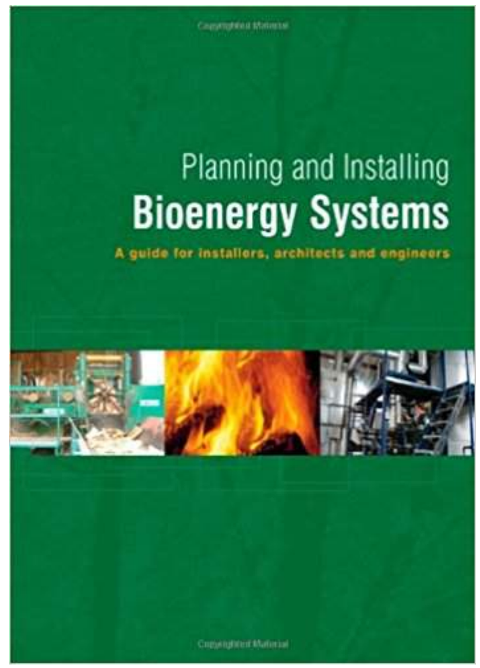
http://www.nyserda.ny.gov/-/media/Files/Publications/Research/Biomass-Solar-Wind/European-wood-heating-technology-survey.pdf

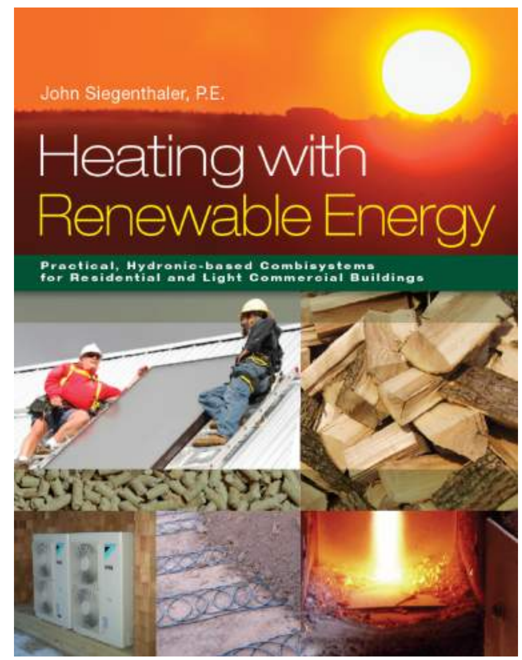
https://www.biomassthermal.org/resource/

http://www.biomasscenter.org/







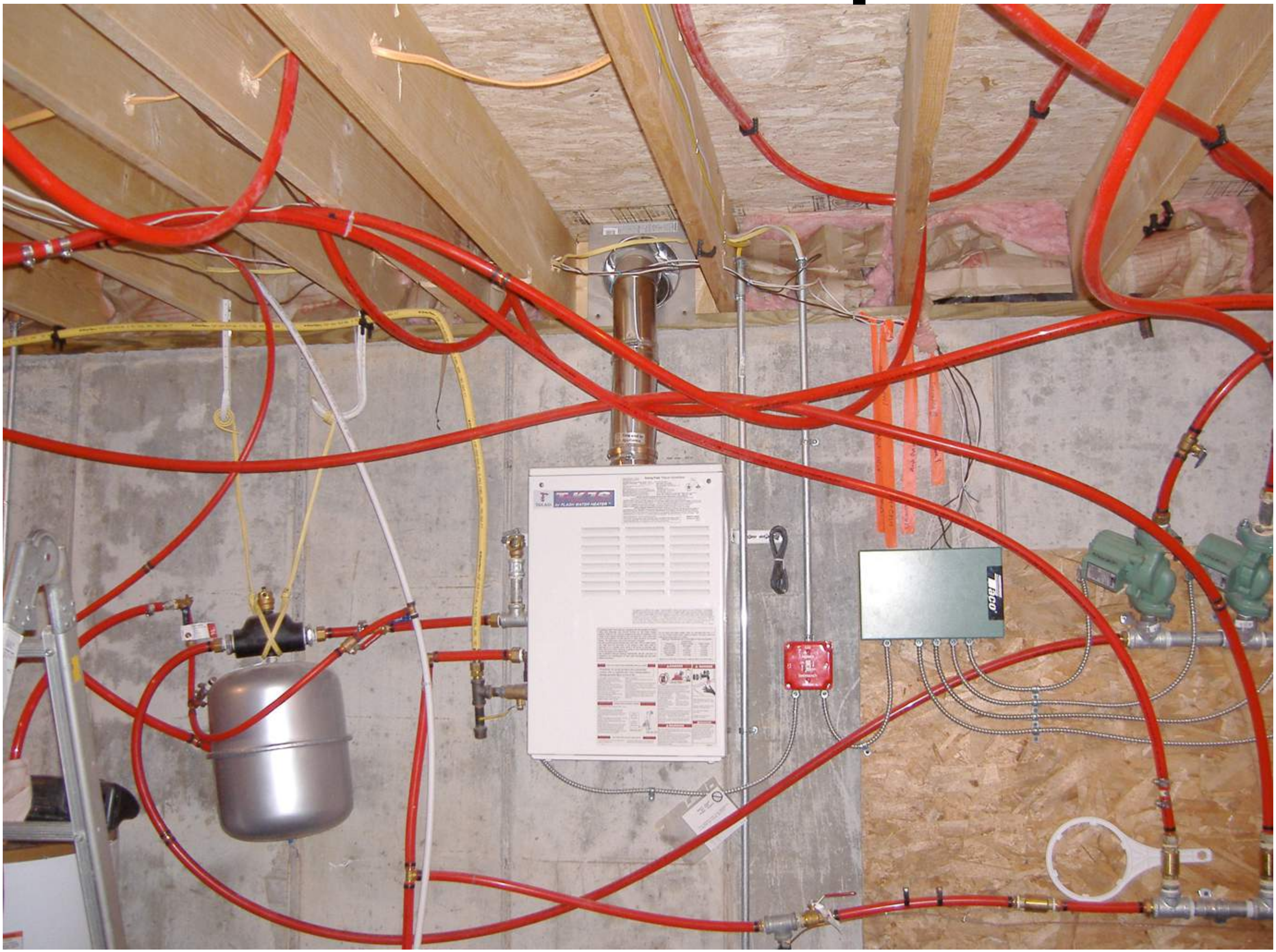


Parting thoughts...

1. Plan ahead...

Parting thoughts...

2. Keep it neat...



Parting thoughts...

3. Keep it simple...

Thanks for attending this training

If you have comments or suggestions regarding this training, please feel free to e-mail them to:

John Siegenthaler
e-mail: siggy@dreamscape.com

and/or to:

Debra Moran
e-mail: Debora.Moran@nyserda.ny.gov